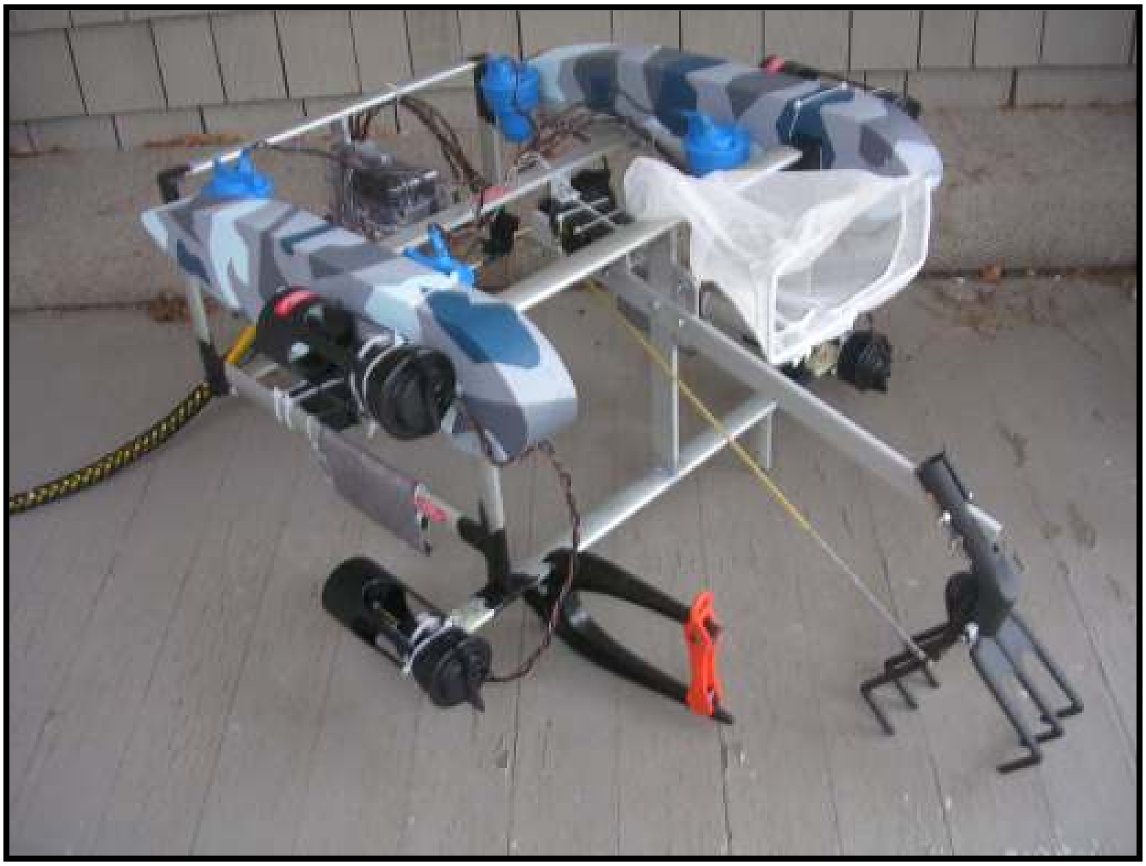
# The Falmouth ROV Team

*presents*



## AlphaROV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1 - Falmouth Academy
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Marine Advanced Technology Education Center
6th Annual ROV Competition

