M.A.R.C. - I
(Modular Amphibious Research Crawler)

Design and Construction of a Remotely Operated Vehicle for Coastal Marine Studies

Jonathan Cies
Lee Frey
Adrian Mackenna
Florida Institute of Technology
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Dr. Andrew Zborowski
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1.1 EXECUTIVE SUMMARY:

1.1.1 INTRODUCTION:

This paper concerns the design and fabrication of a small, low-cost crawling ROV (Remotely Operated Vehicle) to be used for underwater exploration and coastal studies. Its primary function is as a mobile, remotely operated platform for beach, surf zone, and near-shore surveying. However, the MARC-I (Modular Amphibious Research Crawler) prototype has been designed as an open system, easily able to be retrofitted for various other applications.

1.1.2 CONCLUSIONS:

Through the design and construction of the prototype MARC-I underwater vehicle, several design changes have been made. These changes have developed through difficulties in the manufacturing process or from various enhancements deemed necessary by the design team. After having constructed the vehicle and ran several land-based tests and trial operations, the MARC-I prototype has performed better than expected. Its stability, maneuverability, drive characteristics are ideal for surveying applications. Furthermore, the vehicle’s modular design does prove easy to assemble and transport. All materials and components are readily available and running costs are minimal. Overall, the MARC-I shows outstanding promise to be used in the surf zone for coastal studies and other tasks.

1.1.3 FUTURE PLANS & RECOMMENDATIONS:

The most immediate goal of the MARC-I design team is to complete all waterproofing measures, such that the vehicle will be ready for ocean trials. Once these trials have been completed, the vehicle may be outfitted for many activities, primarily surveying. Although this paper does not concern the design of a surveying system for the MARC-I, several options including GPS, Geodimeter, and SONAR systems will be discussed.
2.1: **INTRODUCTION**

Coastal processes, the study of wave mechanics and their effect on near shore zones, such as beaches, has been an increasing area of interest in modern times. Our nation’s coastlines continue to be washed away by waves and their associated currents, and millions of dollars are being spent on beach replenishment projects to pump sand back onto the beaches. But these millions may be spent in vain if the interaction between sediment transfer and wave kinematics is not understood. In order for these processes to be understood, accurate records of the beach’s ever changing bathymetry are needed. Additionally, the exploration of our ocean bottom terrains and sediments has become an increasing area of research interest.

Despite the fact that the majority of coastal activity occurs between 0-100m from shore, this is the zone with the least amount of existing survey data. This zone is difficult to survey for several reasons. Hydrographic surveys using ships and SONAR transducers cannot be used in the nearshore zone due to the shallow water depth and high wave action. Additionally, acoustic signals attenuate in the increased wave action and air bubble concentrations. Conventional surveying (i.e. transit and rod) has a very short range from shore, because water depth quickly exceeds the height of the individual carrying the rod. Some alternative methods of beach surveying have been effectively developed, but are expensive and not easy to transport between beaches.

The ‘C.R.A.B’ (Coastal Research Amphibious Buggy), operated by the US Army Corps. Of Engineers at Duck, North Carolina is a good example of such technology. The CRAB is a manned, 35 ft. tall pyramidal vehicle, designed for coastal surveying along a small stretch of beach in the Outer Banks. The C.R.A.B. serves as a platform for an RTK Differential-GPS package. Although it works well, the C.R.A.B. is designed for a specific stretch of coastline and is nearly impossible to transport over long distances to other beaches. Also, the cost of manufacturing, maintaining, and running such a vehicle makes it an undesirable alternative.

Another solution to the problem of surveying beaches, created by Dr. William Dally of The Florida Institute of Technology is known as “The Surf Rover”. The
Surf Rover is a two thousand pound remotely operated aluminum vehicle with two tractor treads as propulsors. This vehicle is also used as a platform for coastal surveying using a Geodimeter Total Station. Unfortunately the Surf Rover is a much larger, higher cost vehicle than we feel can be practical for frequent, simple operation and fast construction on a limited budget (< $5000.00).

Both of these systems are very effective in surveying, but are also expensive to build, operate and maintain. Also, the large size of these vehicles prevents them from being readily transported from beach to beach. Additionally, the design of these vehicles is single-functional, as they are not especially suited to serve other applications. Through the MARC-I project, it is our goal to design a simple, small, low-cost crawling ROV that will combat all of these problems.
2.2 GENESIS & EVOLUTION:

The MARC-I project had the distinction of being the only ocean engineering marine fields project that was not conceived by outside industry and then brought to the school. As a result the idea for the project had to be built from the ground up. The first step was of course deciding what the vehicle was being built to do. Then it had to be decided what material to use in construction. 6061-T6 Aluminum was chosen for its resistivity to corrosion, ease of machining, availability, and cost. After that came the task of designing the vehicle to do the job. Figure 2.2.1 illustrates one of the first concepts for the vehicle.

![Preliminary sketch for the vehicle](image.jpg)

While crude, Figure 2.2.1 shows the basics of what the vehicle needed to be in order to accomplish its designed task. Even in the early stages the decision was made to make the vehicle a crawler. The idea of a swimming ROV was thrown out because not only
would the dynamics of the near-shore currents make it near impossible to pilot a straight line but a swimming ROV cannot be as easily launched from the beach as a crawling ROV. Plus a crawling ROV allows for continuous surveying from the beach all the way out to the near-shore zone.

Once these crude sketches were generated it was time to combine them into one coherent design that could be presented for approval. This composite design possessed all the traits that, it was thought, would be needed. Those traits were a center section that would be the command module, articulating legs to allow for varied terrain, treads for locomotion in the sand on the front legs, and skids on the back legs to track in the sand. Figure 2.2.2 shows the initial design that was presented.

![Initial Design of the ROV](image)

This initial design represented a starting point. Up until this point in the design process it had been impossible to seek out side help since the project could not really be envisioned without some kind of design plan. Now that the plan was in hand the next step was to seek experienced help outside the group in order to see if the design was
sound and if it was not, to ascertain what changes could be made.
2.3 **DESIGN MODIFICATIONS:**

Looking at Figures 2.2.1 and 2.2.2 in comparison to the final vehicle produced it is obvious that numerous design changes were made. This was to be expected since no one in the group had any real experience in designing ROVs and for the simple reason that new and better ideas come along in the process of getting a final design. Some of the modifications were made on the advice of individuals to whom the project was brought for critique. Other modifications came as a result of practicality of machining and materials available, and still others had to be made on the spot to adapt to sudden changes in the project. The three main areas of the vehicle are its wheels, legs and center section. Each area and the modifications made to it will be treated individually in the following sections.

2.3.1 **WHEELS:**

Once it was determined that the ROV would crawl along the ocean floor it had to be decided how it could best accomplish this. In short, the vehicle needed some kind of wheels. In researching the few vehicles of similar function the one that was given the most consideration was the Surf Rover built by DR. William Dally. This was the ideal vehicle to study since it and the man who created it were both at Florida Tech. Using the Surf Rover as inspiration it as decide to outfit the MARC-I with tank treads for locomotion as is shown in Figure 2.2.2.

Tank treads were chosen because of the nature of the terrain the vehicle would be operating in. The sand in the near-shore zone can become fluid like under the right type of current action and the vehicle needed to be able to operate in such conditions. Tank
useless. The idea that was settled upon was a plastic wear surface that would fit into the bearing and fit the drive shaft like a sleeve.

