gROVer built by NYC ROV

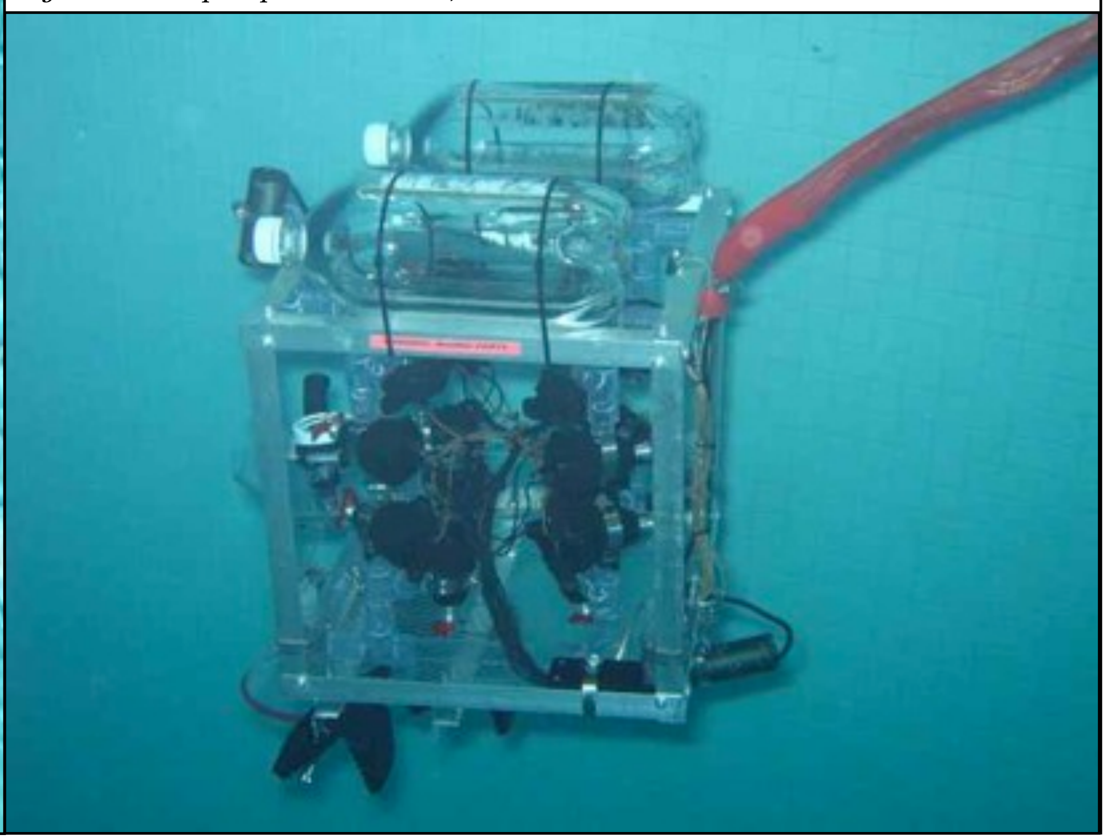
Technical Report 2008

NYC ROV team members, builders of gROVer, from left: Raph Hubbard, 17; Joshua Rosenthal, 16; Aviv Crowell Lang, 15; Spencer Yamada, 17; and Cole Houston, 17. Mentor (not pictured): Kimberly Schwab.

Abstract

gROVer was built by NYC ROV, a homeschooled ROV team from New York City competing for their second time in the MATE ROV competition. In the process of preparing for the competition, we researched a team that brought black smokers to the surface. We learned that, while our missions are very different, the challenges and obstacles we face are very similar. Based on what we learned last competition, we used a new approach towards designing the ROV. It emphasized the vehicle as a cohesive unit. The approach allowed us to use a more powerful thruster array, intuitive controls, and the power of the vehicle to operate the payload tools. We use an angled tube to scrape rock samples off the black smoker, rat traps to collect vent crabs, and an inverted funnel to guide the thermometer into the vent of the black smoker. We devoted more time to aesthetics this year, working to make our vehicle and printed documents both functional and beautiful. We also spent more time fundraising and, in order to raise money, taught an ROV class to children ages 11 to 13 with a kit we designed. These preparations gave us a chance to do better than last year. They have enriched our understanding of ROVs, and improved our teamwork, leadership, and planning. We are grateful for the opportunity to put our knowledge of ROVs to work in a fun and competitive way.

gROVer at a pool practice session,



Contents

Black Smokers

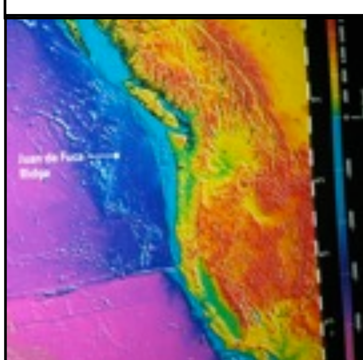
In 1998, a team of engineers, biologists, and oceanographers left Puget Sound and headed for the open sea. Their goal: To do what had never been done before and bring an entire black smoker to the surface. Ten years later, we built an ROV named gROVer. While our mission is very different from the expedition's, the challenges and obstacles we faced were remarkably similar, and were overcome by the same determination and zeal.

To research the Puget Sound expedition, we met with Dr. Ed Mathez, the chief curator of the Hall of Planet Earth at the American Museum of Natural History in New York City – the home of the recovered smokers. Dr. Mathez discussed at length the challenges and lessons learned from the recovery and study of these oceanographic treasures. This discussion impressed upon us how the competition's goals and strategies are very applicable to real world science.

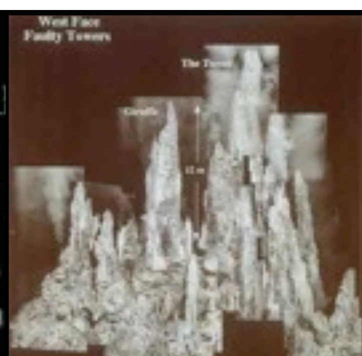
We needed the same determination to build gROVer that the expedition needed to recover the smokers. The sheer cost of mounting such a complex and risky mission only gave them one shot at their goal, and failure or success depended solely on preparation. To maximize their chances, the pilots and engineers practiced, and refined and planned every detail, for any mistake had far reaching consequences. Just like them, we made sure that we planned every detail of our strategy so we would not fail due to lack of preparation.

