ErgoQuest Motorized Mobile Recliner Platform
PROJECT 12

Final Report
December 11, 2007

Uzair Ali
Joseph Blakemore
Eric Paul
Matthew Vivian

ME 450 SECTION 3
Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI

TABLE OF CONTENTS

ABSTRACT

ErgoQuest Inc. has requested that our team redesign their Motorized Mobile Recliner Platform (MMRP) to reduce the cost such that the price is more reasonable for their customers. Specifically, we have been asked to reduce the final production cost from $1250 to less than $500 by choosing better suited motors, batteries, wheels, and controls for the MMRP's functional design. The current components are too robust for the MMRP's applications. Our team has generated new design concepts and researched new components, detailed in this report. We have reached a final design and manufactured a prototype. The redesign accommodates the current ErgoPod reclining chair located in the Duderstadt Center. The final cost for the redesigned MMRP was $891.

1. INTRODUCTION

Currently, consumers can purchase powered wheelchairs to position themselves properly in front of their workstations, but this is not feasible for all users. Unlike standard power chairs or scooters, the Motorized Mobile Recliner Platform (MMRP) is made for reclining chairs that offer a zero-stress working position for users that need to work in a reclined position due to a back condition or similar ailment. Fig. 1 below shows the typical application of the MMRP used in conjunction with a Sit/Stand/Recline Work Station.

Fig. 1: MMRP and Zero-Stress Recliner in Use with Appropriate Work Station

The current MMRP model uses expensive motorized wheelchair components that exceed the requirements for the desired application. As a result, the retail price may be too high for many potential users. ErgoQuest would like to reduce this cost to boost their sales and to allow more people to compute comfortably. Choosing better suited, readily available components is the best way to reduce the cost of the MMRP. These components must be able to meet all customer requirements, discussed in Section 4 on pg. 4, while retaining the basic functionality of the system. A final design has been selected and prototype has been manufactured.

2. EXISTING MOTORIZED MOBILE RECLINER PLATFORM

ErgoQuest's current Motorized Mobile Recliner Platform is shown in Fig. 2 below. The MMRP has a simple base design made of welded 0.125 inch wall steel tubing and 0.25 inch thick steel plates for the chair legs to rest upon. The base is designed such that the chair is only raised by two inches when it is moved from the floor onto the MMRP as seen in Fig. 3. It has two large drive wheels attached directly to the motors on each side as well as two smaller casters at the front and back of the base bolted to the frame to allow for easy rotation. Mounted on a column that sits to the side of the chair's armrest is a joystick controller and a speed regulation knob, which works with a motor controller to regulate the voltage applied to the motors. This allows full 360 degree rotation and a range of speeds from slow to fast [1]. The platform is powered by two 12 V, 30 Ah rechargeable car-sized batteries [2].

Fig. 2: Image of Existing MMRP

Fig. 3: MMRP with Zero-Stress Recliner

The MMRP is costly because the motors, batteries, and controls are taken directly from motorized wheelchairs that are meant for traveling quickly over large distances, and as a result are over designed for the MMRP's intended use. It primarily used to move around and adjust positions within a workstation. The gear drive motors are packaged units that have bearings that can handle the weight of the chair and user so that the wheels can be placed directly onto the motors. Additionally, the battery life is two to four weeks due to the short distances and duration of use. It is also capable of moving both very slowly and moving at speeds of three to four miles per hour, which is faster than what is needed.

Other than the fabrication and welding of the base, the manufacturing process for the current MMRP is very simple because the wheelchair batteries, motors, wheels, and joystick/speed control assemblies are all purchased as one unit that interface with simple connectors. The wheelchair components cost approximately $1,000. The steel and fabrication costs are about $250. A small number of units have been sold and each must be custom fit to the specific recliner. ErgoQuest retails the MMRP for $2195 which could be part of the reason only five units have been sold [2].

3. INFORMATION SEARCH

We completed our information search using the internet since there is a wealth of information available for the details and specifications of numerous products. The information search yielded few direct competitors to ErgoQuest's MMRP. The primary comparisons to the MMRP are power chairs and motorized scooters as seen in Fig. 4 and Fig. 5 on pg. 3. These two comparisons integrate a motorized base with a seat, whereas the MMRP is a stand-alone motorized base. The major differences between the two are the type of base and the control setup. In the power chair, a joystick controller is used whereas in a motorized scooter, there are handle bars for steering with lever motion control [3].

Fig. 4: Power Chair

Fig. 5: Motorized Scooter

We are primarily concerned with the drive system so we focused our search on the products' bases and the motorized components including motors, batteries, and controls. There are a large variety of component options and differences in type, size, and quality available in the market among powered chairs and motorized scooters.

While the power chair and motorized scooter are the primary two comparisons to the MMRP, we also looked at electric golf carts and attempted to find stand alone motorized bases. There were a number of companies who manufactured motorized platform carts, as seen in Fig. 6, which are typically used to move heavy objects over a variety of surfaces [4]. They are capable of carrying over 1000 lbs and therefore have a larger motor, battery, and an associated cost of approximately $3,000. There were not many commercially available stand alone motorized bases, however, we did find the Kadtronix motorized frame seen in Fig. 7. This unit has a capacity of 200 lbs, is capable of 360 degree turns, uses a belt drive with two 24 V Direct Current (DC) motors, and retails for $500, excluding batteries and controls [5].

Fig. 6: Motorized Platform Cart

Fig. 7: Heavy-Duty Motorized Frame

3.1 Technical Benchmarks

While a large variety of motorized scooters, power chairs, and other similar products were available, we limited our technical benchmarks to products with similar functions and within the lower scale of price ranges. Table 1, on pg. 4, shows a basic scooter, electric wheelchair, and a scaled down electric golf cart, whose bases are all comparable to the MMRP [6, 7, 8]. For each product, Table 1 lists technical benchmarks that our team will use to design and evaluate our own final design. By noting these important aspects of competitors' products in the table below, we were able to better understand the acceptable range of values for our own design criteria.

Since it is desired for our final product to cost less than $500, we considered the price to be the most important technical benchmark. The physical dimensions, tire size, and weight capacity were also important design criteria for our product. In addition, we benchmarked electrical components of similar products because the electrical design of our final product determined its ability to operate properly. Therefore, we noted the battery characteristics, motor output, and maximum speed of the three products. Also, we included the turning radius because our product needed to rotate in small areas. Finally, since the control of our product is key to its successful operation, we also noted the type of control system that each product uses.

Table 1: Technical Benchmark Comparisons for Three Alternative Products

Product	**Shop Rider Echo 3 Wheel Scooter**	**Alero Electric Wheelchair**	**Powerhouse Electric Golf BuggyPro**
Image			
Price ($)	600	1,200	2,000
Length (inches)	37	43.7	52
Width (inches)	20	20.4, 22.4, 24.4	28.4
Height (inches)	35	38.8	44.5
Tire Size (inches)	8	12.8” rear, 8” front	13
Weight Capacity (lbs)	250	250	300
Batteries	(2) 12V, 12Ah	(2) U1 12V, 30Ah	(2) 12V, 38Ah
Motor Output (hp)	0.45	0.63	1.01
Max Speed (mph)	3.8	4.5	11.2
Turning Radius (inches)	32	38	20
Control	T-Bar Handle Bar	PG VR2 60 amp, programmable	Variable Hand Control

4. CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

ErgoQuest has given us several requirements we aimed to satisfy in our redesign of the MMRP. Reducing the product cost was the main goal. The MMRP must be able to move forward, backward, and be able to turn. The MMRP must not significantly increase the footprint of the reclining chair. Additionally, the MMRP must be able to hold a minimum weight. The user needs to have precise control over the movements as well. Other desirable qualities are that the system should not require frequent maintenance, operate with a rechargeable power source, and have a long product lifetime. The engineering specifications are summarized in Table 2 on pg. 5. The Quality Function Diagram (QFD) shown on pg. 7 depicts the relative importance of the customer requirements and their corresponding engineering specifications.

Table 2: Engineering Specifications

Engineering Specifications	Measurement Unit	Target Value
Motor Torque	ft-lb	200
Velocity	in/sec	2-8
Speed Settings	Qty	2+
Number of Motors	Qty	2
Battery Duration	hours	12
Battery Voltage	Volts	24
Battery Current	Amperes	10
Width	inches	30
Length	inches	29
Height	inches	2
Material Strength	PSI	53,700
Learning Time	minutes	5
Weight Capacity	Lbs	350
US Production Price	US Dollars	500
Control Reaction Time	Ms	1
Maintenance Frequency	years	1
Appendages to Operate	Qty	1-2
Off-the-Shelf Components	percent	100
Manufacturing Time	hours	8
Failure Rate	percent	0.1
Operational Lifetime	years	20

4.1 Cost Specifications

The end objective of this design project was to produce a model for less than $500. This was the only cost requirement given by ErgoQuest and therefore was the most important design criterion. This was most easily achieved by purchasing standard components best suited for the applications of the MMRP.

4.2 Motion Specifications

The specifications for the motion of the MMRP begin with the ability to move forward and backward as the user desires. If the MMRP cannot do this, then this requirement is not met. The ability of the MMRP to rotate was also a simple requirement that is directly observable. These are some of the most important specifications as they define the fundamental functionality of the finished product.

4.3 Dimensional Specifications

The spatial requirements of the MMRP are dictated by the size of the recliner it is meant to hold. The base of the MMRP must not protrude more than one inch past the edge of the chair on any side, excluding the MMRP wheels. The existing chair must not be raised more than two inches off the floor when placed on the MMRP base.

4.4 Power Specifications

ErgoQuest has requested that the MMRP be battery powered. The batteries must be rechargeable, but should not require charging more than once per day. The batteries must be able to provide the voltage and current that the motors require for the desired motion under a loaded condition.

4.5 Weight Specifications

The MMRP is required to operate properly with a load up to 350 lbs to accommodate larger users. This condition dictates not only the power specifications, but also material choice and frame design.

4.6 Control Specifications

The user must have precise control over the motion of the MMRP. This includes the ability to easily steer the MMRP and to adjust the speed depending on the application. If the user is moving the chair to the computer station it should move on the order of four to eight in/sec. Up close to the station, the user should be able to move the chair slower to facilitate fine adjustments.

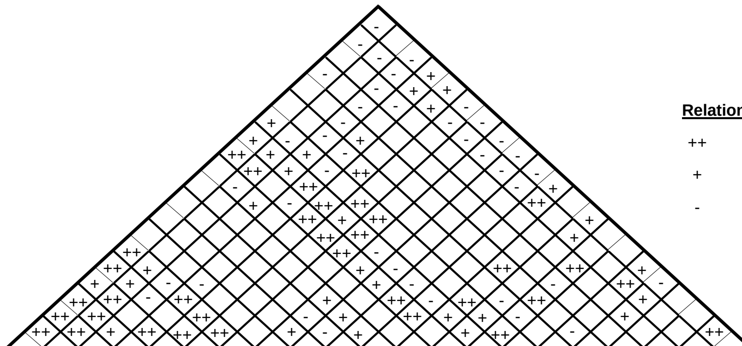
4.7 Maintenance and Lifetime Specifications

It is desirable for any product to last as long as possible with the least amount of maintenance. The current MMRP uses wheels that need to be inflated, which is inconvenient. Therefore, the redesign of the MMRP should not require frequent inflation of its tires or replacement of its components. The system should also last many years so that the user does not need to purchase a new MMRP.

4.8 Quality Function Diagram (QFD)

The QFD, shown in Fig. 8 on pg. 7, relates the relative importance of the customer requirements and the engineering specifications. It also demonstrates how well a sample of competing products meet the customer requirements and how each product compares to the MMRP. Each customer requirement was ranked in its importance on a scale of one to ten, ten being the highest. Each requirement was then compared to each engineering specification as being strongly related, somewhat related, or weakly related. Each relation was assigned a nine, three, or one, respectively. Requirements that were not related to a particular specification were left blank. Using these comparisons, each engineering specification was weighted by importance to the successful completion of the project. Finally, the competing products were also ranked on their ability to meet all design specifications. This allowed us to compare the performance of our final prototype against the current products on the market.

Fig. 8: Quality Function Diagram (QFD)



Relationships

++	Strongly Related
+	Somewhat Related
-	Weakly Related
	Not Related

	Weight*	Motor Torque **	Velocity	Speed Settings	Number of Motors **	Battery Duration	Battery Voltage	Battery Current	Width	Length	Height	Strength of Material	Learning Time	Weight Capacity	US Retail Price **	Control Reaction Time	Maintenance Frequency	Appendages to Operate	Off-the-shelf Components	Manufacturing Time	Failure Rate	Operational Lifetime		Benchmarks: *Powered Wheelchair*	Benchmarks: *Motorized Scooter*
Forward and Backward Motion **	10	9	9	9	3		1	1	1				3	1		1		1						5	5
Ability to Rotate	7	9	1	1	9		1	1	3	3			9	3		1		3						4	4
Side to Side Motion	2	9	3	3	9		1	1		1			9	1		1		3						1	1
Chair Elevation **	8										9	1		1							1			3	3
Footprint of Frame	8								9	9	3	1		1			1				1			5	5
Power Supply	9	9	9	3	9	3	9	9	1	1	3			3	9		9		9		1	3		5	5
Product Weight	2		3	3	9	1	1	1	1	1	1	3		3	3		1							4	4
Cost **	10	1	3	9	9	9	9	9	1	1	1	1		3	9	1		3	3	3				3	3
Control **	9	9	3	3	9		1	1					9			9		9	1					5	5
Wheel Design	7	3	9	3			1	1	1	1	1			3	1		9		3	1		3		5	4
Ease of Use	7	1	1	9	3	3			1	1	1		9			9		9						5	5
Interchangeable Components	1					1	1	1	1	1	1			1	9				9	3				3	3
Base Design	3	1			3				9	9	9	9		9	1									1	1
Weight Capacity **	9	9	9		3							3		9	1						1	1		4	4
Off-the-shelf Components **	9	3	1	1		3	3	3					1		9	1	1	3	9	3	1	1		5	5
Material Type	4								1	1	1	9		9	3		1		1					4	4
Appearance	3								1	1	1				3					3				3	4
Durability	8					3						1		1	1		3				9	9		5	4
Manufacturability	2				1				1	1	1				3				1	9				4	3
Safety	6	9	9	9			3	3				1	3	3		9		1			9	1		5	5
Measurement Unit		in-lb	in/s	Qty	Qty	hrs	V	A	in	in	in	psi	min	lbs	$	ms	yrs	Qty	%	hrs	%	yrs			
Target Value		200	1-9	2+	2	12	24	20	31	30	19		5	400	999	1	1	1-2	100	10	0.1	20			
Importance Rating		10	7	5	9	5	8	8	7	7	7	2	6	7	10	3	7	2	9	6	8	8			
Total		536	461	400	440	192	254	254	175	167	186	136	282	304	321	236	191	244	237	94	169	144			
Normalized		0.10	0.09	0.07	0.08	0.04	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.06	0.06	0.04	0.04	0.04	0.04	0.02	0.03	0.03			

Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

*** Weights are figured on a scale of 1 to 10 (10 being most important)**

**** Most important customer requirements and engineering specifications**

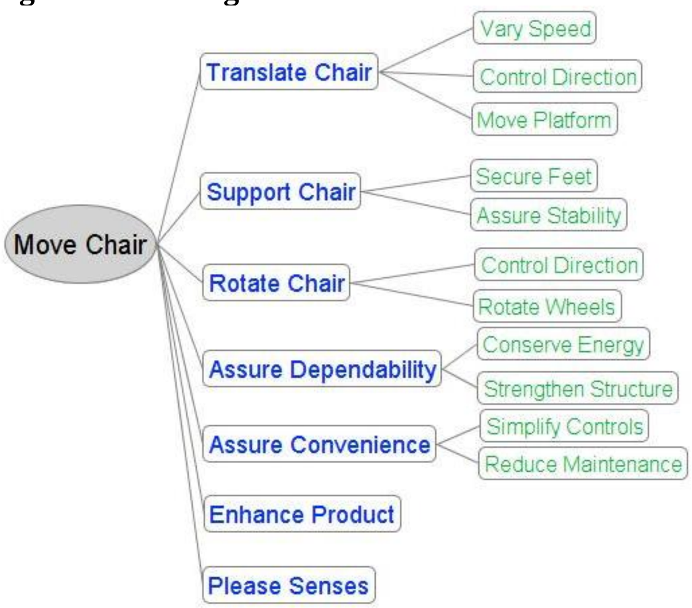
5. CONCEPT GENERATION

After the customer requirements were determined, those requirements needed to be translated into a design for the MMRP. We went about this process with the help of a Function Analysis System Technique (FAST) Diagram and a Morphological Chart. A FAST Diagram shows the relationship between the product functions describing how one function performs a higher order function. These functions were then used in the Morphological Chart, where several concepts were developed for each function. We then combined these concepts into various prototype configurations.

5.1 Function Analysis System Technique (FAST) Diagram

The primary task of the redesigned MMRP was to move and make fine adjustments to the position of the chair that it carries. Therefore, the task function on our FAST Diagram is to move the chair. The FAST Diagram is shown in Fig. 9 below. Translating, supporting, and rotating the chair are all essential to the task of moving the chair so they became basic functions. In addition, assuring dependability, convenience, enhancing the product, and pleasing the senses are essential to the performance of any product, so these were included as basic functions as well. The supporting functions shown in the tertiary level of the FAST Diagram elaborate on how the MMRP accomplishes the basic functions. For example, varying the speed and reducing the cost enhanced the MMRP.

Fig. 9: FAST Diagram



5.2 Morphological Chart

The next step in our concept generation process was to create a Morphological Chart, as shown in Fig. 10 on pg. 9. We used this to develop high-level design concepts. The functions came directly from our FAST Diagram. Multiple concepts were developed for each of these functions. From the variety of concepts, we picked and combined to devise the best design possible.

5.3 Concept Classification

The concepts shown in the Morphological Chart can be classified into several categories. The first category, which pertains to translating the chair, has stationary drives where the motor does not move with the base. The rail system with pulleys is one concept from this category. In the rail system, the motor is stationary relative to the ground and operates a pulley/cable system that moves the base along the rails. The second category, involving translation and the drive system functions, is where the drive motor(s) move with the chair base. One concept from this category is the belt driven wheel, where the chair base-mounted motor drives a belt that in turn rotates the wheel.

The next two categories deal with chair rotation. The first category rotates the entire platform through the drive system. One representation of this is the dual motor/wheel concept where two independently driven wheels are placed on each side of the platform and can be run in opposite directions to rotate the chair. The second category rotates the chair from a stationary base. A concept that accomplishes this task is the motor-driven platform on a swivel.

Our next category is hand-controlled motion, which arises from the fact that the motion of the chair/platform will be dictated by the user. Rheostat speed control is one concept of this, where the user adjusts the platform speed by hand-adjusting the rheostat which dictates the amount of voltage to the motor. Our last category is product improvements, which encompasses many of the concepts from the "assure convenience", "enhance product", and "please senses" functions on the Morphological Chart. A concept from this category were pin mounts, where the chair could be secured to the platform by pins running through the platform and chair.

Fig. 10: Morphological Chart

Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Move Platform	Wheels	Treads	Rail System (w/ pulleys)	Chair Boom	Gear Track
Vary Speed	Rheostat Speed Control	Varied Voltage Batteries	Motor Controller	Voltage Regulator	Potentiometer Joystick
Control Direction	Dual Motor	Transmission	Steering Wheels	Chair Swivel	Turntable
Secure Feet	Adjustable Mounts	Inset Mounts	Pin Mounts	Strap Mounts	On Steel Plate
Assure Stability	Four Wheels	Solid Cast Frame	Welded Steel Frame		
Rotate Wheels	Straight Shaft	Belt Drive	Gear Train		
Conserve Energy	Motor Controller	Varied Voltage Batteries			
Strengthen Structure	Solid Cast Frame	Welded Steel Frame	X-frame (4 casters)		
Simplify Controls	Single Joystick	Dual Joystick (one/two arm)	Toggle Switch	Dual-Rocker Switches	
Reduce Maintenance	Battery Disconnect	Solid Wheels			
Enhance Product	Hand brake	Accessory Platform	Motor casing (noise reduced)		
Please Senses	Painted Frame	Ergonomic Hand Controls	X-frame (4 casters)	Curved Frame	

6. CONCEPT EVALUATION AND SELECTION

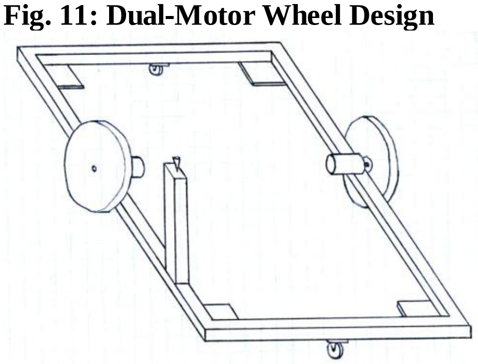
Using the concept categories in the Morphological Chart, our team generated several ideas from which we chose our final design. In order to choose the best design for the new MMRP, we evaluated each concept with the customer requirements. The first and most important of these was to reduce the production cost. Doing so would allow ErgoQuest to reduce the customer price, and reach a larger base of consumers. The next requirements were the chair's ability to translate, rotate, and be supported, which are essential for the user to position themselves properly at their workstations. Speed control of the MMRP was the next requirement, since the user may need to make fine adjustments while at the workstation. Also, the MMRP needed as small a footprint as possible, so that the user can maneuver in tighter quarters. The next evaluation requirement, that the MMRP require infrequent maintenance, which adds a convenience factor for the potential buyer. The ease-of-use requirement also increases user convenience.

6.1 Base Concepts

With the above evaluation requirements in mind, we started combining our concepts from the Morphological Chart into configurations we thought could meet most, if not all, of requirements. Five concepts for the base design were developed and are described below.

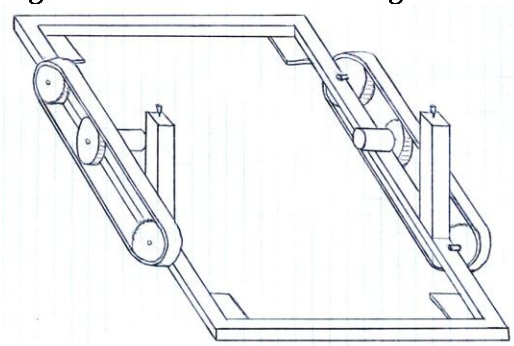
***6.1.1 Dual-motor wheel design*:** This concept, as shown in Fig. 11 below, incorporates the dual motor concept from the existing MMRP, with each motor driving a single wheel. It also includes two casters; one on the front and rear of the platform. There is a single controller for easy user interface. This basic design incorporates the minimum components to fulfill the customer requirements for the MMRP motion. Using the minimum components also reduces cost, thus fulfilling our primary requirement. The casters, though low in cost, may impede immediate motion response to a user input if they are oriented perpendicular to the direction of motion. Also, the use of a single controller may increase cost as it requires a more complex controller. Another downside to this concept is that it distributes the total platform weight on four small points (the wheels), which may leave indentations in the floor under heavy load conditions.