This arrangement made construction easier since there were no small moving parts to be concerned with. It was also well suited for work in the water. Once the vehicle submerges water works into the spaces between the plastic and the drive shaft to act as a lubricant. The plastic chosen for the bearing was an Ultra High Molecular Weight PolyEthylene (UHMWPE). There were plastics with better wear properties but the UHMWPE was not only more economical, it also had a slipperier surface than the other plastics considered which would make it the better choice for a bearing.

With the material for the bearings now determined, the next task was to design their shape. The natural choice was to make the bearing cylinders that slip fit into the aluminum pipe housings that would contain them. The only addition made to this basic shape was a contact wear surface. For the front two bearings the outside would wear due to the motion of the hub. For the back legs the outside would wear due to the motion of the restraining rings. To account for this wear the bearings were give ¼ inch lips for the hubs and rings to move against.

As the preceding paragraph hints at the bearings were designed to be sacrificial. Even though there are no small moving parts sand will get into the bearings and wear it away over time. However the design of the bearing and the economics of the material used allows for ease of replacement.

The Polyethylene bearings which house the drive shafts were given a length of 8.25 inches, which gives the shaft a wide contact area. This design allows the weight of the vehicle to be distributed over a larger area of polyethylene.
treads would allow the vehicle to dig into the sand and push through it for locomotion. Putting paddles on each individual tread would allow the vehicle to paddle through the sand even better. With these ideas in mind the group set up a meeting with Dr. Dally in order to get his input on the project.

Dr. Dally brought up a very practical consideration once he heard of our intention to use tank treads on the vehicle. While treads may be the best option, they are very time consuming to produce and the skill that is required to machine them would have required giving that part of the vehicle to a skilled machinist to complete. The goal of this project was to build a feasible cost-effective working platform for underwater experimentation, not to get bogged down in the details of machining complex precision parts. In order to get the vehicle built in the time allotted the treads had to be dropped.

Taking Dr. Dally’s advice tires were the replacement for the treads. The goal was to get the vehicle up and running and with tires there would be no time lost in machining. Once tires were decided upon the type of tire had to be selected. The paddles on the tank treads were a big part of what made the treads so desirable so in looking at tires it was hoped that something similar could be found. The tires finally chosen to replace the front treads were ATV tires specifically designed to be used on the drive wheels in the sand and had paddles on them for gripping. A possible problem in using the tires was the buoyant force they would give to the vehicle however that was remedied by filling them with water as opposed to air. They appeared to be the ideal choice and so they became the final choice as the replacement for the front treads.

Now that the front wheels were taken care of the back wheel had to be addressed. From the beginning of the design the back wheels only function was tracking, the front
wheels would supply the drive. That is why even in the initial sketched that back wheels were not treads like the front ones. Since they would be tracking they needed to have an ease of movement in the sand that the treads did not have. Looking around at similar environments to the sand the vehicle would be driven in the closest approximation found was snow. As a result the tracking wheels were designed as skids similar in form and function to a ski.

While there was no doubt that the ski legs would track adequately in the vehicle’s design environment they did pose other problems. Depending upon their length they could get caught at the ends which would bow and potentially break the ski. Also depending upon where and how the vehicle turned the ends of the ski could get caught up in surrounding debris or even the tether. So the ski was then replaced with a bowl as seen in Figure 2.2.2. If the bowl was made the same way as the ski it would track as well plus it did not need a large potentially problematic length and did not posses any defined edges that would cause a problem. But the bowl had its problems as well. The main one was that if the bowl filled with sand and debris the resulting drag could substantially affect the vehicle. The option of making the bowls watertight coverings was offered but it too presented numerous problems and so the whole bowl idea was dropped.

Thinking back to Dr. Dally’s recommendations the next option to be explored was tires. But the problem with tires is that they would slip in the sand, there was no means to insure that a tire would track straight. So the next step was to look at the tires selected for the front legs but the way their paddles were orientated, while ideal for driving, made tracking a problem. Then looking through the catalog the drive tires were gotten from it was discovered that there were matching steering tires. These tires had a single rib
centered on the tire that dug into the sand making tracking possible. They were designed specifically for steering in the sand and were the logical choice as replacements for the ski.

2.3.2 DRIVE TRAIN:

Now that the wheel design had been finalized the next step was to create the drive train. The first thing that needed to be determined was the type of motors that would power the vehicle. Reversible AC motors were the final choice. Granted reversible AC motors bring the added complication of designing a relay to control the reversing circuit but the only other option for reversible motors were AC/DC and then a transformer would have to be factored into the design. It was decided that building the relay would be easier than accounting for the transformer.

With the type of motor determined the next thing to be calculated was the power the motors would need to operate the vehicle. To determine this the vehicle was broken down into its component shapes and then the drag force was determined for each of these shapes for a design speed of 0.5 m/s. Next the drag for of the tires in the sand was approximated using the closest coefficients of friction that could be found. The final aspect to add in was the drag force from the tether. Knowing the total drag the vehicle would have to overcome and then adding a 50 percent factor of safety gave the required torque for the motors. The exact equation can be found in Appendix C. Knowing this torque value then made it possible to look through various catalogs for the appropriate motors. The motor that were finally chosen had a torque value double of what was determined ensuring that the vehicle would not be under-powered. With the motors taken care of the next aspect to be considered was how to integrate the wheels.
In purchasing the wheels for the vehicle the accompanying rims were also purchased. These rims had a 5 inch offset to one side and it was thought that this offset could be taken advantage of by making the drive train direct drive and placing the motors within this offset. By doing that even if the motors did not fit all the way inside the offset they would at least be partially protected from damage by debris kicked up by the vehicle. With this idea in mind the next step was to design a housing that would encompass both wheel and motor.

Figure 2.3.2.1: Rendering of the final design of the MARC-1 before the beginning of summer MFP

Figure 2.3.2.1 shows many design changes that have not yet been explained but the one to focus on now is the drive train. As the figure shows the drive wheel are encased by Us. These Us were to be constructed of aluminum channel and welded together. The tip of the U facing outside would have a bearing on it. This bearing would connect to a shaft that connected to the wheel hub. The inside tip of the U would have a mounting plate on it for the back of the motor. The motor shaft would connect to the drive shaft which connected to the wheel hub. For the back wheels both tips of the U would have
bearings connected to a drive shaft that ran the length of the U through the wheel allowing the wheel to spin freely.

The U design seemed ideal and indeed no reason was presented to change this design. The machining was easy enough, the materials were available and as already mentioned the design allowed for some protection of the motors. However there was another reason altogether which lead to the change in the drive train design, the motors. When the U design for the drive train was conceived it was understood that the motors, generously donated by Von Weiss Gear Co., would be arriving within the week. However shipping complications prevented this and time soon became a factor. With the drive train design as it was machining could not be started until the motors arrived so that precise measurement could be taken and the U built accordingly.

Upon the suggestion of our graduate student advisor, Chris Goshow, the U design was dropped in favor of a design that was not dependent upon motor dimensions, and would be easier to construct. Instead of the U depicted in Figure 2.3.2.1 the new design has the leg ending in a saddle cut welded to a simple cylindrical bearing. The inside end of the bearing ends in a motor mounting plate. The outside end of the bearing is flush with the wheel rim.

Figure 2.3.2.2 shows the final drive train of the vehicle. The key thing to note is that this new drive train is not constricted by the motor. In fact the only specifications the motor has to conform to with this configuration is that its drive shaft must be able to mate with the vehicle’s drive shaft. Granted this design also leaves the motors unprotected but it was the only design that allowed for the completion of the drive train before the arrival of the motors.
Even though the U design had to be dropped for the front legs, there was no reason to alter it for the back legs. The only modifications made to the U design were practical in order to ensure stability. Gussets were added to the welded corners for improved strength and saddle cuts were made at the tips of the U so that they could be mated with the bearing instead of welding the end of the bearing to the inside of the U as was originally thought. Since the bearings were no longer capped at the ends restraining rings had to be added to the drive shaft to prevent slippage.