As with us, most of the expedition's effort was spent planning. A year before the actual smoker recovery, the expedition was well underway. The research ship Atlantis, with the ROV Jason on board, set out for the Juan de la Fuca ridge and its hydrothermal vents. Jason was sent down with cutting-edge technology to map the smokers in precise detail, cataloging their size, temperature, and location to within centimeters. The first phase took nearly three weeks at sea with around-the-clock monitoring to take full advantage of the video, still camera, and sonar equipment on Jason. Similarly, we built working models of the mission props in order to simulate the conditions at the actual competition.

The expedition took the compiled data home to plan in detail every movement of the recovery. A comprehensive strategy was developed and rehearsed extensively. Equipment and techniques were experimented with in order to ensure success. We used a similar methodology. Just like the expedition team, we faced uncertainties, despite the extensive practice and preparation in which we had both engaged. The expedition had very little information regarding the interior structure of the smokers. Crucial details like mass and stability were estimated, but the level of precision was nowhere near what was needed. Also, hydrothermal vents are very active and can change dramatically over short periods of time. The whole planning phase could be



Expedition location.



Black smoker planning data.

Dr. Mathez viewing gROVer.

Black smoker on display.

Black Smokers

wasted if the smokers changed shape or a seismic event toppled over all the vents. We also faced uncertainties. We did not know what the water flow from the smoker would be like or how the crabs would be arranged.

The plan devised to bring the smokers to the surface was simple. Using the collected data, several smokers were chosen with varying degrees of temperature, age, size, accessibility, and mass. The selected smokers were then lassoed using rows of steel cables attached to cylindrical cages which were dropped over the smokers. Then an industrial strength, diamond-edged chainsaw wielded by an ROV cut the bottom out from underneath the caged section, allowing for the smoker to be pulled to the surface.

Museum model of black smoker recovery expedition.

However, the plan had its snags. While cutting the first smoker, large cracks appeared, threatening to destabilize the structure and endangering the ROV. On all the smokers, cracks and fissures opened, revealing to the scientists just how fragile the structures are. One clever idea used to combat the problem was to use the natural cracks when cutting, or even forgo cutting completely to save time. Bad weather was also a wild card that slowed down the process considerably and made it impossible at times to deploy or recover equipment. We have planned ahead for unforeseeable problems like those faced by the expedition team by incorporating alternate crab grabbers and other backup systems into our design.

As soon as the smokers were safely secured, scientists began taking samples of the minerals and life within. The samples needed to be taken quickly to minimize contamination by the surface environment. The effect of seawater on the internal chemistry was also a mystery, but it turned out that the interior structure of the smoker effectively sealed out any water from seeping in during the mile and a half trip to the surface. This trait gave the researchers a chance to study the smokers in almost mint condition. All was due to planning and practice.

As we planned for the 2008 MATE competition, we incorporated the characteristics that allowed for the successful recovery of four black smokers into our strategy. We planned and practiced, and tested every system and tool extensively to try to eliminate equipment malfunctions. We also installed secondary systems to guard against unforeseeable problems. By following the example set by the expedition, we set a high standard for ourselves.

Black Smokers [Internet]. New York (NY): American Museum of Natural History; 1998. Available from: http://www.amnh.org/nationalcenter/expeditions/blacksmokers/black_smokers.html;

Lewis, Susan K. (Producer and director). Volcanoes of the Deep [Video]. Boston (MA): WGBH; 1999.

Mathez, E. [personal interview; unreferenced]. New York (NY) : American Museum of Natural History; April 1, 2008.

Into the Abyss [Internet]. Arlington (VA): Public Broadcasting Service; 1998. Available from: http://www.pbs.org/wgbh/nova/abyss;

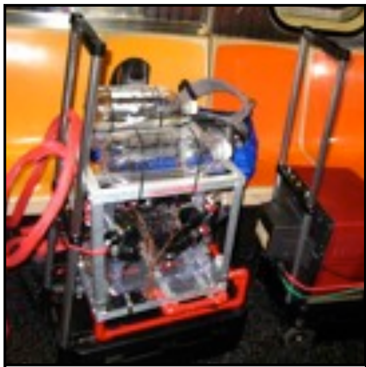
Design Rationale: *Introduction*

Our complete ROV system, packed up and ready for travel.

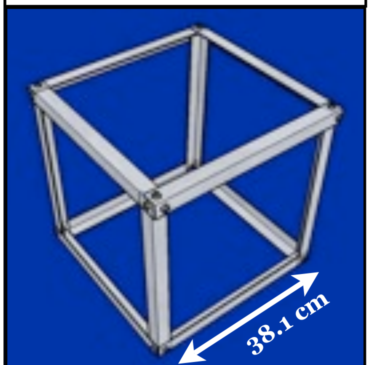
Our design rationale changed this year because we learned a great deal by participating in the 2007 MATE competition. Last year, we started by building a frame and then attached more and more things to it as we went along, in piecemeal fashion. Like last year, we needed to make our ROV system small and compact for travel by subway and taxi. Our overall goal was to build our vehicle as one integrated system, with greater mission speed, power, maneuverability, stability, and transportability than we had last year. In the process, we also wanted to devise a clean, elegant, and aesthetically beautiful design for our vehicle and our documents.

We designed the frame and the propulsion modules to integrate together. We wanted more power and control, so the propulsion modules have more thrusters than we used last year, arrayed in a pattern that enhances our maneuverability. We designed our payload tools to use the propulsion power of the vehicle to minimize power usage. We learned last year that having the payload tools stick out far from the front of the ROV decreased stability. To improve this, we designed the payload tools, sensors, flotation, and ballast to fit neatly in and on the frame, close to the center of the vehicle. Last year, our goal was simply to complete the missions. This year we designed our vehicle to complete the mission tasks as fast as possible. We designed our tether to be thinner and our control system to be compact and user friendly. Our system is designed to fit in or on the the four traveling cases generously donated by PorterCase.