Fig. 11: Dual-Motor Wheel Design



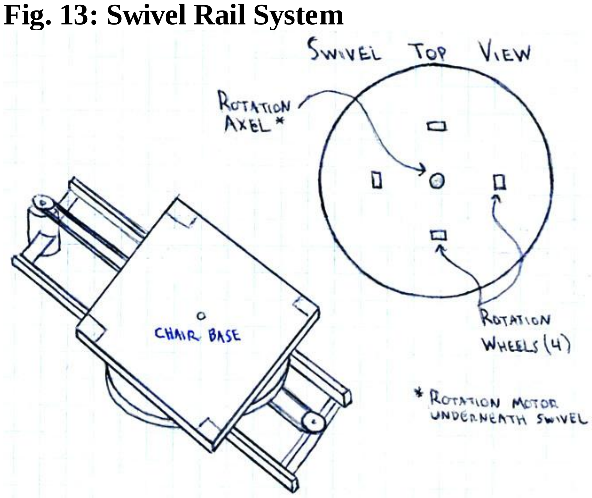
***6.1.2 Dual-motor tank design*:** This concept shown in Fig. 12 on pg. 11 utilizes a similar base and dual-motor setup as the previous concept. Instead of the single controller, however, this concept uses a single forward/backward controller for each track. This design would also satisfy all the motion requirements laid out by the customer. The use of the "tank" tracks eliminates the need for the casters that were used in the previous concept. Also, the tracks would distribute the total platform weight over a larger area, leaving a shallower indentation in the floor. The tracks, though having many positive aspects, would not satisfy our primary cost objective very well. The tracks would require more components and more time to manufacture, thereby boosting production cost. Along with the cost issue, the tracks would increase the footprint of the MMRP. This would make it more difficult for disabled users to get into the reclining chair. Also, the tracks may wear on the flooring when it is rotating.

Fig. 12: Dual-Motor Tank Design



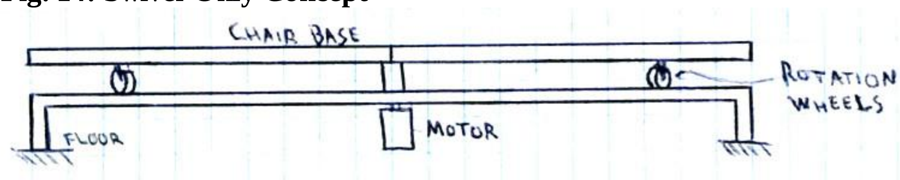
***6.1.3 Swivel rail system*:** This concept, shown in Fig. 13 below, incorporates a stationary base and motor concept that translates the chair platform. The platform is attached to the pulley and moves along the rails. A single motor drives the pulley. The platform is made of two components: the lower portion which is moved by the pulley, and the upper portion which acts like a swivel or turntable. This turntable is spun by a single motor attached to the lower platform and has four guide wheels as shown in Fig. 14 on pg. 12 for the swivel only concept. The user would control the motion of this system with two controllers (not shown in figure). One controller would handle the platform rotation, while the other would handle the translation along the rails. This two-controller design would reduce the overall controller cost. One benefit to using a rail system is that the platform could translate easier than wheels on carpet. This would lead to using smaller and less expensive motors, thus reducing cost. The motor used to rotate the chair would also require less force than the wheel-on-carpet motors. One downfall to this design is that it can only move along a straight line (the rails), eliminating some of the mobility that a wheel or tank track design would have. This concept would also raise the reclining chair feet beyond the specified height of two inches.

Fig. 13: Swivel Rail System



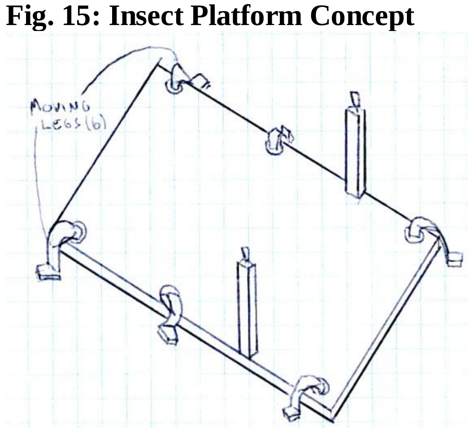
***6.1.4 Swivel-only concept*:** This concept, in Fig. 14 on pg. 12, incorporates the same swivel as mentioned in the previous concept; however, this concept eliminates the track and pulley system all together, providing a very low cost means to rotate the chair into position in front of the user workstation. Eliminating the track also yields a very small footprint. The swivel concept requires that the user have enough space in their workstation to enter the chair while it's in a sideways position, and then rotate to face their computer. The single motor and controller significantly reduce cost compared to those concepts that need two of each. The obvious downfall to the swivel is that the user would be unable to back away from their workstation. This concept would also likely raise the chair beyond the two inch requirement.

Fig. 14: Swivel-Only Concept



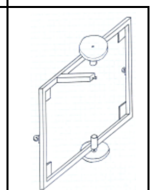
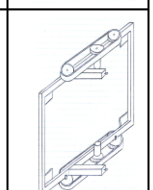
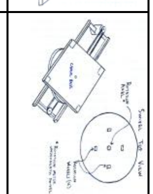
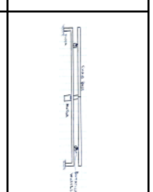
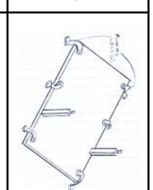
***6.1.5 Insect platform*:** This concept, in Fig. 15 below, draws inspiration from nature with the incorporation of our Morphological Chart concepts. This platform has six independently driven legs that are controlled to move in a manner similar to that of an insect. This concept satisfies all mobility requirements. The controls would be similar to that of the tank design, with one controller for each side. The weight distribution over six points, instead of four like our dual-motor wheel concept, also leaves less chance of floor indentations. The main drawback to this design would be cost. It would require six motors and expensive controllers to operate the legs in proper sequence to yield the correct output motion. Also, the number of parts is quite high and would yield a longer time for manufacturing which would increase the cost. These controllers and motors along with their specified use may also require a greater maintenance frequency than some of the simpler designs. Another drawback to this concept would be the roughness of the ride from the legs lifting and placing, which may make the user uncomfortable while in motion.

Fig. 15: Insect Platform Concept



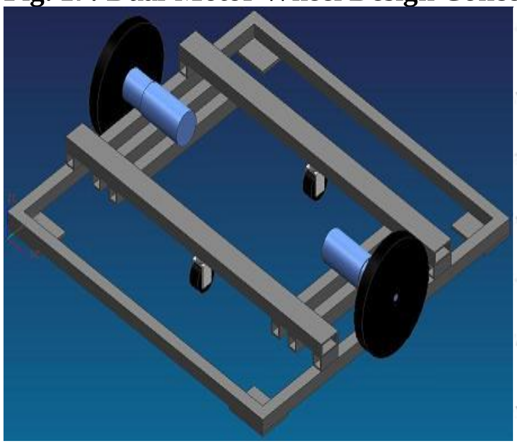
***6.1.6 Base concept selection*:** In order to determine which design concept best fits the customer requirements, a Pugh Diagram was used, shown in Fig. 16 on pg. 13. Our five design concepts are illustrated in the column headers and the customer requirements are shown on the left along with their respective importance ratings. Each design concept was evaluated for how well it satisfied a given customer requirement, and given a score of -, S, or +. A minus sign meant that the design concept poorly satisfied the customer requirement, a S meant that the design concept was satisfactory in satisfying the customer requirement, and a plus sign meant that the design concept excelled in satisfying the customer requirement. The five design concepts were evaluated against every customer requirement and the unweighted and weighted total scores were tabulated. Of the five concepts, the dual-motor wheel design and the swivel-only concepts had the two highest scores. While both of these concepts excelled in more customer requirements than those in which they fared poorly, the dual-motor wheel design excelled in categories that were more important to ErgoQuest. Our team decided that the dual-motor wheel design was the best design for the MMRP concept.

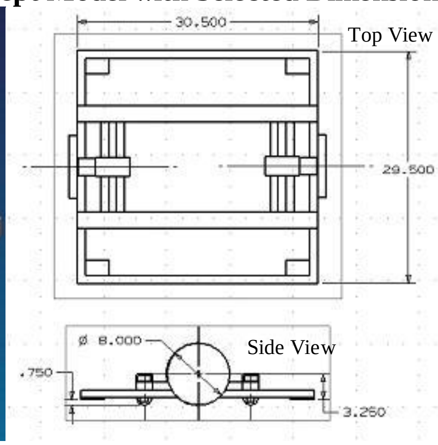
Fig. 16: Pugh Diagram Comparing Base Design Concepts

	Importance	Dual Motor Wheel Design (Datum)	Dual Motor Tank Design	Swivel Rail System	Swivel-Only	Insect Platform
						
Forward and Backward Motion	10	S	S	S	-	+
Ability to Rotate	7	S	-	+	+	-
Side to Side Motion	2	S	-	+	-	-
Chair Elevation	8	S	-	S	S	-
Footprint of Frame	8	S	-	-	S	-
Power Supply	9	S	-	-	-	-
Product Weight	2	S	-	-	+	-
Cost	10	S	-	-	S	-
Control	9	S	-	+	+	S
Wheel Design	7	S	+	S	S	S
Ease of Use	7	S	S	+	+	S
Interchangeable Components	1	S	-	S	S	S
Base Design	3	S	S	S	S	+
Weight Capacity	9	S	+	-	+	S
Off-the-shelf Components	9	S	-	+	S	S
Material Type	4	S	S	S	+	S
Appearance	3	S	+	+	+	+
Durability	8	S	+	-	S	-
Manufacturability	2	S	-	S	S	-
Safety	9	S	-	S	S	-
Total +		0	4	6	7	3
Total -		0	12	6	3	10
Total		0	-8	0	4	-7
Weighted Total:		0	-46	-9	20	-49

Along with the dual-motor wheel design's strengths, the concept also has design heritage. A similar design is currently used for the MMRP, so ErgoQuest will be familiar with the manufacturing tasks, which may reduce manufacturing errors. The prototype is battery powered to eliminate any cords coming from the base that might interfere with the MMRP motion, which is also the power source on the current MMRP. The frame is made from steel for added strength. Our original frame concept was modified to allow for clearance and spatial requirements of the reclining chair. A CAD model of the modified frame is shown in Fig. 17 below, with some representative dimensions and component placements included.

Fig. 17: Dual-Motor Wheel Design Concept Model with Selected Dimensions





6.2 Motor Torque Transmission Concepts

One important aspect of our prototype's function is how the motor torque is translated to the wheel. Several concepts were available to us, ranging in price and complexity.

6.2.1 Drive wheels on motor shaft: The current MMRP uses motors to directly drive the wheels. The wheels are mounted on the end of the motor shafts so there is no need for extra components. This is a very simple and effective way to drive the wheels and makes assembly very easy. A sturdy motor is required to hold the weight of the MMRP though since all of the loading is applied directly to the motor shaft in this configuration. Such motors are often expensive since they contain internal bearings and shafts in order to be able to sustain such loads.

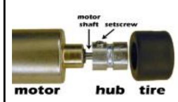
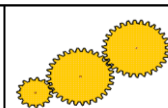
6.2.2 Straight shaft: This concept uses a straight shaft connecting the motor axle to the drive-wheel. This would apply the exact torque and angular velocity that the motor outputs. Bearings would be needed to support any vertical loads on the shaft, since the motor is not meant to support transverse loads. Also, this design would require a coupling method between the drive shaft and motor shaft. The shaft would have to be strong enough not to deflect a significant amount while the MMRP is fully loaded and also be able to handle the demanded torque.

6.2.3 Gear train system: The next concept is to use a gear train system. Gears would be used to translate the motor torque to the drive wheels. The gear train could also be used to modify the motor speed to a desired amount dictated by the speed we desire the MMRP to move at. This concept would require several mounts for the different gear sprockets.

6.2.4 Belt drive: The final concept involves the application of a belt drive system. A belt would connect a disk attached to the end of the motor with a disk attached to the drive wheel. This method could also change the motor force outputted by the motor into some desired amount at the drive-wheel. The belt would most likely be made of some firm rubber compound. The gear and disks would have to incorporate teeth between the disks and belt to prevent against slippage under high torque conditions.

6.2.5 Motor torque transmission concept selection: We used the Pugh chart shown below in Fig. 18 to compare each concept. The straight shaft was the selected method for translating the motor torque to the drive wheel. This method would be the least expensive and also the simplest to implement. The gear-train would be complicated to perfectly align and mount on our base and would take up more space. The belt drive would have similar spatial issues and the rubber could wear out over time. The gear and belt drive would also be more expensive than the straight shaft after all part and manufacturing costs are tallied. The drive wheels connected directly onto the motor shaft concept was not chosen due to the high cost of the required motors.

Fig. 18: Pugh Diagram of Motor Torque Transmission Concepts

	Importance	 Drive Wheels on Motor Shaft (Datum)	 Straight Shaft	 Gear Train System	 Belt Drive
Forward & Backward Motion	10	S	S	S	S
Ability to Rotate	7	S	+	-	S
Side to Side Motion	2	S	+	-	S
Chair Elevation	8	S	S	S	S
Footprint of Frame	8	S	S	S	S
Power Supply	9	S	+	+	S
Product Weight	2	S	+	+	S
Cost	10	S	+	-	-
Control	9	S	S	S	S
Wheel Design	7	S	S	S	S
Ease of Use	7	S	S	S	S
Interchangeable Components	1	S	S	S	-
Base Design	3	S	S	S	S
Weight Capacity	9	S	S	-	S
Off-the-shelf Components	9	S	-	S	S
Material Type	4	S	S	S	S
Appearance	3	S	S	-	-
Durability	8	S	-	-	-
Manufacturability	2	S	-	-	-
Safety	6	S	S	S	S

Total +	0	5	2	0
Total -	0	3	7	5
Total	0	2	-5	-5
Weighted Total:	0	11	-30	-24

6.3 Battery Concepts

One of the customer requirements of the MMRP is that it be powered by batteries. Since the user could potentially get the wheels caught in a power cord plugged into the wall, it was decided that batteries should be used to power the MMRP.

6.3.1 Battery power concepts: There are two main circuit configurations that could be used to power the MMRP. Each motor could be powered with its own battery or the two motors could both be run from the same power source. Using a single power source simplifies the circuitry and reduces the number of required components. A single power source can be achieved two ways; either using a single powerful battery, or wire two smaller batteries in series. According to Kirchhoff's Voltage Law, connecting two 12 V 10 Ah batteries in series will produce 24 V while maintaining a total charge of 10 Ah. The use of two 12 V batteries can reduce the cost of the power source while simultaneously simplifying the wiring.

The type of battery is also important. Non-rechargeable and rechargeable batteries are available. Non-rechargeable batteries are not acceptable for the MMRP due to the customer requirement to minimize maintenance frequency. Rechargeable batteries are available as nickel-cadmium (NiCad), nickel-metal hydride (NiMH), lithium ion, or lead acid. NiCad batteries are good rechargeable batteries but often have a “memory” effect. This is when the battery is recharged before being completely discharged and the capacity of the battery decreases each time this occurs.

6.3.2 Battery concept selection: In order to simplify the circuitry and reduce the cost of components, we decided to run both motors off the same power source. Using two batteries in series is also a more cost effective solution than using a single larger battery. The cost of the MMRP is the most important design criterion from the customer so we have chosen to use two batteries in series to power the MMRP.

Lithium ion and NiMH batteries are expensive, therefore they were not chosen. NiCad batteries were not chosen due to the memory effect. Rechargeable lead-acid batteries are common and are less expensive, though less environmentally friendly. We chose to use lead-acid batteries since cost was the most important requirement.

6.4 Directional Motor Control Concepts

Due to the decision to use the dual-motor configuration, it was necessary that the control device fully utilize the capabilities of the motors to move the MMRP in multiple directions. It does so by operating both motors simultaneously or individually and in both the forward and reverse directions to allow for 360 degree rotation. When choosing the best concept or type of directional control for the MMRP ease of use, quality of control output, simplicity of design, and low cost were the primary selection criteria. To physically control the direction of travel for the user, a number of options were considered.

6.4.1 Toggle or rocker switches**:** The simplest method of direction control would be to use two toggle or rocker type switches, with one being used for each motor. These switches are required to be the on-off-on type where for each motor, one direction is used for forward motion and one direction is used for reverse motion. It was best to have switches which automatically move back to the center “off” position so that neither motor is accidentally left in the forward or reverse positions. Examples of potential toggle and rocker switches are shown below in Fig. 19 and Fig. 20, respectively [9, 10]. Large varieties of switch styles are available and range in price from about $2 to $20 each.

Fig. 19: Toggle Switch-On/off/on, self-neutral

Fig. 20: Various Rocker Switches

These two switches could be placed side by side so that the user can easily control both switches with one hand or offer the flexibility to place the switches on opposite sides of the wheelchair and allow two-handed operation if desired. The user may push both switches forward to drive the chair forward or choose one switch to turn the chair. Moving the two switches in opposite directions would allow the user to spin the chair 360 degrees in either direction.

6.4.2 Switch style joystick**:** Another option was to use a simple joystick similar to those used for computer games. These come with the option of two, four, and eight directional switching. The major advantage of using a joystick over two toggle type switches is the improvement in the ease of use, since one device could be used to control both motors at the same time with all the same functionality of the two toggle switches. This type of joystick varies in cost from $20 to $240 each and a standard low cost switch type joystick can be seen in Fig. 21 on pg. 17 [11, 12].

Fig. 21: Typical Switch Style Joystick: ETI Systems J1001 "Switch Stick"

***6.4.3 Potentiometer joystick*:** When performing our market research of traditional wheelchairs we found many used joysticks with potentiometers that can control the speed directly within the joystick. These types of joysticks vary greatly in cost from $75 to over $400. The major differences are in the ability of the joystick to use the full potentiometer as a voltage divider to regulate speed versus only a percentage of the 340 degree potentiometers from the 45 to 70 degrees of motion in the joystick. The output varies greatly and can be very precise from these types of controls. While there are a number of joysticks with built in potentiometers available in the lower price range of these devices, the drawback is that most have a maximum input voltage of 10 V or 12 V [12]. Therefore for our 24 V motors, whose selection is detailed in section 7.3, potentiometers must be used in conjunction with a motor controller which we are trying to avoid due to the increased cost and more complex designs.

***6.4.4 Directional control concept selection*:** In order to provide the user with a simple and easy to use control that has good control output at a low cost, a potentiometer-type joystick would not be feasible due to its high cost. While both switch-type joysticks and two on/off/on self neutral toggle switches used together would provide the necessary directional control we believe the advantages of using a joystick over dual toggle switches offsets the small cost difference. The joystick is easy to use and the learning curve is less than that of dual toggle switches. By continuing to use a joystick the actual feel to the user for the redesigned MMRP is very similar to the current MMRP and other motorized wheel chairs on the market. Therefore a switch-type joystick was used.

6.5 Motor Speed Control Concepts

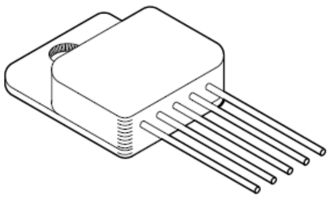
The speed at which the motors operate is another important factor in controlling the MMRP's movement. The basic means of controlling the motors' speed and thus the speed at which the MMRP will move comes from varying the voltage the motor receives. It was necessary that the MMRP's speed control was capable of allowing both a faster and a slower speed for fine control. We determined several ways this could be accomplished.

***6.5.1 Rheostat*:** The first and most basic way to do this is with a rheostat. A rheostat is similar to a potentiometer but is usually larger and capable of handling higher currents and voltage. It dissipates voltage from the battery, thereby reducing the voltage sent to the motor. The amount of voltage it dissipates can be controlled by the rheostat dial seen in Fig. 22. The voltage is dissipated in the form of heat over the resistor. One downfall to this method of speed control is that the heat coming from the rheostat may be felt by the user. Rheostats vary in the amount of voltage they can handle and resistance delivered, and can be found for under $10 [13].

Fig. 22: Knob Style Rheostat Dial [14]

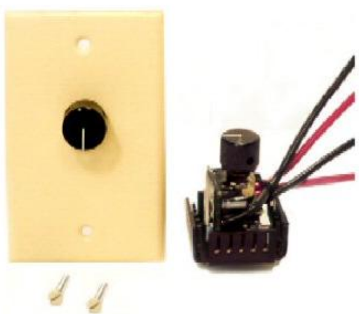
***6.5.2 Adjustable voltage regulator*:** The second method to control speed without a direct controller would be to use an adjustable voltage regulator, Fig. 23 below, in conjunction with a potentiometer. The potentiometer or rheostat dial still dictates how much voltage is burnt off, and therefore how much voltage sent to the motor. Now, instead of the voltage being dissipated at the potentiometer near the user's hand, it is rejected down at the voltage regulator. Adjustable voltage regulators range in price from $0.45 to over $100, and come in a variety of voltage and current ratings [15].

Fig. 23: Adjustable Voltage Regulator



***6.5.3 Lighting dimmer switch*:** The third method that could be used to easily control the speed would be to use a dimmer switch to vary the voltage provided to the motors. These would be simple to install and cost from $40 to $100 for a 24 V DC model with enough current. A typical dimmer switch can be seen in Fig. 24 [16].

Fig. 24: Lighting Dimmer Switch



***6.5.4 Motor controller*:** Traditional wheelchairs use a motor controller which directly regulates the current and voltage supplied to the motors. These come in a large variety of sizes and types but typically require a signal to be sent to the motor controller either by a computer code or by the use of a potentiometer type joystick as discussed before. This option is more complex than the previously discussed options and cost from $25 to over $400 [17].

***6.5.5 Speed control selection*:** Traditional wheelchairs use an expensive motor controller which is used in conjunction with a potentiometer joystick or other handle bar type controls to command both direction and speed. Low cost motor controllers do exist; however, they generally cannot handle the necessary current and require a more costly potentiometer joystick as well. In order to significantly reduce costs, we would like to eliminate the motor controller by using a separate directional and speed control device. The rheostat option is not feasible due to the heat loss being at the user's fingers as well as the lack of high current and high voltage rheostat products. Therefore only the adjustable voltage regulator and the dimmer switch are good options for low cost and simple speed control.

7. COMPONENT SELECTION AND ENGINEERING JUSTIFICATION

Many components must be selected to complete the redesign of the MMRP. Each must be engineered specifically for the desired use of the MMRP while maintaining standards of reliability, manufacturability, and cost effectiveness. The electrical and mechanical parts must be compatible and the whole system must be easy to assemble and maintain.

We first designed the base and its supports to handle the design loads and support all of the components that are mounted to it. We then specified the motors, for which we needed to determine the appropriate amount of torque to move the MMRP. Next, we considered the batteries to power the motors, the joystick to control the motor direction, speed control, and the wiring to connect and operate the electrical components. We also needed to analyze the loadings and specifications for the auxiliary components. Dimensioned drawings for custom parts and datasheets for purchased components are shown in the Appendix beginning on pg. 47.

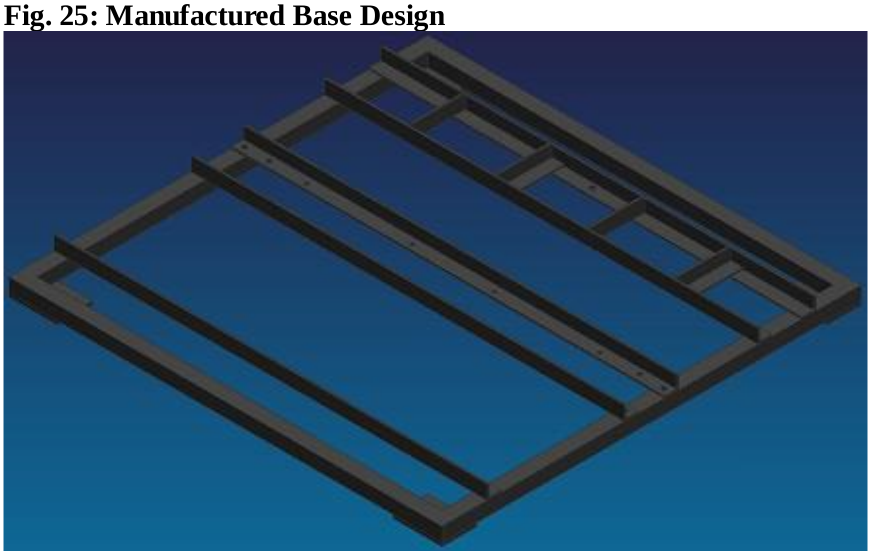
7.1 Base Design Selection

The base of the MMRP must hold the weight of the user and the recliner chair. It must also hold all the components securely and provide structural stability to the system.