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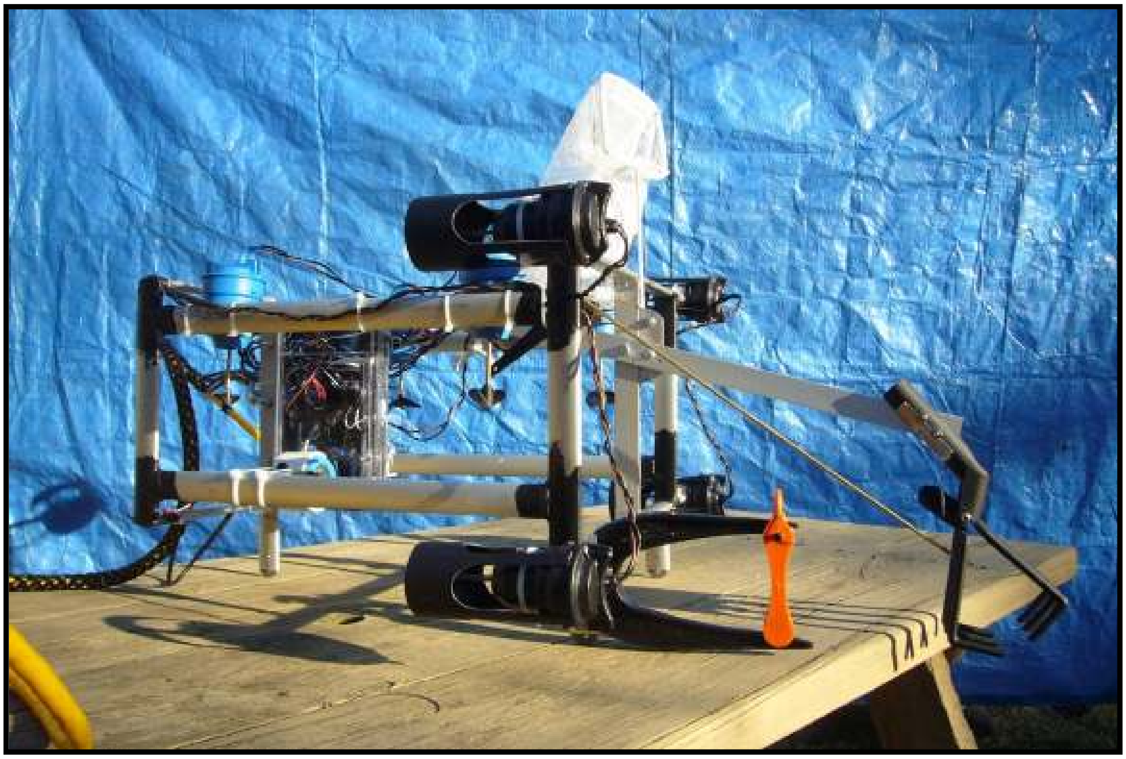
**I Abstract.** This year, the Falmouth ROV team designed our ROV based on both the new missions of the 2007 MATE ROV competition and the lessons learned from our experiences in the 2006 competition. We attempted to use the same control systems and electronics while redesigning the physical vehicle to allow it to complete the new missions easily, effectively, and quickly. Hopefully this vehicle is modifiable and versatile enough to allow other future Falmouth ROV teams to use as a starting point, or at least an assistant in testing. We began by visiting different companies in Falmouth that build underwater vehicles to understand more about their structure and construction process. After the visits, we began to plan and design our own ROV. We made great efforts to reconsider the shape of the vehicle, along with the type, shape, and placement of the thrusters. With the individual components working separately, we attached them to the chassis and began testing the vehicle. The completed ROV is larger than our last, occupying approximately 10 liters of volume. We have tested it to a depth of 5 meters on a 15 meter long tether; all components were stress-tested to withstand the mission challenges. Its nine motors are positioned such that it can move laterally, horizontally, and vertically. It has a manipulator to grab objects and an underwater camera with night vision. These capabilities should allow it to complete the missions for the MATE ROV competition, despite the many challenges.

Word count: 243

**II Photographs of completed ROV.**
Note: flotation was removed for visibility.


Side view


Back view

Front view

Top view with flotation

**III Life at the poles.** Humans have lived in and researched the Polar Regions for centuries. To most people, these regions remain mysterious, remote, and barren of life. The inhabitants, however, view the land as something that they have to work with, not fight against, and they have adapted over time to make life possible even in these cold regions. This year, scientists across the world have decided to focus on the polar regions. To this end, they have called 2007-2008 the International Polar Year (IPY). Learning more about the polar regions can teach the world important lessons about climate change, and scientific and social responsibility.

The Arctic region encompasses the areas whose average temperature in the warmest months is less than 10˚C and includes the northern parts of Canada, Finland, Greenland/Denmark, Iceland, Norway, Russia, Sweden, and United States. About 3.5 million people live in this region and have to tolerate the unfavorable living conditions. Some still live a nomadic lifestyle, but many live in permanent dwellings. Many people have migrated to the region and live in large towns that depend on forestry, mining and tourism. Unfortunately, the hundreds of species of plants and animals common to the Arctic are threatened directly and indirectly by human activity in the region.[1]

Antarctica is almost completely covered by ice: 98% of the continent is covered up to 4 km deep. The ice flows from the center to the surrounding ocean, and often ice breaks off, calves, and drifts along as icebergs. Despite the many species that inhabit the surrounding ocean, the emperor penguin is the only animal that remains on land year round. The Antarctic region is visited by thousands of tourists each year and many scientists reside there provisionally. The Antarctic Treaty was signed by 45 countries that govern the region and regulate civilian scientific investigation. [1]

The people who inhabit the poles have had to adapt to their surroundings over the years. As non-indigenous people came to the Arctic, they found that they had to adapt to more than just the climate. The newcomers had to adapt to the culture that has evolved with the indigenous people. According to natives' religions, humans and animals can communicate and animal spirits affect the fortune of humans. They also maintain the ideal of sharing, essential for survival. Although some of their beliefs have weakened over time as Christian missionaries and government officials have brought their influences to the area, the human-nature connection remains strong. [2]

The native and non natives alike developed similar techniques in adapting local materials for their use. Many of the natives invented tools in order to improve hunting methods, as it was a way of existence. Among the tools and weapons used to hunt seals and birds was the innovative ice scratcher: seals are comforted by and attracted to the sound of another seal scratching the ice, so this tool imitated the sound to lure the seals. They tried to improve their methods of travel with inventions such as the snowshoe and the kayak with spaces to keep hunting weapons such as a seal dart, line hook, and spears. Some learned to skin a seal in one piece, a difficult art, and filled the skin with air to use as a float. Because of the dire cold conditions, they also developed clothing to protect them. They now use snow goggles to protect their eyes from sun damage. Also, they use seal skin to create waterproof boots and mittens. Hooded parkas can be made from seal intestines.[3]