In all the discussion of the drive train so far no mention has been made specifically of the bearing. It basic shape, cylindrical, survived unmodified since its initial conception but its exact mechanics have not yet been explained. Since the bearing had to function underwater and be environmentally friendly the idea of grease was immediately thrown out. The next option was some type of ball bearing arrangement. However if sand or other debris worked into the ball bearings that bearing would lock up and become
The design and the assembly of the shaft/bearing/hub system is actually a very simple system, yet it was one of the most difficult to design and construct. The complication lies in the necessity to be able to disassemble the entire drive train system easily and quickly. Thus the operator must be able to access the necessary nuts and their complimentary bolts with relative ease. The design resulting from these careful considerations and some thought is displayed in Appendix B. This arrangement allows the operator to remove the drive shaft and the motor from the system after the removal of only 5 bolts. One of the bolts passes through the hub to the drive shaft binding them, and the other four are the motor mounting bolts.

A retaining ring sandwiches the polyethylene bushing between itself and the wheel hub, allowing no horizontal movement of the shaft. Both the hub and the retaining ring were surfaced on the lathe so that each presents a perfectly smooth contact surface to the polyethylene bushing, reducing the wear on the polyethylene.

The motor shaft is inserted inside a drilled hole in the drive shaft. The drive shaft is coupled to the motor shaft by a pair of stainless steel set screws. The set screws were opted over an internal key way to be machined on the inside of the drilled end of the drive shaft because of the extreme difficulty of machining this design. The set screws are located 0.5 and 1 inches away from the end of the shaft, so that they sink into the motor shaft’s key way. The drive shaft itself is comprised of aluminum round and is machined to a 1.45 inch diameter.
2.3.3 LEGS:

In comparing Figure 2.2.2 with Figure 2.3.2.1 probably the two most obvious differences are the switch from four legs to three and the removal of the suspension system. The suspension system will be addressed first. In order for the vehicle to be able to operate effectively it had to not only be stable underwater but also be able to navigate uneven terrain. So at first a suspension system seemed like a natural choice, if each leg could articulate independently the vehicle would be able to surmount any obstacle it encountered.

However in consulting Dr. Graeme Rae several points were raised for consideration. The first was that for the suspension system to work as envision a strong spring would be needed, which lead into the second point. The way the suspension was set up each front leg was tied to its corresponding back legs so that the motion or lack therefor of the opposing legs would balanced with the spring force would span the legs back into their original position. In effect the suspension system became a matter of balance.

Dr. Rae basic argument was that by applying a the suspension system as designed would be unnecessarily complicating the design of the vehicle. Making the spring too weak would mean that the vehicle would want to sag with the legs sticking straight out form the center section which would give the vehicle a ground clearance equal to the wheel radius. If the spring was too strong then the legs would have a tendency to pull together which would make the vehicle into a shape resemble a spinning top and thus easy to overturn. Restriction could be placed on how much the legs could articulate but that again would require too much work. The goal of the project was to create a functional vehicle, not consume time in designing elaborate subsystems.
However eliminating the suspension meant that something else had to be done to the vehicle so that it would remain stable and be able to handle uneven terrain. The first alteration was to give the vehicle a larger footprint of 6 feet wide by 10 feet long. The larger base meant that a larger moment would have to be applied in order to overturn the vehicle. Also the larger footprint meant that alterations in terrain would have to be on a larger scale to affect the vehicle. In short, with the larger base it would not trip over a rock and crash.

Increased stability to make up for the removal of the suspension was also the reason the number of legs was reduced from four to three. A tripod is more inherently stable that a four leg design. With a tripod no matter the ground undulation two of the three legs will always be on the ground. With four legs that is not always possible. To prove this point simple find some uneven ground and try to place a table one it in such a way that the table is stable. The repeat the exercise with a tripod. The geometry of the tripod makes for easier placement.

The other reason for taking away one of the back legs was due to the decision to switch from skids to tires. In order for the tire to be able to track effectively it was necessary to mount it on a swivel so that it would have a full $360^\circ$ of free motion. If there were still two back legs then the distance between them would have to have been substantial so that both tires could freely swivel. Eliminating one of the legs eliminates this problem.

The last design modification made on the legs that will be discussed has already been alluded to in the previous paragraph, the addition of a swivel to the back leg. The swivel became necessary one the switch to tires was made. When it was thought that the back
leg would end in a ski or bowl the swivel was not necessary. In both cases the contact surface would have been smooth and rounded so sliding in any direction would not be a problem. Proof of this can be demonstrated by taking a ski or bowl and moving it on sand or snow. The shape and texture allow for ease of motion in all directions.

With a tire that is not the case. The rubber will have better gripping properties and not be as easy to slide sideways. And when sliding a tire it can easily become caught or tripped up which can lead to overtopping. Plus the tire selected for the back leg was designed specifically for better tracking in sand which would make it even more difficult to slide sideways. The only solution was to make the back tire capable of motion in any possible direction. The way to do that was to put it on a swivel.

The actual design for the swivel is the same as the design for the bearing. The back leg is saddle cut and welded to a cylindrical piece of aluminum. The different is that the cylinder on the back leg is perpendicular to the horizon as opposed to parallel as is the case with the front legs. The bearing that inserts with his cylinder has lips on both ends. The top end because it will bear with the restraining both of the swivel and the bottom end because it will wear with the bottom half of the bearing. The bottom half of the bearing is again a aluminum cylinder fitted with a UHMWPE bearing that has a lip. This bottom lip wears again the bottom lip of the top cylinder. These two lips moving against each other are the bearing of the swivel. The bottom cylinder was then welded to the U joint at a 30 degree angle to allow for better distribution of forces. The design of the swivel can be seen in Figure 2.3.3.1.
2.3.4 CENTER SECTION:

Figures 2.2.2, 2.3.2.1 and 2.3.3.1 show the evolution of the center section throughout the design process. To get a better understanding of the alterations this portion of the vehicle has undergone first take a closer look at the final design for the center section as illustrated in Figure 2.3.4.1.

Figure 2.3.4.1 shows in better detail the extent of the alteration undergone by the center section during the design process. When the vehicle was in the early stages of
design the parameters being followed were those for a swimming vehicle even though the MARC-I was to be a crawling vehicle. This is evident in Figure 2.2.2 for if the legs were removed the center section could easily become equipped with fins and propellers and become a swimming ROV. Indeed that was one of the initial concepts discussed in the project. However for the MARC-I to be able to be both a swimming and a crawling ROV meant that it could not be built to the best specifications for either mode of transport.

Once that realization came about the idea to make the MARC-I both swimming and crawling was dropped. Once that idea was dropped the design as it stood for the center section became a problem. That design was a can with an acrylic dome that would house all of the electronics and the camera for the vehicle. The problems with this were many. First off there was the dome can interface. If the seal was not done right water would enter the can and the control systems would be ruined. Then there was the matter of buoyancy. Making the can watertight meant that it would be full of air when the vehicle submerged adding an unnecessary and unwanted buoyant force. Also as was mentioned already the can would provide a large surface area for the waves to apply an overturning moment to as the vehicle entered the water. This same problem was faced with the tires but the same solution, filling the can with water, could not be applied. The last major problem with the can was space. The MARC-I was being designed as a platform for research and exploration however in keeping the can the amount of equipment the vehicle could house at a given time would be limited.

