# ROV Engineering Report
## *Knight Diver ROV*

Submitted by the

**Robinson High School**
**Knight Diver ROV Team**
**Tampa, Florida**

June 7, 2004

Submitted to the Marine Advanced Technology Education Center
(Note: Further modifications may occur as water trials continue.)

Team Members:

| | |
|---|---|
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## Abstract (250 words)

This technical report describes the Remotely Operated Vehicle (ROV) *Knight Diver*, built by the Robinson High School Knight Diver ROV Team 2004.

The ROV was designed to compete in the 2004 ROV Design Competition hosted by the Marine Advanced Technology Education Center (MATE). The mission of the *Knight Diver* is to explore "Mystery Reef" and complete accomplish scientific and recovery mission tasks. These tasks include recovery of a lost towfish, finding and identifying a U-boat captain's bell, patching a hole in a leaking barrel, finding and collecting specimens of fish, finding a source of methane and tagging the tubeworm cluster next to it, finding and tagging a mussel bed, and recovering five samples of authigenic carbonate.

This paper also discusses the design rationale for the ROV, the design challenges encountered, troubleshooting ideas, lessons learned, ideas for future improvements, and the use of ROVs in the exploration and understanding of our National Marine Sanctuaries.

## ROV Final Design

Knight Diver ROV is 136.3 cm long (50 cm without grabber), 37 cm wide, 39.2 cm high and has a dry weigh of 6.03 kg or 59.161 newtons (13.3 lbs). The entire unit, including tether and control box has a weight of 12.97 kg or 127.219 newtons (28.6 lbs). A grabber is located on the front of the ROV, directly below the dual camera system. The XY-axis thrusters are attached to the upper cross members. The Z-axis thrusters are attached to the side supports. The main termination can is located over the center axis on the rear upper crossbar.

1. **Frame**
   The frame is made of schedule 40 PVC pipe, Schedule 40 PVC fittings, as well as Schedule 80 PVC nipple connectors and bushings.

2. **Control System**
   The control system consists of two main control units. First, in order to maneuver the ROV with fine movements a control box was built with a switch to control each individual motor. The thruster control unit is built within a plastic housing, project box (Radio Shack #270-1807) 17.78 X 12.7 X 7.6 cm (7 X 5 X 3 in.). For safety and to protect the unit from a power surge a Universal panel-mount fuse, 5 x 20 mm was installed. A 25-amp fuse has been placed in the holder. The overall unit has been wired with a lighted SPST Rocker Switch (Radio Shack #275-712) rated 30A at 12VDC to serve as an on/off switch. Individual thrusters are controlled by DPDT Momentary Flip Switch (Radio Shack #275-709). The XY-axis thrusters have their switches mounted to the top surface of the control box. The Z-axis thrusters have their switches mounted to the front side panel of the box.

   The second control unit is a Futaba four-channel controller for the grabber. This radio control unit functions on 72 MHz.

3. **Video Camera & Monitor**
   To help navigate the Knight Diver we selected two X-10 Nightwatch2 black & white video camera. We are using an RCA 5 inch (12.7 cm) AC/DC black and white TV and a Symphonic 9 inch (22.86 cm) AC/DC color TV/VCR as our monitor combination. (Note: Original design was to use cameras provided by Carrillo Underwater Systems as part of a scholarship. These cameras have not arrived at the time this report was submitted.)

4. **Retrieval Mechanism**
Our retrieval mechanism is a mechanical grabber. This design was inspired by Team Davinci's (Orlando, FL) Mars Rover Robotic, *Strider*. The grabber is 27.3 cm long, 20.3 cm wide including support frame, and protrudes/extends 27.3 cm forward of the ROV. The actual grabbing surface is 10 cm long by 10 cm wide, for a total grabbing surface of 100 $cm^2$. The grabber is powered by two HiTech HS-311 Standard Servo Motors fitted with a large wide X arm (#151SH). Each servo motor is water proofed with a coating of Dip-It plastic, then sealed within a latex case (balloon). These servo motors allow the grabber to open to 180 degrees. It is positioned along the center axis.

5. **Tether**
Six 18 AWG 2 conductors electrical wire conducts power through the tether to the ROV. The tether also contains two coaxial cables – one for each of the video cameras. The final cable running down the tether is a 4 conductors 22 AWG conduit conducting power to the manipulator arm. The tether shielding is ¾ inch braided sleeving, which has pool noodle floatation spaced every 1.5 meters (5 feet) for floatation.

6. **Thrusters**
The Knight Diver ROV is equipped with six thrusters. These thrusters are made from 1100 GPH Rule Bilge Pump Replacement Cartridges (Model 27DR), Master Airscrew hubs, and 1.5-inch Dumas left-handed nylon propellers with a 1/8-inch bore. The propellers have been tapped with a 10-24 tap to attach them to the hub. Each thruster is protected with a 6-amp fuse that is a part of the cartridge assembly. Four thrusters are in a 45-degree quad configuration to move the ROV on the XY plane. Two thrusters provide up/down thrust.

7. **Power**
Our main power source is 12-volt battery. Power is fed through banana plugs and 14 AWG power wire into our control box. The main power is protected with a 25 amp fast acting fuse. Ancillary power includes 110/120-volt AC power adapters for the cameras and monitors. A 4.8 VDC Nickel-cadmium rechargeable battery (NR-4QB) provides power for the servo remote control receiver. And the Futaba controller is powered by a 9.6VDC Nickel-cadmium rechargeable battery (NT8F008).