7.1.1 Specifying the base design: We based our design on ErgoQuest's original base that was made to hold the 350 lb weight of the user and chair. The cross pieces of the frame needed to be modified to fit our specific chair, however. They needed to secure the motor and bearing mounts, the casters, and the batteries. It all needed to be designed for easy manufacturing and had to be as inexpensive as possible.

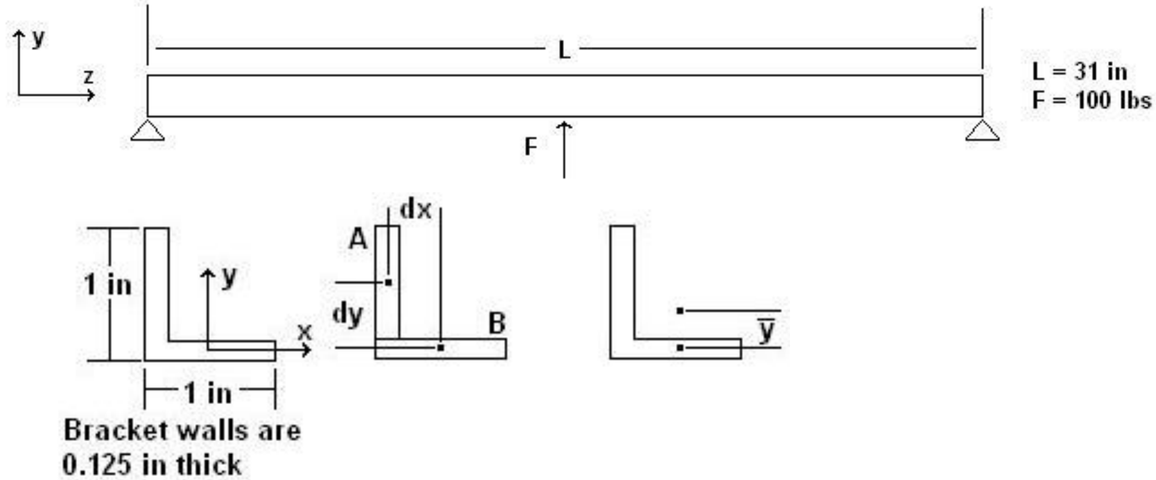
7.1.2 Selecting the base design: In order to save time and resources we chose to use much of the original design. The main frame, shown in Fig. 25, is made of welded one inch square tube steel. Dimensioned drawings of the base are shown in Appendix 16.8.1, pg. 56.

Fig. 25: Manufactured Base Design



The feet of the chair rest on 0.25 inch thick steel plates. The cross pieces are made from one inch angle steel with 0.125 inch thickness. Five of these are used to secure the motors, batteries, casters, and auxiliary components. The angle brackets were designed for a caster load of 100 lbs including a factor of safety. The bending stress analysis of the angle brackets is shown on pg. 20.

Angle Bracket Bending Load Analysis:



$$\sigma_z = \frac{M_x \bar{y}}{I_x}$$

$$I_{xA} = \bar{I}_{xA} + A_A dy_A^{\,2} = \frac{1}{12} b_A h_A^{\,3} + b_A h_A dy_A^{\,2}$$

$$I_{xA} = \left(\frac{1}{12}\right)\left(\frac{1}{8}in\right)\left(\frac{7}{8}in\right)^3 + \left(\frac{1}{8}in\right)\left(\frac{7}{8}in\right)\left(\frac{1}{2}in\right)^2 = 0.0353in^4$$

$$I_{xB} = \bar{I}_{xB} + A_B dy_B^{\,2} = \frac{1}{12} b_B h_B^{\,3} + A_B dy_B^{\,2}$$

$$I_{xB} = \left(\frac{1}{12}\right)(1in)\left(\frac{1}{8}in\right)^3 + (1in)\left(\frac{1}{8}in\right)(0in)^2 = 0.000163in^4$$

$$I_x = I_{xA} + I_{xB}$$

$$Ix = 0.0353in^4 + 0.000163in^4 = 0.0355in^4$$

And

$$\bar{y} = \frac{\Sigma \tilde{y} A}{\Sigma A} = \frac{dy_A A_A + dy_B A_B}{A_A + A_B}$$

$$\bar{y} = \frac{\left(\tfrac{1}{2}in\right)\left(\tfrac{1}{8}in\right)\left(\tfrac{7}{8}in\right) + (0in)(1in)\left(\tfrac{1}{8}in\right)}{\left(\tfrac{1}{8}in\right)\left(\tfrac{7}{8}in\right) + (1in)\left(\tfrac{1}{8}in\right)} = 0.233in$$

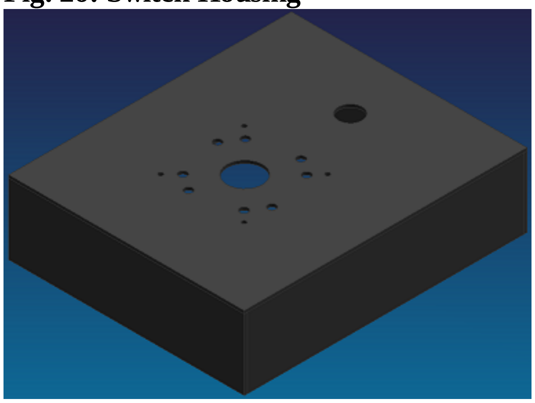
Therefore

$$\sigma_z = \frac{M_x \bar{y}}{I_x} = \frac{(100lbs)(15.5in)(0.233in)}{0.0355in^4} = 10{,}200psi$$

We calculated the stress to be 10,200 psi yielding a safety factor greater than five when compared to the steels rated yield stress of 53,700 psi.

7.1.3 Switch housing: The directional control and battery charge switches both require mounting to the MMRP. This was the task of the switch housing box, shown in Fig. 26 below. We designed this from 0.0625 inch mild steel plate. The housing is mounted to a 19 inch long, inch x inch steel square tube welded to the base (not shown in Fig. 25). It was necessary to allow plenty of space inside the box to run the wiring to both the directional controller and battery charging switch, and also the mounting post. The box has five sides – one top plate for the switch mounting and four side plates. We did not put on a bottom plate to facilitate easy assembly. The controller was placed toward the back of the plate, and the battery charging switch toward the front so that the user does not inadvertently hit the charging switch while operating the MMRP. A dimensioned drawing of the switch housing is shown in Appendix 16.8.4 on pg. 60.

Fig. 26: Switch Housing



7.2 Support Design Selection

The MMRP is supported by two drive wheels and two casters. Splitting the load equally between these four wheels requires each to hold approximately 100 lbs at any given time.

7.2.1 Specifying the supports: The radius of the drive wheels determines the torque required of the motors, so smaller wheels are desirable. Due to the geometry of the recliner the MMRP is meant to carry, the casters must be mounted at the same height as the main base. The casters we chose hold 100 lbs each and have a two inch diameter. Smaller casters cannot hold the necessary weight while larger ones raise the base above the allowed maximum of two inches. The drive wheel selection is further discussed in Section 7.8.

7.2.2 Selecting the casters: Standard casters were chosen that are rated for 100 lbs and have a two inch diameter. They are mounted by a single bolt and are mounted three inches off the ground. They were purchased from Lowe's for $4.50 each [18].

7.3 Motor Selection

The MMRP must be able to move under a variety of loaded conditions. In order to evaluate the torque required of the two motors, some preliminary testing was necessary. Once the testing was completed the motors were specified based on the speed and torque required to move the loaded MMRP according to the customer design specifications.

7.3.1 Preliminary testing: The MMRP redesign team went to two locations to perform tests to determine the amount of force required to move a load similar to that expected of the MMRP. A force gauge was attached to four different carts which were each loaded with two different amounts of weight. A photo of one testing condition is shown in Fig. 27 on pg. 22.

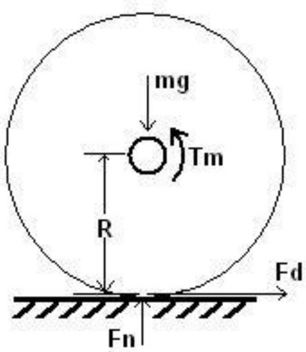
Fig. 27: Example cart testing setup

The carts were placed on a rough parking lot and then pulled by a rope, parallel to the ground, attached to the other end of the force gauge. A rough surface was used so that the measurements had an inherent safety factor over the intended use of the MMRP on a smoother, carpeted or hardwood floor. The minimum force required to move the carts from a stationary position was measured several times under 300 lb and 470 lb loads with two different wheel configurations. The first configuration had the wheels initially set parallel to the direction of motion.

The second configuration started with the casters turned perpendicular to the direction of motion to simulate a worst-case scenario. After turning the MMRP during normal use, it is possible that the casters could be oriented this way, so this condition must be accounted for in the redesign. The same tests were repeated for a loaded shopping cart on three types of carpeting to more accurately simulate the intended use of the MMRP. Over all cases it was found that the maximum force required to move the MMRP from a stationary position was 50 lbs Most testing conditions required forces between 25 lbs and 35 lbs but designing with 50 lbs in mind adds a comfortable safety factor under a wide range of loads.

7.3.2 Specifying the motor: The torque and speed of the motors were determined by the size of the drive wheels. The casters mount to the base three inches above the floor. Since the motors are mounted to angle brackets at the same height as the casters, the bottom of the motors must also mount no lower than three inches above the floor. This dictates a minimum drive wheel radius of three inches. A free body diagram of one drive wheel, Fig. 28, is shown below.

Fig. 28: Free Body Diagram of Drive Wheel



The weight of the chair and user, *mg*, and the normal force from the floor, F_n, cancel each other out and there is no acceleration in the vertical direction. The force required to move the MMRP, F_d, is applied by the motor torque, T_m, at the floor. Eq. 1 relates the motor torque to the driving force and the radius.

$$T_m = F_d \times R \qquad \text{(Eq. 1)}$$

In order to save money on motors, we aimed to select a motor with as small a torque as possible as higher torque motors cost more. Since larger wheels demand larger torques of the motor, we needed to choose as small a wheel as possible. Table 3 below shows the required torque associated with different drive wheel sizes.

Table 3: Increasing Wheel Size Increases Required Torque

Drive Wheel Size (inches)	Required Torque to Move MMRP (in-lbs)
3.0	150.0
4.0	200.0
5.0	250.0

Setting F_d equal to 50 lbs, from the preliminary tests, it was then determined that a wheel with a four inch radius would require a motor with a minimum stall torque, T_m, of 200 in-lbs in order to move the MMRP under a fully loaded condition. A three inch wheel had the smallest required torque. However, accounting for the dimensions of the motors as mounted on top of the angle brackets, a three inch radius drive wheel would not reach the floor. In the end, a four inch radius was chosen because it is a standard size that enabled easy mounting of the motors and kept the torque requirements as low as possible.

The engineering design specifications dictate that the MMRP be able to move at a minimum speed of two in/sec and a maximum speed of eight in/sec. Eq. 2 below was used to calculate the motor speed needed to achieve this motion.

$$\omega(RPM) = \frac{v(in/\sec)}{R(in)} * \frac{1(rev)}{2\pi(rad)} * \frac{60(\sec)}{1(\min)} \qquad \text{(Eq. 2)}$$

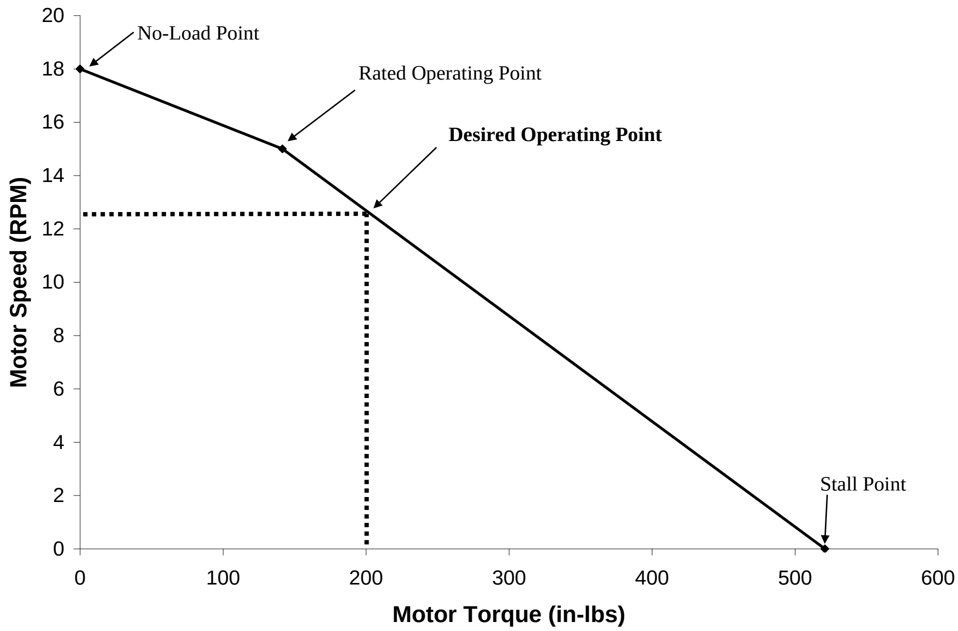
Here ω is the output speed of the motor in revolutions per minute (RPM), v is the linear velocity of the MMRP, and R is the wheel radius. Using the four inch wheel radius and a linear velocity of eight in/sec it was calculated that the motor must be able to produce the required torque at a maximum speed of 19 RPM.

7.3.3 Selecting the motor: We searched online for DC gear motors from a variety of suppliers. Many motors we found were either too fast or too expensive. An exception to this was Anaheim Automation, who supplies many planetary gear motors with internal gearboxes that can deliver the necessary torque and speed at lower costs [19]. It was decided that the Anaheim Automation Model no. BDPG-60-110-24V-3000-R168 would be an appropriate fit for the MMRP. A similar motor is shown below in Fig. 29.

Fig. 29: Similar Planetary Gear Motor

With a stall torque of 520 in-lbs and a rated speed of 15 RPM for $97.20 this 24 V DC motor is adequate for the MMRP redesign. At 200 in-lbs the motor runs at 12.7 RPM as shown on the motor curve in Fig. 30 on pg. 24. This will cause the MMRP to move at 5.3 in/sec, which is acceptable for most applications. Detailed dimensions and information of the motor can be seen in Appendix 16.2 on pg. 48.

Fig. 30: Motor curve shows sufficient torque and speed at the desired operation point



7.4 Battery Selection

We decided to use lead acid batteries in the concept selection and the appropriate battery has been chosen based on voltage and charge.

7.4.1 Specifying the batteries: The main components drawing power from the batteries are the two motors. The motor specifications dictate the battery specifications. The motors require 24 V DC power and 2.2 A at the rated speed. Extrapolating the current to the stall torque gives a required current of 8.7 A for each motor at peak. Including a 15% safety factor, the batteries must be able to provide 10 A to run the motors at peak. To start both motors at once therefore briefly requires a total of 20 A. Estimating that the MMRP will be used for an average of one minute per use, at 10 A for each motor, the batteries must each have a capacity of 10 Ah to run the motors for one hour, or 60 uses. Since the motors do not draw 10 A while running, this is an underestimate of the batteries lifetime. This allows the user to move in and out from the computer desk a minimum of 30 times before the batteries must be recharged. Considering the current MMRP uses 30 Ah batteries that last for up to four weeks under its intended use, a capacity of 10 Ah should be enough to accommodate any user for at least one day before the batteries need to be recharged. ErgoQuest currently instructs its customers to recharge their MMRP everyday despite the level of charge remaining. Combining this practice with long-lasting batteries will allow the user to have adequate charge to power the MMRP whenever needed.

7.4.2 Selecting the batteries: After searching the inventory of several battery manufacturers and distributors, it was found that 24 V batteries are much more expensive and are somewhat rare compared to lower voltage models. A certain 24 V battery with a capacity of 18 Ah sells for more than $230.00 each [20]. Since the cost of the MMRP is one of the most important design requirements, this battery is unacceptable. Very few batteries were located with the necessary voltage and even fewer were found with the necessary capacity. It was decided that a cheaper solution would be to simply wire two 12 V batteries in series. The selected battery is shown in Fig. 31 on pg. 25.

Fig. 31: B. B. Battery 12 V, 12 Ah Rechargeable Battery

According to Kirchhoff's Voltage Law, wiring two 12 V 10 Ah batteries in series will produce the 24 V needed to run the motors while maintaining a total capacity of 10 Ah. The Digi-Key Corporation sells a rechargeable 12 V, 12 Ah battery for $49.21 each [13]. This is within budget and is a good choice for the redesign of the MMRP. A datasheet for the batteries is shown in Appendix 16.4, pg. 51.

7.5 Battery Charger Selection

The batteries are rechargeable and therefore require a battery charger to be charged.

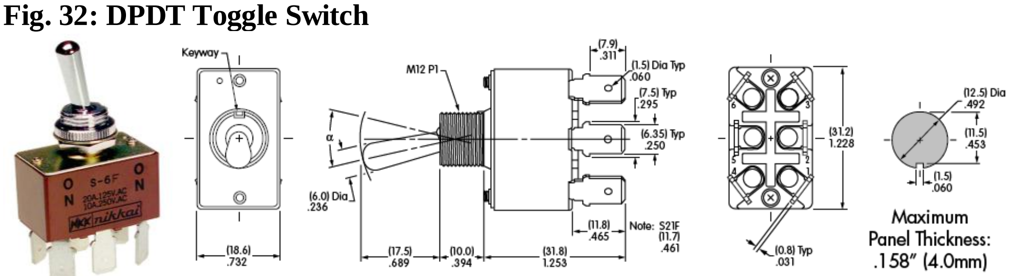
7.5.1 Specifying the battery charger: The charger is dependent on the batteries' terminal type. The batteries we chose have 0.25 inch spade terminals. The charger must be able to interface with these. The charger must also be able to charge two 12 V batteries at once and must be able to do so overnight.

7.5.2 Selecting the battery charger: The charger we chose, Battery Wholesale's CH-120500 for $13.95 [21], is designed to charge 12 V batteries. It is a trickle charger so it only imparts a small amount of current and can slowly charge two batteries at once. To connect the charger to the batteries, we require the use of a switch to change the batteries from series to parallel connection for charging. This enables us to wire the batteries in parallel to charge both batteries at once, discussed further in Section 7.14.

7.5.3 Battery charger switch selection: A double-pull-double-throw toggle (DPDT) switch was included in the circuitry to allow easy switching between charging the batteries in parallel and running the motors in series. This means that the battery charger is always wired to the wheel chair circuitry so all the user has to do to charge the MMRP is plug the charger into the wall and switch the toggle switch to the "charge" configuration. When the user is ready to use the MMRP, they change the toggle switch to the "run" configuration and will have the two batteries attached in series providing the full 24 V to the motors. This switching scheme requires the DPDT configuration. For more details on the specific wiring see the wiring schematic in Section 7.14 on pg. 30.

It was necessary that the DPDT switch handle 10 A, 12 V DC, and 120 VAC since it will be connected directly to the 120 V AC power from the wall. The NKK Switches of America S6F-RO 20 A On/On DPDT Toggle Switch shown below in Fig. 32 was selected. It has a low cost of $7.15 from Digi-Key and also has 0.25 inch spade connectors that match the battery and joystick, so similar fasteners can be used throughout the MMRP [13].

Fig. 32: DPDT Toggle Switch

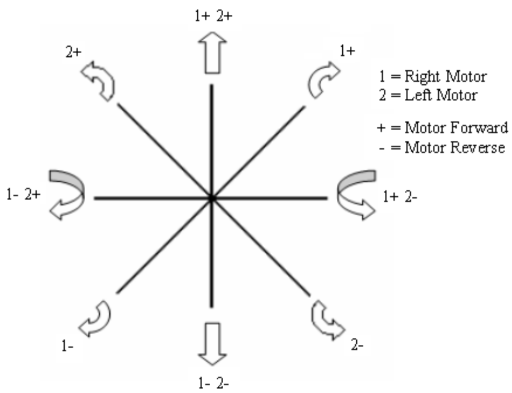


7.6 Directional Motor Control Selection

The MMRP's directional control device must be able to provide the full range of motion as well as handle the electrical requirements dictated by the motors. It was previously decided, in Section 6.4.4 on pg. 17, to use a switch-type joystick. Now, the control specifics of the joystick and the chosen model will be discussed.

***7.6.1 Specifying the directional motor control*:** In order to provide the full eight directions of control – forward, reverse, forward right, forward left, reverse left, reverse right, spin clockwise 360 degrees, and spin counter clockwise 360 degrees – it is necessary that each motor can be operated in either direction both individually or simultaneously. The controller provides the requested motion by commanding the motors in the proper direction as seen in the directional switching schematic in Fig. 33 below. This requires the controller to have four separate switches. Due to the use of a 24 V motor with a maximum current draw of 10 A, the switch-type joystick must meet the resulting electrical demands. It is required that the chosen joystick offers the eight directions of control and each of the four switches handle a minimum of 24 V in DC and a current of 10 A.

Fig. 33: Schematic of Motors Directional Switching



***7.6.2 Selecting the directional motor control*:** The two primary joysticks we compared were the ETI Systems J1001 Low Profile "Switch Stick" Joystick and the APEM 100114 Switch Joystick. The ETI Systems joystick has four 5 A, 250 V AC SPST switches and is available for $20.66 from Newark. This joystick would be available with 10 A or higher current switches for a high volume order or by replacing the switches included with inexpensive higher current switches [12].

The only switch-type joystick we were able to find that met the current and voltage requirements was the APEM 100114 Switch Joystick shown in Fig. 34 below. This joystick has four 10 A, 250 V AC Switches and is available from Newark for $20.13 plus an additional handling charge because they are produced in the United Kingdom. It was decided that the APEM 100114 Switch Joystick would be the most appropriate directional motor control for the MMRP. See Appendix 16.3 on pg. 49 for the APEM Switch Joystick Datasheet for more information [12].

Fig. 34: APEM 100114 Switch Joystick

7.7 Motor Speed Control Selection

The MMRP's speed control device must be able to reduce the motors' voltage to a more appropriate level for slower speeds as well as meet the electrical requirements dictated by the motors.

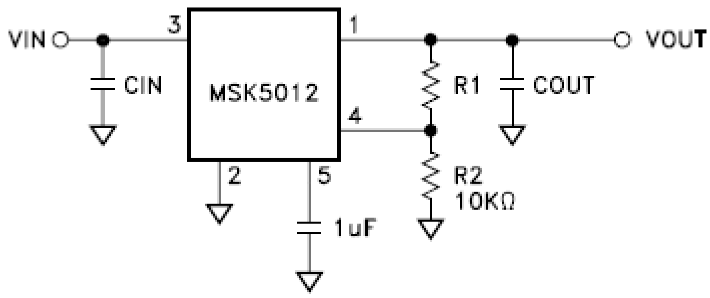
***7.7.1 Specifying the motor speed control*:** The requirements for speed control are that it can handle 24 V DC and up to 10 A for each motor or 20 A total. Since it was previously decided to use either an adjustable voltage regulator or a dimmer switch either of these motor speed controllers must be capable of handling the 24 V DC and 10 A as well as be able to dissipate the heat to reduce the 24 V down to a more appropriate level around 10 to 16 V that will provide the lower speed level desired.

If one dimmer switch or one adjustable voltage regulator were used it must be able to handle 20 A. Since many of these devices cannot handle up to this current either two dimmer switches or two adjustable voltage regulators could be used each with a rated maximum current of 10 A, one for each motor. The main requirement for this option is that the speed regulation is adjusted equally so that both motors will move the MMRP at the same speed. This is achieved by using a dual channel potentiometer so that one dial controls both circuits separately. With the adjustable voltage regulator the potentiometer must be purchased separately so this is easily achieved; however, for the dimmer switches the potentiometer dial is included so this would require removing and purchasing a separate dual channel potentiometer and re-wiring the dimmer switch.