Snow goggles. (Smithsonian Institution, <alaska.si.edu/img/object_thumb/E024340.jpg>)

Over the past few decades the interest in the Polar Regions has greatly increased. Noting the increasing importance of global warming to modern peoples, scientists have recognized the need to study these regions. Also, when the USSR fell, the new Russian government opened up a large section of the Arctic for research. Unfortunately, exploration into these areas has created social unrest because the rights of the natives have been disregarded. In the past Natives had no interest in owning land, but now some are considering it to prevent the destruction of their homes.[2] If conducted properly, research in the Polar Regions can demystify the areas and provide fascinating information for the rest of the world.

[1] http://www.globaleducation.edna.edu.au/globaled/go/pid/3115

[2] http://www.thearctic.is/articles/overviews/homeland/enska/kafli_0203.htm

[3] http://alaska.si.edu/browse.asp

**IV Design rationale.**

*Note that bold text describes the inset photograph.*

*V.i Chassis.* We designed the chassis around the thruster configuration and the missions. We chose aluminum as the material for its ease of use, strength, and light weight, rejecting PVC pipe because of the difficulty in fully sealing or unsealing the pipes and connecting components to round objects. We used airfoil-shaped "spreaders" made for sailboat masts for most of our structure; by fully sealing the frame, we halved the weight while maximizing strength (objects with greater moments of inertia are stronger) and minimizing drag. To attach the airfoil pieces to one another, we used aluminum solder, creating joints

that, in our tests, were stronger than the aluminum itself. Last year, using only aluminum bars, our frame frequently fell apart at the epoxy joints. The airfoils have very small drag coefficients so that our ROV is easily driven by our 4 forward thrusters. Our flotation is **expanded PVC foam**, which does not compress even at extreme depth (kms) and provides a high amount of flotation for a low amount of volume. We positioned foam and ballast to prevent tipping: PVC foam flotation on top, lead weights on the bottom. By attaching enough flotation to make the ROV positively buoyant, if any system malfunctions or fails, the ROV will float to the surface for recovery. In addition, any loads picked up will require less force to manipulate. We painted the flotation in the official "arctic camouflage" style in honor of the IPY.

*V.ii Thrusters*. Given the prospect of a speed bonus and time limit, we designed the thrusters and their configuration to maximize power and agility. We decided to avoid ballast control and control surfaces (such as might be found on AUVs and military submarines), so motor functions control all movement. These features are primarily useful for movement in one direction, while we need the ability to maneuver precisely in a confined space. We chose to use nine motors: four for forward, reverse, and turning, four vertical (up and down) motion, and one for lateral movement. This configuration gives us direct control of motion in the three axes, as well as control over yaw. To avoid pitch or roll, which would only complicate matters, we arranged the flotation and ballast for maximum stability (as stated in the chassis section). We had two options for motors: pre-waterproofed bilge pumps or DC motors that we would waterproof with custom housings. In the interest of effective waterproofing and costs, we chose bilge pumps. Bilge pumps (conveniently 12V) come off the shelf with impellers, not propellers, so instead of attaching tubes to the output of the bilge pumps, we decided to modify the motors into real thrusters to maximize efficiency. We considered model boat and airplane propellers, buying and testing various sizes of each against the other. We used two motors attached to one another so that the motors pushed against each other. We knew which propeller was best based on which way the two-motor system moved. After more than twenty tests on two, three, and four bladed propellers of sizes from 42 to 60 mm, we determined that a 50 mm, two-bladed model boat propeller gives the best thrust to power-consumption ratio.

All motors are made to run at a certain speed under a certain load. By finding the right propeller, we came as close as possible to the optimal load and speed specifications of our bilge pumps. After machining shafts from brass tube and gluing them on with epoxy, our **bilge pump thrusters** were ready to go. Using multiple motors spread the load on each motor and eliminated the need for a single, cumbersomely large motor. Last year, our thrusters constituted the largest part of our power budget, yet came nowhere near the limits. This year, we wanted to use as much of the power budget as possible, so we put on as many motors as we could. Each one draws approximately 6 amps under full load. However, there should never be a circumstance meriting full throttle on all nine motors. To prevent failure or malfunction, however, we have fused each channel of motors in addition to the main 25 amp fuse. This precaution should ensure flawless functionality. Last year, our bilge pump motors' housings cracked and leaked at 20 feet depth, so this year we coated them in a flexible plastic substance that should allow the motors to flex without leaking. Last year, we autopsied a dead motor and found that by putting axle grease on the simple lip seal we could significantly increase each thruster's depth rating. We also made sure that no water could wick down inside the stranded wire insulation by carefully sealing the end of each wire with silicone seal or Scotchkote. We made plastic shrouds to fit over the four thrusters outside the frame of the vehicle. They not only prevent objects from touching the propellers, but also focus the thrust, making each thruster more efficient.