Design Rationale:



gROVer on the subway.



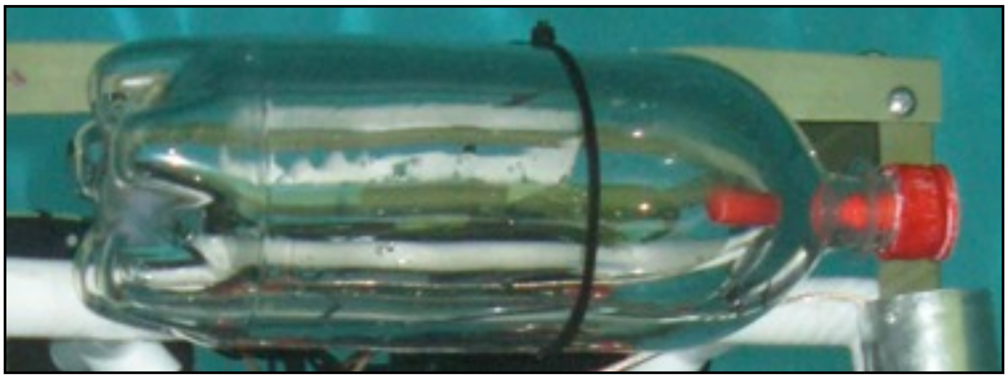
Exterior frame drawing.

Lead-shot in Nalgene bottle.

Fizz Keeper.

Frame:

Our frame consists of two sections: an outer skeleton of aluminum angle and an internal frame of PVC pipe. The outer frame serves as a unifying structure for the ROV, protecting the propulsion module in the water and in transit and providing a frame on which to mount gROVer's components. We chose aluminum angle for our outer frame because it is light and strong, and can easily support mounted items. The inner frame consists of two identical PVC propulsion modules. One is suspended from the top of the outer frame, while the other sits on the bottom. We chose to make them out of PVC pipe because we can position our thrusters at any angle with the use of elbows and tees. The cube shape of the outer frame provides maneuverablity and stability in the water and easy transportation on land.

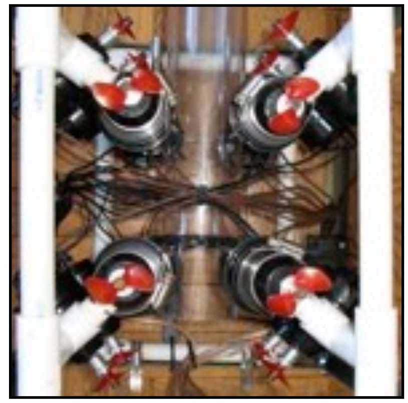


Two liter plastic soda bottle with Fizz Keeper mounted to top of frame.

Ballast:

Our ROV uses a fixed-buoyancy system. It has a pair of three-liter soda bottles sealed with Fizz Keepers for floatation. The Fizz Keepers are small pumps designed to screw onto the mouths of opened soda bottles and pressurize the air inside to maintain the soda's fizz. We use them to pressurize the air in our floats so that the bottles do not compress with increased water pressure. The floats are hose clamped to top of the outer frame and can be removed easily for transportation, reducing the height of the ROV by 10 cm. In addition, this flexible exterior mounting system allows us to easily change the size of the floats without modifying the frame. It also allows us to easily shift the location of the floats in relation to the payload tools and sensors mounted on the outer frame, helping us to achieve stability. Lead shot contained in small Nalgene bottles attached to the bottom inside corners of the frame serves as ballast. Using lead-shot ballast allows us to trim the ROV in very small increments.

Design Rationale: *Propulsion*



Propulsion modules mounted in frame.

Our propulsion system is the core of our vehicle. Last year, we built a frame and attached everything else to it. This year, we planned the ROV as a whole. Working from the inside out, we built the propulsion module as compactly as possible, which in turn let us keep the frame to its minimum size. Also, because our propellers are on the inside, not attached on the outside, they are safer and much better protected.

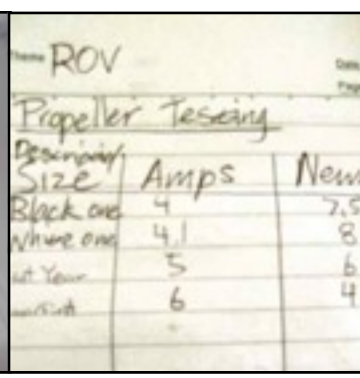
Our propulsion module consists of sixteen thrusters. Four point up, four down, four toward the back, and four toward the front. They are connected by PVC pipe. The arrangement gives us a full range of maneuverability One reason we decided on so many thrusters is that we needed our ROV to be powerful. This extra thrust enhances our mission performance by increasing speed and allowing us to effectively use the ROV's vehicle-powered payload tools. Though its sixteen smaller thrusters aren't as efficient as fewer larger ones, this is what our budget would allow. With this many thrusters, we encountered the challenge of staying within the 25-amp limit. We overcame it by not running any of them in reverse. Without the need to switch the direction of power flow (to run the thrusters in reverse), we can simply have one ground wire for the thrusters. Also, when a thruster is on in reverse, pushing water towards itself instead of away, it does not give much thrust. It does, however, draw its normal amount of amperage. Because we never run the thrusters in reverse they always provides the ROV with maximum propulsion.

Another feature of our propulsion module is its PVC joints. These allow the angle of our horizontal motion thrusters to be adjusted easily. If we point them straight forward and backward, we can increase our speed in those directions. As we turn them more toward the edges, our forward-backward speed decreases, but we are better able to go sideways and pivot. The adjustability of our propulsion module made testing for the optimum position much easier.