The solution to this problem that was finally agreed upon was to go completely modular. The idea of a center section was dropped in favor of a center joint. Electronics
like the camera would be put in self contained housing that could be placed anywhere on
the vehicle. By isolating the electronics the buoyancy force resulting form the watertight
housing would be lessened and distributed and if one housing failed all the electronics
would not go with it. Now that the switch had been made to a center joint, the next task
was to design it.

By this time the tripod configuration for the legs had already come about so the idea
in designing the center joint was to make it like the top of a pyramid only flattened so as
to allow space for instruments. The first design was very similar to Figure 2.3.4.1 with
the only differences due to the fact that at the time the idea of a suspension system was
still being entertained. Those differences had to do with the orientation of the leg sleeves
and restraining bolts.

Figure 2.3.4.1 shows the leg sleeves coming off of the center joint at angles in the x,
y, and z-directions. When the center joint was first conceived the sleeves came straight
out parallel to the top of the center joint and were open at the bottom. This was done to
allow the legs the fullest possible range of motion. There was also only one restraining
bolt per leg perpendicular to the range of motion that acted as a swivel point. However
once the suspension was done away with the sleeves had to be orientated and fixed in
order for the vehicle to have the desired footprint. Then without the need for a swivel
point a second bolt was added to each sleeve to relieve any torque that might come about
as a result of vehicle operations and to lessen the amount of movement possible by the
leg within the sleeve. The sleeves were then enclosed to allow for the second bolt
perpendicular to the first.
Looking at Figure 2.3.2.1 shows a cylinder mounted on the top of the center section angled down toward the wheels. This is the pressure vessel that houses the vehicle's camera. In subsequent drawings of the center section it is absent. The decision was not made to remove the camera, without it steering would become a difficult matter.

However upon reflection a better place was found for the camera. It was moved between the legs so that in the event that the vehicle toppled it would not snap off as it could have being exposed where it was on the top of the vehicle.

Once the new location as determined the mount had to be redesigned and replaced. The placement of the mount it between the sleeves for the front legs. This allows it to be screw mounted flat o the center section. The shape of the mount is a right triangle. The camera housing mounts onto the hypotenuse which is angels 5 degrees shallower than the angle the legs make with the ground so that the camera view is pitched forward of the wheels. The housing is equipped with a dovetail groove. A mounting piece was created to mate with this groove and then screw mounted to the rest of the camera mount allowing the camera to slide and lock into place and then slide off when not needed.
2.4 ELECTRICAL SYSTEM:

The MARC-1's electrical system consists of two simple circuits, 120 VAC and 12 VDC. The design of this system was intended to simplify the power requirements for the vehicle. By using 120 VAC at no greater than 30 Amps, the vehicle may be powered from a standard household wall outlet or a portable gasoline AC generator. AC power is more desirable than DC because there is considerably less loss of power through the tether cable. A conversion from AC to DC power may be done at the vehicle, provided there is a watertight housing for the power converters. This complicates the machining process and requires the addition of pressure vessels, underwater connectors, and more electronics. By using straight AC power, we have considerably cut down on the cost, complexity and limiting factors (i.e. depth-rated housings) of the project.

The estimated power requirements for full range motion without prematurely overhanging the drive motors is 1500 W. This power budget is obtained by calculating the power requirements for both AC motors, overhung at a maximum of 15 A load each, plus the requirements for a 12 VDC / 500 mA power supply.

\[(2 \text{ Motors})(15 \text{ A})(120 \text{ VAC}) = 1440 \text{ W}\]
\[(1 \text{ 12VDC Power Transformer})(0.5 \text{ A})(120 \text{ VAC}) = 60 \text{ W}\]
\[\text{OVERALL POWER BUDGET} (1440 + 60) = 1500 \text{ W}\]

This power budget assumes a 15 Amp current draw from each motor, which is highly unlikely, even in the event of an underwater ground fault, due to the fact that the vehicle is protected by two in-line 15A circuit breakers. Nevertheless, this draw is possible...
based on the fact that the circuit breakers will support up to 15 A load each. Thus it is recommended that the user supply \textbf{at least 1500 W @ 120 VAC} from a portable generator in order to be sure that the vehicle has adequate power to pull itself out of difficult situations.

\textbf{2.4.1 DESCRIPTION OF WIRING DIAGRAM:}

The vehicle’s electrical system is composed of three major parts, the \textbf{CONTROL BOX} at the surface, the \textbf{TETHER} or umbilical cable, and the \textbf{ROV}. The following sections discuss the wiring schematic and systems for each of these parts. Please refer to Appendix D while reading through this section in order to trace the circuits without confusion. Most electrical components are readily available from Radio Shack unless otherwise specified in Appendix E.

\textbf{2.4.2 CONTROL BOX:}

The vehicle’s surface control box contains one input side, in which a 120 VAC cable enters. On this side a \textbf{12 VDC @ 500 mA plug-in power supply} also enters. The 12 V power supply will be used to run all control signals within the vehicle. These input cables (2 AC, 1 GND, 2 DC) can be tapped from the 6-pin gray terminal block on the inside of the control box. From this terminal block, each side of the ROV (Port & Starboard) will be supplied independent, identical circuits.

The electrical operating scheme of the MARC-I is designed to separate the control box from the vehicle, such that any underwater ground faults, power surges, internal shorts, or other electrical dangers are electrically isolated from the user. This is achieved through the use of several relays running on a 12 VDC circuit. The control box
also contains **two 15 A in-line circuit breakers** as a redundant safety system. In the event of an underwater ground fault or short circuit, these breakers will flip and cut all AC power through the tether to the vehicle.

The relay system inside the control box utilizes two 12 VDC relays (one each port & starboard) to handle the switching of the high-current 120 VAC power to the vehicle. By throwing a control switch, the user feeds 12 VDC to a relay, signaling it to switch 120 VAC down the tether cable to the vehicle. Thus, the user never “sees” the high-current AC voltage, but merely switches a low-current (500 mA) DC control voltage to operate the relays.

Each control switch is a double-pole, double-throw toggle switch. This is used to drive the reversing circuit, allowing each drive motor to be run either forward or reverse so that the vehicle can turn and maneuver. By switching to the lower position, each switch now not only supplies 12 VDC to the power relays, but also down a pair of wires to the vehicle, where it is used to drive the motor reversing relays.

The last stage of the control box are the two outputs, the TETHER and the VIDEO-OUTPUT from the vehicle’s on board camera. The tether enters the control box and can be tapped from the eight-pin black terminal block inside the box. Four indicator lights on the control box are used to denote whether or not power is being sent to each motor, in forward or reverse. The camera’s video signal can be connected to via the external female RCA jack. This jack supplies a line-level composite video signal and requires a video monitor or video-input equipped TV or VCR to be displayed.
2.4.3 TETHER:

The tether cable chosen for the MARC-I was a 3-multipair cable manufactured by Alpha Wire & Cable, and available from Newark Electronics (see Appendix E). The cable is approximately 500 ft. long, with a dry weight of 42.5 lb. The cable consists of three individually twisted shielded pairs of 18 AWG wire, with a bare ground (shield) wire in each. Each wire has a nominal resistance of approximately 10 Ohms. The red/black pair is used for the port motor AC power, the white/black pair for the starboard motor. The green/black pair is used for 12 VDC control signals and for transmission of the camera’s video signal. The black wire in this pair is used for the starboard reversing signal (+12 VDC), and the green for the port signal. The bare conductor in this set is used as common.