# Budget/Expense Sheet

The following sheet lists the expenditures for The Knight Diver ROV. Only monetary donations are represented in the figures, however, the names of companies or individuals that have donated product are also denoted.

**2004 Robinson High School - Knight Diver ROV Team**

| ROV Parts | Unit Cost | Number of Units | Gifts/Donations | Total |
|---|---|---|---|---|
| PVC Frame & Fittings | varies | numerous | FL Industrial | $123.90 |
| Lexan | $1.79 | 1 | | $1.92 |
| Motors: | | | | |
| Servo | $8.99 | 4 | | $39.81 |
| Bilge Pump | $37.50 | 6 | | $287.02 |
| Propellers & Hubs | varies | numerous | | $91.70 |
| Electrical Components: | | | | |
| Electrical Wire | varies | 5 types | Sound Marine | $175.00 |
| switches | varies | numerous | | $40.95 |
| connectors & terminator bars | varies | numerous | | $64.14 |
| fuses & holder | varies | 10 & 2 | | $8.65 |
| Electrical Misc. (box, tape, solder) | varies | numerous | | $82.93 |
| R/C Controller | varies | 2 | | $130.00 |
| Cameras | $69.99 | 2 | | $69.99 |
| Monitors | varies | 2 | | $171.00 |
| Aluminum | varies | 5 | | $20.72 |
| Hardware | varies | numerous | | $52.54 |
| Misc. (sealants, goggles,etc.) | varies | numerous | | $297.70 |
| Tools | varies | numerous | | $421.37 |
| Experimental Toys | varies | 7 | | $51.00 |
| Reference Books | varies | 11 | | $241.37 |
| | | | Subtotal: | $2,371.71 |
| | **$100.00** | | MATE Donation | **$100.00** |
| | | | **Total:** | **$2,271.71** |

| Reef Mock-up Parts | Unit Cost | Number of Units | Gifts/Donations | Total |
|---|---|---|---|---|
| PVC pipe & fittings | estimate | | | $25.00 |
| Bucket | estimate | | | $5.00 |
| Lava Rocks | estimate | | | $5.00 |
| Fish: wood, weights, paint | estimate | | | $25.00 |
| Bell | estimate | | | $7.00 |
| Hardware | estimate | | | $25.00 |
| O-Ball | $6.95 | 2 | | $13.90 |
| | | | Subtotal: | $105.90 |
| | | | **Total:** | **$105.90** |

| Travel | Unit Cost | Number of Units | Gifts/Donations | Total |
|---|---|---|---|---|
| Airfare | $158.14 | 5 | | $790.70 |
| Airfare for later return | | | | $413.39 |
| Booking Fees | $25.00 | | | $25.00 |
| Taxes | $32.06 | 5 | | $160.30 |
| Rental Car | $90.89 | 2 | | $250.00 |
| Gas | | | | $150.00 |
| Extra Room at Competition | $185.00 | | | $250.00 |
| Shipping of ROV | | estimate | | $100.00 |
| | | | Subtotal: | $2,139.39 |
| Travel stipend for room, food for team, advisor, & mentor | $1,500.00 | | MATE Donation | $1,500.00 |
| | | | **Total:** | **$639.39** |

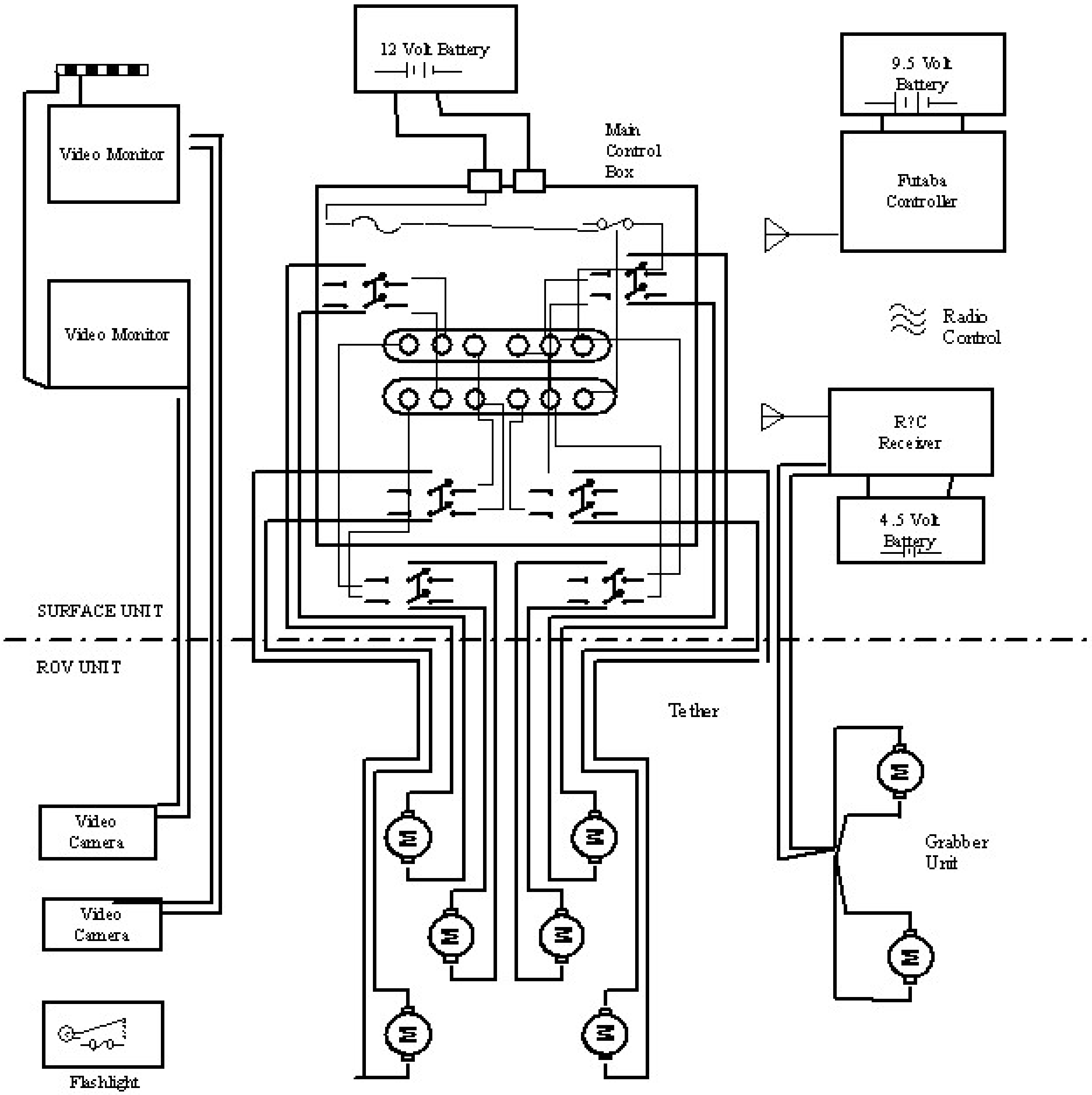
| Promotion/Presentation Materials | Unit Cost | Number of Units | Gifts/Donations | Total |
|---|---|---|---|---|
| Knight Diver Shirts | | | | |
| R/C Cars & Track for Fundraiser | | | | $243.34 |
| | | | Subtotal: | $243.34 |
| | | | **Total:** | **$243.34** |