Our propeller attachment system is a great improvement over last year's as well. The attachment device is ready-made. It consists of three parts: a shaft collar, a propeller, and a screw. One end of the shaft collar fits over the shaft of the thruster. A screw is inserted through the center of the propeller and into the other end of the shaft collar. The system is quicker to assemble and stronger than last year's. Even this year's propellers are a great improvement, giving more power for less amperage.

Thruster attachment.

Propeller attachment.



Propeller testing data.

Building a propulsion module.

Design Rationale: *Payload Tools*

Prototype crab grabber.

Rock scraper.

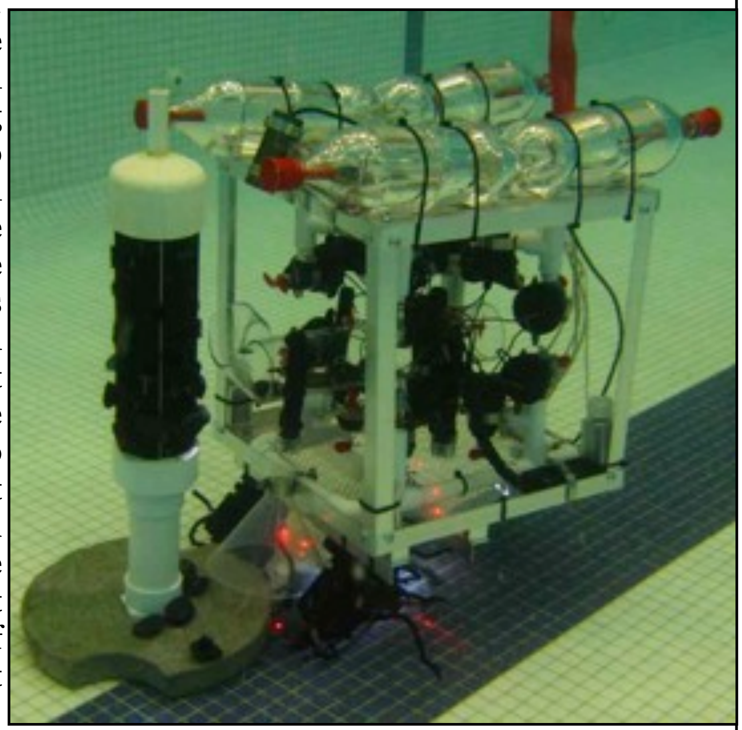
Inserting thermometer.

Rat trap crab grabber.

Our payload tools use the propulsion power of the ROV, instead of their own power, to accomplish the missions. All of our payload tools are mounted close to the body of the ROV, maximizing stability and minimizing the likelihood of entanglement.

To collect rock samples from the black smoker, we built a clear tube set at a 45-degree angle. When we push it against the black smoker and drive up, the rocks are scraped into the tube. The rocks then roll to the center of the vehicle, keeping the additional weight centered and maintaining stability.

We initially designed a "crab grabber," a clear plastic tube modified by cutting slits into it and attaching rubber wedges to the remaining "fingers". This tube fit over the crabs and functioned like a spring, opening to admit the crab when the ROV pushed down and gripping the crabs when the vertical pressure was released. This worked very well on land, but the ROV lacked the power needed to reliably operate it underwater. As an alternative, we mounted three rat traps on the bottom of the ROV. When a rat trap is pushed down on a crab, the spring is depressed and the crab is caught. We mounted them on one bar originally, but the vibration from one trap closing made all of the others follow suit. We solved this problem by mounting them on two bars. Changing the release springs also made it harder for the rat traps to close accidently.



gROVer approaching the black smoker to scrape off rocks.

To measure the temperature of the smoker, we inserted a temperature probe inside a funnel which guides the thermometer right into the hole. The funnel increases the target area from the 1.5-cm diameter of the smoker opening to the 15-cm diameter of the funnel's base, increasing the speed of the mission.

Design Rationale: *Sensors*

Camera attached to tilt mechanism.

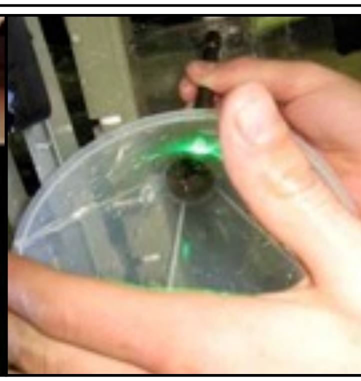
We incorporated five sensors into our ROV: two cameras with tilt mechanisms, a thermometer, a depth gauge, and a Doc Watson meter.

We designed our vehicle with two cameras with tilt mechanisms to speed the completion of the missions. Our cameras are high resolution color cameras from Lights Camera Action. We placed a 25-rpm gear motor inside an aluminum candle mold and sealed it with silicone, epoxy, and rubber, and epoxied an airplane prop adapter to the motor shaft. We then mounted an aluminum bar to the prop adapter and used hose clamps to attach a camera to the bar. These tilt mechanisms gave us a 160-degree field of view. Unfortunately, the inexpensive gear motors we used were prone to failure. We did not feel we could spend the money on more expensive, and, hopefully more reliable gear motors. Consequently, we made the difficult decision to abandon the camera tilts before the international because we did not want to risk failure during the competition.

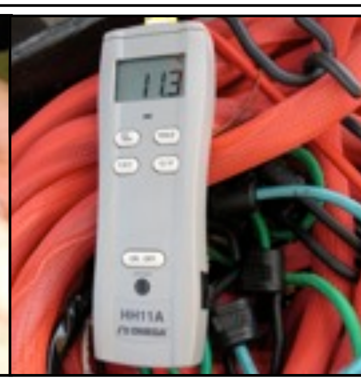
Our view is also enhanced by a quad splitter, allowing us to see multiple views at once. We experimented with a 3-D viewing system but determined that the poor image quality it produced eclipsed the enhanced depth perception, so we decided not to use it.

The thermometer probe is mounted inside a funnel to increase the target area, as described in the payload tools section. The depth gauge is a Suunto Gecko digital diving computer that is highly accurate. Our Doc Watson meter monitors DC amp hours, kilowatt hours, amps, watts, and volts, assisting us in troubleshooting.