***7.7.2 Selecting the motor speed control*:** When considering the adjustable voltage regulator option, it was found that the adjustable voltage regulator produced by M S Kennedy cost $98.00 each for the 10 A version, MSK5012, or $140.00 for the 20 A version, MSK5021. The MSK5021 version would require only one regulator, so it would be a cheaper solution. The M S Kennedy devices have a high cost because none of the parts are plastic due to the aerospace applications for which they are made [22]. There are Adjustable Voltage Regulators available from Mircel such as the MIC29712BC which is available for $13.61 [23] and works in the same fashion as the MSK chip. The drawback of this chip is that the maximum current is 7.5 A so we would be required to use this chip in conjunction with a current regulator or some type of resistor in parallel to reduce the maximum current to 7.5 A [22].

The MSK5012 pictured below is adjustable from 1.3 V to 36 V and can handle 10 A making it appropriate for our application. The MSK5012 voltage regulator adjusts the output voltage through a voltage divider by using a potentiometer attached between pins 1 and 4 in Fig. 35, below. This is a low-cost potentiometer due to the small current and power seen by the potentiometer. It is important to note that the MSK 5012 chip also requires a 1.0 μF capacitor attached from pin 5 to the ground and a 10 kΩ Resistor, R1, as part of the voltage divider. Additionally calculations would be required to determine the necessary heat sink required to dissipate the heat generated by the chip [22]. The MSK5021 works in the same way and has similar requirements for a potentiometer, capacitor, and resistor. Due to a lower associated cost than that of two MSK5012 chips this would be a better alternative.

Fig. 35: MSK 5012 Wiring Schematic



Dimmer switches are also available from a wide range of companies that are capable of 24 V DC and both 10 A and 20 A currents. Platinum Lighting makes a variety of 24 V DC rotary dimmers such as the ADM-54L-24V 11 A DC dimmer for $55.83 [24]. Two of these could be used with a dual channel potentiometer as discussed before.

A better option is the 0 to 10 A rotary dimmer switch model IMT-ILDIM-ROT10 available from SailorSams.com for $65.55 pictured below in Fig. 36. It is specified that the max continuous current is 10 A; however here the maximum surge current of 5 seconds is specified as 40 A and a maximum surge current of 0.01 seconds as 80 A [25]. We could use this model to provide our speed control for a lower cost. It is also very simple to wire and does not require purchasing additional resistors, capacitors, or heat sinks, making it a good choice.

Fig. 36: IMT-ILDIM-ROT10 Dimmer Switch

Since a motor was chosen for this prototype that provides an expected operating speed of 5.3 in/sec, it was decided that, for the purpose of building our prototype, none of the discussed adjustable speed controllers should be used. However, this did not affect the overall quality of the prototype because the MMRP's speed can be adjusted by regulating the voltage supplied to the motors when operating in charge mode as discussed in Section 7.14.1.

7.8 Drive Wheel Selection

Given the four inch radius requirement, we searched online for suppliers of drive wheels.

7.8.1 Specifying the drive wheels: The wheels needed to have a 0.5 inch bore with a 0.125 inch keyway to be compatible with the drive shaft, couplers, motors, and bearings described later in this report. They had to be able to support 200 lbs each which includes a factor of safety of two. They must not be inflatable to comply with the decreased maintenance frequency customer requirement.

7.8.2 Selecting the drive wheels: The selected drive wheel pictured in Fig. 37 below, part number NPC-PT318, was purchased from The Robot Marketplace for $25.50 each. Specifically, the two wheels were eight inches in diameter, with 0.5 inch bore for the drive shaft, and a 0.125 inch keyway. The wheels are solid rubber and can handle a load of 200 lbs each [26].

Fig. 37: NPC-PT318 Drive Wheels

7.9 Drive Shaft Selection

Since the motor alone cannot support the weight of the MMRP, a drive shaft supported by bearings is needed to transmit the power from the motor to the drive wheels. The motor's shaft diameter is 0.5 inches. In order to facilitate coupling between the motor and wheels, a 0.5 inch diameter 7.5 in long AISI 1045 Steel drive shaft was chosen. It is fully keyed with a 0.125 inch keyway compatible with the motor and drive wheels. The drive shafts were purchased as one 18 inch length rod, Model No. 1497K953, from McMaster-Carr and will be cut to length to save money on materials. The shaft sustained the expected moment of 750 in-lbs. It also was able to handle the required motor torque of 200 in-lbs required of the MMRP. A detailed analysis of the bending stress on the shaft can be seen in Appendix 16.5, pg. 53.

7.10 Coupler Selection

Couplers are used to attach the drive shaft to the motor shaft. Couplers with two different bores are much more expensive than single bore models so a coupler with a 0.5 inch bore was used to match the drive shaft and motor shaft. Two included set screws are used to hold the coupler on the shafts. A datasheet adapted from that available from McMaster-Carr is shown below in Fig. 38. The couplers, Model No. 6412K41, can take a maximum torque of 473 in-lbs and a maximum speed of 3450 RPM [27]. They were chosen for their low cost and compatibility with the other components.

Fig. 38: Coupler Information Provided by McMaster-Carr

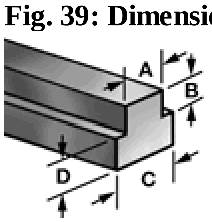
Bore	Lg.	OD	Screw Size	Steel Max. rpm	Steel Max. Torque, in.-lbs.		Each
With ANSI Keyway							
1/2"	1 1/2"	1"	1/4"-20	3450	473	6412K41	$9.16

7.11 Key Stock Selection

The drive shaft, couplers, and drive wheels all have a 0.125 inch keyway. To fill this keyway and to keep the individual components from spinning independently a 0.125 inch key is required. We chose a standard 0.125 inch square alloy 360 brass key, 12 inches in length, Model No. 98500A100, also available from McMaster-Carr. It is cheap and easy to cut and will fill all of the keyways. With a tensile strength of 50 ksi, the brass is strong enough to handle the MMRP's applications [27].

For the motor, a stepped key is required due to the motor's shaft keyway being in metric units while the coupler's keyway is in English units. The dimensions of the required keyway, shown in Fig. 39 below, are A = 0.124 inches, B = 0.080 inches, C = 0.159 inches, and D = 0.077 inches. Due to the irregular size, we were required to machine this key on a mill for each of the two motors.

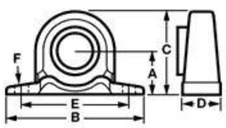
Fig. 39: Dimensions of Motor to Coupler Keys



7.12 Bearing Selection

Two bearings are used on each shaft to support the weight of the MMRP. The bearings, Model No. 5913K41, were chosen from McMaster-Carr because of their low cost and to save on shipping by ordering all components at once from a single supplier. A datasheet adapted from that available from McMaster-Carr is shown in Fig. 40 on pg. 30.

Fig. 40: Bearing Information Provided by McMaster-Carr



For Shaft Dia.	Ctr. Ht. (A)	Dyn. Load Cap., lbs.	Max. rpm	O'all Lg. (B)	O'all Ht. (C)	Base Wd. (D)	Ctr.-to-Ctr. (E) Min.	Max.	Bolt Slot (F), Lg. x Wd.		Each
Steel											
1/2"	7/8"	2110	5500	3 3/8"	1 3/4"	1"	2 1/2"	2 7/8"	1/2" x 5/16"	5913K41	$10.95

The bearings can handle a maximum speed of 5500 RPM and mount to the drive shaft securely with two set screws [27]. They are also manufactured to allow three degrees of misalignment. This is especially helpful since it eases the requirement on precision machining. A dimensioned drawing of the bearing provided by McMaster-Carr is shown on Appendix 16.6, pg. 54. In order to align the bearings at the height of the drive shaft, it was necessary to mount them on 0.25 inch spacers.

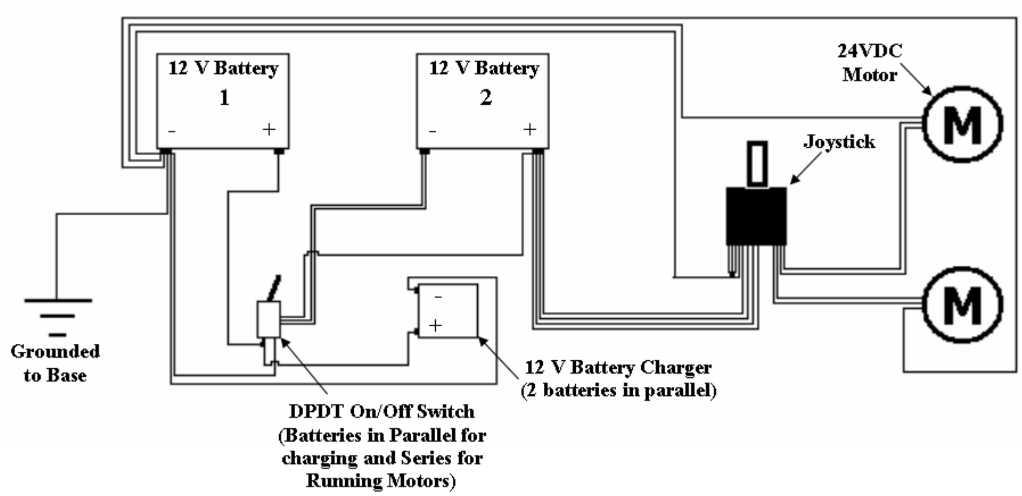
7.13 Wire Selection

For the electrical wiring in the MMRP we chose Single-Conductor Machine Tool Wire (MTW) 10 A, 16 AWG, 0.120" OD, 600 V DC, McMaster Part Number 71245K2, at $17.33 per 100 feet [27]. In order to simplify the wiring and use the standard color scheme, we ordered 25 ft of black wire for the hot lead of the circuit, 25 ft of white wire, and 25 ft of green wire for the grounding. Since our circuit requires 20 A from the batteries to the joystick controller we will run two pieces of the 10 A wire in parallel and use one piece everywhere else. 12 AWG wire, meant for 20 A, was used for the portion of the circuitry that goes from the batteries to the terminal block of the joystick due to the larger currents in this area.

7.14 Wiring Plan

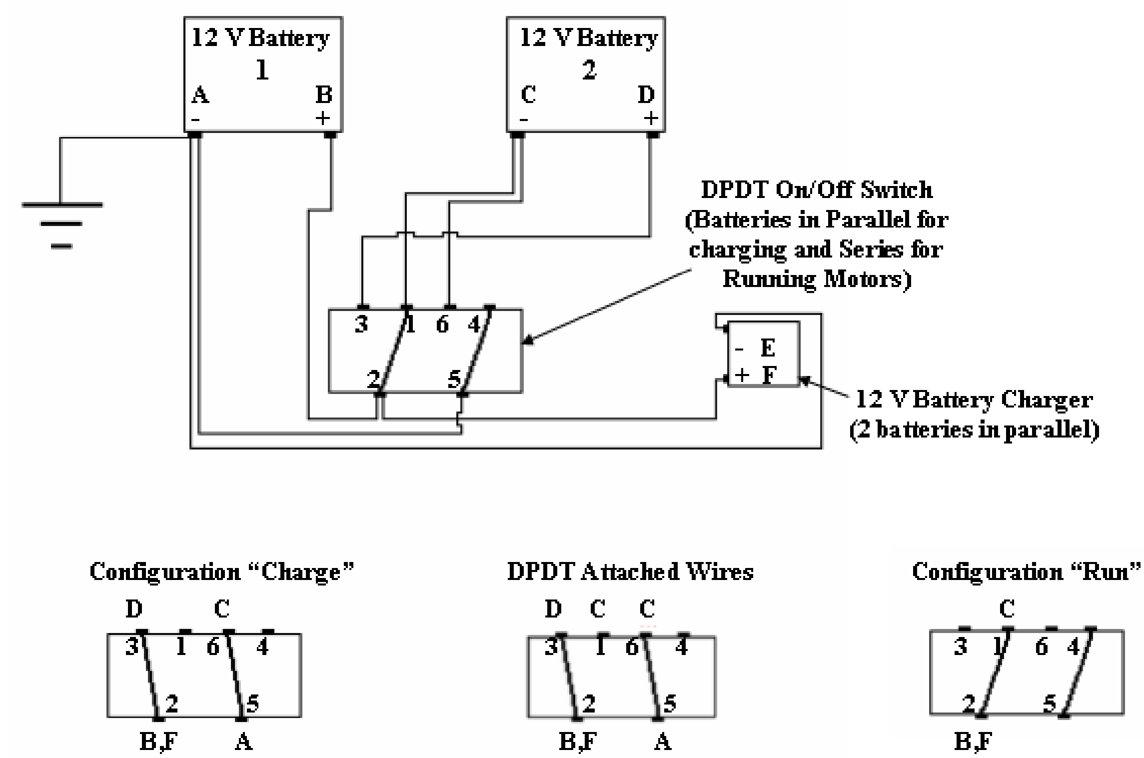
The entire wiring schematic for the MMRP is seen in Fig. 41 below. The batteries are connected in series through the DPDT switch when in normal use, and the positive voltage of battery two is connected to each of the four switches in the joystick. Two switches correspond to each motor to allow for the motors to be run in the forward and reverse directions. Each of the four joystick switches are grounded to the negative terminal of battery one. Both of the motors are also grounded to the negative terminal of the battery. The negative terminal of the battery is then directly attached to the base of the MMRP with a bolt to make the net ground equal to zero volts. The battery charger remains attached at all times but only affects the circuit when plugged in and the DPDT switch is turned to the “charge” position as discussed in the next section.

Fig. 41: Wiring Schematic



7.14.1 Double Pull Double Throw (DPDT) switch wiring: Since the motors are powered by the two batteries run in series and battery charging must be done in parallel, either the wiring must be disconnected each time the batteries are charged or a simple DPDT switch must be used. This prevents damage to the batteries and makes charging much more convenient for the user. A DPDT switch, shown in Fig. 42 below, changes the wiring from a series to a parallel connection. Follow the letters in the figure to the "run" configuration versus the "charge" configuration to understand how the wiring is completed. The numbers one to six shown in Fig. 42 correspond directly to the actual numbers on the DPDT switch.

Fig. 42: DPDT Switching Schematic



It is important to note that the battery charger is an open circuit when it is not plugged into the wall so that the battery one does not have the positive terminal directly connected to the negative terminal when the user switches to "charge" mode and does not have the charger plugged into the wall. This prevents discharging and damage to the batteries. It was also important to design the switching scheme such that if the user was to accidentally run the motors while either in "charge" mode and/or has the charger plugged into the wall, it will not cause damage to the batteries. In the situation of running the motors in "charge" mode, the motors will only run off of the second battery, which is properly grounded, yielding a slower speed.

7.14.2 Directional switch wiring: As mentioned previously, the joystick has four switches to run two motors in two different directions. In order for the motors to be run in both directions positive voltage must be run through the motor in opposite directions. One wire serves as the positive voltage from the battery while the other wire is run to the negative terminal of battery one and is in effect grounded, as seen in Fig. 43 on pg. 32. When the user switches the joystick, as seen in Table 4 on pg. 32, the wires reverse and now the grounded wire is positive voltage and the positive voltage wire is grounded. It is important to note that it is impossible based upon the joystick configuration for both switch A and switch B to be active at the same time, and thus current can only travel in one direction.

Fig. 43: Joystick Directional Switching (Single Motor)

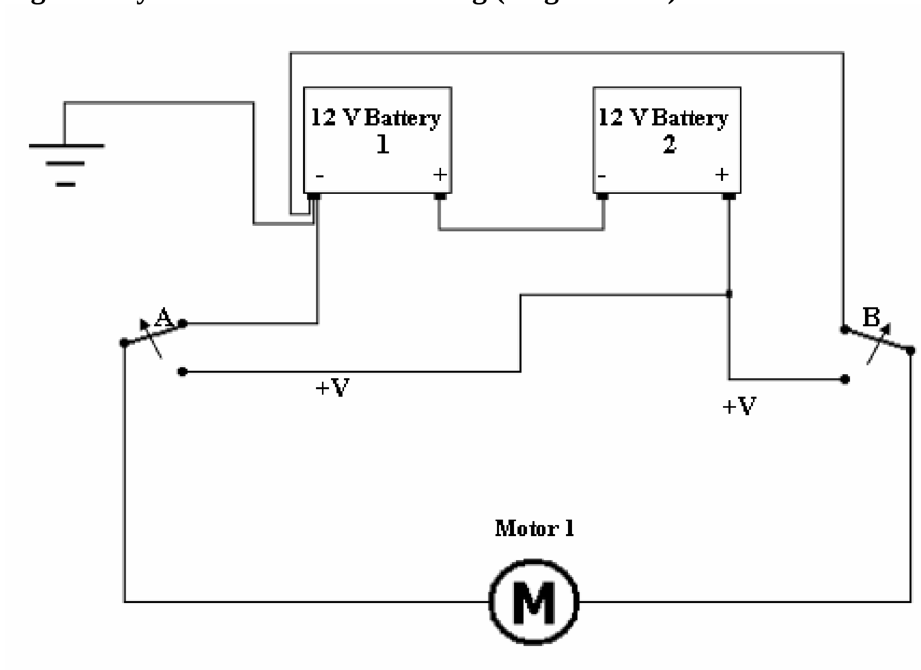
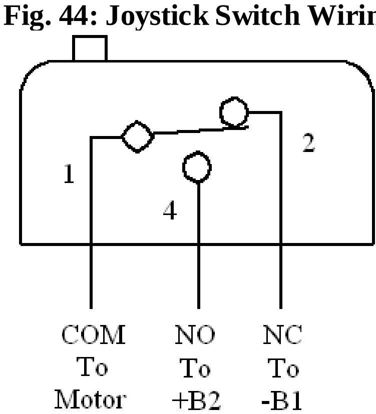


Table 4: Motor Direction

	Condition	Action	Motor 1
Center Off	A Default, B Default	Motor Brake	-
	A Default, B Active	Motor CW	-
Impossible	A Active, B Active	Motor Brake	+
	A Active, B Default	Motor CCW	+

As mentioned previously the joystick has four separate switches which complete the circuits to power the motors. Each switch is wired according to Fig. 44 below such that the communication (COM, 1) terminal is attached to the motor, the normally open (NO, 4) terminal is attached to the positive terminal of battery two, and the normally closed (NC, 2) terminal is attached to the negative terminal of battery one (ground). It is important that the two switches placed opposite of each other in the joystick have their COM terminals each connected to the same motor but different wires. This is how motor one in Fig. 43 is able to receive current in two different directions. Motor two is configured in the same fashion using the other two oppositely placed switches.

Fig. 44: Joystick Switch Wiring



7.15 Wire Connector Selection
The joystick, batteries, and DPDT switch all use 0.25 inch spade connectors so connections are compatible. In order to make a tight connection that can be crimped to the wires and snapped in and out, for replacement of parts, quick disconnect terminals were used. Where only one wire connects to the spade connectors, a 0.25 inch fully insulated female quick disconnect terminal was crimped to the wire and secured to the spade connector. Where multiple wires are connected to the same terminal (the negative terminal of battery one (ground) and the positive terminal of battery two) we will use Quick-n-Secure Connect Terminal Blocks, McMaster Part Numbers 8841T11 and 8841T31, an example of which is seen in Fig. 45 below, and mount the block to the frame with zip ties [27]. A single wire will then be run to the batteries. In other instances where two wires need to be run to the same location insulated piggyback quick disconnects will be used as pictured below in Fig. 46. The motors will be wired using the combination of female/male quick disconnects so that they may also be easily removed or replaced [27]. Additionally, where the ground wire is mounted to the base, a ring terminal was bolted directly to the frame of the MMRP.

Fig. 45: Example Quick-n-Secure Connect Terminal Block

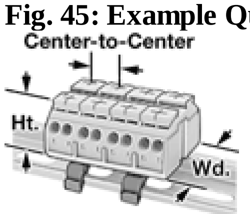


Fig. 46: Female, Male, and Piggyback Quick Disconnect Terminals (Respectively)

7.16 Motor Mount Selection
The motor mounts were selected to be made of aluminum since it is capable of holding the weight of the motors and is easy to machine. The bearings will take all other loads, so the strength of the motor mount was not considered. The motor mounts have two holes on the bottom that are tapped to fit a bolt that will be run through the angle bracket frame to secure the motor directly to the frame. Due to the weight of the motors, it was decided to use both a shaft side and back side motor mount so that there are four points of contact instead of two to mount the motors. The detailed drawings of both the shaft side and rear side motor mounts are seen in Appendix 16.8.2-3 on pg. 58-59.

8. QUALITATIVE ANALYSIS

Once the engineering analysis was performed for the individual components of the MMRP, we performed an overall qualitative analysis considering Design for Manufacturing and Assembly (DFMA), Design for Environment (DFE), and Failure Mode and Effects Analysis (FMEA).

8.1 Design For Manufacturing and Assembly (DFMA)
DFMA was used to produce an MMRP design that is easy to manufacture and assemble. The first consideration when we applied DFMA was how to manufacture the base of the MMRP. It was decided that a machining/welding process should be used as opposed to a casting/molding-type method, due to the low numbers produced and economies of scale.

We then considered four other guidelines pertaining to our product assembly. The first guideline was Design For Joining (DFJ). Our caster choice eliminates fasteners (DFJ)-1; it only has one bolt used to attach it, compared with other caster choices that had four bolts. The open design and spaced out components allow access for tools (DFJ)-2. Our chosen orientation of motor mount fasteners also allows easy tooling access. The next guideline considered was Design for Assembly Systems (DFAS). Our open design and well spaced components also permit assembly in open spaces (DFAS)-3. None of the components are enclosed. The last guideline considered was Design for Part Handling (DFPH). This is satisfied in our design by maximizing part symmetry (DFPH)-1. The motor mounting brackets are symmetrical front to back and can be installed with either face toward the motor.

8.2 Design For Environment (DFE)

It is important to consider the environmental impact of manufacturing, operation, and disposing of products. We considered five guidelines from the National Research Council (NRC) of Canada in our MMRP design. The first was physical optimization through easy maintenance and repair, which is satisfied by our components being simply attached to, but not enclosed by, the MMRP frame. The next guideline, also involving physical optimization, was modular product structure since the components may be used with various MMRP frame sizes. Along with physical optimization, we also considered material optimization. This is satisfied in our design by using hollow steel bar material for our base, and also by using the base structure as mounting locations instead of making additional mounts, other than the motor mounts.

The final guidelines dealt with optimizing end-of-life systems. The first satisfied is the product re-use guideline. The MMRP's frame is very robust, which allows the MMRP to be refurbished with new electronic components (motors, batteries, etc.) and reused. The last guideline satisfied is material recycling. Much of the MMRP is recyclable. The steel frame, batteries, motors, and controllers may be recycled at specialized recycling centers.

8.3 Failure Mode and Effects Analysis (FMEA)

An FMEA was conducted to identify how our product might fail. It is important to consider these possibilities to ensure the safety of the user and to satisfy ethical responsibilities to our client. We implemented a Design-type FMEA diagram for our entire prototype, as we deem each part integral to the MMRP's function. Our FMEA is shown in Fig. 47 on pg. 35.

The FMEA diagram shows that the wiring and drive wheel had the highest Risk Priority Number before implementing the recommended actions. Special care was taken while installing the wiring, ensuring that there were no sharp edges near the wire mounting location and that there were no bare wires exposed. There should also be special care while installing the drive wheel, such as ensuring the key-stock is properly inserted and fastened, and that the wheel shaft assembly is properly aligned when mounted.