In order to transmit the camera signal along the 12 VDC line, a capacitive coupling system was used, along with an inductor to isolate the signal from the DC power supply. By using a 10 microfarad capacitor on each end of the tether, a DC block was created to ensure that the camera would not “see” 12 VCD on it’s signal output line.

2.4.4 ROV:

The tether enters the vehicle through the tether-management system on the aft leg. It is then routed through the vehicle’s legs to avoid entanglement with the environment. The onboard circuitry includes a small B&W digital board camera. The camera is available from Supercircuits Inc. (see Appendix E). To avoid the need for powering the camera through the tether (to keep its diameter at a minimum), the camera can be powered from a 9-volt battery or the 8-AA pack provided.
Each side of the vehicle (P/S) has a wheel driven by an AC Electric gearmotor. The gearmotors are available through Dayton Motor Co. via Grainger distributors (see Appendix E), but were obtained directly from their manufacturer in this case. The manufacturer, Von Weiss Gear Co. generously donated the motors from their Orlando office. Each motor has an output torque of 500 in.-lb. at 20 RPM with a full-load current draw of 2.35 A, and can be reversed by switching power to different coils within the motor. This switching is achieved using a double-pole double-throw relay (the same as those found in the control box) to switch the wiring scheme. When the control switches are flipped into reverse, the 12 VDC control voltage coming down the green/black pair signals the relays to flip, thus changing the direction of rotation of the motors. Again, each motor is on an independent circuit allowing opposite switching for turning and maneuvering. The selected motors are not variable speed, because they are AC powered. Variable speed motors may be used (AC/DC for instance), provided they still have the same power requirement and output characteristics, however it is not necessary given the operating characteristics of the motors and the slow speed of the vehicle.

In order for the user to interface other peripherals and instrumentation, one of two types of systems must be designed. One option is to build a self-contained instrumentation package, complete with its own onboard data-logger and sealed an some type of pressure vessel. This vessel can then be “strapped” onto the upper deck of the MARC-I, or wherever deemed necessary. A second option would be to interface equipment into the MARC-I’s tether in order to receive information in real-time at the surface. This can be achieved by multiplexing and capacitively coupling data and control signals through the tether in a similar manner to the way that the camera signal is
being sent through the 12 VDC line. If such circuitry becomes a problem, the simplest remedy would be to purchase a tether cable with more conductors. This is the easiest option, however a thicker tether increases drag on the vehicle from dragging friction. Nevertheless, the MARC-I’s electrical system can be easily outfitted to accommodate other electronics and onboard equipment packages besides the submersible video camera and drive motors.
2.5 TRANSPORT & ASSEMBLY

The MARC-I was not designed to be the first of its kind but rather as a solution to some of the problems plaguing its predecessors. One of those problems was transport. Two of the MARC-I most prominent predecessors, the CRAB used by the Army Core of Engineers at Duck, NC and Dr. William Dally’s Surf Rover, illustrate this problem. Both are such massive constructs that movement is either impossible, the CRAB, or can be done only by the means of a specialized transport, the Surf Rover. In effect each vehicles range has been effectively limited by the practicality of transport.

The MARC-I is not hampered by such restraints. With the removal of the six restraining bolts the vehicle breaks down into 4 component parts, the two front legs, the back leg, and the center section. The only exterior pieces to add are the control box, generator, and tether. Each piece individually can be moved by one person and all the components can fit in the back of a standard flatbed truck as is shown in Figure 2.5.1.

There is no need for a specialized crew or a specialized transport with the MARC-I. It can simple be loaded into truck, taken to the desired location, and deployed. In effect there is no limit to where the MARC-I can be deployed. The only space needed is enough to assemble the vehicle and then a place for the tether, generator, and operator. If the need arose it is even possible to deploy the MARC-I from the deck of a ship. The modularity allows for the MARC-I to be transported anywhere.
As was mentioned in the section on transport one of the problems with the predecessors to the MARC-I was the need for specialized training or equipment to deploy the vehicles. This is not the case with the MARC-I. The only technical knowledge needed to assemble the MARC-I is how to use a ratchet and socket. Figures 2.5.2 and 2.5.3 illustrate the ease of moving and assembling the vehicle respectively.
The first thing to do in disassembling the MARC-I is to disconnect the wiring into the components associated with the legs and center section. At this time this is accomplished by undoing wore nut and separating the wires but in the future it will be done by means of disconnecting the underwater connectors found at the junctions of
each of the vehicles components. With the wiring undone the camera housing can be 
removed and placed aside until the vehicle is to be loaded. Next the six restraining bolts 
should be removed from the legs. If the bolts resist try moving the legs a bit or 
hammering them out with a rubber mallet.

Once the bolts are removed the legs may be removed. As one person holds the center 
section another holds the leg being removed and proceeds to twist and pull it out. 
Straight pulling it out will not work, the leg needs to be twisted to help it along. The 
same procedure should then be repeated on the other two legs. For assembling the 
reverse of the above procedure should be followed only it is recommended that the front 
legs be attached before the back leg and that one restraining bolt is placed in each leg as 
it is placed in its sleeve to prevent it from turning while the other legs are attached. A 
minimum of two people are required to assemble the vehicle but no more than three are 
necessary.
2.6 Land Trials:

After assembly the next step is testing to see if the design will work. It was decided to test the vehicle on land before water trials were attempted so that the vehicle could be observed in motion and recovery, if necessary, would be easier. The first test done before the vehicle even moved and inch was to see if the motors would be able to turn the wheels. That being determined the vehicle was then placed on the ground to run under its own power.

The first set of tests done were designed to see how much of a sudden change in elevation the could overcome. Without the suspension the legs would not be able to articulate over sudden outcroppings and ditches instead the vehicle would have to climb over them. These tests were run in sand since that is the vehicles intended operating environment and consisted of placing object of various height in the vehicles path to see if it could overcome them. It was determined that the vehicle could overcome any object of a height equal to or less than the diameter of the front tires, 20 inches.

The next test was one of maneuverability. Each motor was reversible and independently controlled but what remained to be seen was if the motor could supply enough moment to turn the swivel. The motors possessed more than enough power to turn the swivel and the truing radius was determined to be the length of the vehicle, 10.5 feet. It was also determined that one motor running alone possessed the ability to turn the vehicle in a gradual arch.

These initial tests were run with the vehicle plugged into a wall outlet on level terrain. The next test was to take the vehicle out onto more contoured ground and run it off a
generator. An 800 Watt generator was just barely not sufficient to power the vehicle but a 2500 Watt generator provided more than enough power. The site chosen to test the vehicle at was the construction site that is to soon be the new baseball field for Florida Tech. This site was chosen because the construction had left large mounds, averaging 10 feet in height, of sand and clay possessing various gradations.

The first mound the vehicle tried to surmount was of clay and possessed an approximate slope of 45 degrees. The vehicle failed to surmount it but not because of lack of power. Rather once the vehicle had all of its body except the rear tire on the slope the tires began to dislodge clay instead of move the vehicle and then the swivel turned under the vehicle weight making a straight course up the mountain impossible. The clay did not possess the consistency the vehicle needed for traction and the hesitation was enough time for the swivel to turn under the weight of the vehicle, something that would not have happened if the rear tire could have gained the sloe quicker.