**TOTAL Expenses:** **$4,860.34**

**TOTAL Donations:** **$1,600.00**

**TOTAL Team Expenditures:** **$3,260.34**

# Electrical Schematic

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|---|
| **MATE ROV Competition 2004** |
| Electrical Schematic for **Knight Diver ROV** |
| June 5th, 2004 |
| T. R. Robinson High School, Tampa, Florida |

## Design Rationale

As a first time team our design process was tenuous and chaotic. Our initial research on ROVs began with a video describing many different submersibles and their uses. Our instructor then reviewed with us the variety of ROVs currently in use. We explored many photos, videos, and the Internet. This background research laid the foundation for us to move towards designing and building our own ROV for the specific purpose of competing in the MATE National ROV Design & Build Competition. Our instructor laid out the following plan and attempted to keep us on track.

1. Define the need
2. Determine Specifications
3. Brainstorming
4. Analysis of Solutions
5. Modification of Design Based on Analysis
6. Selecting the Best Design
7. Assembly and Building
8. Make changes based on Building Process
9. Analysis and Testing
10. Modifications Based on Testing
11. Final Design and Evaluation

The 2004 MATE Competition Guidelines for the Ranger Class defined the requirements for our ROV. These requirements include:

- The ability to complete 7 scientific and recovery mission tasks within 25 minutes.
- Depth rating of 5 meters (m)
- Ability to be piloted by camera
- Ability to find and recover a towfish weighing 9.8 Newtons (N) in air.
- Find and identify the U-boat captain's bell by reading the name of the U-boat as it is inscribed on the bell.
- Patch a hole in a leaking barrel by placing a patch that is circular with a 10 centimeters (cm) diameter.
- Find and collect a specific species of fish weighing 3 Newtons (N) or less.
- Find the source of methane and tag the tubeworm cluster next to it by placing an O-ball on the cluster.
- Find and tag the mussel bed by placing an O-ball on the mussel bed.
- Find the authigenic carbonate formation and bring back a sample by retrieving a small piece of lava rock

The design of our ROV was constrained primarily by the following:

- Budget of $3000.00 (U.S. currency)
- Capable of fitting through an entrance that will be no less than 60 cm (either circular or square)
- Capable of maneuvering in a space 0.8 x 0.8 x 0.8 m.
- A minimum 12 m tether from control shack to ROV
- Capable of being transported either by hand or cart
- Must not damage any part of the pool deck or bottom tiles
- Must be set up and deployed in 5 minutes
- May not release hazardous or non-biodegradable materials into the environment
- Only DC volts may run down the tether
- Must operate from a 12 to 13.5 volt, 25 amp power source

- Must connect to the power source via male banana plugs
- Must have short-circuit protection (fuse)
- Maximum DC voltage is 13.5 volts
- Maximum DC amperage is 25 amps
- Competition officials must be able to place a multi-meter inline to monitor voltage and amperage
- Power supplies must be at least 3 meters (m) from the pool edge

Each team member developed his or her own conceptual design for the ROV. These designs were drawn on paper and brought to the overall brainstorming meeting. These conceptual designs were presented. As a team we evaluated and weighted the criteria for designing our ROV. Each concept ROV was then compared to the weighted criteria, requirements, and constraints to determine our initial optimum design. The initial optimum design for our prototype ROV was a combination of elements from the various conceptual designs.