Fig. 47: Design-type FMEA Diagram

Part & Functions	Potential Failure Mode(s)	Potential Effects of Failure	Severity (S)	Potential Causes/ Mechanism(s) of Failure	Occurrence (O)	Current Design Controls/ Tests	Detection (D)	Recommended Actions	RPN	new S	new O	new D	new RPN
DC Planetary Gear Motor - drive wheels, translate & rotate chair	fatigue, electrical short, seizure, misalignment	improper or no motion	8	cracks, power surge, unintended part touching	1	multiple runs, ensure proper install	1	ensure proper install, properly size motor	8	8	1	1	8
Switch-Type 10A Joystick - simplify controls, control motor, reduce cost	sticking, electrical short, misalignment	failed or improper motion	8	part rubbing, power surge, improper installation	3	multiple runs, ensure good electrical connection	1	ensure proper install, solder connections	24	7	1	1	7
Adjustable Voltage Regulator - vary speed	electrical short, misalignment	desired speed not reached	5	power surge, improper installation	2	multiple runs	2	ensure proper install, solder connections	20	4	1	2	8
Axle - transmit motor torque to wheels, support chair	fatigue, fracture, deflections, misalignment	no motion	9	high use, cracks, high weight load, imroper machining	2	multiple runs	2	ensure proper install, choose proper material & dimensions	36	9	1	2	18
Bearings - support shaft, minimize noise	wear, binding	noise, higher motor requirement, no motion	8	high use, loss of bearing smoothness	1	multiple runs	2	properly size, ensure proper install	16	8	1	2	16
Collar - connect motor drive shaft to axle	fatigue, fracture	no motion	9	cracks, high torque loading	2	multiple runs	1	ensure proper install, type selection	18	9	2	1	18
Drive Wheel - translate & rotate chair, support chair	wear, loosen	platform fall, no motion	9	high use, high weight load	3	multiple runs	2	properly size, ensure proper install	54	9	1	2	18
Caster - support chair, assure stability	bind, loosen	platform fall, difficult or no motion	7	carpet debris, high use	2	multiple runs	1	properly size, ensure proper install	14	7	2	1	14
12V Battery - power motor	electrical short, corrosion	no motion, potential user harm (corrosion)	10	unintended electrical loading, time	2	multiple runs	1	properly size, ensure proper install	20	9	1	1	9
Wiring - conduct electricity through system	detach, sever	no motion, user shock	10	installed improperly, axle/motor contact	2	multiple runs, visual inspection	3	properly gauge, ensure proper install	60	9	1	2	18
Steel Frame - support & strengthen structure, ensure stability, reduce maintenance	fatigue, fracture, deflections	platform fall, difficult or no motion	7	weakened material at weld, cracks, high weight load	1	load beyond intended weight	3	redundant welds, proper material strength & sizing, visually inspect welds	21	7	1	2	14

9. FINAL DESIGN

The final design components have been detailed above in Engineering Analysis, Section 7. The complete list of components that go into our final prototype, along with a cost breakdown by component, is shown in the Bill of Materials (BOM) shown in Fig. 48 on pg. 36. The most expensive components of our prototype are the motors, $97.20 each, and the batteries, $49.21 each. Together, these account for much of the prototype's total cost. These components are also the most critical for our prototype to function, so the total cost of the prototype is roughly distributed based on the importance of the components.

The total cost of the purchased components and additional parts was $551 without tax and shipping and $641 including both shipping and tax. The majority of the suppliers offer price breaks when ordering larger quantities, generally five pieces or more. We estimate a manufacturing cost of about $250 for the stock steel and labor to weld the frame together based upon information from ErgoQuest Inc. This brings the total cost of production for one unit to $891.

Reciept #	Quantity	Part Description	Purchased From	Part Number	Price (each)	Shipping & Tax	Total
1	2	24V DC Planetary Gear Motor	Anaheim Automation	BDPG-60-110-24V-3000-R168	$97.20	$7.34	$201.74
2	1	Switch-Type 10A Joystick	Newark	APEM 100114	$20.13	$15.00	$35.13
3	2	8" Drive Wheels	NPC Robotics	NPC-PT318	$25.50	$12.40	$63.40
4	1	Piggy-Back Crimp-On Quick Disconnect Terminal, 25	McMaster-Carr	72065K25	$8.38	$4.25	$22.77
	1	Insulated Quick Disconnect Terminal (Male), 10	McMaster-Carr	7243K37	$2.56	-	-
	1	Insulated Quick Disconnect Terminal (Female), 50 qty	McMaster-Carr	7243K21	$7.58	-	-
5	1	12V Trickle Battery Charger	BatteryWholeSale	CH-120500	$13.95	$10.45	$24.40
6	2	0.125" x 0.125" Key Stock, 12" length (Brass)	McMaster-Carr	98500A100	$1.16	$4.75	$100.47
	1	16 AWG Wire (25 ft) - black	McMaster-Carr	71245K21	$3.62	-	-
	1	16 AWG Wire (25 ft) - red	McMaster-Carr	71245K22	$3.62	-	-
	1	16 AWG Wire (25 ft) - green	McMaster-Carr	71245K25	$3.62	-	-
	2	0.5" Bore, 1.5" Length, 1" OD Coupler with Keyway	McMaster-Carr	6412K41	$9.16	-	-
	4	Load Bearings	McMaster-Carr	5913K41	$10.95	-	-
	1	18" Drive Shaft with keyway	McMaster-Carr	1497K953	$20.42	-	-
7	1	12 AWG Wire (10 ft) - red	McMaster-Carr	71245K44	$2.61	$4.00	$9.25
	1	Terminal Block - 2 Circuits, 20 A - black	McMaster-Carr	8841T11	$0.88	-	-
	1	Terminal Block - 4 Circuits, 20 A - black	McMaster-Carr	8841T31	$1.76	-	-
8	1	DPDT Switch (20A)	Digi-Key	360-1929-ND	$7.15	$12.18	$19.33
9	2	12V, 12 Ah Rechargeable Battery	Digi-Key	522-1013-ND	$49.21	$17.65	$116.07
10	1	15 oz Pro Spray Primer	Lowe's	Primer	$4.97	$0.81	$14.35
	1	15 oz Black Semi-Gloss Paint	Lowe's	Spray Paint	$4.97	-	-
11	76	Various Fasteners	Stadium Hardware	Washers, bolts, nuts, screws	$0.28 (avg)	$1.27	$22.44
12	2	2" Casters	Lowe's	Swivel Gray Wheel	$4.28	$0.55	$9.79
	2	0.375" Hex Nuts	Lowe's	Hex Nuts	$0.10	-	-
13	1	4" Wire Ties, pack of 30	Lowe's	Wire Ties	$1.18	$0.13	$2.29
14	1	155" x 1" x 1" - 0.125" Wall Angle Bracket Mild Steel	University of Michigan		$0.00	$0.00	$0.00
	1	15" x 3" x 0.25" Plate Mild steel	University of Michigan		$0.00	$0.00	$0.00
	1	118" x 1" x 1" - 0.125" Wall Tube Mild Steel	University of Michigan		$0.00	$0.00	$0.00
	4	3.5" x 2.5" x 0.5" Aluminum Block	University of Michigan		$0.00	$0.00	$0.00

(Total w/o Tax & Shipping)	**$550.65**
(Tax & Shipping)	**$90.78**
(Total w/ Tax & Shipping)	**$641.43**

Fig. 48: Bill of Materials

The 3D model of the redesigned MMRP is shown below in Fig. 49 and the associated assembly view is shown in Fig. 50. Engineering drawings for the prototype's base, back end motor mounts, front end motor mounts, and switch housing are in Appendix 16.8 beginning on pg. 56. A dimensioned setup of the drive-train assembly is shown in Fig. 51 on pg. 38 and its respective assembly view in Fig. 52 on pg. 38.

Fig. 49: Three-Dimensional Model of Redesigned MMRP

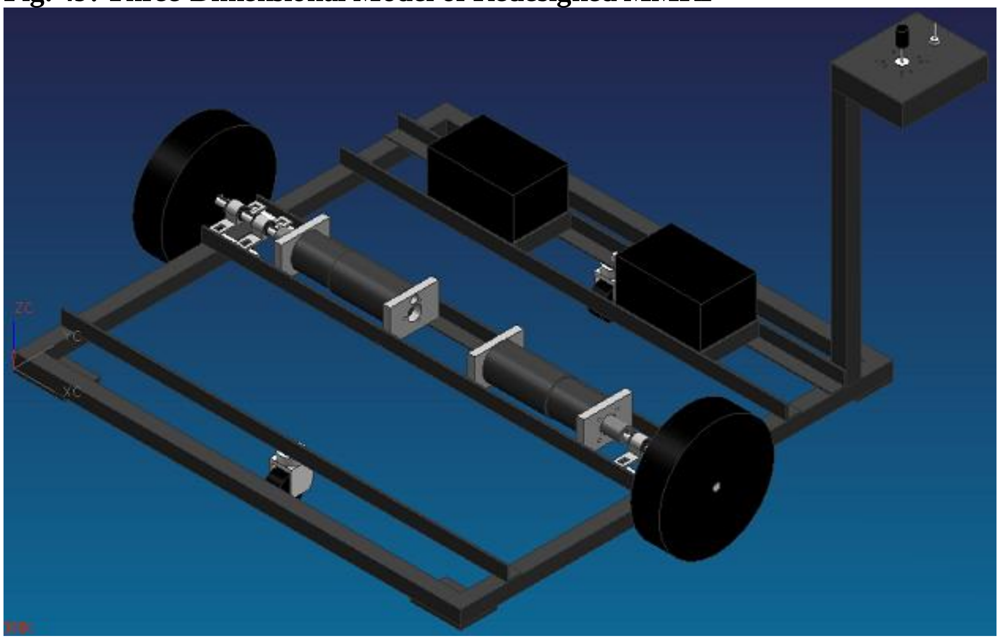


Fig. 50: MMRP Assembly View

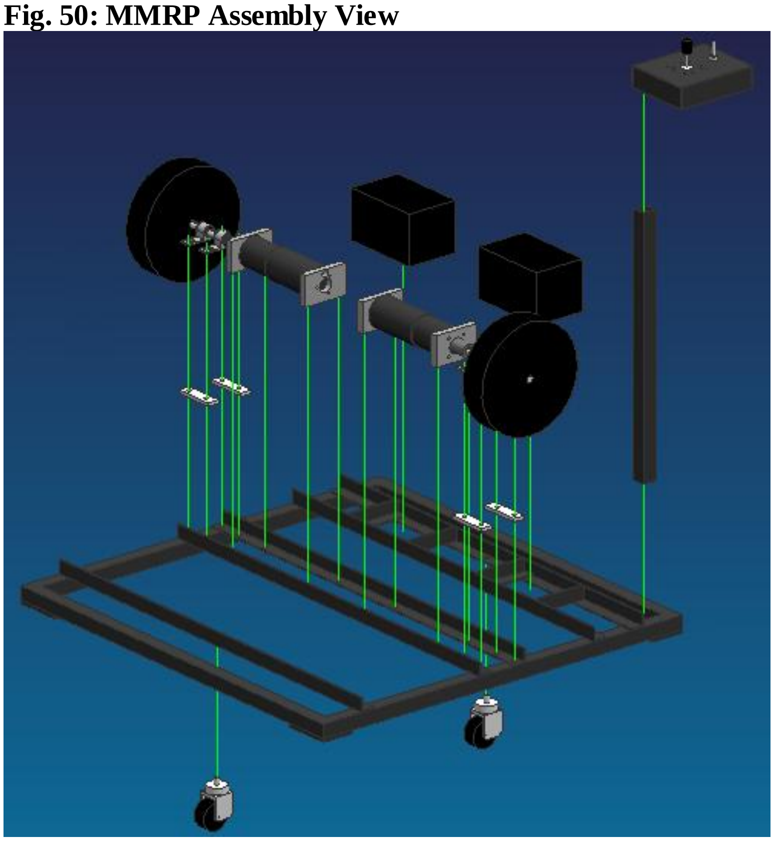


Fig. 51: Detailed Setup of Drive Train Mountings

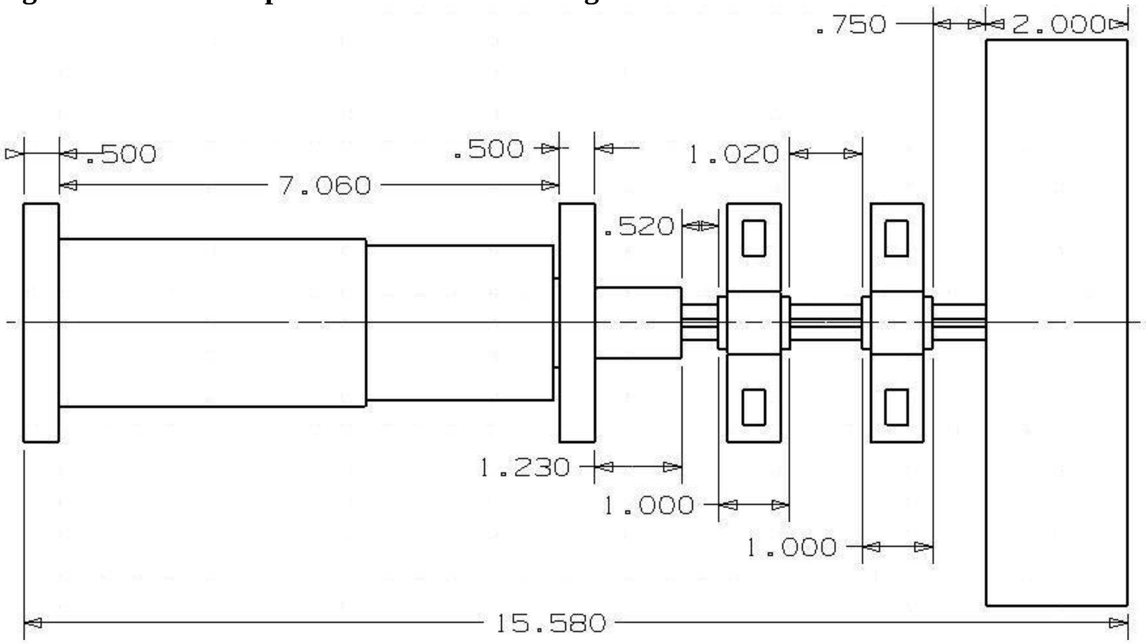
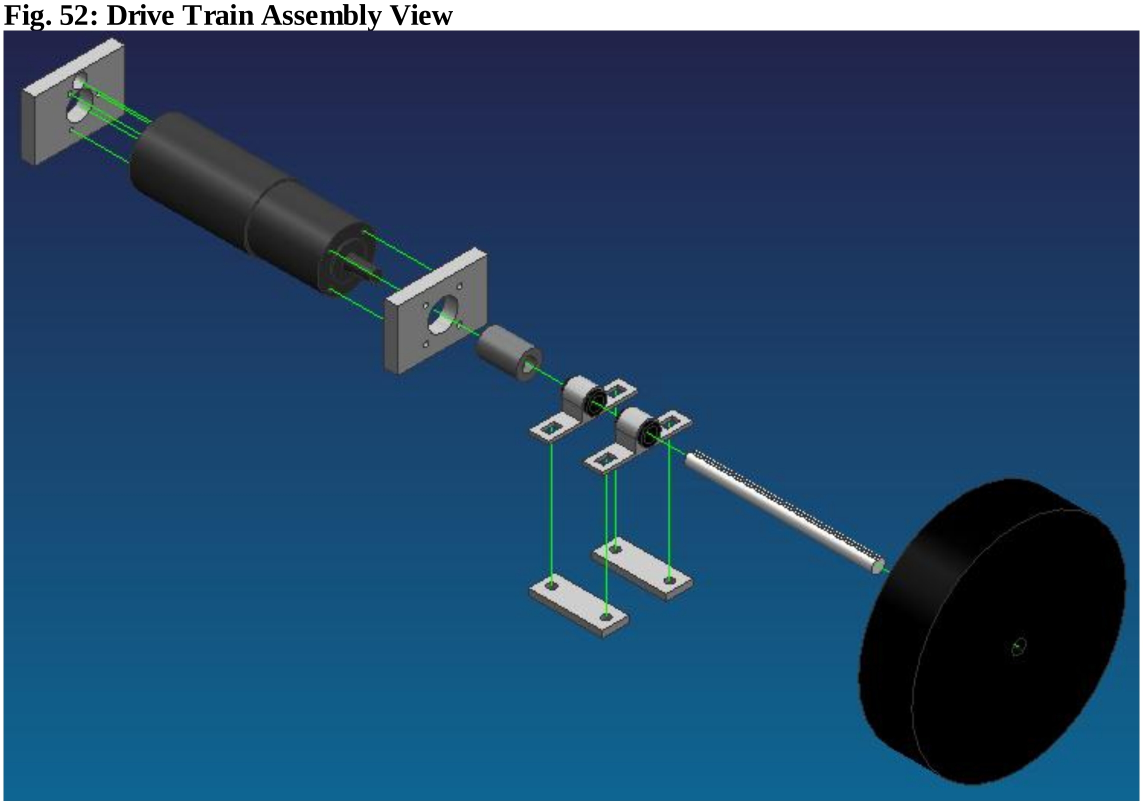


Fig. 52: Drive Train Assembly View



10. MANUFACTURING AND TESTING PLAN

10.1 Manufacturing and Assembly

The final design of the MMRP was manufactured for the Design Expo so that we had a fully functional prototype displayed. In order to accomplish this, we developed a Manufacturing and Assembly Plan shown in Appendix 16.7 on pg. 55. All manufacturing and assembly was done in house at the University of Michigan Engineering Undergraduate Student Machine Shop. The material for the steel base, motor mounts, and switch housing were supplied by the machine shop. The fasteners and casters were purchased at a local hardware store, while the rest of the components were ordered online as detailed in the BOM on pg. 36 and discussed in their respective engineering analysis sections.

From the Manufacturing and Assembly Plan we manufactured the base, two back end motor mounts, two front end motor mounts, and the switch housing. The detailed Process Plan Sheets are found in Appendix 16.9 on pg. 62 and the dimensioned CAD drawings shown in Appendix 16.8 on pg. 56. For final assembly, follow the Manufacturing and Assembly Plan and see the detailed layout of the MMRP and the drive train assembly shown in Figs. 51 and 52 on pg. 38.

Since the MMRP is not mass produced, we do not foresee any reason to deviate much from our Process Plan Sheets for Ergoquest to produce additional units. For future production of MMRP bases we recommend ordering all the components at least two weeks prior to manufacturing. The manufacturing process is more time consuming than the previous MMRP due to the fabrication of four motor mounts and two stepped motor keys, otherwise the assembly is mostly welding and fastening the various components together as before.

Our team does not foresee any major ethical issues arising from making the redesigned MMRP available for public use. Careful manufacturing and attention to detail will yield a safe design for the customer. The important checks in the manufacturing process are that: all wires are properly secured to the frame with no bare wire showing, that the controls, motors, and batteries function properly, and that the welds are true.

10.2 Testing Plan and Results

Several tests were done once our prototype was completed. These tests were meant to verify the structural and electrical/system integrity, and also confirm that the system components functioned properly. During machining and fabrication many visual tests were performed to make sure the components fit together as expected. Before operating the motor we ensured that the drive shaft was in proper alignment with the coupler, bearings, and drive wheels. We also ensured the drive wheels and casters were all at their appropriate heights and equally supported the MMRP base.

The first of the electrical tests were conducted on the motors and batteries. Each motor was connected to a battery to verify that both motors and batteries worked. The leads were then switched on the motor and battery to verify the motor would run in both directions. All motors and batteries functioned as expected. The next test was an unloaded controller functionality test. Here we connected the controller, motors, and batteries according to our wire schematic and then put the controller through its eight directions as shown on Fig. 33 on pg. 26 to verify that it ran the motors in their expected directions. This test was successful and demonstrated that we could implement directional control through switches and proper wiring instead of a more complex controller.

The final test was conducted on the fully-loaded prototype to ensure that the MMRP could withstand the weight requirements laid out for it. The MMRP functioned as expected when two group members with combined weight of 300 lbs both sat in the chair on top of the chair. The MMRP also performed as expected at the Design Expo under a variety of loading conditions and operator ages (from 11 to 60 years of age). All of the users were able to master operation of the MMRP within a few seconds. Testing was also performed to see if the MMRP moved at the appropriate speeds and had fine control. The MMRP ran at 7.5 in/sec in high speed mode and at 3.75 in/sec in low speed/charge mode. We ensured the joystick was easy to use and interacted well with the motors. The only unexpected problem that occurred during testing was that the switch housing post partially broke off from the frame. This occurred because we did not weld the post directly to the motor angle bracket as specified by our design. Therefore we suggest, as noted in the Manufacturing and Assembly Plans, that this be done in the future.

After testing how well the Motorized Mobile Recliner Platform and its components met the desired engineering specifications we decided whether or not the redesigned MMRP achieved its overall goal. It significantly reduced production cost while keeping its desired functionality.

11. FUTURE IMPROVEMENTS

The MMRP prototype fulfilled its main design objectives. While it met the desired engineering specifications – it can hold the desired weight, raises the chair by less than two inches, can move the user in and out of their work stations at the desired speeds, and is easy to control – there is still room for improvement.

11.1 Motor Improvements

It would be desirable to simplify the manufacturing process by finding a similar motor that has built-in motor mounts. This would avoid the need to mill multiple pieces and then drill and tap holes for bolts to both secure the motor mounts to the motors and motors to the frame. When searching for a different motor it is also recommended to find one with English unit keyways to match the other keys and keyways. This would eliminate the need to manufacture an irregular shaped stepped key and simplify the manufacturing process. An additional internet search did not yield a suitable replacement motor but there are vendors willing to create custom motors, though these are often much more expensive than off-the-shelf models.

Depending on the use of the MMRP it may be beneficial to choose a motor with similar torque but higher speeds. The current MMRP speed is well suited for the application of moving in and around a workstation; however, if the user is to use the MMRP to move greater distances it would be beneficial to have a faster MMRP. Faster motors often have less torque. This may result in losing the option of having both a low and high speed mode. Our current setup regulates speed by regulating voltage. A faster motor with lower torque might not be able to move the loaded MMRP at less than maximum voltage, which would limit the user to one fast speed.

11.2 Motor Mount Improvements

If the current motors are kept, it is possible to eliminate the back side motor mounts from the MMRP design. The locations of the back end screw holes for the motor were not given in the motors' engineering drawing and were not the same for the two purchased motors. This caused difficulty in manufacturing because the holes had to be located before drilling the motor mounts. This could be avoided by eliminating these motor mounts and replacing them with a thin piece of flat steel welded between the two angle brackets so that the back end of the motors are still supported. If someone were to accidentally step on the back side of a motor this steel would reduce the deflections of the rear side of the motors. These two steel pieces could easily be welded to the bottom side of the angle brackets and thus reduce the risk of damage to the MMRP while simplifying the manufacturing and lowering production costs. The current rear motor mount design and the suggested replacement can be seen below in Figs. 53 and 54 on pg. 41.

Fig. 53: Current Rear Motor Mount

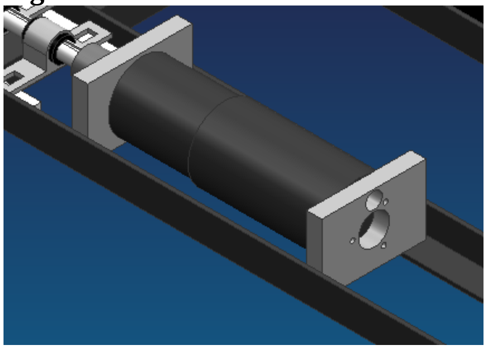
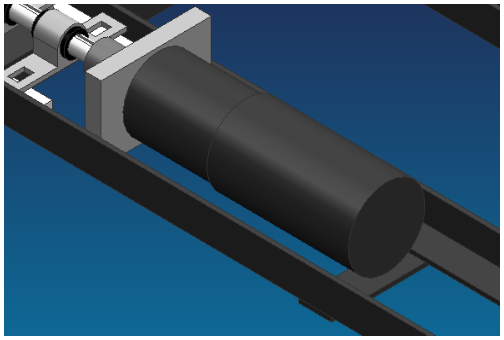


Fig. 54: Suggested Improvement



11.3 Battery Mounting Improvements

It is recommended that the batteries both be secured to the frame and be placed inside a plastic battery case or tub. When performing assembly and maintenance on the MMRP it was noticed that the batteries appeared secure. If someone were to make this assumption and the MMRP were turned on its side for transportation, the batteries could fall out. This could be avoided by adding a Velcro strap to each battery or with a cheaper alternative using cable or zip ties as used in the prototype. The plastic battery case is recommended such that in the unlikely event of the lead acid batteries spilling, the acid is contained inside the case and a mess is avoided.