*V.iii Camera.* In order to complete the missions, we needed a simple, small camera with decent resolution, low power consumption, and some sort of low-light adaptability. A few hours of web surfing returned a cheap, water resistant, black and white, infrared-assist **camera**. We bought it, cut the wires so we could use our own, added plasti-coat and silicone for waterproofing, and designed a servo to add tilt functionality. In addition to this camera's simple night-vision (infrared LEDs surround the lens), it is also conveniently able to withstand temperature far below zero Celsius, according to its specifications. Based on our experiences last year, we took precautions in preventing water from seeping through the wire into the camera housing. The camera can plug directly into a topside, standard television. After constructing the ROV and beginning to test it, we thought that the camera we modified would not work. We thought interference from the motors made the camera output fill with static. After a few runs, the output became hazy and dark, probably from moisture in the housing condensing onto the electronics or lens. Soon, we found that the true problem might be a high resistive voltage loss because of the tether. When we decreased the resistance of the tether by adding more, thicker conductors, the camera was still muddy. We ordered a new camera and machined our own housing, using the same waterproofing techniques as before. While the new camera does not have LEDs or a housing of its own, its extremely good low light capabilities, higher resolution, and small size make it better than the commercially enclosed camera we bought before. We used a brass tube and pieces of clear polycarbonate to make the housing, then surrounded the camera with foam to hold it in place and mechanically isolate it within the brass tube.

*V.iv Manipulation*. Last year, we used a simple latch system to control our payload and manipulate objects. This year, we decided such a simple solution would be ineffective. In order to pick up the balls and weighted PVC pipe for this year's missions, we designed a grasping claw. The claw is made of two **garden cultivators,** hinged so that it can grab most objects. A servo pushes and pulls the lower trowel through a spring loaded brass tube that we built. This allows the claw to keep pressure on an object without overloading the servo. We also have a modified butterfly net to catch the ping pong ball. To reduce drag, we will remove the butterfly net when we do not need it. The system we currently have will allow future teams to build their own manipulators and still use the basic infrastructure we spent hundreds of hours this year soldering together. In addition to this servo-powered manipulator, we also attached the so-called **"Happy Hooker"** used by boaters to attach their lines to piers. It will allow us to easily and effectively string the messenger line through the loop in the first mission. The Happy Hooker serves a double purpose: the orange part can be removed, allowing it to function as a simple hook. The hook can skewer samples for collection or carry the rubber gasket in the wellhead mission. To waterproof our servos, we deconstructed them, filled them with transmission fluid—which is non-conductive and less viscous than alternatives—added o-rings, and finally coated them in epoxy. This should prevent them from leaking or rusting. Testing the servos after cooling them to near zero degrees Celsius, we found that while they worked more slowly, they still moved. We also extensively tested for leaks to avoid damaging pool systems and found that no transmission fluid came out.

*V.v Motor Controllers*. We could have used simple on/off switches to control the motors, but we decided that a more precisely controllable ROV would grant us a significant advantage. We could also have used a simple potentiometer system to vary the electrical resistance, but motors become highly inefficient without their rated voltages. Instead, we used the **electronic speed controls** from last year that could deliver full performance in the whole spectrum of motor speeds, including reverse. Using a donated **R/C airplane controller**, we were able to use the electronic speed controls to power the motors onboard the ROV. While the four speed controls cost over $300, we needed them to use the low-power R/C receiver. The Vantec speed controls take the low voltage signal from the receiver and a 12V input and send PWM (pulse width modulation) voltages to the motors. This method allows proportional control in all dimensions, as well as proportional turning for the forward/back thrusters. By sending radio signals down the tether instead of wires for each individual motor, we significantly reduced the size, weight, and drag of the tether. The challenge is that all the electronic components on the ROV must be effectively waterproofed. We used a watertight plastic container (Pelican case) with a rubber seal. On the bottom of the box, we attached strain-reliefs so that straining the wires would not result in a leak in the electronics box. We then coated the exposed wires on the bottom of the box with multiple layers of Scotchkote, then covered that in silicone to waterproof and electrically insulate them. Last year, we filled our electronics box with mineral oil so that even if it did leak, our electronics would not fry, but hoped that this year that measure would be unnecessary; the Pelican case is rated to more than 50 feet. During the 2006 regional competition, we realized that the leads on one of our main thrusters was wired backwards, causing the ROV to go haywire. Using the airplane controller, we were able to reprogram that channel mid-mission in minutes, and then complete many of the missions in the time we had left. It is a feature that we dread using, but love to have.