## Partial Results from Analysis of Conceptual Designs

| Criteria | Weight (Range 0-10) | Design (Score 0-5) | Multiple of score by Weight | Design (Score 0-5) | Multiple of score by Weight | Design (Score 0-5) | Multiple of score by Weight |
|---|---|---|---|---|---|---|---|
| Appearance | 4 | 5 | 20 | 4 | 16 | 2 | 8 |
| Propulsion System | | | | | | | |
| 1. Speed | 7 | 3 | 21 | 4 | 24 | 3 | 21 |
| 2. Maneuverability | 9 | 3 | 27 | 4 | 36 | 2 | 18 |
| Frame | | | | | | | |
| 1. Stability | 8 | 5 | 40 | 5 | 40 | 2 | 16 |
| Manipulator/Payload | 6 | 5 | 30 | 5 | 30 | 5 | 30 |
| Control System | 6 | 0 | 0 | 3 | 18 | 5 | 30 |
| Camera System | 10 | 3 | 30 | 4 | 40 | 3 | 30 |
| Buoyancy Control | 5 | 2 | 10 | 3 | 15 | 0 | 0 |
| **Totals:** | | | 148 | | 219 | | 123 |

Design rational for individual components is described below.

1. **Frame**
   We looked at many different photos of ROVs to get ideas for the frame materials and shape.

   The idea to build our frame out of Schedule 40 PVC came from the book *How to Build Your Own Underwater Robot and Other Wet Projects* (Bohm & Jensen). Our instructor had already built an ROV from this book and the PVC had worked well for her design. The other advantage of Schedule 40 PVC was cost. At approximately $2.00 per 3.05 m (10 ft.) length it allowed us to purchase large quantities. It was easily cut to our size requirements without any special equipment. Whenever we needed to make changes in our design or sizes, it was easily accomplished. Furthermore, it was readily available at many home improvement stores. Many of the students had experience with PVC as well since many of them had assisted their families with lawn irrigation systems. This background knowledge of the material allowed us to immediately begin working without much training or learning curve.

   Most ROV shapes we observed were either a box shape or a triangular shape in cross section. We opted for the box shape for ease of cutting and stability purposes. It also provided us the most space to affix our accessories such as cameras and grabber.

2. **Control System**
Our control system was the most difficult portion to design. Most of our experience with controllers comes from video game experience. Ultimately we would have liked to have joystick control or computer control of the ROV, however our personal experience with electronic wiring was minimal for a few members and completely absent for the rest or the team. We relied heavily on the wiring schematics in the book *How to Build Your Own Underwater Robot and Other Wet Projects* (Bohm & Jensen) and the recommendations made by Sound Marine Electronics. Since wiring was not planned or worked on until the month of May, we had to simplify our initial design from joystick control to DPDT switches. These allowed us to reverse the polarity of the motors in order to reverse the direction of thrust. For better control of the thrusters we switched from the DPDT flip switch to the DPDT momentary flip switch. This gave us better control in the water trials. The layout of the main control box was left to our ROV pilot since he would be the end user. Weighing the video game controllers he was familiar with, he decided to mount the switches in a manner similar to the Playstation 2 controller since he was familiar to this layout.

We knew that our grabber arm would need to be run off of servo motors, however we did not know how servo motors functioned. Trail and error soon demonstrated that the servo motors we had decided to use would not run off of a 12-volt battery. Attaching these servo motors to a 12-volt battery destroyed the circuitry of the servo motors. We also did not have control of when the servo motor would open or close. Knowing that servo motors are used in remote control applications we began researching how these motors are actual controlled. Sending a pulse of variable width controls servomotors. The duration of the pulse determines how far the motor turns. We purchased a Tamiya 4-channel remote control hardwire box (#70106) and tried to wire the servo motors to this box. The wiring was unsuccessful and we returned the remote control for another option. Hobbytown USA recommended the Futaba 4-channel controller with a y-harness. The largest engineering challenge with this system was whether or not the signal would carry to the ROV underneath the water.

3. **Video Camera & Monitor**
The competition guidelines state that the ROV must be controlled and piloted via a camera system. This is to simulate real world application of ROVs. For this reason we weighted our camera system as extremely important. Without a camera we will be unable to complete any of the mission tasks. We chose to use the Carrillo Underwater Systems camera because we had been awarded a scholarship for lights and cameras from this company. These cameras have been commercially designed for underwater applications.

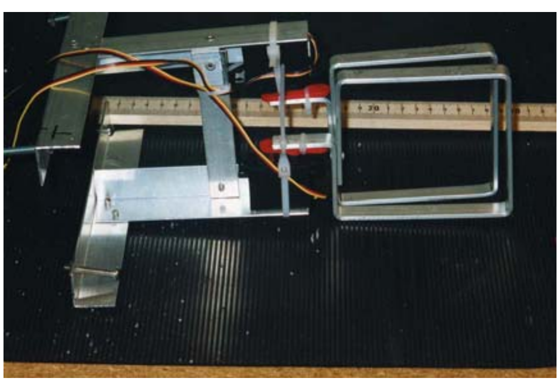
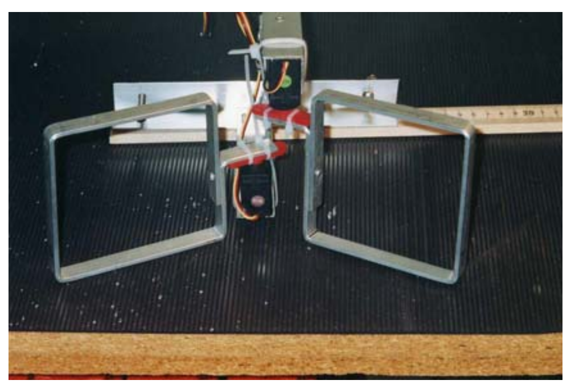
With the weighted importance of the camera guidance system we also decided that it was important to have a back-up camera system. We selected to use the X-10 Nightwatch 2 camera for several reasons. The camera met most of our requirements – light sensitivity, picture quality, small size, lightweight, and it had a 60 ft, hardwired cable. We constructed a watertight housing for this camera using a 8 cm length of 2 inch Schedule 40 PVC pipe, and 2 PVC end caps. The PVC pipe was fitted with a 1 ¼ PVC connector to serve a mount for the camera. The front-end cap was drilled out with a 1-inch hole saw to form a window. This window was then covered with a 1-½ inch circle of lexan. The lexan was affixed behind the window with marine goop. All seams were sealed with aquarium silicon. The back end-cap was fitted with a male and female ½-inch CPVC connector. These connectors were threaded through the hole that was drilled through the center of the end cap. The seams were again sealed with aquarium sealant. The cable was threaded through the length of PVC and the camera was mounted to the interior. The cable was then threaded through the CPVC connects in the back end cap. Both end caps were affixed to the PVC pipe with PVC cement and the seams were sealed with aquarium sealant. Finally, the connectors where the cable came through the housing were sealed with aquarium sealant.