11.4 Rear Caster Support Improvements

The rear caster was mounted on an inch x inch steel angle bracket attached to the frame of the base. The angle bracket was found to visibly twist upon full-load testing. The deflection calculations showed that an ample factor of safety in the design was applied; however, it is recommended that in future designs the rear caster be mounted on standard inch x inch tube stock, the same being used for the main square of the MMRP frame. This will eliminate the twisting and also reduce any the perceived deflection in the bracket.

11.5 Directional Control Improvements

While the MMRP provided the full range of motions at the desired speeds, in the higher speed mode the motion of the MMRP was not always smooth. If the user did not push the joystick straight forward the controller would sometimes oscillate between two motors forward to only one motor forward and appear jerky to the user. Within a few minutes of use it is easily learned to push the joystick all the way in the desired direction but this jerky motion could be avoided by either placing capacitors directly in line with the wires providing current to the motors. The capacitors would slow down any rapid changes in current supplied to the motors. It might also work to use the four direction limiter plate included with the joystick. This would not allow the user to accidentally switch to an in-between direction, which would make the MMRP motion smoother as the user would have to switch back to the neutral position whenever they wanted to change directions. However, this removes four directional control choices (where only one motor turns) currently used to drive the MMRP. This same effect could be achieved with a custom eight directional plate without limiting control options.

11.6 Switch Housing Post Improvements

When installing the final wiring it was found that the inch x inch tube steel switch housing post was difficult to run wires through. We were able to fit all the wires through the post but it would ease the manufacturing process by using an inch x inch "C" channel. The wires could then be zip tied or taped together with electrical tape and then simply pushed into the "C" channel.

11.7 Customizable Feature Additions

It was also suggested to determine whether a method for showing if the batteries are actually being charged could be implemented. It would be possible to put an LED light or similar red and green light into the circuit to show when the charger is working properly. This could be a custom feature for users that may desire it as it will incur additional costs.

12. CONCLUSIONS

The existing ErgoQuest Inc. Motorized Mobile Recliner Platform may be too expensive for some potential customers. The redesign of the MMRP sought to address this cost problem. The MMRP faces competition from several power chairs and carts, though none fit the niche of working as a stand alone base that can power "zero-stress" reclining chairs like the MMRP does. Several customer requirements were considered in the redesign, including functionality, the use of standard parts, and cost. From these, we developed engineering specifications and established our design criteria as shown in Fig. 8 on pg. 7.

In order to produce the best redesign for the MMRP, we first broke down the MRRP task function to its basic and supporting functions. From there we developed multiple concepts that performed the functions required of the MMRP. Each concept was evaluated against the customer requirements and the dual-motor wheel design was chosen as the best concept. We then performed quantitative and qualitative engineering analysis for the conditions seen by the MMRP and researched components that would satisfy these requirements as discussed in Section 7. We found that the drive wheels should be able to carry 200 lbs and the motors produce a torque of 200 in-lbs. FMEA showed that the wiring and drive wheels had the highest risk priority on possible failure, but could be improved with careful installation.

The redesigned MMRP achieved its goal of providing similar functionality to the existing model while greatly reducing the cost of production. The final design is detailed in Section 9. A comprehensive list of the chosen components and their associated costs can be seen in the Bill of Materials in Fig. 48 on pg. 36. The final cost of the components is $615 bringing the final production cost, including the steel frame and manufacturing, to approximately $865 for one unit. This number would reduce significantly by producing more than five units at a time. A working prototype was manufactured and displayed at the University of Michigan Design Expo in Lansing, MI on December 4th, 2007.

The MMRP is easy to use, provides eight directions of control including 360 degree rotation, and has a high speed mode of 7.5 in/sec and a low speed mode of 3.75 in/sec. It safely holds 350 lbs, raises the existing chair 1.75 inches, and provides 2.5 hours of continuous run time which was ample run time between charges. The MMRP runs off of two 12 V, 12 Ah lead acid rechargeable batteries run in series to provide 24 V to the motors in high speed mode. Through the use of a simple switch, speed control is achieved by running off 12 V from only one battery in the low speed mode and 24 V off both batteries in the high speed mode. The MMRP is easily recharged by switching to charge mode and plugging the charger into a standard wall outlet. It uses solid rubber wheels which do not require inflation to reduce maintenance. Standard components were used to simplify and reduce the cost of manufacturing. Manufacturing plans are detailed in Section 10 of this report.

13. ACKNOWLEDGEMENTS

For all of the help and guidance we received on this project we wish to thank the following:

Kazuhiro Saitou and the other ME 450 faculty and professors: For their guidance during the course of our project.

Peter Adamczyk from ProCEED Laboratory at the University of Michigan: For his extensive knowledge of mechanical and electrical components and their interactions. Peter was instrumental in deciding the important characteristics and verifying our chosen components.

Bob Coury from the Engineering Undergraduate Student Machine Shop: For providing welding training, machine instruction, and recommendations during manufacturing.

Jeff Vanden Bosch, Sponsor, ErgoQuest, Inc.: For sponsoring our team to work on this project.

14. REFERENCES

[1] Ergoquest MMRP and Recliners Basics
http://www.ergoquest.com/

[2] Current MMRP Specifications, Manufacturing Costs, and Sales
Jeff Vanden Bosch
President, ErgoQuest, Inc.
Office: 888-298-2898, Cell: 616-308-8986

[3] Scooter vs. Power Chair
http://www.thescooterstore.com/products/scooter_vs_powerchair.aspx

[4] Motorized Platform Cart
http://estore.sjf.com/sjf.nsf/vwLevel3Lkup/A558485234581C77862570E4004CDF5C?OpenDocument&Count=5&EndVars

[5] Kadtronix Heavy-Duty Motorized Frame
http://kadtronix.com/robotframe.htm#RFR1

[6] Shop Rider Echo 3 Wheel Scooter
http://www.1800wheelchair.com/asp/view-product.asp?product_id=2292&src=feat0

[7] Alero Electric Wheelchair
http://www.1800wheelchair.com/asp/view-product.asp?product_id=762&src=feat0

[8] Powerhouse Electric Golf Buggy Pro
http://www.118golf.co.uk/scripts/prodView.asp?idproduct=869&j=1

[9] Tamiya 2 pole on/off/on DPDT toggle switch
http://www.superdroidrobots.com/shop/item.asp?itemid=728

[10] Rocker switches from DNA Group
http://www.dnagroup.com/rocker-switches.htm

[11] ETI Systems Joysticks
http://www.etisystems.com/
Sales Representative at Precision Sales: 1-800-523-3561

[12] APEM Components 1000 Series Switch Joystick and Various Switches
http://www.apem.co.uk/Switch_joysticks.htm
http://cpc.farnell.com/jsp/search/results.jsp?N=411+1002722
http://www.apem.com/pdf/js1000series.pdf
http://www.newark.com
http://www.findchips.com

[13] The Digi-Key Corporation
http://www.digikey.com

[14] Knob Style Rheostat Image
www.marine-plus.com

[15] MSK5012 and MSK5021 prices
Greg Overend, M S Kennedy Corporation
g.overend@mskennedy.com

[16] Platinum Lighting Dimmer Switches
http://www.platinumlightinginc.com/DIMMER/dimmer.html

[17] Various Motor Controllers
http://www.superdroidrobots.com/

[18] Lowe's
3900 Carpenter Road
Ypsilanti, MI 48197
(734) 477-5980

[19] Anaheim Automation
http://www.anaheimautomation.com

[20] GC Electronics
http://www.gcelectronics.com

[21] Battery Wholesale
http://www.batterywholesale.com/newsite.html

[22] Adjustable Voltage Regulator MSK 5012 Datasheet
http://www.mskennedy.com/client_images/catalog19680/pages/files/5012ri.pdf

[23] MIC29712BC Adjustable Voltage Regulator
http://www.micrel.com/_PDF/other/LDOBk_ds.pdf#page=3

[24] ADM-54L-24V 11 A DC dimmer
http://www.platinumlightinginc.com/html/dimmer_list.html

[25] IMT-ILDIM-ROT10 Dimmer Switch
http://www.sailorsams.com/mall/dimmers-ilvpc.asp

[26] Drive Wheels
Ron Zinter, NPC Robotics, ronz@npcinc.com
www.robotmarketplace.com/marketplace_wheels.html

[27] McMaster-Carr
http://www.mcmaster.com

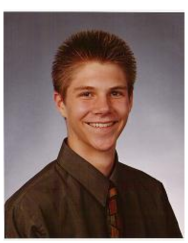
15. TEAM MEMBER BIOGRAPHIES

15.1 Uzair Ali

Uzair M. Ali is a senior in mechanical engineering at the University of Michigan. He will graduate in the spring of 2008. He plans to earn his Master's degree in biomedical engineering next year at Michigan and is currently in the process of obtaining recommendations and applying to graduate school. Uzair is from Canton, MI and graduated from Salem High School in 2004. Uzair is actively involved in the Tech Day Planning Committee and the Muslim Engineering Students Association (MESA). He has risen to leadership positions in both organizations: For Tech Day, he is currently the Committee Coordinator and was the Volunteer, Recruitment, and Publicity Co-Chair last year. For MESA, he has been the president since January and will serve through December. Uzair has had two internships with Johnson Controls Inc. (JCI) in Plymouth, MI.

In his free time, Uzair enjoys watching sports and rooting for his hometown Detroit teams: the Tigers, Red Wings, Pistons, and the Lions. Of course, Uzair also roots for the Michigan Wolverines. In addition, Uzair enjoys reading in his free time. This past summer, he read four books. The last book he read was "The World is Flat" by Thomas Friedman, which motivated him to work harder and longer in everything that he does because it made him realize that one billion Indians and one billion Chinese want his (prospective) jobs.

15.2 Joseph Blakemore



Joseph C. Blakemore was born in Ann Arbor, Michigan and has lived here his whole life. He began attending the University of Michigan in 2003 to pursue a degree in Mechanical Engineering. He has wanted to be an engineer for as long as he can remember and is looking forward to his graduation in December 2007. Joseph attends Christ the King Catholic Church in Ann Arbor with his family and hopes to stay in the area after graduation. Joseph dreams of making a career in the aerospace industry, particularly in the field of space research. He is currently employed at Superior Text where he is the manager of the newly created Rebinding Department, which he designed. Joseph is also working on expanding the department to include printing and publishing applications for individuals and schools. He enjoys playing soccer and has trained in Tae Kwon Do since he was ten. He earned his third degree black belt in 2005 and plans on attaining the rank of master in the future.

15.3 Eric Paul

Eric L Paul was born and raised in the small town of Adrian, MI on August 16, 1983. He spent his childhood, up until age 5, living in the countryside surrounding Adrian. He has a half sister 14 years older than him and a niece and a nephew. In the country he played countless hours in the sun and helped his dad on small construction projects around the house. This "work" accompanied with his many dollars invested in Legos inspired his creative thoughts and mechanical mind. This mind was later developed with the help of erector sets and the building (and destruction) of remote control cars.

His parents unfortunately divorced as he entered kindergarten. He and his mom moved closer to the center of the city. He decided to set out to find a companion since he didn't have a sibling to keep him company at home. He went door to door in his neighborhood, knocking and asking for any little kids that may be in the house. He made several close friends this way and found kids to play with. Of course, he still made time for his Legos and other creative outs. One way he dealt with the emotional hardships of the divorce was to focus hard in school. He excelled with all his hard work and found reward and comfort in his achievement.

Eric enjoys a wide variety of hobbies and activities. Skiing and playing soccer rank among the top. He and his dad have been going on an annual ski trip together since Eric was four to Crystal Mountain near Traverse City, MI. Eric found a love for doing construction with his dad and brother-in-law. He also enjoys camping, backpacking, and climbing. Eric came to the University of Michigan in August 2002 after graduating high school. He originally came in with the intent to become an architect, since he also had a deep passion for art and architecture. After some consideration, he decided that he would be better suited and happier as a mechanical engineer. He transferred to engineering his second year. Through his college career, Eric has worked at TRW, GE, and Boeing. He plans to return to Boeing upon graduating in December 2007.

15.4 Matthew Vivian

Matthew D. Vivian grew up in Plymouth, MI with his Mom, Dad, and younger brother Chris. Growing up Matt was always interested in the way things worked and how objects and buildings were built so becoming an engineer sounded like a fitting choice. Attending Michigan has been a dream since his parents, both Michigan alumni, took him to football games and other events throughout his childhood.

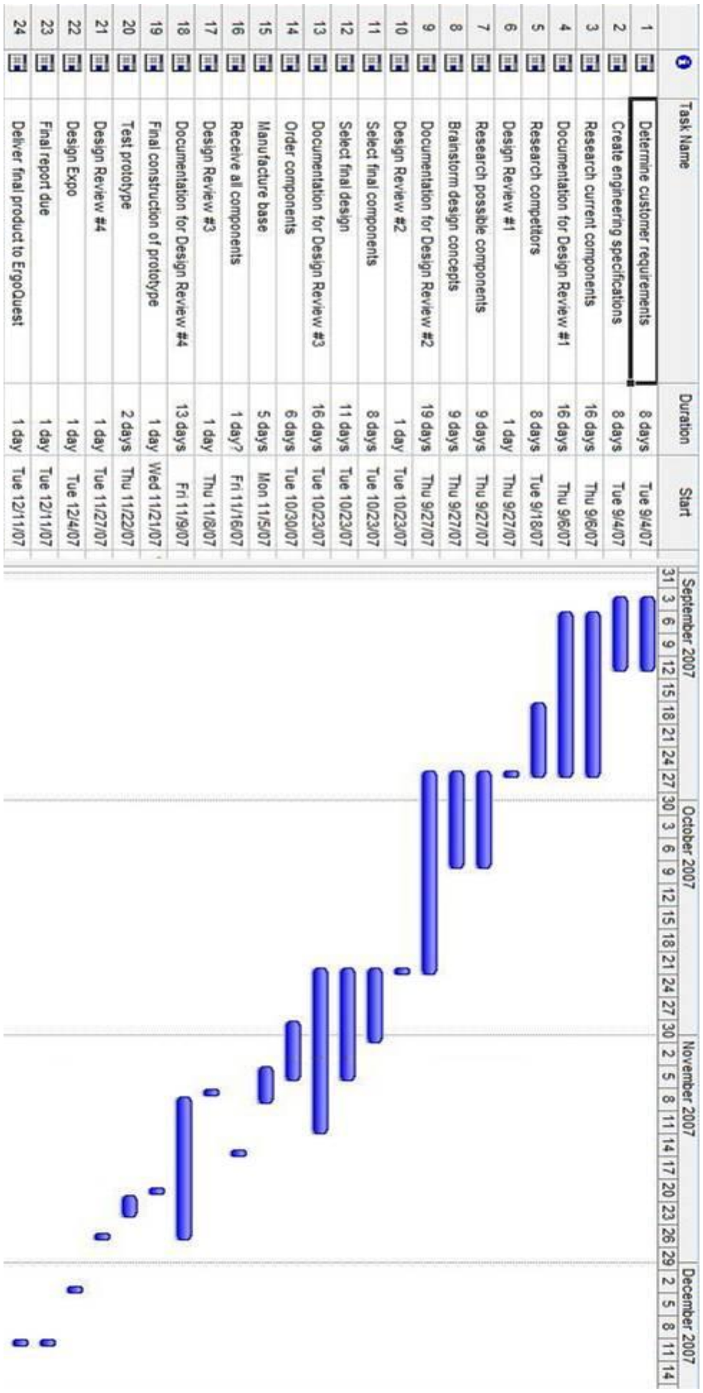
In his free time Matt loves to water ski including Slalom, Trick, Jump, and Wakeboarding. He is a member of the Michigan Water Ski Team where he was Captain of the team twice and helped the team to attended Nationals twice in Sacramento, CA and Austin, TX. Matt's favorite hobby is spending summers and weekends at his cottage on the lake in the Irish Hills, MI. Additionally, he likes to play and watch a large variety of sports as well as travel.

Currently Matt is a senior in a dual degree program for Mechanical and Civil Engineering at the University of Michigan. He has interned with Ford Motor Company, Shell Oil, and the Michigan Department of Transportation. Matt is actively involved in Chi Epsilon, the Civil Engineering Honor Society where he has been President and Vice-President. He will be graduating in December of 2007 and is actively searching for his dream job.

16. APPENDICES

16.1 Gantt Chart

This is our timeline for the MMRP's redesign.



	Task Name	Duration	Start
1	Determine customer requirements	8 days	Tue 9/4/07
2	Create engineering specifications	8 days	Tue 9/4/07
3	Research current components	16 days	Thu 9/6/07
4	Documentation for Design Review #1	16 days	Thu 9/6/07
5	Research competitors	8 days	Tue 9/18/07
6	Design Review #1	1 day	Thu 9/27/07
7	Research possible components	9 days	Thu 9/27/07
8	Brainstorm design concepts	9 days	Thu 9/27/07
9	Documentation for Design Review #2	19 days	Thu 9/27/07
10	Design Review #2	1 day	Tue 10/23/07
11	Select final components	8 days	Tue 10/23/07
12	Select final design	11 days	Tue 10/23/07
13	Documentation for Design Review #3	16 days	Tue 10/23/07
14	Order components	6 days	Tue 10/30/07
15	Manufacture base	5 days	Mon 11/5/07
16	Receive all components	1 day?	Fri 11/16/07
17	Design Review #3	1 day	Thu 11/8/07
18	Documentation for Design Review #4	13 days	Fri 11/9/07
19	Final construction of prototype	1 day	Wed 11/21/07
20	Test prototype	2 days	Thu 11/22/07
21	Design Review #4	1 day	Tue 11/27/07
22	Design Expo	1 day	Tue 12/4/07
23	Final report due	1 day	Tue 12/11/07
24	Deliver final product to ErgoQuest	1 day	Tue 12/11/07

16.2 Motor Specification Sheet

This is the chosen motors' datasheet showing its detailed specifications (gear ratio 1:168).

BDPG-60-110 Series Planetary Gearmotor

ANAHEIM AUTOMATION

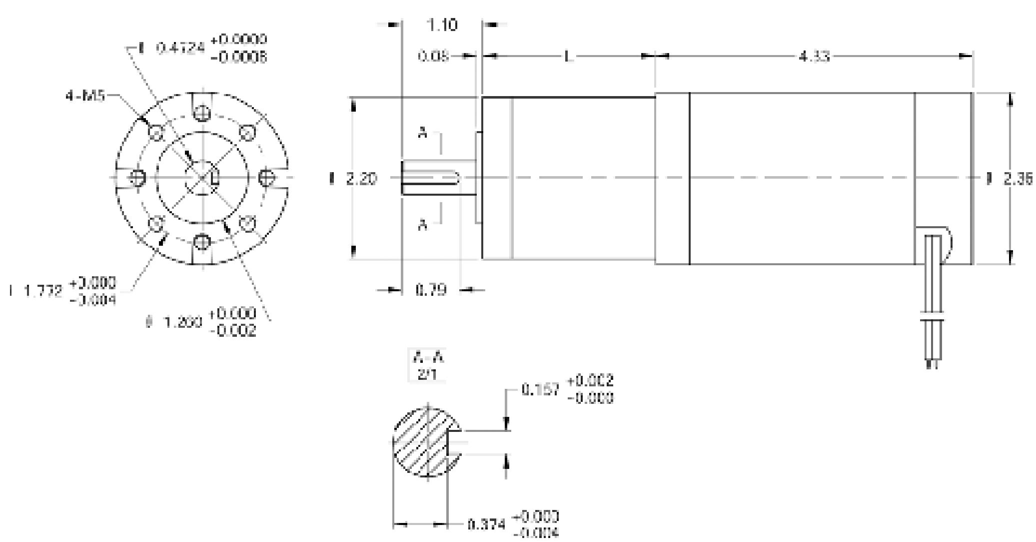
- DC Brush Planetary GearMotor
- Value Line - designed for high quality and a low price
- Perfect for OEM applications
- Up to 4166 oz-in (300 kg-cm) of Continuous Torque
- 60 mm motor body diameter
- Custom versions are available for orders over 100 pieces

BDPG-60-110-24V-2000-Rxx Specifications

Gear Ratio Rxx	3.6	4.25	13	15	18	47	55	65	76	168	198	234	276	326
Length (L) (in)	1.79	1.79	1.79	1.79	1.79	2.22	2.22	2.22	2.22	2.65	2.65	2.65	2.65	2.65
No Load Speed (RPM)	555	470	154	133	111	42	36	30	26	12	10	8.5	7.2	6.1
Rated Speed (RPM)	460	365	119	103	86	33	28	24	20	9.2	7.8	6.6	5.6	4.7
Rated Torque (kg-cm)	4.3	5.0	14	17	20	50	58	73	81	170	200	237	279	300
Peak Torque (kg-cm)	30	30	100	100	100	300	300	300	300	600	600	600	600	600

BDPG-60-110-24V-3000-Rxx Specifications

Gear Ratio Rxx	3.6	4.25	13	15	18	47	55	65	76	168	198	234	276	326
Length (L) (in)	1.79	1.79	1.79	1.79	1.79	2.22	2.22	2.22	2.22	2.65	2.65	2.65	2.65	2.65
No Load Speed (RPM)	833	706	230	200	167	64	54	46	39	18	15	13	11	9.2
Rated Speed (RPM)	694	588	192	167	139	53	45	38	33	15	12	10	9.0	7.7
Rated Torque (kg-cm)	4.1	4.8	14	16	19	48	56	66	77	163	192	227	268	300
Peak Torque (kg-cm)	30	30	100	100	100	300	300	300	300	600	600	600	600	600



910 E. Orangefair Ln. Anaheim, CA 92801 Tel (714) 992-6990 Fax (714) 992-0471
www.anaheimautomation.com

16.3 APEM Switch Joystick Datasheet

This is the chosen joystick's datasheet showing its detailed specifications.

1000 SERIES - MICROSWITCH JOYSTICKS

PRODUCT CONFIGURATION

STANDARD OPTIONS

The 1000 Series is available with a range of standard options. To specify your joystick, simply choose one option from each column. An example is shown below.

SERIES	MOUNTING	POLES	LEVER	HANDLE	LIMITER SET	GAITER	MODIFIER
1	D	1	5	F	1	5	00
6A - V4* (1)	22mm Bush* (D)	Single Pole (1)	Long* (1)	Round (C)	Not Supplied (0)	Screw Mount (1)	None (00)
16A - V3 (2)	4 Point Screw (V)	Di-pole* (2)	Standard V4* (5)	Cylindrical (D)	Standard (1)	Bush Mount* (5)	+ Limiter Fitted (34)
10A - V4* (3)			For Push Button V4* (6)	Conical (F)			Slot Limiter Fitted (39)
			For Di-poleV4/V3 (7)	Tall Conical (H)			
				Push Button* (M)			

* Denotes unavailable with V3 construction.

EXAMPLE CONFIGURATIONS

TECHNICAL SPECIFICATION

All parameters and dimensions shown maybe subject to specification, please refer to Apem for details.