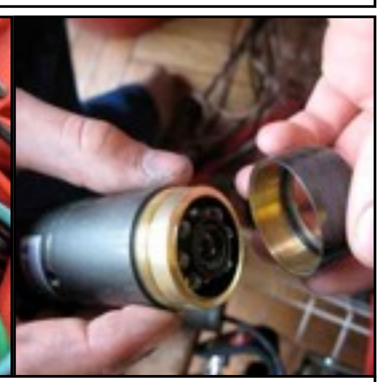
Prototype camera tilt.



Target light testing.

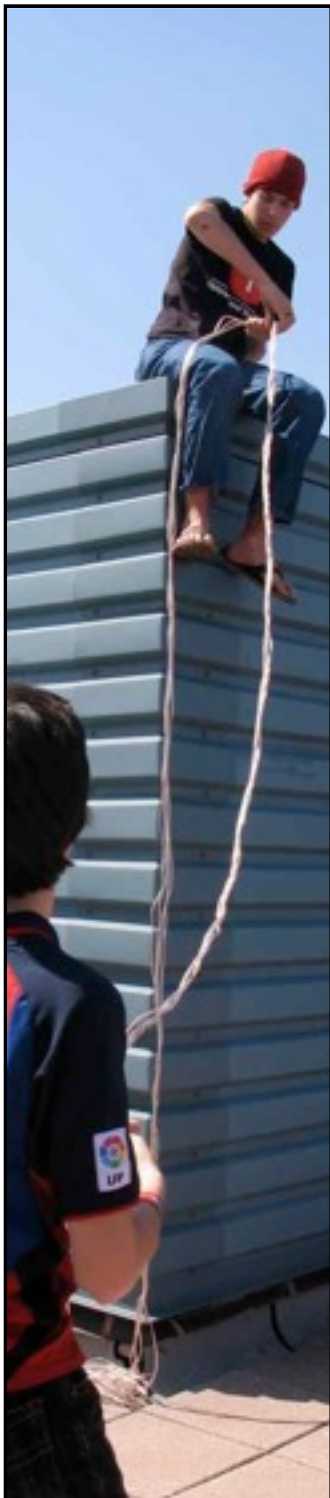


Thermometer display.



Replacing camera lens.

Design Rationale: *Control System*



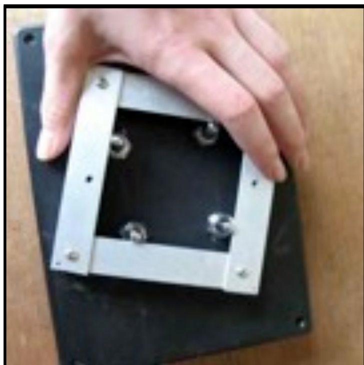
Spencer and Joshua untangling the tether wires on the roof of the building where we work.

When designing the control system, we decided that it had to be, first and foremost, simple enough to troubleshoot and repair at any time. In order to satisfy this requirement, we decided upon a manual control system. We avoided software because we had seen many teams that were debilitated due to a software bug that developed at the last minute. We did not want that to happen to us. We have found that a manual system is easy to troubleshoot and to repair at any time, even during a mission. A manual system also provides an intuitive user interface, which was the second requirement for our control system. The first design that met these two criteria was the Joy Square.

The Joy Square was an aluminum angle square set around an array of momentary DPDT center-off, normally-off switches that controlled the ROV's horizontal movement. These switches were angled in the same direction as their corresponding thrusters on the ROV. The pilot controlled the ROV by moving the Joy Square in the direction he wanted the ROV to go, thus tripping the switches and starting the thrusters. A separate switch was provided to control vertical movement of the ROV. The Joy Square allowed the pilot to control all the degrees of movement associated with the ROV easily and intuitively, but it had several problems. Due to the shape and size of the aluminum angle, it would often pop off the switches it was designed to control. The setup also required a minimum of 32 wires in the tether, which made it very large and unwieldy, impeding our movement and complicating transportation.

After discovering the problems with the Joy Square, we decided to investigate the use of joysticks, and found that they were easy to operate and user-friendly. We also realized that, due to our thruster arrangement, we did not have to run our thrusters in reverse. Therefore, we could connect all the thrusters on the ROV to the control box by a single ground wire. By doing so, we maximized our power supply and decreased our tether diameter, as only 7 wires ran down to the thrusters. We were pleased by this discovery and decided to incorporate it into our final control system. However, while the joysticks were very user-friendly, there were two problems with them. First, we did not have any documentation of the amperage rating for the joysticks. Since we were running a large amount of amperage through the snap action switches in the joysticks, we did not feel comfortable using them without knowing their specified load. The second problem was that it was hard to trim the ROV, especially when it was moving sideways. In light of these problems, we opted to use regular momentary DPDT center-off switches. They are safe, and using them makes it easy to trim the ROV. Surprisingly, they are more user-friendly than the joysticks because we can put them in a small project box that the pilot can hold in his hands, not unlike a video game controller. A switch controlling

Design Rationale: *Control System*



Prototype joy square.

Prototype joystick system.

The final control system.

Tether contents.

vertical movement is also mounted inside an individual project box. The entire control system is housed inside a PorterCase for travel.