As of May 24th we have not received delivery of the Carrillo Underwater Systems cameras. Two cameras have been requested. Carrillo Underwater Systems has stated that the construction of the cameras has been delayed due to supplier issues and family obligations. If we do not receive delivery of these cameras by May 31st, 2004 we will finalize our construction with the X-10 Nightwatch2 Camera system.

## 4. Retrieval Mechanism

Our instructor gave us many toys and brochures that had a wide variety of manipulator arms and grabbers for us to evaluate. Our mission tasks require that we have the capability to pick up several different items of differing shape and size. We conducted several trials with the various toys to determine whether or not they would be best for picking up the items we needed to pick up. The results were as follows:

| Manipulator | O-Ball | Volcanic Rock | Balsa Wood | Rope |
|---|---|---|---|---|
| Robotic arm | Grabbed well, but ball would get caught on jaws upon release. | Grabbed and held on to rock because of large rubber pad, but required precision piloting. | Was able to grip wood but required precision piloting to grab at the correct angle. | Rope slipped from grip. Required precision piloting. |
| Trash grabber | Grabbed well, but ball would get caught on jaws when released. | Rock slipped from grip. | Wood slipped from grip. | Unable to grip rope. |
| Bug jaws | Grabbed well, but not enough surface to hold ball for length of time. | Not enough surface area to hold rock. | Too small of an opening to grab wood without precision piloting. | Unable to hold weight of rope. |
| Pololu Joinmax Gripper | Grabbed well, but ball would fall out of grip. When released ball would get caught on jaws. | Did not hold in grip well, rock slipped from grip. | Had to have articulating motion or rov had to be piloted into position to grab. | Precision piloting was needed in order to grab. |
| Glove Grabber | Grabbed & Released well | Grabbed and conformed to rock shape | Closed far enough to hold thin wood | Grabbed and held |

**Photos of Grabber Unit**

5. **Tether**

Our thrusters were already prefabricated with 16 AWG wire. We wanted to select wire that would carry enough voltage to the thruster units with the least amount of resistance and the least voltage drop. Originally we were going to use 14 AWG speaker wire. This wire had little voltage drop over the distance of our tether, plus it was flexible. However, shortly after experimenting with this wire, Sound Marine Electronics generously offered to donate 18 AWG 2 conductor electrical wire. Although this wire was not as flexible, it did have a tough exterior to protect the conductors from the elements and any environmental hazards. It was selected primarily for cost.

Sound Marine Electronics also donated Cat. 5 cable to supply power to our servomotors on the grabber. This wire would have enough conductors to power the servomotors and it was lightweight. While working with this wire and attempting to splice it to the y-harness to the servomotors we became increasingly frustrated with how fragile the wire was. Instead of begin twisted wire it was solid. The wires would frequently break during manipulation. It was decided that we needed to find a different wire that could withstand being handled and bent. Since this wire would be fed down our tether and would potentially have to handle torque and stress it had to be more durable. It was decided to use sprinkler wire instead. Two lengths of this wire were used, each containing 4 conductors of twisted 22 AWG wire. This wire was much easier to manipulate. It did not break while we were working so it met our durability requirements. The tether is shielded with ¾ inch braided sleeving.

Our camera cables and wire for the grabber are also run inside the tether. We originally wanted to attach these final cables to the outside of the tether. This design will allow for a quick change of cameras in the event of a camera failure. However, there was no protection for these cables. Due to the importance of both systems, it was decided that they should be run inside the protective covering with the other wires.

6. **Thruster**

We considered a number of different types of motor and propeller combinations as a thruster unit. Since our propulsion system had the second highest weigh in our criteria we took a lot of time to determine what system would work best for our mission tasks.

Our first consideration was the actual motor we would use. We had several brands of bilge pump motors (Johnson, Rule, Shurflo Piranha) and two different Radio Shack motors that we originally considered. We extracted the bilge pump motors from their casings in order to evaluate them side by side with the Radio Shack motors. The bilge pump motors all appeared to rotate faster than the Radio Shack motors. We inferred that this faster rotation meant they would have more power and thrust. All of the motors appeared to be equally balanced. All motors turned in a counterclockwise motion.

Taking into consideration the fact that our ROV would be functioning in water and our motors would need to be waterproofed, we decided to use a bilge pump motor. Rule bilge pumps, manufactured by ITT Industries, make replacement cartridges for bilge pumps. These replacement cartridges allow for easier access to the motor shaft and impeller. For this reason we chose Rule Bilge Pump Replacement Cartridges.