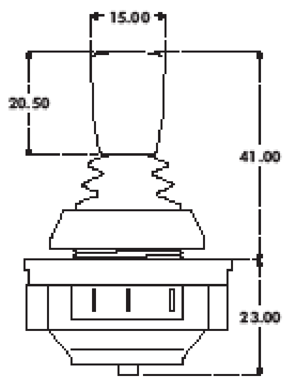
Mechanical Life	: >5 Million Operations	Lever Travel	: +/-12 Degrees from Centre
Lever Material	: Stainless Steel	Body Material	: Mineral Filled Nylon-6
Handle Material	: Nylon or Aluminium	Gaiter Material	: Neoprene
Mounting - Screw	: 4 x M2.5 Stainless (Slotted)	Mounting - Bush	: Single Point 22mm Diameter
No. of Switches	: 2, 4, or 8	Nominal Current	: 6A, 10A or 16A
Maximum Voltage	: 250V AC	Contacts 6A - V4	: Gold
Contacts 10A - V4	: Silver	Contacts 16A - V3	: Silver
Switch Contacts	: Changeover	Termination	: Solder (V4) - Faston (V3)
Contact Life	: Load Dependent	Temperature Range	: -20C to+50C
Weight	: 40 grams	Above Panel Seal	: IP65

www.apem.com 6

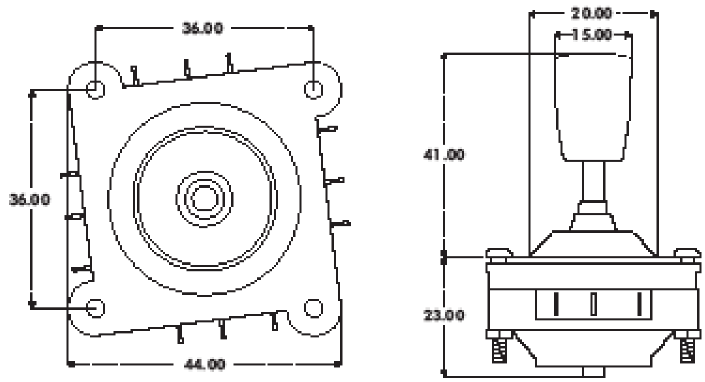
1000 SERIES - MICROSWITCH JOYSTICKS

USEFUL DIMENSIONS

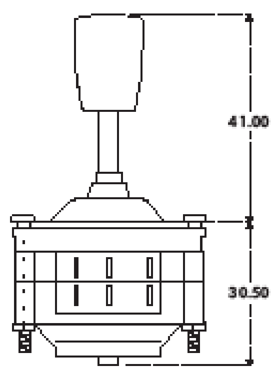
V4 BUSH MOUNT



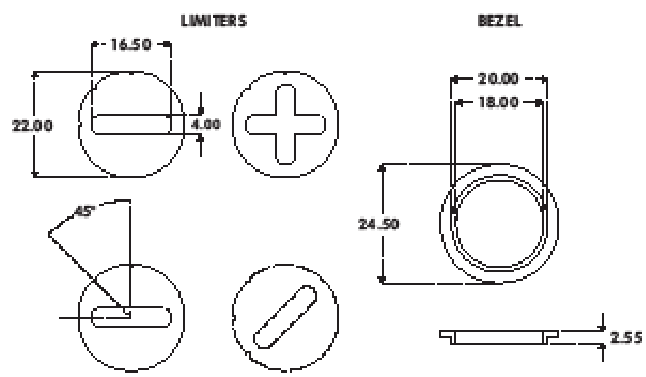
V4 SCREW MOUNT



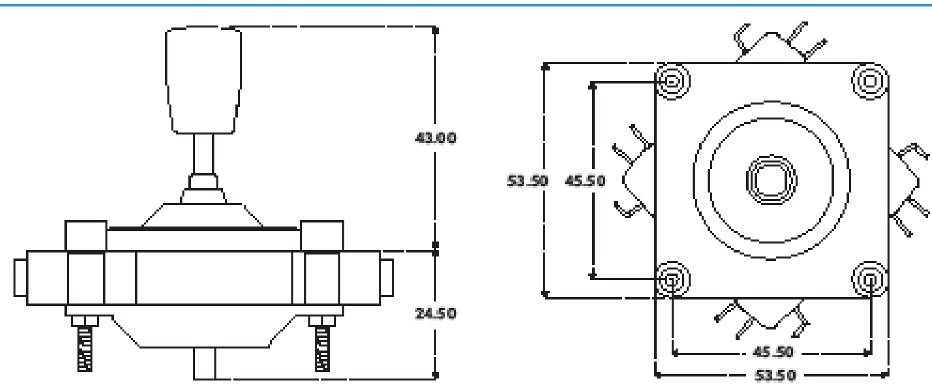
V4 DI-POLE



LIMITERS AND BEZEL SET



V3 SCREW MOUNT



16.4 Battery Datasheet

This is the chosen batteries' datasheet showing its detailed specifications.

Valve Regulated Lead-Acid Rechargeable Battery

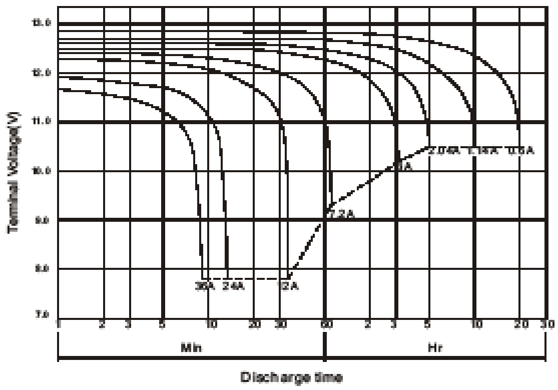
BP12-12

The battery is constructed by plates, separators, safety valves and container. Since the electrolyte is held by a glass-mat separator and plates, the battery can be used in any direction and position without leakage.

PERFORMANCE SPECIFICATIONS

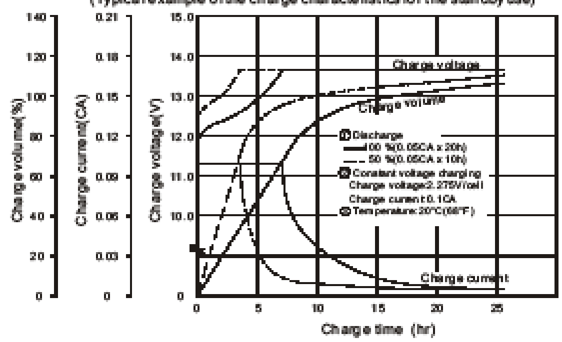
Nominal Voltage(V)	12 volts(6cells in series)
Nominal Capacity(AH)	
20 hour rate F.V.(1.75V/cell) (600mA to 10.50volts)	12A.H.
10 hour rate F.V.(1.75V/cell) (1140mA to10.50volts)	11.4A.H.
5 hour rate F.V.(1.75V/cell) (2040mA to 10.50volts)	10.2A.H.
1 hour rate F.V.(1.55V/cell) (7200mA to 9.30volts)	7.2A.H.
Approximate Weight	3940g(8.69lbs.)
Terminal	
Standard	Type T2
Optional	Type T1
Internal Resistance (Fully Charged Battery)	<18m Ω
Maximum Discharge Current For 5 sec.(A)	180A
Maximum Charge Current(A)	3.6A
Ambient Temperature	
Charge	0°C(32°F)~40°C(104°F)
Discharge	-20°C(-4°F)~50°C(122°F)
Storage	-20°C(-4°F)~40°C(104°F)
Vibration test:	
Frequency: 16.7HZ	
Amplitude: 4mm	
Vibrate the battery horizontally or vertically for 60 minutes. The battery have no abnormality.	
Case	ABS
Dimension(mm/inch)	
Length ±1.5mm	151/5.94
Width ±1.5mm	98/3.86
Container Height ±1.5mm	94/3.70
Total Height ±2mm	98/3.86
Application	UPS, Laboratory Equipment, Toy-Cars, Power Packs, Fishing Lights.

BP12-12 Battery discharge characteristics (25°C/77°F)



Battery Charging Characteristics

(Typical example of the charge characteristics for the standby use)

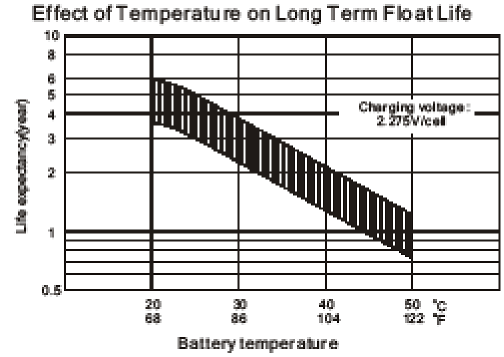


Charging Procedure

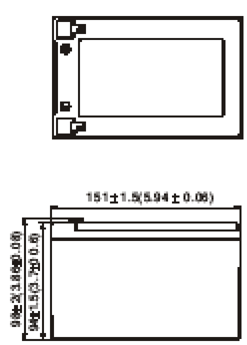
Application	Charging method	Charging Voltage at 20°C (V/cell)	Temperature compensation coefficient of charging voltage (mV/°C/cell)	Max. charging current (CA)	Charging time 0.1CA, 20°C (h)		Temp (°C)
					100% discharge	50% discharge	
For standby power Source	Constant voltage & Constant current charging (with current restriction)	2.25~2.30	-3	0.3	24	20	0~40 (32~104°F)
For cycle service		2.40~2.50	-4	0.3	16	10	

*Temperature compensation of charging voltage is not needed, when using the batteries within 5°C to 35°C range.

Effect of Temperature on Long Term Float Life

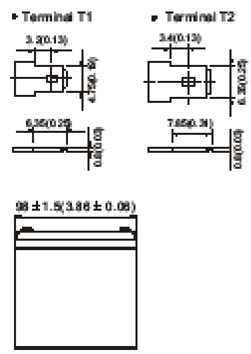


OUTER DIMENSIONS



TERMINAL TYPE

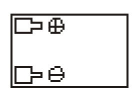
mm(inch)



Constant power discharge characteristics at 25°C/77°F

Final Voltage	Discharge time								
	5Min	10Min	15Min	30Min	1Hr	3Hr	5Hr	10Hr	20Hr
	Battery output power(W)								
10.80V	433.9	319.4	256.0	152.3	87.34	34.98	24.12	13.48	7.05
10.50V	502.2	346.0	267.7	158.1	89.96	35.68	24.48	13.68	7.20
10.20V	533.6	358.5	276.0	161.7	91.57	36.00	24.61	13.75	7.23
9.90V	557.5	367.1	282.4	164.0	92.67	36.25	24.70	13.79	7.25
9.60V	576.0	374.4	288.0	165.6	93.60	36.47	24.77	13.79	7.25

TERMINAL POSITION



B.B. BATTERY CO., LTD. Web Site: http://www.bb-battery.com

USA:
B&B BATTERY(USA) INC.
6415 RANDOLPH ST.COMMERCE,
CA,90040 U.S.A.
TEL:1-323-278-1900,1-800-278-8599
FAX:1-323-278-1268
E-Mail:sales@bb-battery.com

EUROPE:
B&B BATTERY(EUROPE) B.V.
3 WIJNGAARDVELD, 9300 AALST,BELGIUM
TEL:(00)32-53781567
FAX:(00)32-53781567
E-Mail:hansdevriese@bb-battery.com

CHINA FACTORY:
B.B. BATTERY CO., LTD.
CHENG DONG TRIAL AREA,HUANG GANG,
RAOPING, GUANG DONG,CHINA,515700
TEL:86-768-7601001-2
FAX:86-768-7601469
E-Mail:maggy@bb-battery.com

HONG KONG:
NATIONAL TRADING LTD.
TEL:852-2301-3800
FAX:852-2739-1182
E-Mail:bbhk@hkstar.com

JAPAN:
B&B BATTERY(JAPAN) CO., LTD.
1375-11 NARAHARA-MACHI,HACHIOJI,
TOKYO 193-0803,JAPAN.
TEL:81-426-25-6375
FAX:81-426-25-6375
E-Mail:miyata@bb-battery.com

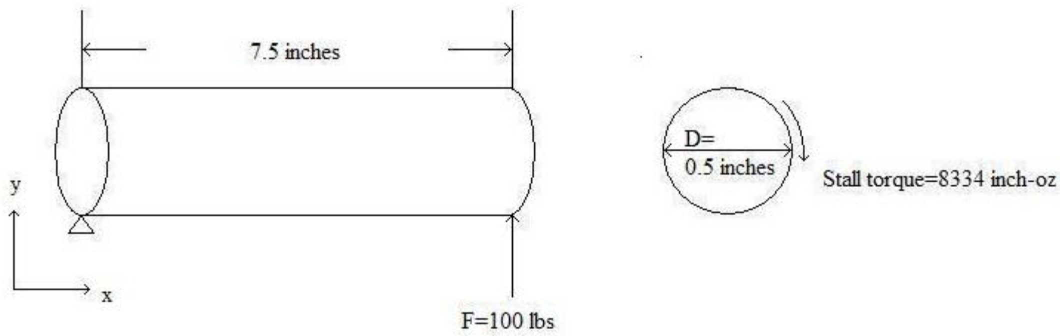
TAIWAN:
B.B. BATTERY(TAIWAN) CO., LTD.
TEL:886-6-602-5150
FAX:886-6-689-8087
E-Mail:maggy@bb-battery.com

ISO14001

REV. Jun. 2005

16.5 Drive Shaft Loading Analysis

This is analysis to verify that the drive shaft can sustain the required loading and motor torque.



There are two stresses in different directions on the drive shaft.

1) The stress acting in the x-direction is caused by supporting the MMRP and user weight:

$$\sigma_x = -\frac{M_z y}{I_z}$$

$$M_z = Fd$$

Each drive wheel will carry 100 lbs of weight.

$$M_z = (100\ lbs)(7.5\ in) = 750\ inlbs$$

$$I_z = \frac{bh^3}{12} = \frac{(7.5\ in)(0.5\ in)^3}{12} = 0.078125\ in^4$$

$$\sigma_x = -\frac{M_z y}{I_z} = -\frac{(750\ inlbs)(0.25\ in)}{(0.078125\ in^4)} = -2{,}400\ psi$$

2) The stress caused by the motor torque, acting in the z-direction:

$$\sigma_z = \frac{M_x y}{I_x}$$

$$I_x = \frac{\pi D^4}{64}$$

$$I_x = \frac{\pi(0.5\ in)^4}{64} = 0.003067\ in^4$$

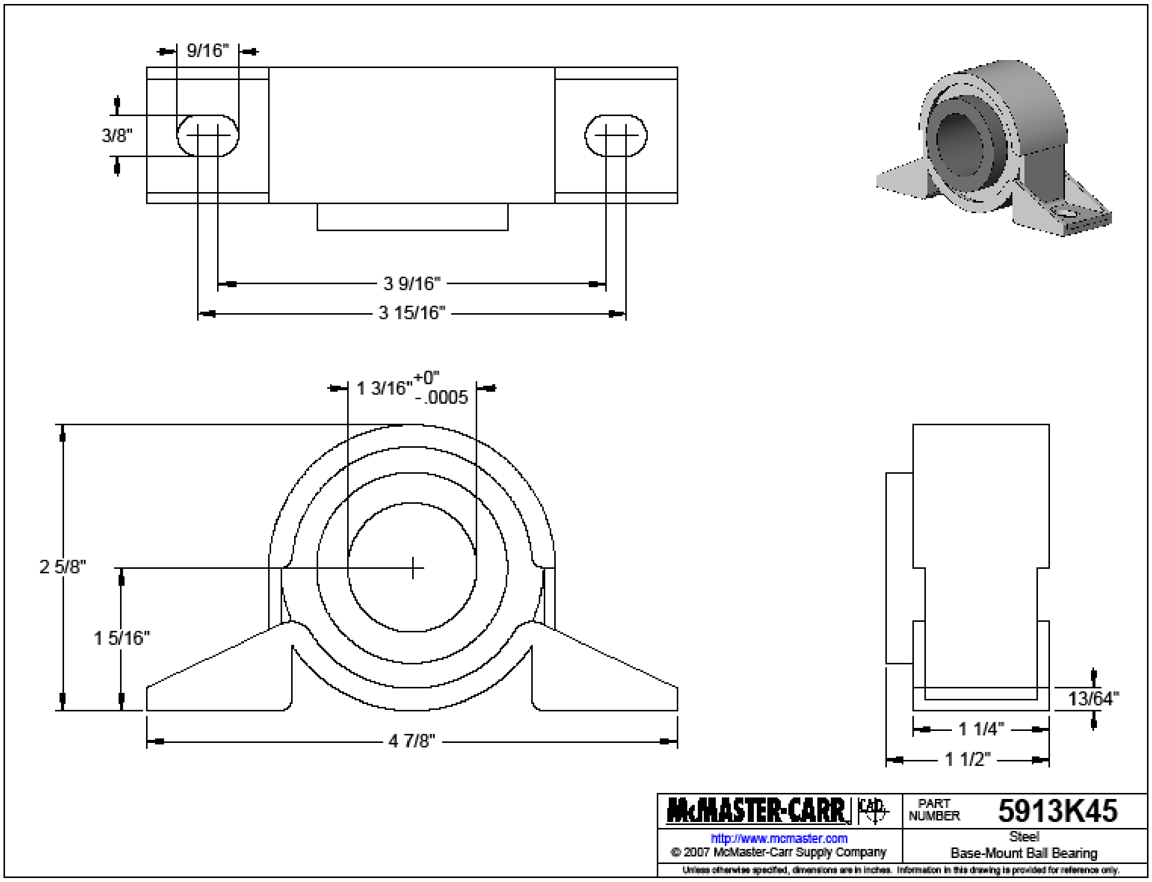
$$M_x = stall\ torque\ of\ motor = 8334\ inoz(\frac{1\ lb}{16\ oz}) = 520.875\ inlbs$$

$$\sigma_z = \frac{M_x y}{I_x} = \frac{(520.875\ inlbs)(0.25\ in)}{(0.003067\ in^4)} = 42{,}400\ psi$$

Compare these two stresses to the yield strength of AISI 1045, $\sigma_Y = 84{,}800\ psi$. The stresses caused by the total weight and the motor torque will not exceed the yield strength of the drive shaft. The safety factor in the x-direction is 35. The safety factor in the z-direction is 2.

16.6 Dimensioned Drawing of Bearing

This is the chosen bearings' detailed engineering drawings.



16.7 Manufacturing and Assembly Plan

This section details the steps required to manufacture and assemble the MMRP prototype.

No.	Process Description	Details
1	Machine 2 Shaft End Motor Mounts	Process Plan Sheet on pg. 62
2	Machine 2 Back End Motor Mounts	Process Plan Sheet on pg. 62
3	Machine Stepped Key for motors (x2)	Mill to dimensions shown on pg. 29
4	Mill out wire slots in switch housing post	See Dimensioned Drawing on pg. 61
5	Manufacture Switch Housing	Process Plan Sheet on pg. 62
6	Manufacture Base Frame	Process Plan Sheet on pg. 62
7	Attach motor to Shaft End Motor Mounts (x2)	4- M5 screws and washers
8	Attach motor to Back End Motor Mounts (x2)	3- M4 screws and washers
9	Mount motor mounts to motor L brackets (x4)	2- 1" 1/4-20 bolts + washer each motor mount
10	Determine length of drive shaft and cut to size (x2)	Cut with hack saw
11	Attach couplers to motor and drive shafts (x2)	1/8" x 1/8" Key in shaft keyhole, Stepped Key in motor keyhole, secure with set screws
12	Slide bearings over drive shaft and mount to frame (x4)	Place bearings on shaft and secure with set screw + 2- 5/16" bolts and washers each* ^
13	Install drive wheels (x2)	1/8" x 1/8" Key stock in keyhole and set screws
14	Mount casters to Base Frame (x2)	2- 3/8" nuts and washers
15	Install joystick to housing	4- included 2M mounting screws
16	Install switch to housing	1/2" Mounting nut
17	Place batteries in battery supports (x2)	Secure with large zip ties
18	Run wire to components and cut to desired lengths	See Wiring Schematics on pgs. 30-32
19	Attach electrical fasteners to wires	Quick disconnects crimped to wire
20	Ground negative battery terminal to frame	Crimped spade connector bolted to frame
21	Attach wires to components	Attach quick disconnects

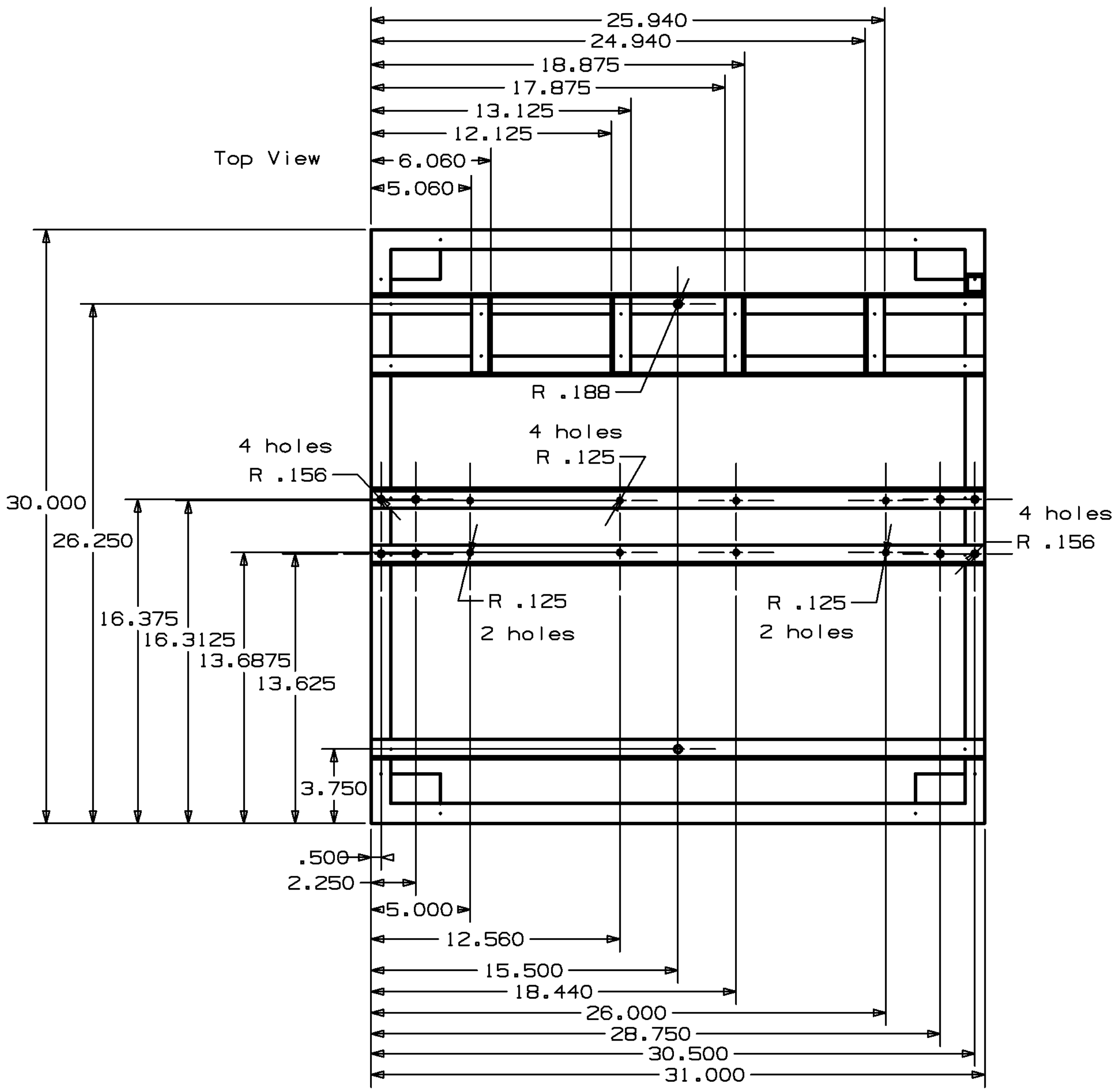
* In order to limit translational motion of shaft the two bearings should be mounted at opposite ends of their "play" such that the shaft cannot move

^ 1" length for L bracket and 2" length for going through base

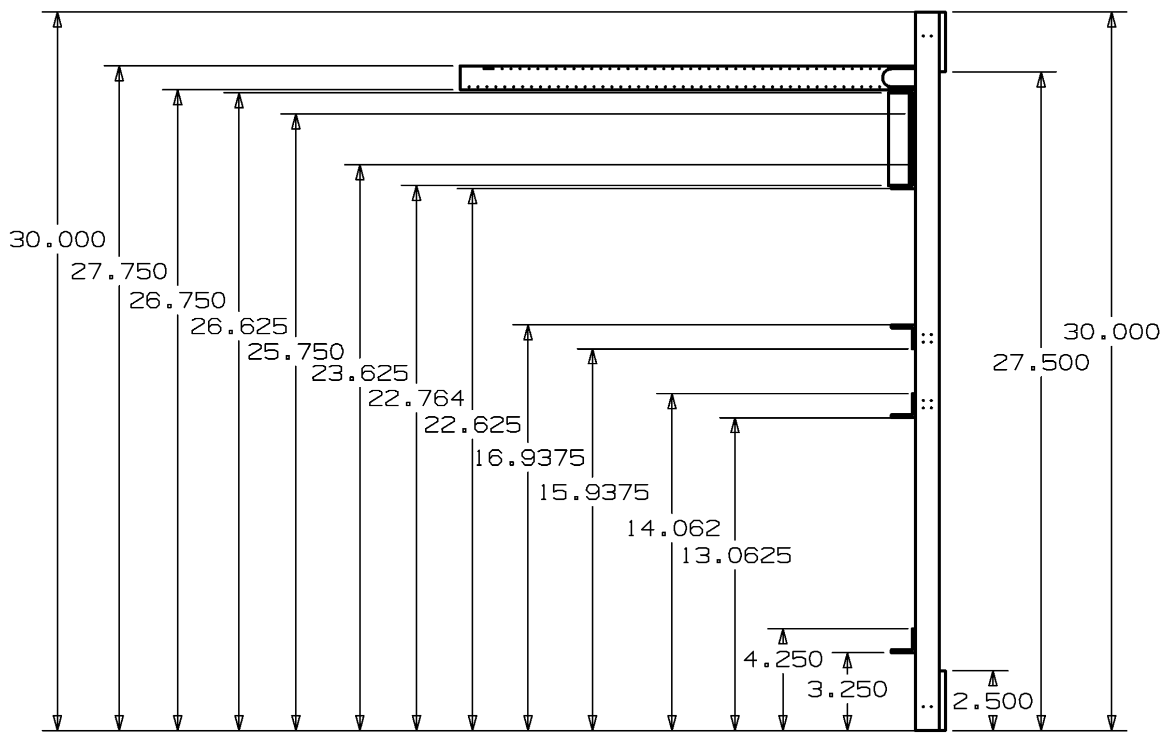
16.8 Dimensioned CAD Drawings

This section shows the detailed CAD drawings for each of the major components of the MMRP. Dimensions to fabricate each part are shown.