*V.vi Tether.* The tether is the ROV's lifeline, carrying power and signals. We needed three components in the tether: power, control signals for the motors, and output signals for the video. The power is split amongst the various needy components onboard the ROV itself in order to maintain a low size and low drag tether. Thus, only five conductors are required for the tether: positive 12V power, negative 12V power, ground, video signal, and radio signal. In our tests to find whether the radio signal, power, or video signal traveling down the same tether could cause interference issues, we found any effects negligible. This left three conductors free for future use. We determined the tether's length (~15 m) with the philosophy that it is better to have too much rather than too little tether. Even with an excellent ROV, a tether that is too short is severely limiting. We found that the added tether length caused a high amount of resistance when we tried to run our components. In order to alleviate the problem, we used four conductors for power instead of two. SOSI's donated cable has three #24 AWG twisted pairs and one #20 AWG twisted pair, for a total of eight conductors. The conductors are bundled and wrapped with a Mylar tape followed by braided Kevlar that is surrounded by a yellow polyurethane jacket. The OD of the cables is about 0.44". The cable is not neutrally buoyant, but is close to being so. Because these wires are quite high gauge for the amount of current and low voltage we are using, we decided to add two #14 AWG conductors (speaker wire) to the outside of our tether to decrease the resistance. The extra conductors work in parallel to the others we already had connected, minimizing our resistive loss. Without the speaker wire, we measured a voltage drop of seven volts when we tried to draw full load. With it, we measured a drop of only a few volts. Our tests showed the resistance increase caused by lengthening the tether from 15 m to 23 m to be significant, so we went with a shorter tether.

*V.vii Integration.* Each part of the design rationale had the end task in mind. With the individual parts working, the ROV will be able to use the Happy Hooker to thread the messenger line, use the butterfly net to catch the ping pong ball, and use the claw to retrieve the hollow ball, deploy the PAS, manipulate the hot stab, and insert the gasket. In order to install the gasket, we will transform the happy Hooker into a standard hook that will hold the wellhead cover.

**V Future improvements.** Laser range finders would be cheap to make and easy to integrate, facilitating range finding. More degrees of freedom for the claw would make the ROV a more versatile underwater vehicle. A second camera on a strut above the ROV could give a third-person "eye in the sky" view, or possibly on the tether itself. More waterproofed and modified bilge pumps would allow us to switch out broken ones quickly and easily. Using transmission fluid in the bilge pumps themselves would decrease their chance of leaking, although they would become less efficient. A home-brew controller or receiver would add an extra electrical engineering challenge and the advantage of customizability. A waterproofed flashlight would add increased visibility. A pressure gauge in view of the camera would provide an indication of the ROV's depth.

**VI Challenges.** The first time we attached everything together at once, nothing worked. Suddenly, we realized that we had switched the power leads. We disconnected them as soon as possible, but knew that we might have damaged them already. When we reconnected the power correctly, some motors worked, but others were malfunctioning. After disconnecting different components one by one, we eventually narrowed down the source of the problem to the camera servo and some other problem with the vertical thrusters. After removing the camera servo and replacing it with a spare we happened to have, everything was fixed save the vertical thrusters, which still only spun one direction. On a hunch, we guessed that the vertical thrusters were trying to draw more power than their wires or their electronics could handle. We added a ten ohm resistor to the vertical thruster, but it quickly fried. We realized that it was only rated to one watt. When we tried an 11W, one ohm resistor, the problem went away only when two of the four vertical motors were attached. Finally, we attached two one ohm resistors in parallel, and to our great relief, everything worked. Later, we had more power issues and realized that our tether just did not have enough heavy gauge wire to handle all the current we were using.

After adding some 14 AWG speaker wire to the tether, the resistance became low enough to eliminate the voltage drop that caused our malfunctions.

**VII Troubleshooting techniques.** Solution techniques for various problems differed depending upon the specific problem. Generally, the problem was analyzed first. During the challenge described above, we determined what was happening first: the motors were on the fritz. Tests were carried out in order to determine the true cause of the malfunction. We removed individual components and tested them separately. We used a multimeter to try to find shorts and measure voltages and currents. All variables were investigated to ascertain whether or not a human error was the culprit. We tried to find broken wires or circuits that were touching each other within the electronics box. Once the problem was determined, it was discussed, and the best solution was executed. We originally decided to add resistors but found that solution was insufficient to fix the voltage drop problem. Instead, we increased the tether's current carrying capacity by adding two leads. Our solutions included replacing the malfunctioning part, working around the problem, or researching a possible fix. To find out how much more wiring we needed on the tether, we researched resistive loss. Online forums are a great resource for troubleshooting solutions. We found an article with a resistive loss equation and used it to calculate the amount of wiring we needed. The general troubleshooting steps explained here apply to almost all of the problems we had.

**VIII Lessons and new skills.** We learned much during the construction phase of the project from trial and error, and tips from mentors. Eben Franks, from Benthos Inc., let us test-drive his company's ROV, the Stingray. We observed how much tether we used while driving in a pool, how an ROV handles in water, and importantly, we learned of a device called a Happy Hooker. This tool was designed for threading moorings, the substance of our first mission. Threading a string through a loop generally takes a high degree of dexterity, but the simple yet ingenious device would allow us to easily thread the line and carry it back to the surface. We also discovered that the Happy Hooker would probably require more force than a tiny ROV—as compared to the Stingray, with half horsepower thrusters—could provide. With this in mind, we modified the Happy Hooker in order to reduce the amount of thrust our ROV would have to supply.