In order to evaluate the power of each Rule bilge pump, we constructed a PVC mount for the motors. It was then submerged into an aquarium of freshwater. The motor was activated and the amount of thrust was evaluated by placing our hand in the stream of water being pushed by the propeller we had placed on the shaft. We chose the 1100 GPH Rule Replacement Bilge Pump Cartridges as our motors because they are more powerful than the 350 GPH, and the 700 GPH.

We designed a nozzle from 2 inch PVC in order to protect to propellers from debris and to protect the pool from damage from the spinning propeller. This nozzle was designed after a kort nozzle, which our research told us could also help to increase the thrust from the propeller.

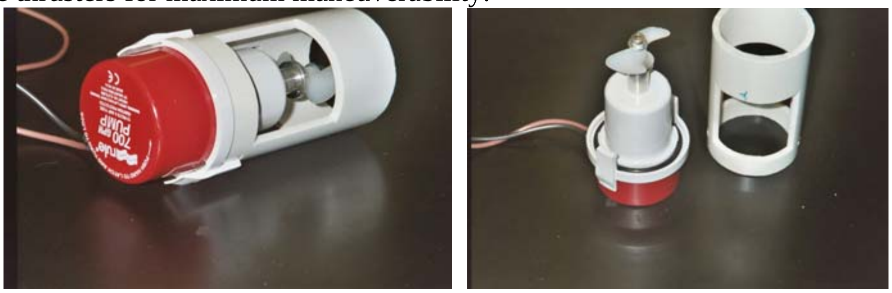
Once we selected our motor, we had to determine which propeller we would attach to the shaft. Bob Musselman of Admiral C & B Propeller gave us a lecture on how propellers work. After learning the different factors that affect a propeller and how much thrust it can provide, we decided we needed a non-metal propeller with a low pitch, larger surface area, and 3 blades. This type of propeller would provide adequate thrust but allow for more maneuverability. We went to all of the local hobby shops in search of a 3 bladed propeller but were unable to find one at these shops. Our search took us to the Internet, where we continued to have problems finding 3 bladed propellers. We purchased several 2 bladed propellers for evaluation. The propellers we compared included the followings:

- X Brand 55mm (Hobby Lobby)
- #3003 Nylon Propeller 1.75" Dia. Kit #3003 (Dumas Products)
  1.75" Dia. 1.50" Pitch Left Hand 1/8" Bore
- #3004 Nylon Propeller 1.75" Dia Kit #3004 (Dumas Products)
  1.75" Dia. 1.50" Pitch Left Hand 3/16" Bore
- #3105 Bronze Propeller 1.75" Kit #3105 (Dumas Products)
  Bronze Propeller 1.75" Dia. 1.50" Pitch Two Bladed Left Hand 3/16" Bore

We selected the #3003 Nylon Propeller 1.75" Dia. Kit #3003 (Dumas Products)
1.75" Dia. 1.50" Pitch Left Hand 1/8" Bore because it fit inside of our nozzle, was lightweight, inexpensive, and provided more maneuverability than the racing propellers.

Several methods were used to attach the propeller to the shaft of the motor. We used bushings, set-pins, J.B. Weld, cauter pins, and a Master Airscrew Hub. We decided to use the Master Airscrew Hubs for several reasons. First, they were easy to attach to the shaft. Second, they moved the propeller further away from the motor allowing more water to flow across the blades without interference. Third, the hub allowed for easy change of propellers in the event of damage. The only modification that was necessary was to change the hardware to stainless steel.

The entire thruster unit is connected into the PVC frame with ¼ inch diameter, 3 inch long Schedule 80 nipple connectors. A Schedule 80 PVC bushing adapter is placed between the threaded ½ PVC T-connector and the ¼ Schedule 80 nipple connector. This connection was sturdy, allowed us to place the thruster anywhere on the frame. It also allowed us to adjust the angle of the thrusters for maximum maneuverability.



**Photos of Thruster Unit**

7. **Power**
   As mandated by competition guidelines, our main power source is 12-volt battery. Power is fed through banana plugs and 10 AWG power wire into our control box. The main power is protected with a 25 amp fast acting fuse. This fuse was selected because it would blow as soon as we surpassed the 25 amp maximum requirement. It would also protect our electronics better than a slow acting fuse. Ancillary power includes 110/120-volt AC power adapters for the cameras and monitors. The adapters were supplied with the monitor. A 4.8 VDC Nickel-cadmium rechargeable battery (NR-4QB) provides power for the servo remote control receiver. And the Futaba controller is powered by a 9.6VDC Nickel-cadmium rechargeable battery (NT8F008). Both Nickel-cadmium batteries were supplied with the Futaba controller.

## Challenges

1. Inexperience in the field of engineering was a challenge, yet it was also the reason we entered into this project. Not only were the student members of the team inexperienced, the instructor/advisor had minimal experience in the field of engineering. To overcome this gap in our knowledge base, our instructor/advisor purchased numerous books on robotics for team members to reference. She also assigned research and background readings. She often created worksheets and fact sheets to focus our research and practice exercises. This helped to provide some of the fundamental basics. However, there were other times when we needed to call upon the expertise of others. Often it was difficult to find someone with either the knowledge or the willingness to help the team.