The next mound was sand and possessed an approximate slope of 30 degrees. The vehicle had no problem surmounting it and there was almost no loss of traction due to scouring on the part of the front tires. The rest of the land trials were more of the same. In the end what was learned was that the mechanics of the soil failed before it could be determined if the vehicle could surmount a given obstacle or not and that there was a certain window of time between when the vehicle began it ascent to when it had full purchase of the slope that had to be adhered to or else the swivel would tun due to the weight of the vehicle and send the vehicle off at an angle. The slopes the vehicle were tried on were much more extreme than anything that will be encountered in the near
shore zone so terrain should not be a problem for the MARC-I. However it remains to be seen what the water trials will show. Photos from the land trials can be found in Appendix F.
2.7 FUTURE PLANS & RECOMMENDATIONS:

The MARC-I ROV was designed to be a multi-functional vehicle. It is our hopes that it will be used for many different applications, not just coastal surveying. Through this project we have created a versatile, low-cost remotely operated platform that can be outfitted to perform nearly any underwater, near-bottom task. Future plans for the vehicle can’t really be concretely defined at this point because the possibilities are virtually limitless. Some considerations include design and implementation of the following:

- Advanced navigation electronics
- Surveying packages
- Oceanographic instrumentation
- Sediment and water samplers
- Mine detection devices
- Articulating manipulators
- Hybrid propulsion system to allow the vehicle to operate as a swimming ROV
- Sonar equipment and/or seabottom-penetrating hydrophones
- Marine magnetometers
- Faster, more powerful drive motors
- On-board power supply and/or alternate power source
- Wireless control system
- Autonomous control system
- etc., etc. ... ??????

As one can easily see, there are virtually unlimited options for future applications, research and development. For the time being, the next major goal for the MARC-I is to
complete waterproofing procedures in order to get the vehicle in the water for ocean testing. These procedures consist of installing waterproof connectors and cables inside the ROV's legs, allowing it to be more easily disassembled and electrically separated into its four modules. Also, the drive motors are currently undergoing extensive redesign to make them waterproof. This includes machining a new sealed end plate for the motor casing (see Appendix E, motor assembly diagram), in order to remove the cooling fan and seal the rear portion of the motor housing. Then, each seam will be sealed using a flexible epoxy resin compound and both the gearbox and motor housing will be oil filled and pressure compensated. By oil-filling and these chambers and installing pressure compensators, there will be no differential hydrostatic pressure on any of the rotary seals or seams because internal and external pressures will be equalized (see below Figure 2.7.1). This allows the motors to then be submerged to a virtually infinite depth (theoretically).

*Figure 2.7.1:*

- **OIL - FILLED MOTOR HOUSING**
- **EXTERIOR HYDROSTATIC PRESSURE ON COMPENSATOR BLADDER AND HOUSING**
- **FLUID FLOW BETWEEN BLADDER AND HOUSING EQUALIZES PRESSURE GRADIENT**
Once these waterproofing measures are finished, all that is needed for our first ocean trial is the use of a gasoline generator rated at a minimum of 1500 Watts and a TV monitor to display the camera signal. These items are currently being borrowed for the project, but it is recommended that they eventually be purchased in order to make the MARC-I a completely self-contained ROV package.

Although this paper does not discuss the design of a surveying package for use onboard the MARC-I, several possibilities may be considered for future design projects. Of these, the simplest means of outfitting the MARC-I for surveying would be to use a Geodimeter Laser Tracking System. By mounting a geodetic prism on a large mast on top of the vehicle, its elevation and position can be found. Unfortunately, this system would limit the vehicle’s operating depth for surveys, but this may not be a problem due to the long, shallow nature of the Atlantic continental shelf. Another possibility may be to use a sensitive SONAR system to determine the vehicle’s depth as a factor for elevation below the horizon. Furthermore, a surface GPS system may be interfaced for accurate Latitude / Longitude positioning. These are only a few options and will require extensive research and design planning. Ultimately however, the MARC-I would be able to support any of these systems.
3.1 REFERENCES:


APPENDIX A:
MARC-I SPECIFICATIONS:

Power Supply
120 V AC @ 1500 W

Footprint Dimensions
10.5 ft. x 6.5 ft.

Ground Clearance
3.25 ft.

Motor Output (ea.)
500 in-lb. @ 20 rpm

Turning Radius
10.5 ft.

Tether Length
500 ft.

Maximum Depth
500 ft.

Speed
0.5 m/s

Camera Resolution
380 lines B&W

Frame Material
6061-T6 Aluminum

Bearing Material
UHMW Polyethylene

Fasteners
Type 316 Stainless Steel

Maximum Angle of List
60 degrees

Maximum Angle of Pitch
78 degrees
APPENDIX B:
Drive train Assembly

- Hub Bolt
- Retaining Ring Bolt
- Set Screws
- Motor Shaft
- Motor Mounting Plate
- Drive by polyethylene bushing
- Drive shaft
- Aluminum ATV wheel
- Rubber sand tire
- Sand paddles
- Dayton AC gearmotor
Art Wheel Assembly
APPENDIX C:
**ROV Power Requirement Calculations**

### Force of Water Drag \( F_d = 0.5 \rho C_d A V^2 \)

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<th>Width (in.)</th>
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<th>( \rho = )</th>
<th>( V ) (m/s)</th>
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**TOTAL FRAME AREA (m\(^2\)) = 0.190791**

\( C_d \) for Frame = 1.3

\( F_{df} \) (lbs.) = 8.21920331

### Tire Dimensions (front projection)

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**TOTAL TIRE AREA (m\(^2\)) = 0.42312**

\( C_d \) for Tires = 0.24

\( F_{dt} \) (lbs.) = 3.36514113

\( F_d(\text{total}) \) (lbs.) = 11.5843444

### Force of Rolling Friction \( W_f/r \)

\( W \) (lbs.) = 50

\( f \) (in.) = 0.5

\( r \) (in.) = 10

\( F_r \) (lbs.) = 2.5 \( \times 3 \) wheels = 7.5

### Force of Tether Drag Friction \( \mu N \)

\( \mu = 0.3 \)

\( N \) (lbs.) = 42.5

\( F_{tf} \) (lbs.) = 12.75

**TOTAL DRAG FORCE (lbs.) = 31.8343444**

\( F.O.S. = 1.5 \)

**DESIGN DRAG FORCE (lbs.) = 47.7515167**

**Drive Motor Torque Requirement (in.-lbs.) = 238.757583**

**Florida Institute of Technology**

OCE-4542

Dr. Andrew Zborowski

L. Frey

J. Cies

A. Mackenna

7/25/98
APPENDIX E:
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**SHIPPED APR 17 1998**
## PURCHASE REQUISITION

**FOR PURCHASING USE ONLY**

**VENDOR**
BEACH SPORTCYCLES

**ADDRESS**
1127 W. KING ST.
Cocoa, FL 32922

**PHONE**
(407) 631-5571

**SHIP TO:**
DHES F.I.T.
150 W. University Blvd
Melbourne, FL 32901
Attn: Dr. A. Zabriskie

**DATE REQUESTED**
5/1/99

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*SEE "PARTS UNLIMITED"
CATALOGUE FOR ALL
PAGE #1'S

4/10

**TOTAL**
450.70

**ACCOUNT NO.**
MFP
BEACH SPORTCYCLES, INC.
1127 W. KING ST * COCOA, FL 32922
PH 407-631-5571 * F 407-636-WAVE

FLORIDA TECH
150 W. UNIVERSITY BLVD.
MELBOURNE FL 32901

ACCT NO: 4076746110  RECEIPT: 031800-12401
DATE: 05/21/98  PO: P00020528  PAGE: 1
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407/674 8110

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<td>11</td>
<td>K2981</td>
<td>DUNE RIB 22</td>
<td>S40</td>
<td></td>
<td></td>
<td>53.95</td>
<td>53.95</td>
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<tr>
<td>11</td>
<td>H184400</td>
<td>H/D 10.48 3+</td>
<td>S70</td>
<td></td>
<td></td>
<td>78.95</td>
<td>236.85</td>
</tr>
</tbody>
</table>

CASE ORDER FOR FLORIDA TECH NO: P00020528 - TERMS ARE NET 30 -

ORDERED PARTS WERE PICKED UP IN GOOD CONDITION AND DELIVERED TO LEE FREY ON 11/98.