Four of our members competed in last year's competition, so the new members learned a lot of basic techniques and rules about building ROVs. Simple technical lessons were the most common. In the construction of the frame, we used aluminum airfoils attached to one another by aluminum solder. To prevent a buildup of aluminum oxide, we had to scrub the surface we wanted to solder. The oxidized form of the metal prevents bonding, so for maximum strength, we used a wire brush to scrape off any oxide that formed. For those of us who had never done soldering, we learned about heat conductivity and how to use a propane torch. Almost all of our frame soldering required the pieces to be set in a metal vice. The aluminum frame conducts heat readily; additionally, the vice we used could easily damage the frame if clamped too hard. We used two pieces of scrap flotation to act as padding and made sure to use vice-grip pliers as heat-sinks so that the flotation would not melt. The newer members of the team learned the most about electronics and wiring: how to test resistance, what resistance is, and many other aspects of powering and controlling the servos and motors.

This technical knowledge was all necessary, but it would all have been worthless without knowing how to interact with other team members: everything from productive brainstorming, building on another's idea, or gently explaining why an idea is not feasible or if there is a better alternative or method. The skills we developed here allowed us to function far more effectively and efficiently as a team. Most important of all was managing time. Theoretically, more hands would make a job faster, but in practice, we had trouble. We found that, without assigning specific tasks to smaller portions of the group, all of us would try to work on a single task at once. Because most ROV work is on a small part, only two or three people could actually have their hands on it at a given time; additional team members just stood around, accomplishing nothing and wasting time. To ameliorate the problem, we created a list of tasks or established them in discussion before starting work, then assigned tasks to subgroups. When we could, we tried to allow some crossover between groups so that each team member knew how and why the other group was doing its task or to give suggestions on how to improve the others' work. This allowed much greater productivity and construction rate than at previous meetings.

We had anticipated the cycle of problem and troubleshooting in construction practices, but not with time and manpower management. We attribute this difference to our eight-person group, as opposed to four last year. We hope that we can start a tradition at our school: a group of seniors will mentor a group of juniors each year. The skills we learned to use for the ROV can be applied to everyday situations, such as rewiring a broken lamp, replacing fuses, or using a variety of tools to build or solder an object. We know that our experience building the ROV will help us in the future.

**IX Reflections.**

*Evan (senior).* This year, I was able to further exercise my fundraising skills. I gained valuable experience working with and teaching inexperienced members of the team. I also gained more experience in problem solving techniques with larger groups, such as satisfying everyone's ideas while still getting things done. Over the course of the project our team worked more smoothly by delegating tasks to suit individual strengths. The main skill I learned was how to maximize the time we had each week to work on our ROV. It was important to keep the team working even if a particular tool or the ROV itself was unavailable. We were fairly efficient in managing our time and keeping busy.

*Reese (junior).* This ROV project has been one of the greatest commitments of time I have made to a project in my life. Having said that, I must also say that it has taught me more than any other project I have undertaken in my life. It has taught me: how to operate as part of a large team, how to pitch and fundraise for a project, various practical skills for working with metal, and how to visualize an idea, then design it, troubleshooting and adapting to any complications on the way. I have done engineering projects in the past, but for me this is the next step up. This project marks a transition from my simple projects of yesterday to the more complex projects that I hope to complete at college and beyond.

I have developed a strong feeling of trust among team members. Being on a large team and having everyone contribute to a single goal requires a great deal of organization and teamwork. It also means that many smaller jobs must be delegated to individual members or small groups; it is crucial that the team can count on those members to responsibly carry out their tasks. After working with this team for the last several months, I can confidently say that I would trust every member to be responsible and professional about completing any task put before them. I have gained a sense of true teamwork. Everyone pulls their weight and works hard for the team's benefit.

*Addison (junior).* The creation of an underwater robot has been an educational and informative experience. I have learned much of construction, practical applications of math and science, as well as simple tricks that would drastically improve my original methods of construction, such as using alcohol to clean a surface before applying an adhesive instead of just using a damp cloth.

Importantly, I developed a new concept of teamwork. Previously I had merely thought of a team as group of people working to achieve a common goal; a simple yet incomplete definition of the term. When we began to work on the ROV, it was immediately clear that each member had different strengths and skills. Some spearheaded the fundraising effort, contacting potential donors and arranging meetings. Some were excellent at the conceptual design of the machine, having a general idea of the shape and structure of the robot, and whether or not various options would be feasible. Others were able to bring these ideas to life in physical from, knowing how best to construct the designs presented to them. But it was not who had what skills, but how those individuals worked together to best put these skills to use.