2. Scheduling posed a significant challenge. Team members had school, work, families, and personal obligations to fulfill. Our meetings were after school on our own time, it was rare that there was an opportunity during the school day for us to meet as a team. Often there was a lack of communication because some team members were at some meetings and some were at others. Making sure everyone got the information they needed was difficult and caused problems as team members attempted to fulfill their assignments and responsibilities. Originally the team met once every two weeks. These meetings occurred for one hour during the school day. It quickly became apparent that this was not sufficient time, so we held an additional meeting once a week after school. These meetings often conflicted with sports practice. By March, we it was apparent that we needed to dedicate far more time to building so we could begin water trials. The team voted to meet twice a week after school. Increasing the number of official meeting times was difficult. Each meeting required School Board approval. Often we held informal "unscheduled" meetings after school.

3. We also faced organizational challenges. Our instructor/advisor did a good job of pointing out what needed to be done, and what areas we needed to focus our efforts. We also had a team leader that had lots of ideas, and motivated the team. Brainstorming went well, but when it came time to make decisions about what materials and component to use, then acquire those materials we often had the expectation that our advisor would tell us what to do, or provide us the materials. Team members were not doing anything outside of team meetings. To help us become more productive, our advisor suggested we begin our meetings with an agenda. Our first task at each meeting would be to review the progress of team members on their assigned tasks. These tasks were assigned at the end of each meeting. This would hold each of us accountable for getting things done outside of meetings. It also helped the student team members to take ownership of the ROV project, making us more independent in our problem solving abilities.

4. Funding was one of the largest challenges. Although our advisor worked hard to get local companies to sponsor our team by donating materials and funds, we often found companies to be unresponsive. Many local stores referred us to the corporate headquarters. Despite sending multiple letters, leaving phone messages, and following up many of these corporate headquarters did not respond. Other companies replied with statements such as, “we receive many of these requests, but are unable to help at this time”, or “due to the current economic status of our company, we have suspended such activities at this time”. We found that locally owned and operated companies were more willing to help us out. Most companies that responded to our requests were able to provide a discount on product rather than a donation of product. Only one company was willing to give a financial donation, but prior to sending the check, the partnership split and the remaining partner did not want to support the team. More often than not, it was our advisor that funded our project. We are very grateful to her and her family for their generosity with their time and money, we know that teachers do not make much money and she willingly gave whatever was needed to make our project a success.

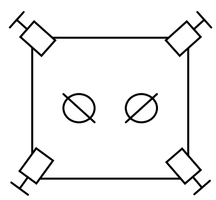
5. Team member retention was a unique challenge. We experienced drop out of team members for a variety of reasons including: administrative withdrawals of students from the school, dismissal from the team for lack of attendance, commitment to project, or behavioral issues. There were times when the loss of team members seemed devastating to the project. We usually felt this way when the team member was in a leadership position or had very specific skills that others of us did not have. On the other hand, there were times when we seemed to be more productive when there were fewer people around. During team meetings that had high attendance we often felt like we were wasting time answering questions and catching people up that had not been involved due to absenteeism. Sometimes these team members would argue that their ideas were not incorporated into the ROV and would want to change things that had been decided in earlier meetings. This would often lead to arguments that resulted in tension between team members. In many cases, team members that were removed from the team either by the school or by our advisor were often team members that were not reliable enough to complete tasks on time, which often slowed the team down as well. Working out these team dynamics was often the most stressful part of handing the ROV project.

## Troubleshooting Techniques

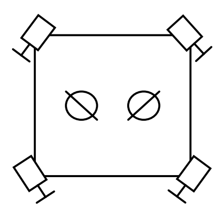
This being our first competition, the trouble-shooting techniques that we utilized were often trial and error. We would also take our ROV to our team of experts for assistance in trouble shooting.

Once we began water testing our ROV we discovered that our thruster arrangement did not provide us the maneuverability we desired. Below are diagrams of our thruster arrangements.

**Thruster arrangements**



Initial thruster arrangement



Final thruster arrangement

Although the initial thruster arrangement was suggested by Harry Bohm in is book *Build Your Own Underwater Robot,* it did not provide the tight radius for turning that we were looking for. The placement within the frame on both the XY axis and the Z axis had been chosen based on what we had seen in photos of commercial ROVs. We returned to these photos to determine the exact angle and vectors that were used for the thrusters. Our final arrangement is based on these photos. It allows for much quicker turning.

Water trials also revealed that our thrusters needed a solid unit in order to provide maximum thrust. The first time we engaged the thrusters in the water, the pivoted at the point where they were connected to the frame. We used PVC cement to created solid crossbars for the thrusters.

## Lessons Learned

1. We learned that to be a successful team, team members must be willing to compromise their ideas and take suggestions. If the team doesn't work together, time will be wasted arguing rather than designing and building. Team members must be willing to listen to their teammates. Also, team members must be mindful of their communications techniques. Sometimes constructive criticisms came across as cut downs and would often lead to anger between team members. With cooperation, more is accomplished.

2. Remaining dedicated and following through with assignments is vital to the team being successful. Setting a timeline with deadlines will help to keep us on track. Since this was our first attempt to build an ROV, we did not know that amount of time it would take to complete any task. We also had to wait for materials to be shipped to us. The school year ended on May 27th, 2004 and we had not begun our water trials.

3. Problem solving can be a frustrating process. We learned that we needed to methodically work through issues. We needed to record what we tried and whether or not the result was positive. This would avoid duplication of efforts and minimize our frustration level when things did not go as planned. Sometimes we simply had to leave a problem to another practice, this gave team members time to think about different options. Also, tensions seemed to arise due to malfunctions and plans gone awry it allowed us to make more efficient use of our time.