SIGNED BY LEE FREY
-722-9898 PHONE
<table>
<thead>
<tr>
<th>WAREHOUSE LOCATION</th>
<th>McMaster Carr Part Number</th>
<th>Fill Quantity</th>
<th>Item Description</th>
<th>Your Line</th>
<th>You Ordered</th>
<th>We Shipped</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-6-03 04</td>
<td>8701 K57</td>
<td>4 FT</td>
<td>Ultra-high Molecular Weight Polyethylene Rod 3 1/2&quot; Diameter</td>
<td>16 HNG</td>
<td>4 FT</td>
<td></td>
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</table>

$65.32
<table>
<thead>
<tr>
<th>Order No.</th>
<th>Date</th>
<th>F-17</th>
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<table>
<thead>
<tr>
<th>Name</th>
<th></th>
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</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Address</th>
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<th></th>
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</table>

<table>
<thead>
<tr>
<th>SOLD BY</th>
<th>CASH</th>
<th>C.O.D.</th>
<th>CHARGE</th>
<th>ON ACCT.</th>
<th>MDSE RETD</th>
<th>PAID OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>QTY</th>
<th>DESCRIPTION</th>
<th>PRICE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5/16&quot; Solid Round</td>
<td>47.80</td>
<td>47.80</td>
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<table>
<thead>
<tr>
<th>TAX</th>
<th>TOTAL</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>51.30</td>
</tr>
</tbody>
</table>

All claims and returned goods MUST be accompanied by this bill.

Received
By

Thank You
<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pc 1/2 in 1/2 pc</td>
<td>7.62</td>
</tr>
</tbody>
</table>

**FLORIDA TECH**

**PETTY CASH VOUCHER**

- **PAID TO:** Jonathan Cios
- **DATE:** 5/7/92
- **INDEX/ACCOUNT #:** HEP 72199
- **AMOUNT:** $7.62
- **VENDOR:** DON BELL INC.
- **PAYEE:**
- **REC'D BY:**
- **APPROVED BY:** Zm. D.
FLORIDA TECH

PETTY CASH VOUCHER

PAID TO: Adrian MacKenna DATE: 6/12/98
INDEX/ACCOUNT #: MFP 73199 AMOUNT: $ 48.15
VENDOR: Don Bell, Inc. I certify I made this purchase on behalf of Florida Tech:
FOR: Aluminum Plate PAYEE: 
REC'D BY: APPROVED BY: Zim 8
DON BELL, INC.
2808 South Harbor City Blvd.
Melbourne, Florida 32901
(407) 725-8008
FAX (407) 962-7007

Customer's
Order No.     Date 5-15-76

Name

Address

Phone:

<table>
<thead>
<tr>
<th>SOLD BY</th>
<th>CASH</th>
<th>C.O.D.</th>
<th>CHARGE</th>
<th>ON ACCT.</th>
<th>MOSE. RETD</th>
<th>PAID OUT</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>QUAN.</th>
<th>DESCRIPTION</th>
<th>PRICE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>ses 1y 2x1'</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>11111111111</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

"All claims and returned goods MUST be accompanied by this bill."

0025754 Received
By

TAX

TOTAL 100

GS-202-3 PRINTED IN U.S.A.

Thank You
DON BELL, INC.
2808 South Harbor City Blvd.
Melbourne, Florida 32901
(407) 725-9009
FAX (407) 962-7007

Customer's Order No. Date 5/16/98
Name E. L. T
Address
Phone:

<table>
<thead>
<tr>
<th>QUAN</th>
<th>DESCRIPTION</th>
<th>PRICE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3&quot; Aluminum S #</td>
<td>14.10</td>
<td>14.10</td>
</tr>
</tbody>
</table>

SOLD BY CASH C.O.D. CHARGE ON ACCT. MED. RETURN PAID OUT

0025755 Received
By

TAX

TOTAL 144.10

Thank You.
**PETTY CASH VOUCHER**

**PAID TO:** LEE FREY  
**DATE:** 5/19/98

**INDEX/ACCOUNT #:** MFP 72155  
**AMOUNT:** $45.00

**VENDOR:** DON BELL, INC.  
**FOR:** Aluminum tubes

**REC'D BY:**  
**APPROVED BY:**  
I certify I made this purchase on behalf of Florida Tech:

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>DESCRIPTION</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 ( \times ) 3 in. x 4 in. frame</td>
<td>$15.00</td>
</tr>
</tbody>
</table>

**TAX:** 2.70  
**TOTAL:** 47.70

---

**DON BELL, INC.**  
2808 South Harbor City Blvd.  
Melbourne, Florida 32901  
(407) 725-8008  
FAX: (407) 962-7007
Dayton Shaded Pole and Permanent Split Capacitor Type Gearmotors

Gearmotor Installation, Maintenance and Warranty Information

IMPORTANT: This manual only furnishes general installation and maintenance information. Refer to the enclosed Product Specific Information Manual furnished separately for additional information.
WARNING

ECRITICAL SAFETY INFORMATION

POWER SOURCE

The equipment described in this manual is designed to operate from 120V, 60Hz power. The power cord must be connected to a properly grounded outlet. If the outlet is not grounded, it must be replaced with a properly grounded outlet. Failure to do so may result in electrical shock.

When installing or operating the equipment, follow these guidelines:

1. Never attempt to install or operate this equipment without proper training or supervision.
2. Always follow the manufacturer's instructions for installation and operation.
3. Never attempt to alter or modify this equipment without the manufacturer's written approval.
4. Keep the equipment in a clean, dry location.
5. Regularly inspect and test the equipment for functionality.
6. Keep all cords and connections secure and free from damage.
7. Never attempt to operate the equipment while wet or in a damp environment.
8. Keep the equipment at least 6 inches away from any other electrical devices.

GENERAL SAFETY INFORMATION

MECHANICAL SAFETY

Never work on the equipment when it is plugged in or while it is running. Always turn off the power before working on the equipment. Make sure the equipment is unplugged before performing any maintenance or repairs.

HIGH VOLTAGE

Always wear appropriate protective gear when working on the equipment. This includes gloves, safety glasses, and a face shield.

INFLAMMABLE LIQUIDS

Never store flammable liquids near the equipment. Keep the area clear of any flammable materials.

INITIAL INSPECTION AND HANDLING

Check the equipment for any visible signs of damage or wear before initial use.

STORAGE

Never store the equipment in a damp or humid environment. Always store the equipment in a dry, well-ventilated area.

Follow these guidelines to ensure the safe and proper operation of the equipment:

1. Keep the equipment clean and dry at all times.
2. Never attempt to operate the equipment while it is wet or in a damp environment.
3. Always follow the manufacturer's instructions for installation and operation.
4. Keep the equipment away from any sources of heat or fire.
5. Regularly inspect the equipment for any signs of wear or damage.
6. Keep all cords and connections secure and free from damage.
7. Never attempt to operate the equipment while it is running or while it is plugged in.
8. Always store the equipment in a dry, well-ventilated area.