*Sarah (junior).* Since this ROV competition is unlike anything I've ever participated in before, it helped me develop many new skills and interests. I've learned that some innovation can produce items equal to or even better than ready made items. We were able to use simple garden trowels to construct a claw that is unpurchaseable. Not only have I learned techniques for constructing the vehicle and design integration, but I have also come to realize the importance of teamwork and communication. This experience has been both challenging and rewarding and it has introduced me to the appeals of design and engineering.

*Chris (junior).* In the time we had, none of our eight team members could have produced alone what we have together. Doing something like building an ROV has always been something I wanted to do, but there was no way I could have built one by myself. I knew from the beginning how to do some of it, but teaming up with other similarly minded students has both enabled me to do things beyond my own capabilities, and encouraged me to learn more about the things other students do better than myself, such as complex electrical wiring. Being on this team has also opened my eyes to the various frustrations and difficulties that collaboration of thought and work brings. There were some key design elements, some decided upon before I arrived on the team, that I personally disagreed and will hopefully do differently when I compete in next year's competition, such as the use of rounded foil-shaped beams for the construction of the frame. The frame material is lightweight, strong, and hydrodynamic, but was difficult to work with and attach the components of the ROV. However, we were able to meet the challenges the foil-shaped beams presented and have maintained their benefits. I hope we can both mechanically do some things differently next year and perhaps think a little differently about the new and hopefully exiting ideas that turn up in next year's project. I am happy and proud to have been part of building this hopefully successful ROV, and I am also thankful for what I have learned by being a part of the human dynamics and mechanical evolution.

*Ben (senior).* Preparing for this year's competition has been far different from last year. Although we had to work out all the basics of construction, fundraising, etc. last year, we still had a lot to learn this year. Leading a team of eight, I realized just how much logistics a person has to manage in order to make sure work gets done effectively and efficiently. Also, in trying to start a tradition, we constantly had to keep in mind that our junior members knew little to nothing about how to go about building an ROV and would need to be taught. Finding a balance between simply telling them and making them find out on their own was essential. At the same time, though, we had to make them feel as though they were significantly contributing to the ROV even if some of the tasks they had to do were rather menial (i.e., producing three more motor shafts after we taught them to do the first).

Along the same lines, we had to find a balance between allowing juniors to take certain tasks, such as designing the manipulator, or using our senior experience from last year to influence our designs. We slowly learned that it was best to make teams with a mix of juniors and seniors. To my surprise, I found that to lead, you have to keep taps on what everyone's doing and encourage good communication. You not only have to actively seek people out to find out their progress, but also keep taps on them and make sure you understand what they're trying to do and why at every step of the process. Lastly, I learned that, although it would be best for people to volunteer for tasks when you send out an e-mail saying, “We have to do this, this, and this by the end of the week,” sometimes you have to say “You do this, you do this, and you do this,” because people will just assume someone else will do it.  Knowing your team members’ strengths and weaknesses can help make everyone enjoy the work they’re doing, but most of the time you have to guess.  The kind of leadership I had to develop for the ROV competition will serve me well in the future.

**X Acknowledgements.** The Falmouth ROV team would like to thank the numerous individuals and organizations that helped and supported us. Webb Research Corp. sponsored our project fiscally.  Deep Sea Systems International, Inc. and Wood Lumber Co. made generous donations of materials. In addition, Benthos allowed us to use its pool for testing the ROV once it was completed. Our science department liaison Peter Conzett allowed us to construct the ROV for our senior project, and Dr. Johnson helped the juniors to combine the competition with the format of a science fair project. Dr. Albert Bradley and Ben Allen of the Woods Hole Oceanographic Institution provided us with guidance in the planning of the ROV.  Mr. Schmitt allowed us to use his tools and showed us how to solder aluminum.

Note: The ROV was named after Russian physicist Zhores **Alferov** with altered spelling.

## APPENDIX

### Budget/expense sheet (summary)

*Detailed sheet follows*

**Expenses**

ROV

| | |
|---|---|
| Thrusters | $200 |
| Frame | $250 |
| Manipulator | $200 |
| Electronics | $200 |
| Total Expenses: | $850 |

**Resources**

Monetary

| | |
|---|---|
| The Hutker Family | $320 |
| Previous ROV funds | $105 |
| Webb Research Corp. | $150 |
| Deep Sea Systems | $500 |
| Onset Computer | $700 |
| Auctioned Demo | $650 |
| Total monetary resources: | $2425 |

Donated items

| | |
|---|---|
| Tether (SOSI) | $100 |
| Total donated items: | $100 |

Reused items

| | |
|---|---|
| Electronic speed controls | $300 |
| Airplane controller | $230 |
| 13" TV | $60 |
| PVC foam | $100 |
| Total reused items: | $690 |

*Note: these three items were donated in 2005 by Deep Sea Systems* (Airplane controller, 13" TV, PVC foam)

Balance for FY 2007: ........................ $1575

Extra funds will be used to reimburse travel expenses along with the regional (New England MTS) and international (MATE) travel stipends ($1000 each)