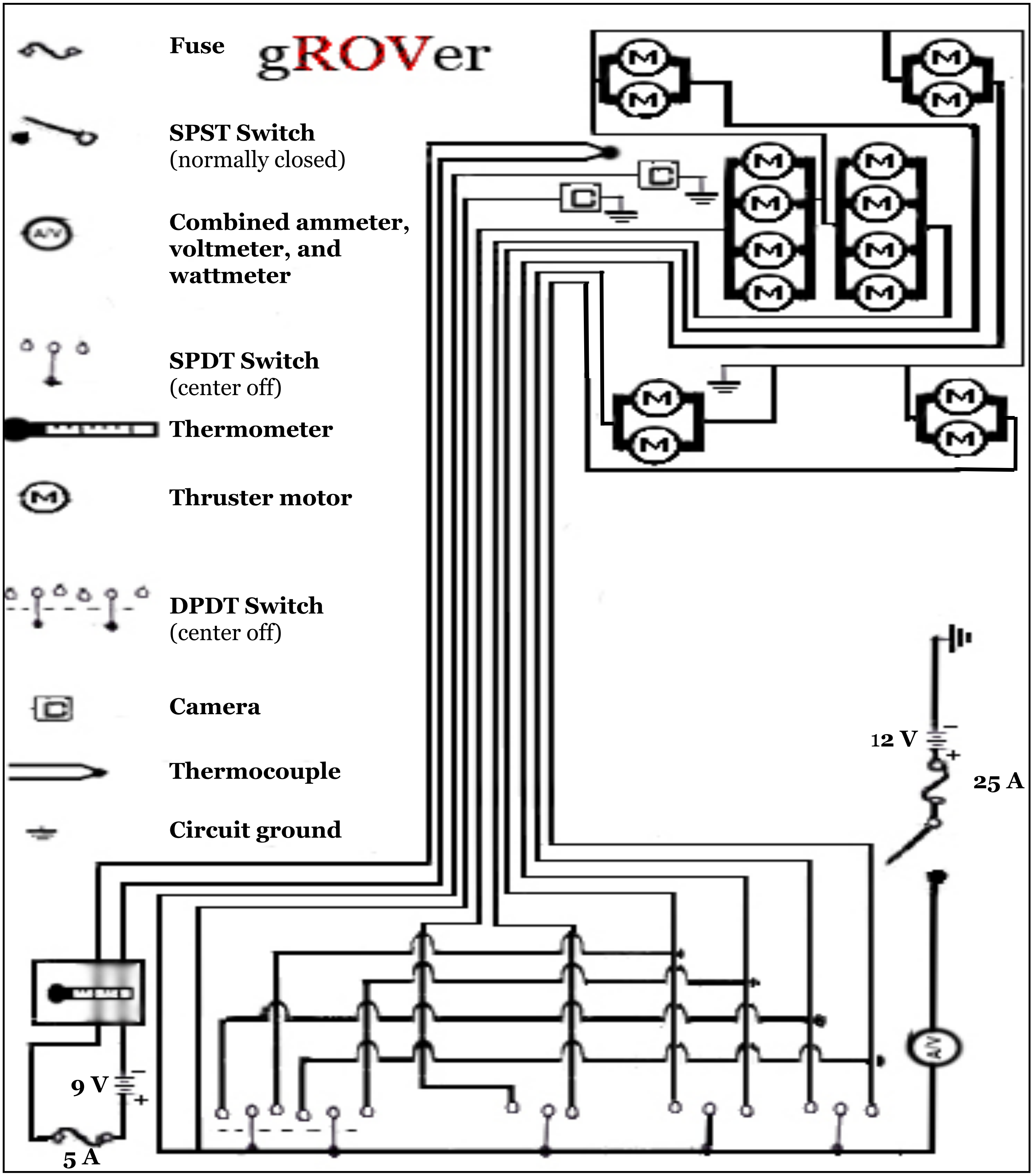
Our 30.5-meter tether is composed of 15 wires. One 12-gauge wire serves as a ground wire for all the thrusters. Two sets of 14-gauge speaker wire provide the power to the vertical thrusters, and four sets of 16-gauge speaker wires provide the power to the horizontal thrusters. Included in the tether are two cables that carry the power and video signal for the cameras and one thermocouple wire for the thermometer. We learned last year that a positively buoyant tether is very easy to control. This year, we decided again to make it positively buoyant, and have run 30.5-meters of 2-cm diameter caulk-backing foam down the tether. We also enclosed the tether in expandable sleeving. Expandable sleeving is a braided tube not unlike a giant Chinese finger trap. It has many advantages over slit loom, which we used last year. While slit loom allowed us to add wires to the tether if necessary, it also allowed wires to escape from the bundle. Expandable sleeving prevents wires from escaping, as it encloses the entire tether. Slit loom also had to be closed with cable ties, which made for a very messy tether. Expandable sleeving removes this problem since it is closed already. Finally, expandable sleeving has one major advantage over a simple tube. Due to the weave of the material from which it is made, the diameter increases when the sleeving is shortened and decreases when it is stretched. This allows for easy threading of the tether, and maintains the tether in a bundle when it is pulled, thus helping with strain relief. In order to further decrease strain on our tether, it is secured to the frame of the ROV with hose clamps.

Bundling the tether.

Also important to our control system are two safety features. The first is a 25-amp fuse that protects the entire circuit. The second is a kill switch. The kill switch is a SPST lit automotive switch. It can be opened at any moment to kill the ROV's power. Since it lights up when it is open and the ROV is attempting to draw power through the circuit, it also functions as a useful troubleshooting tool.

The next page contains our schematic diagram.

Schematic drawing



Challenges

NYC ROV riding the #1 train home after pool testing.

Many of the challenges that we faced while building gROVer arose because we are homeschooled students living in New York City. Because we are homeschooled, we do not have the access to many of the facilities and services that more formal schools enjoy, such as easy access to pools, shops, labs, school system funds, or teachers with relevant technical knowledge. Because we have no shop, we have to make do with a team member's apartment. It is small and cramped, and the family cats often get in the way of the work. One time they knocked over a motor we were waterproofing with epoxy, ruining a camera tilt mechanism. Our greatest ongoing challenge, however, is that here are no pools nearby, which means we have to travel anytime we want to test gROVer.

Travel to a pool by taxi is expensive: $40 round-trip to the closest pool we have access to. The time spent in travel can be longer than the time spent testing. We can wait over an hour, late at night, to get a cab at the pool we practice at in the South Bronx. One cabbie told us that we don't get picked up because the drivers think we are carrying a bomb. He confessed to driving around the block a few times before he felt we were sufficiently safe to pick up. Taking the subway is even more of a hassle, because we have to carry the ROV up and down many flights of stairs and cope with crowds and worried looks from passengers who are suspicious of our vehicle.