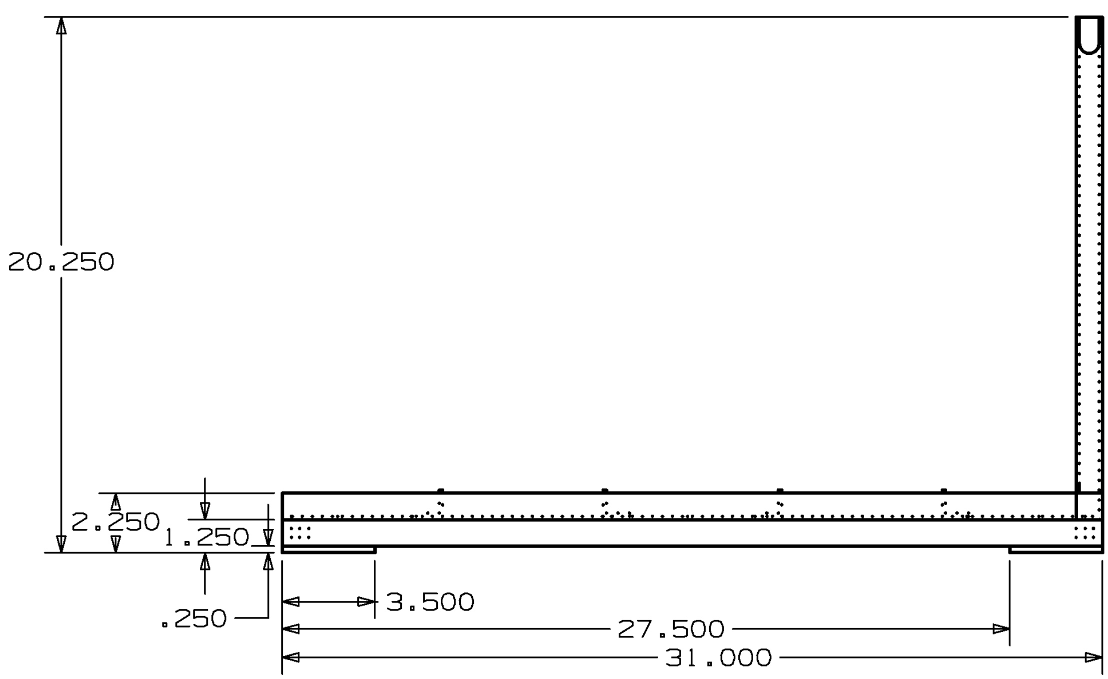
16.8.1 Base



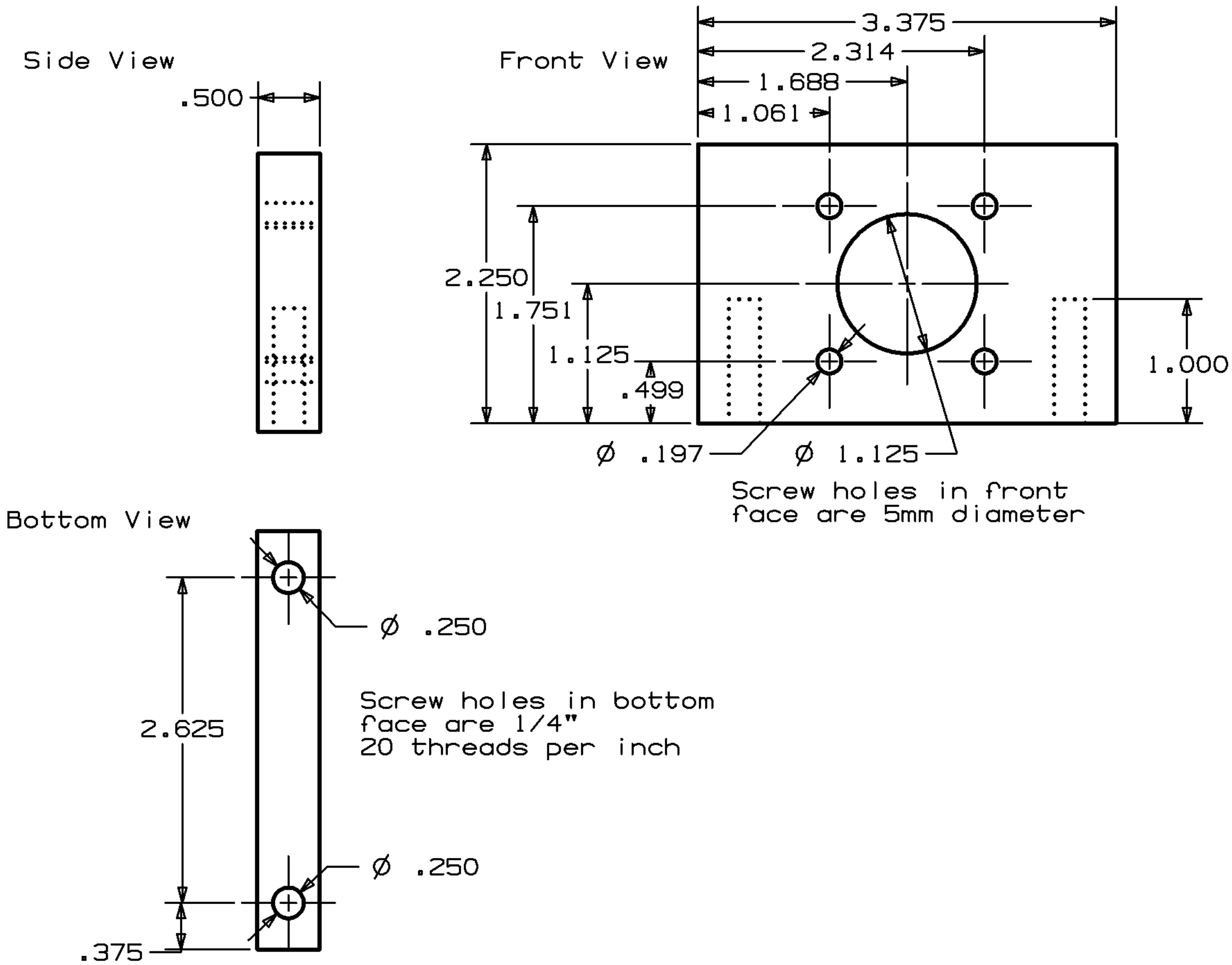
Right Side View



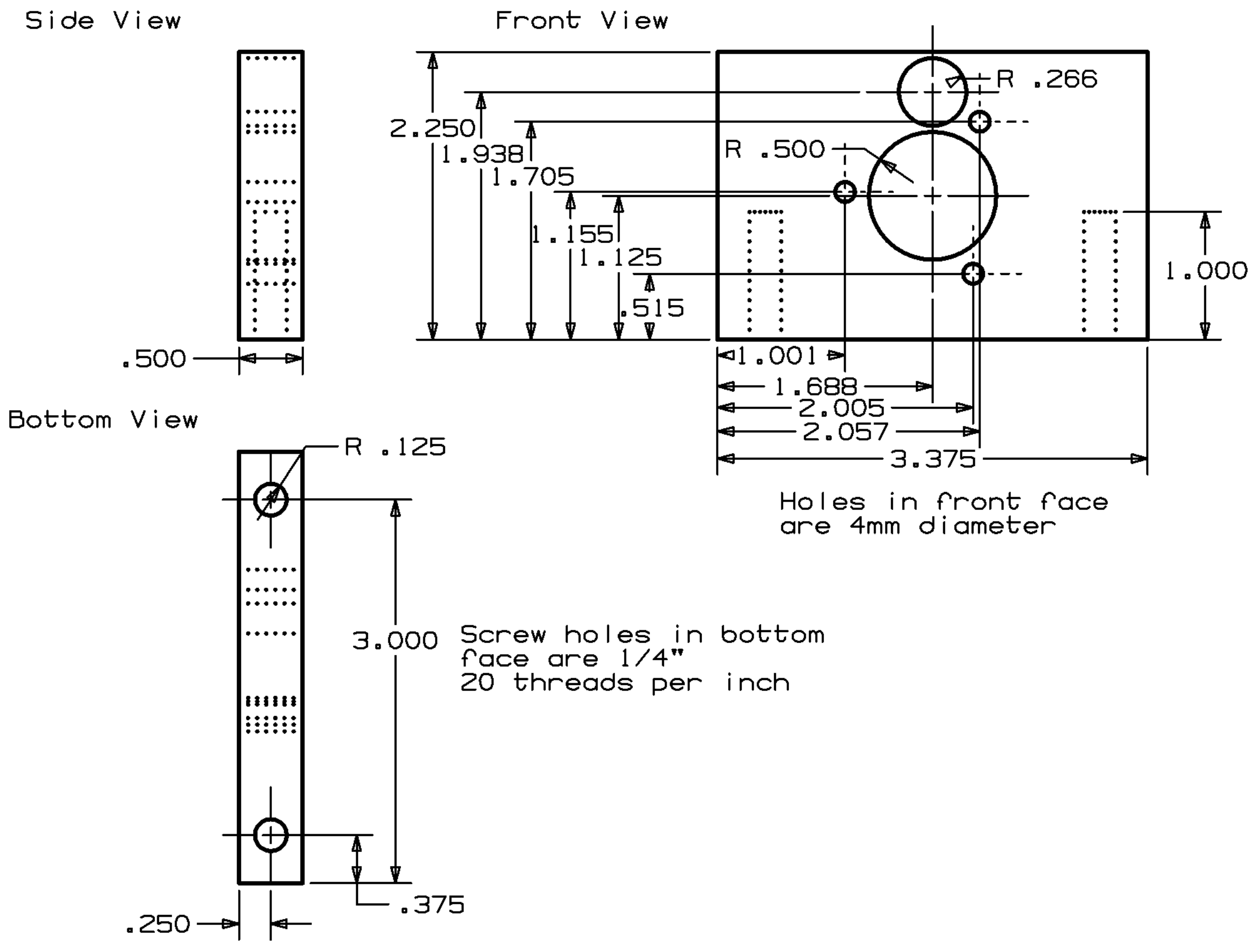
Back End View



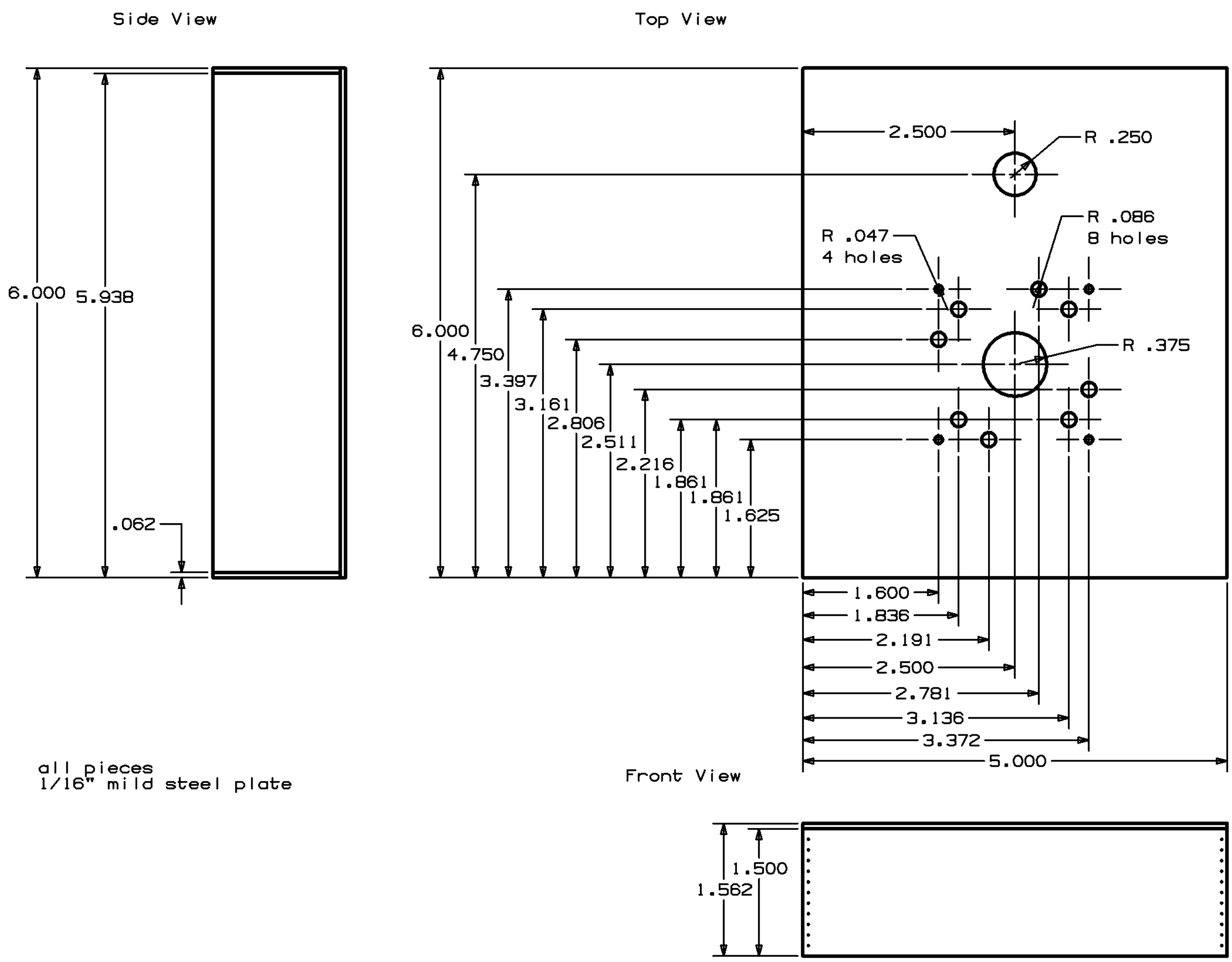
16.8.2 Front motor mount



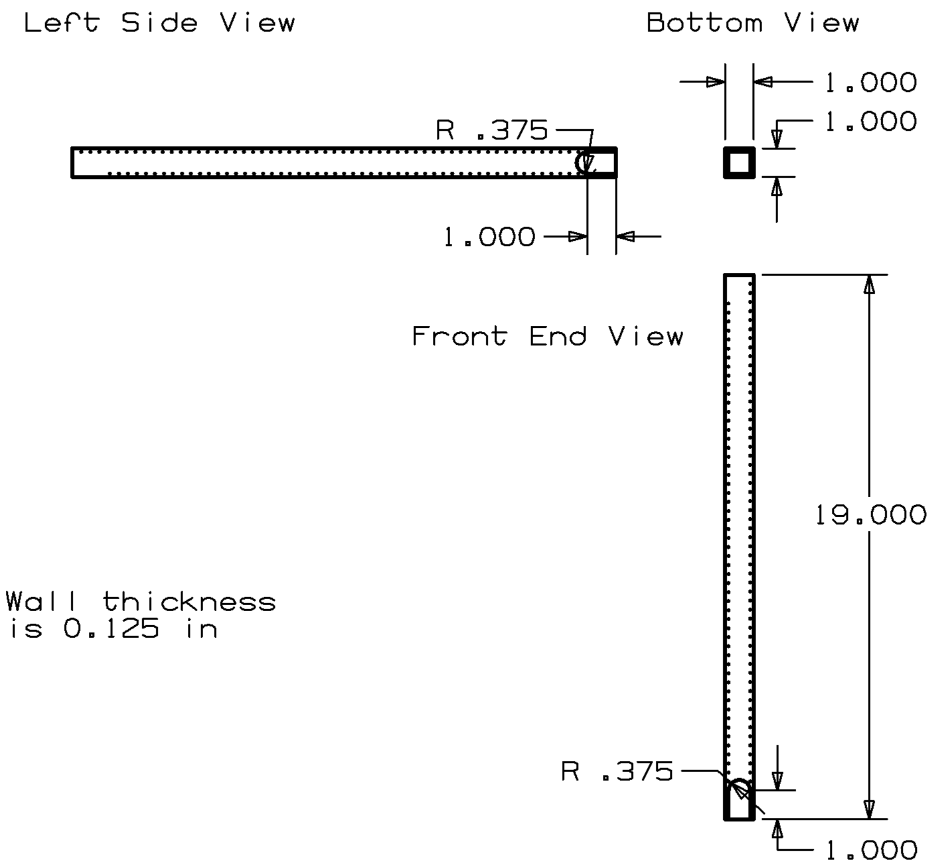
16.8.3 Rear motor mount



16.8.4 Switch housing



16.8.5 Switch housing post



16.9 Process Plan Sheets

This section details the specific steps to manufacture the major parts that needed to be made.

Part Name: Base Frame
Raw Material Stock: 1" x 1" x 1/8" wall "square" and "angle", 2.5" x 3.5" x 1/4" "plate" mild steel

No.	Process Description	Machine	Speed (RPM)	Tool
1	Cut square, L, and plate pieces to length	Bandsaw	75	Saw Blade
2	File sharp edges			File
3	Chemically clean pieces			Chemicals
4	Drill various mounting holes	Drill Press	75	Drill
5	Abrasively clean areas to be welded			Hand grinder
6	Chemically clean weld areas			Acetone
7	Weld square frame and joystick post together		50% speed	MIG Welding @ 22V
8	Weld corner chair plates to frame (4 pieces)		50% speed	MIG Welding @ 22V
9	Weld non-motor L brackets onto frame (3 pieces)		50% speed	MIG Welding @ 22V
10	Weld motor assembly L brackets to frame (2 pieces)*		50% speed	MIG Welding @ 22V
11	Weld tube post and switch housing to base		50% speed	MIG Welding @ 22V

* Do not weld along edge of L bracket where switch housing tube post will be mounted so that post can be butted directly against L bracket

Part Name: Shaft End Motor Mounts x 2
Raw Material Stock: 1/2" Aluminum

No.	Process Description	Machine	Speed (RPM)	Tool
1	Cut 2.5" x 3.5" x 1/2" block out	Bandsaw	300	Saw Blade
2	Mount part horizontally in indexing fixture on mill	Mill		
3	Square Part	Mill	1500	Φ 0.5" End Mill, 2 flute
				Edge Finder
6	Drill 5 center holes	Mill	600	Center Drill
7	Drill 4 Φ 0.199" holes w/ #8 bit	Mill	600	Φ 0.199", #8 Drill
8	Drill Φ 1.0" hole w/ 1" bit			Φ 1.0" Drill
	Mount part vertically in indexing fixture on mill	Mill		
11	Locate center of edge of part	Mill	600	Edge Finder
12	Drill 2 center holes	Mill	600	Center Drill
13	Drill 2 Φ 0.199" holes, 1.0" deep w/ #8 bit	Mill	600	Φ 0.199", #8 Drill
14	Tap threads 1/4 - 20 by hand for bottom piece (2 total)			Tap 1/4 - 20

Part Name: Back End Motor Mounts x 2
Raw Material Stock: 1/2" Aluminum

No.	Process Description	Machine	Speed (RPM)	Tool
1	Cut 2.5" x 3.5" x 1/2" block out	Bandsaw	300	Saw Blade
2	Mount part horizontally in indexing fixture on mill	Mill		
3	Square Part	Mill	1500	Φ 0.5" End Mill, 2 flute
				Edge Finder
6	Drill 5 center holes	Mill	600	Center Drill
7	Drill 3 Φ 0.172" holes w/ 11/64" bit	Mill	600	Φ 0.172", 11/64" Drill
8	Drill Φ 1.0" hole w/ 1" bit			Φ 1.0" Drill
	Mount part vertically in indexing fixture on mill	Mill		
11	Locate center of edge of part	Mill	600	Edge Finder
12	Drill 2 center holes	Mill	600	Center Drill
13	Drill 2 Φ 0.199" holes, 1.0" deep w/ #8 bit	Mill	600	Φ 0.199", #8 Drill
14	Tap threads 1/4 - 20 by hand for bottom piece (2 total)			Tap 1/4 - 20

Part Name: Switch Housing
Raw Material Stock: 1/16" "plate" mild steel,

No.	Process Description	Machine	Speed (RPM)	Tool
1	Cut to correct size per Engineering Drawing	Bandsaw	100	Saw Blade
2	File sharp edges			File
3	Drill 4 Φ 0.094" holes w/ #3/32" bit	Drill Press	400	3/32" Drill
4	Drill 8 Φ 0.172" holes w/ 11/64" bit	Drill Press	400	1/2" Drill
5	Drill Φ 0.5" holes w/ 1/2" bit	Drill Press	400	11/64" Drill
6	Drill Φ 0.75" holes w/ 3/4" bit	Drill Press	400	3/4" Drill
7	Chemically clean pieces			Chemicals
8	Abrasively clean areas to be welded (if necessary)			Hand grinder
9	Chemically clean weld areas			Acetone
10	Weld box per Engineering Drawing		50% speed	MIG Welding @ 22V