4. Jumping into a project headfirst is not always the best method. We learned we should always stop and think about the logic and physics behind our plans before we enact them. We should do our research and read the instructions or requirements. An example of this occurred when we were selecting our motors for the thruster units. We had seen an ROV build by our advisor using high-speed 12VDC Motors. We tested the motors and decided they would not be powerful enough to lift objects we needed to lift during our mission tasks. We decided to get bilge pumps and use those motors. We purchased 2 different models of bilge pumps. Using a Dremel tool we released the motors from their housings, a total of four motors. We examined all the various specs about the motors, RPM, GPH, amps, direction of shaft rotation, and balance. Only after we had made our decision on which motor we wanted to use did we begin to consider ways to waterproof the motors. Finally, we realized that the motors were already waterproofed in their bilge pump housings. At nearly $40 a bilge pump, it was a costly experiment.

5. Documentation throughout the design process is vital. Although we had a product by the end of this process we had a difficult time writing our engineering report because we did not document each step. It took a lot of time, discussion, reflection, and redoing work that had already been done in order to be accurate in our report. Being able to communicate our ideas to the world is

just as important to engineering as having the idea itself. Not matter with scientific discipline you are involved in you must be able to communicate in both written and verbal formats for your ideas to be received, reviewed, and accepted by the scientific community. In the future we will be diligent about documenting our progress. Most of the documentation we had was from our reports we had to provide to Carrillo Underwater Systems as a requirement for our scholarship. Without us knowing, or instructor/advisor did document our progress and kept a photo journal of our work. Only when we were completely stuck on a topic and our deadline for the report was quickly approaching did she offer her documentation for our reference.

6. When conducting our analysis, we have also learned that it is important to use measurable variables and data instead of subjective opinions. When we evaluated our motors for our thrusters our results were purely subjective. These opinions, although we feel they served our purpose are not very valid when another person questions our decisions. It has been difficult to sound credible when asked, “How do you know that is the most powerful motor?, or How do you know that motor provides the most thrust?, or exactly how much more thrust is the 1100 GPH motor providing over the 700 GPH or 500 GPH?” Our instructor/advisor had always told us to record our observations and make certain that our results are measurable. She often asked us if our descriptions were as specific as we thought they could be and if the results were measurable. Often she would ask us how we measured our results and if our measurement was subject to bias. We were more interested in moving ahead with the building process rather than taking the time to be specific on our comparisons of the motors. Now we understand the importance of being specific and finding methods such as force meters to measure our results.

## Future Improvements

1. The wire we used was thicker than we had originally anticipated. This presented a challenge as we tried to thread it through the ½ inch P VC frame. If we decided that PVC was still the best choice for our frame we would change to ¾ inch PVC. This would provide us more room to thread the wire.
2. We would use pronged connectors to allow us to remove the tether from both the ROV and the control box. Currently all of the electronics are hardwired. We had connected all of the wires before we considered options for covering and protecting the tether.
3. We would use a potentiometer to control the overall power to each thruster. Our only option with the current design is to pulse the electricity to the thrusters.
4. Future improvements would include propeller/thruster control via a joystick or overall r/c controller. This would allow us to fine tune our movements through the water and provide more maneuverability. It would also be easier on our fingers than the current DPDT momentary switches.
5. We would incorporate a circuit breaker to reduce the cost of fuses.
6. Our next project we will be certain to maintain a journal and diagrams throughout the entire design process. This would make the reporting of our project much easier rather than having to rely completely on our memory.

## ROV Exploration of National Marine Sanctuaries (500 words)

As a team we decided focus our research on the Florida Keys National Marine Sanctuary due to its close proximity to our school. Information was obtained via an email interview with Bill D. Causey, Superintendent, Florida Keys National Marine Sanctuary and Brian Keller, Research Coordinator, FKNMS.

Doug Weaver has used ROV to characterize bottom types and investigate fish communities associated with two features in Tortugas Ecological Reserve South, which is the largest marine reserve in U.S. waters. Specifically, he examined Riley's Hump, which is a reef fish spawning aggregation site, and part of Miller's Ledge, which may also serve as a spawning aggregation site. Doug currently works at the Flower Garden Banks National Marine Sanctuary (doug.weaver@noaa.gov). Doug used an ROV provided by the National Undersea Research Center at Key Largo, which is managed by the University of North Carolina at Wilmington, directed by Steven Miller (smiller@gate.net).

Another researcher who has used ROV in the Florida Keys National Marine Sanctuary is Mark Fonseca, who has used a MiniBAT towed operated vehicle to characterize bottom types and trawl impacts (Mark.Fonseca@noaa.gov). A summary of this effort is posted at http://shrimp.ccfhrb.noaa.gov/~mfonseca/ASEHC.pdf.

The FKNMS also was surveyed during Sustainable Seas Expeditions, which took place between 1999 and 2003. This included use of autonomous underwater vehicles such as Deep Worker and Deep Rover. A report on SSE is posted at http://oceanservice.noaa.gov/websites/retiredsites/sse_pdf/sse.pdf.

The Florida Keys National Marine Sanctuary is also utilizing ROVs to search for illegal wire fish traps. We were unable to reach law enforcement officers for further discussion.

Additionally, the FKNMS also was surveyed during Sustainable Seas Expeditions, which took place between 1999 and 2003. This included use of autonomous underwater vehicles such as Deep Worker and Deep Rover. A report on SSE is posted at http://oceanservice.noaa.gov/websites/retiredsites/sse_pdf/sse.pdf.

** Reference provided within the text.

## Acknowledgements

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Additionally, we especially thank our main sponsors for their generous support allowing us to participate in the 2004 ROV Design Competition:

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