To cope with our travel challenges, the first donation we sought were PorterCases, compact travel cases that double as wheeled carts. We designed our system to fit in or on these cases so that we can easily wheel everything around the city, or, quickly fit it all in the trunk of a cab. This compact scheme prepared us well for travel to competitions, making shipping much easier.

One team member cannot move the system alone, so transportation became an opportunity for teamwork and fun. Whenever we travel, we first converge on our apartment workshop to gather what we need. We typically test on Friday or Saturday nights because these are slow times for the pools, the only times we can work. Our travel alone becomes a social affair. We enjoy conversations with the cabbies bold enough to pick us up and ask what we are up to. Subway riders noticed the rat traps on gROVer and wondered if we could catch rats underwater. Riding the train together provides many opportunities for socializing and playing around.

Facing our travel obstacles with functional design, team spirit and good humor transformed these challenges into an opportunity for creativity and fun.

Troubleshooting


Some of the tools, supplies, and replacement parts we carry with us.

We began the process of getting ready for this year's competition with greater knowledge and experience than last year. Therefore, we have caught some design flaws before they became problems; in essence, we have used last year's troubleshooting experience to minimize the need this year. Nonetheless, of course, difficulties did occur, and we dealt with them effectively.

Much of our trouble-shooting happened at pool testing sessions. Because we had limited pool access, we made sure we used these visits well. We always brought tools with us. Both our ballast system and payload tools have needed on-spot adjustment. We also systematically planned troubleshooting into our pool sessions. After testing recent changes to the ROV and practicing mission tasks, we always reviewed how things went. We then made a list of necessary improvements and tried to implement them by the next pool session. An example of this method can be seen in our rock scraper. During testing we found, primarily by underwater observation, that the front of the ROV would tilt too far down as the vehicle tried to collect a rock sample. We solved the problem in two steps. First, during the same pool session in which we experienced the problem, we shifted the floatation of the vehicle farther forward. This adjustment caused the front of the ROV to be slightly higher than its back, counteracting the tendency of the rock collection to tilt it downward. We determined that the next step of our troubleshooting would be to change the shape of the scraper's opening. Accordingly, we trimmed the mouth of the pipe so that it would better fit the side of the smoker. The new shape spread the resistance between smoker and scraper over the whole opening, allowing for a much smoother collection. By the next pool session, we could gather the rocks easily.

One invaluable troubleshooting technique we use is our "flight check list." We found this particularly useful at last year's competition. A few minutes before doing a mission, our stress levels tend to be higher, and ROV malfunctions harder to catch. Fortunately, our flight check list makes it easy to ensure that all aspects of the ROV are working properly and safely. And to make this system effective, we plan, like last year, to have a set of pool-side tools at the ready.

Our team's troubleshooting ability is one of our greatest strengths. When a problem occurs, we are prepared with our knowledge and tools to fix it. But we don't just wait until something breaks. We actively plan the evaluation of the vehicle's performance so that we can improve it. And when we get to the competition, we will use our flight check list to ensure a smooth mission performance.

Lessons Learned


A paper model funnel.


Marking prototype funnel.


Making funnel prototype.


Completed funnel prototype.

While building gROVer, we learned many things and improved in many ways. Two of the most important lessons we learned are how to work as a team and how to increase depth perception.

One of the experiences that developed our teamwork the most was the designing of the thermometer mount. One Monday, we gathered as a team to discuss how to insert the thermometer into the smoker vent. One team member thought that we might be able to use a giant ring that would fit around the outside of the smoker. After we discussed that idea, another team member proposed a new concept. He thought that we should use an inverted funnel in order to guide the thermometer into the vent, but the rest of the team did not understand how it would work and was slightly skeptical. After a bit of frustration, he decided to build a model. Right in the middle of building the model, a third team member saw the light and decided to help him out. They both worked on creating the same model, but due to some miscommunication and lack of tools, they started jumping up and down and jockeying for control of a saw. By the time the model had been built, the rest of the team had caught onto the idea, and helped to refine it.

From that experience, we learned how to build as a team. To an outside observer, it might seem that all that was really happening was a giant argument with a saw flying through the air. To us, it was a precious experience. We learned that the "argument" was a product not of angst and competition, but of people trying to understand each other and refine ideas. This experience yielded a much better design than any of us could have devised individually. More importantly, it gave us a greater respect for one another's opinions and improved our collaborative thinking.

We learned more technical, engineering-oriented lessons as well. Like last year, we experienced difficulty sensing depth perception underwater. We found that the part of the mission which requires the most depth perception is in taking the temperature of the black smoker fluid. Our inverted funnel helps, but we found that when we drove the ROV down, we often missed the smoker entirely. We discovered that positioning a laser above the clear funnel lets us see when the probe is directly over the vent. When the vertical pilot sees the red laser dot on the vent top, he drives the vehicle down, confident of thermometer insertion. We plan to use this strategy in the future to improve depth perception.

We value the lessons we learned this year. We greatly improved our collaborative thinking and discussion skills, and we have been able to use these abilities to learn a great deal on the technical side of our ROV project as well.

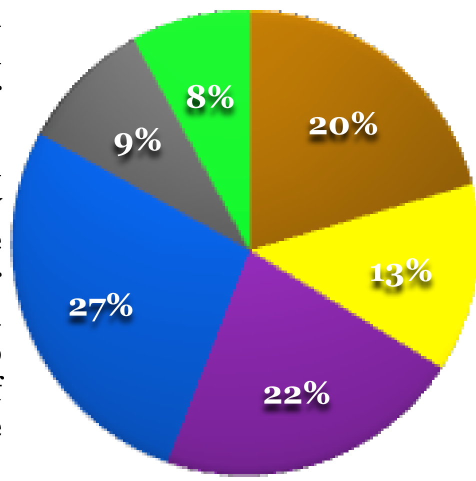
Financial Summary: *Vehicle value*

gROVer is of far greater financial value than the rookie vehicle we built last year ,costing $1,100, for less family cash outlay than last year. We achieved this by reusing parts from last year, getting more cash and material donations, and teaching an ROV building class to younger homeschoolers as a fundraiser.