Read the equipment's manual and follow all instructions for proper operation.
Leveage Factors

**Engine**
- 2.5 HP
- 1.5 HP
- 1.0 HP
- 0.75 HP

**Pump**
- 2 HP
- 1 HP
- 0.5 HP
- 0.25 HP

**Motor**
- 1 HP
- 0.75 HP
- 0.5 HP

**Controller**
- 10 Amp
- 5 Amp
- 3 Amp

**Type Actions**
- Adjust lever of governor or starter according to position of drive action.
- When engaged, adjust lever of governor or starter according to position of drive action.
- Adjust lever of governor or starter according to position of drive action.

**Detailed Overhauling Load Calculations**
- Apply correct load calculation for the specific application.
- Correct load calculation for the specific application.
- Correct load calculation for the specific application.

**Load Factor Table**
- Maximum load factor is 1.0.
- Load factor must be adjusted for proper operation and condition.
- Load factor must be adjusted for proper operation and condition.

**Connecting Power to Gearmotor**
- Connect gearmotor for proper voltage and condition.
- Connect gearmotor for proper voltage and condition.
- Connect gearmotor for proper voltage and condition.

**Operation of Gearmotor**
- Operation of gearmotor can be adjusted for proper voltage and condition.
- Operation of gearmotor can be adjusted for proper voltage and condition.
- Operation of gearmotor can be adjusted for proper voltage and condition.

**Power Requirements**
- Power requirements can be adjusted for proper voltage and condition.
- Power requirements can be adjusted for proper voltage and condition.
- Power requirements can be adjusted for proper voltage and condition.

**Environment**
- Environment must be considered for proper voltage and condition.
- Environment must be considered for proper voltage and condition.
- Environment must be considered for proper voltage and condition.

**Installation**
- Installation must be considered for proper voltage and condition.
- Installation must be considered for proper voltage and condition.
- Installation must be considered for proper voltage and condition.

**Maintenance**
- Maintenance must be considered for proper voltage and condition.
- Maintenance must be considered for proper voltage and condition.
- Maintenance must be considered for proper voltage and condition.

**Safety**
- Safety must be considered for proper voltage and condition.
- Safety must be considered for proper voltage and condition.
- Safety must be considered for proper voltage and condition.

**Troubleshooting**
- Troubleshooting must be considered for proper voltage and condition.
- Troubleshooting must be considered for proper voltage and condition.
- Troubleshooting must be considered for proper voltage and condition.
<table>
<thead>
<tr>
<th>Symptom</th>
<th>Corrective Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>No power</td>
<td>1. Check local circuit breaker is open or tripped. 2. Check fuse or circuit breaker. 3. Check for loose connections. 4. Check for overloaded condition.</td>
</tr>
<tr>
<td>Power company</td>
<td>1. Check for overloaded condition. 2. Check for loose connections. 3. Check for defective gear(s).</td>
</tr>
<tr>
<td>Low voltage</td>
<td>1. Overload during operation. 2. Overload fault. 3. Check for loose connections.</td>
</tr>
<tr>
<td>Geometric size</td>
<td>1. Overload during operation. 2. Overload fault. 3. Check for loose connections.</td>
</tr>
<tr>
<td>Load of increase</td>
<td>1. Overload during operation. 2. Overload fault. 3. Check for loose connections.</td>
</tr>
<tr>
<td>Geometric size</td>
<td>1. Overload during operation. 2. Overload fault. 3. Check for loose connections.</td>
</tr>
</tbody>
</table>

**Troubleshooting**

- **Information Manual**
  - Product Specific Information Manual: Information related to the product.
  - Use only Dayton authorized replacement parts.

- **Ordering Replacement Parts**
  - Refer to the end of the manual for ordering information. The information is not all-inclusive and does not necessarily apply in all cases when associated with the information in the manual.

- **When Replacing Geometric**
  - Use only Dayton authorized replacement parts.

**Recommended Maintenance**

- Regularly inspect the insulation. Check for loose connections and worn motor windings.
- Periodically inspect the insulation. Check for loose connections and worn motor windings.
- Remove dirt accumulation and ground motor windings. This accumulation can cause
- Remove dirt accumulation and ground motor windings. This accumulation can cause
Problem: The system is not heating or cooling efficiently.

1. Check power to the system.
2. Check thermostat.
3. Check for obstructions in the airflow.
4. Check for low voltage.
5. Check the fan operation.
6. Check the refrigerant levels.
7. Check for leaks.
8. Check the blower motor.
9. Check the compressor.
10. Check the condenser coil.
11. Check the evaporator coil.
12. Check the thermostatic expansion valve.
13. Check the system controller.
14. Check the control board.
15. Check the circuit breaker.
16. Check the fuse.
17. Check the wiring harness.
18. Check the motor control.
19. Check the relay.
20. Check the control board.
21. Check the power supply.
22. Check the transformer.
23. Check the condenser fan motor.
24. Check the compressor motor.
25. Check the high pressure switch.
26. Check the low pressure switch.
27. Check the pressure transducer.
28. Check the pressure sensor.
29. Check the pressure relief valve.
30. Check the pressure regulator.
31. Check the pressure control valve.
32. Check the pressure control switch.
33. Check the pressure control timer.
34. Check the pressure control relay.
35. Check the pressure control solenoid.
36. Check the pressure control valve.
37. Check the pressure control switch.
38. Check the pressure control timer.
39. Check the pressure control relay.
40. Check the pressure control solenoid.
41. Check the pressure control valve.
42. Check the pressure control switch.
43. Check the pressure control timer.
44. Check the pressure control relay.
45. Check the pressure control solenoid.
46. Check the pressure control valve.
47. Check the pressure control switch.
48. Check the pressure control timer.
49. Check the pressure control relay.
50. Check the pressure control solenoid.
51. Check the pressure control valve.
52. Check the pressure control switch.
53. Check the pressure control timer.
54. Check the pressure control relay.
55. Check the pressure control solenoid.
56. Check the pressure control valve.
57. Check the pressure control switch.
58. Check the pressure control timer.
59. Check the pressure control relay.
60. Check the pressure control solenoid.
61. Check the pressure control valve.
62. Check the pressure control switch.
63. Check the pressure control timer.
64. Check the pressure control relay.
65. Check the pressure control solenoid.
66. Check the pressure control valve.
67. Check the pressure control switch.
68. Check the pressure control timer.
69. Check the pressure control relay.
70. Check the pressure control solenoid.
71. Check the pressure control valve.
72. Check the pressure control switch.
73. Check the pressure control timer.
74. Check the pressure control relay.
75. Check the pressure control solenoid.
76. Check the pressure control valve.
77. Check the pressure control switch.
78. Check the pressure control timer.
79. Check the pressure control relay.
80. Check the pressure control solenoid.
81. Check the pressure control valve.
82. Check the pressure control switch.
83. Check the pressure control timer.
84. Check the pressure control relay.
85. Check the pressure control solenoid.
86. Check the pressure control valve.
87. Check the pressure control switch.
88. Check the pressure control timer.
89. Check the pressure control relay.
90. Check the pressure control solenoid.
91. Check the pressure control valve.
92. Check the pressure control switch.
93. Check the pressure control timer.
94. Check the pressure control relay.
95. Check the pressure control solenoid.
96. Check the pressure control valve.
97. Check the pressure control switch.
98. Check the pressure control timer.
99. Check the pressure control relay.
100. Check the pressure control solenoid.