**Budget/expense sheet (detailed)**

| Date | Quantity | Item | per item | Cost | Vendor |
|---|---|---|---|---|---|
| 3/18/2007 | 2 | Cable Ties | 2.39 | 4.78 | Eastman’s Ace Hardware |
| 3/18/2007 | 1 | Blue Plasti Dip | 10.49 | 10.49 | Eastman’s Ace Hardware |
| 3/18/2007 | 1 | Butterfly Net | 7.99 | 7.99 | Eastman’s Ace Hardware |
| 12/30/2006 | 1 | Blue Plasti Dip | 10.49 | 10.49 | Eastman’s Ace Hardware |
| 12/30/2006 | 1 | Great Stuff Foam | 4.79 | 4.79 | Eastman’s Ace Hardware |
| 12/30/2006 | 8 | Fasteners | 0.36 | 2.88 | Eastman’s Ace Hardware |
| 12/30/2006 | 1 | Zinc Green Rod 3/16x36 stl | 2.99 | 2.99 | Eastman’s Ace Hardware |
| 12/30/2006 | 1 | Brass Round Tube 36x3/16 | 3.99 | 3.99 | Eastman’s Ace Hardware |
| 12/30/2006 | 1 | Brass Round Tube 36x5/32 | 3.79 | 3.79 | Eastman’s Ace Hardware |
| 12/18/2006 | 6 | Small Airfoil Spreader | 20.50 | 123.00 | Dwyer Aluminum Mast Co. Inc. |
| 1/10/2007 | 10 | 750 gph Bilge Pump | 17.99 | 179.90 | West Marine |
| 1/15/2007 | 2 | Electric Connectors | 2.23 | 4.46 | Wal-Mart |
| 1/16/2007 | 2 | Solderless connectors | 2.99 | 5.98 | AutoZone |
| 1/16/2007 | 1 | 2 Pole Flat | 2.99 | 2.99 | AutoZone |
| 1/21/2007 | 1 | 3 pack Mini Brush | 4.49 | 4.49 | Eastman’s Ace Hardware |
| 2/11/2007 | 1 | Block-Term 20 Amp 10 | 5.69 | 5.69 | Port Supply |
| 2/11/2007 | 1 | Block-Term 20 Amp 8 | 4.19 | 4.19 | Port Supply |
| 1/20/2007 | 2 | Hardware | 0.45 | 0.90 | Eastman’s Ace Hardware |
| 1/20/2007 | 2 | Hardware | 0.21 | 0.90 | Eastman’s Ace Hardware |
| 1/20/2007 | 4 | Hardware | 0.20 | 0.80 | Eastman’s Ace Hardware |
| 1/20/2007 | 1 | Narrow Hinge | 4.29 | 4.29 | Eastman’s Ace Hardware |
| 1/18/2007 | 2 | High Torque Sail Servo | 52.99 | 105.98 | Tower Hobbies |
| 1/18/2007 | 1 | High Torque Sail Servo | 54.99 | 54.99 | Tower Hobbies |
| 1/18/2007 | 1 | Promotional Discount | -25.00 | -25.00 | Tower Hobbies |
| 1/20/2007 | 1 | Clear Pelican Micro Case | 35.00 | 35.00 | Southwest Public Safety |
| 2/10/2007 | 2 | 12H Terminal ST | 3.80 | 7.60 | Johnson Electric Supply |
| 2/10/2007 | 1 | 3M 15oz Scotchkote | 21.68 | 21.68 | Johnson Electric Supply |
| 2/10/2007 | 1 | Block-Term 20 Amp 6 | 3.69 | 3.69 | Port Supply |
| 2/10/2007 | 1 | Block-Term 20 Amp 10 | 5.69 | 5.69 | Port Supply |
| 2/10/2007 | 1 | 5200 Polysr Caulk | 4.69 | 4.69 | Port Supply |
| 2/10/2007 | 1 | Block Term 20 Amp 10 | 5.69 | 5.69 | Port Supply |
| 1/11/2007 | 4 | Small Airfoil Spreader | 20.50 | 82.00 | Dwyer Aluminum Mast Co. Inc. |
| 2/10/2007 | 1 | Black Plasti Dip | 10.99 | 10.99 | Eastman’s Ace Hardware |
| 2/10/2007 | 10 | Fasteners | 0.19 | 1.90 | Eastman’s Ace Hardware |
| 2/20/2007 | 1 | Camera | 29.99 | 29.99 | Digital Peripheral Solution |
| 2/25/2007 | 1 | Butterfly Net | 10.99 | 10.99 | Eastman’s Ace Hardware |
| 3/1/2007 | 1 | Happy Hooker | 38.49 | 38.49 | West Marine |
| 4/1/2007 | 1 | Camera | 59.95 | 59.95 | Polaris USA |
| 4/4/2007 | 1 | 75’ 14 AWG speaker wire | 5.99 | 5.99 | Radio Shack |
| total | | | | 850.09 | |

Any items not listed were donated.

**Electrical Schematic**