We solicited cash contributions in a bimonthly newsletter we created to update interested people on our progress. Securing material contributions required us to speak to companies, asking if they would be willing to donate products.

Raph helping a student strip wires.

To teach the ROV class we first designed and built an ROV kit to serve as the basis of our curriculum. Then, we recruited six middle school aged homeschoolers eager to build their own ROVs. We taught the class and then held an ROV competition among the students. Teaching the class allowed us to raise funds, develop our teaching skills, field test our kit and build our support base.



- Class fees $900
- Cash contributions $588
- Family contributions $797
- Material donations 2008 $1,200
- Paid for in 2007 $390
- Material donations 2007 $350

Total value of vehicle		**$4,225**
FRAME		**$221**
Angle (m)	5.5	$35
Pipe (m)	2.5	$11
Tees	16	$87
Elbows	8	$39
Screws	30	$3
Nuts	30	$2
Washers	30	$2
Bar Stock (m)	0.3	$7
Hose Clamps	30	$28
PVC Cement (Bottles)	1	$7
BALLAST		**$51**
Soda bottles	2	
Fizz Keepers	2	$7
Lead shot (k)	227	$38
Nalgene bottles	4	$6
PROPULSION		**$527**
Thrusters	16	$423
Props	16	$18
Shaft attachers	16	$86
PAYLOAD TOOLS		**$59**
Clear tube (m)	0.6	$25
Rat traps	4	$23
After-market springs	4	$3
Funnel	1	$8
SENSORS		**2492**
Thermometer	1	$170
Cameras purchased 08	2	$390
Cameras purchased 07		$390
Camera donation 08		$350
Camera donation 07		$350
O ring		$3
Candle molds	2	$9
Epoxy (Bottles)	1	$8
Rubber (cm²)	40	$12
Prop adapters	2	$20
Aluminum bar stock (cm)	14	$5
Gear motors	2	$43
Silicone (Bottles)	1	$11
Lights	5	$114
Power meter	1	$67
Depth gauge	1	$300
Monitor		$250
CONTROL SYSTEM		**$500**
DPDT switches momentary	5	$83
DPDT switches standard	1	$18
SPST switches	1	$3
Project boxes	6	$36
Hookup wire (m)	6	$7
Solder (Rolls)	3	$13
Fuses	1	$6
Fuse holder	1	$7
Heat shrink tubing (Packs)	3	$15
Toilet bowl wax (Packs)	1	$12
Control system box		$300
TETHER	**(m)**	**$293**
Expandable sleeving	30.5	$117
12 gauge speaker wire	30.5	$38
14 gauge speaker wire	30.5	$23
16 gauge speaker wire	61	$31
18 gauge speaker wire	91.5	$38
Caulk-backing foam	30.5	$46
MISC. SUPPLIES		**$82**
Electrical tape (Rolls)	2	$8
Duct tape (Rolls)	1	$16
Cable ties (Packs)	5	$58

Financial summary: *Total project value*

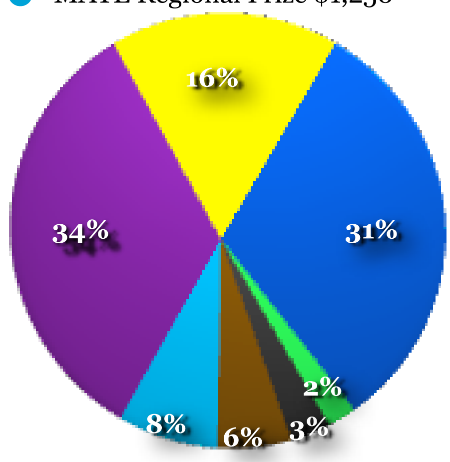
One of the first things we did when we started planning for the 2008 competition was to put together a preliminary budget. At last year's competition, we were told that our financial statement should reflect all of the team's expenses, including travel, food, lodging, research and development, etc. – not just the amount of money that was spent building the vehicle. Last year, we were surprised by expenses such as taxi fare and international shipping costs. We learned that we needed to design our vehicle so that it can ship more cheaply or travel on the plane with us. Taxi fare is a big budget item, but it is necessary because it is very difficult and time consuming to travel with our entire system on the train, unless several teammates travel together.

When we finished mapping out the anticipated total value of our project, if we were to compete at the internationals, we were stunned to discover a total of over $15,000. In order to keep our costs, noted as family contributions on the pie chart at right, as low as possible, we engaged in a lot of fundraising.

One vital item not yet included in our accounting is the value of pool time. We have not yet devised a fair, in-kind, rate for the value of testing time at the three different pools we use.

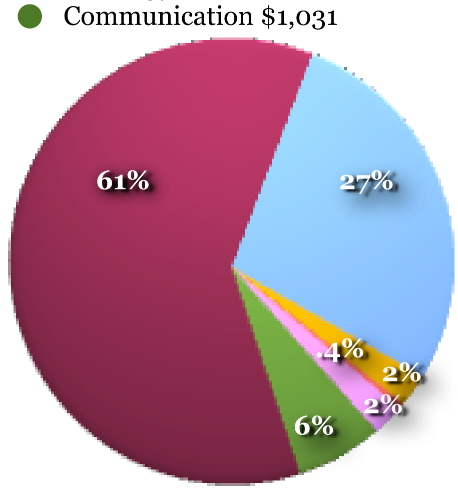
Total project income

- Family contributions $5,863
- Cash contributions $2,623
- Material donations 2008 $4,656
- Material donations 2007 $350
- Paid for in 2007 $490
- Class $900
- MATE Regional Prize $1,250



Total project value

- Travel $9,732
- Vehicle $4,388
- Spare parts $388
- Props $67
- R&D $376
- Communication $1,031



PROJECT VALUE **$16,132**

Vehicle value		$4,388
Non-vehicle value		**$11,744**
SPARE PARTS		**$388**
Thrusters	5	$131
Props	5	$7
Shaft attachers	5	$29
Rat traps	2	$14
Replacement lens	1	$39
Camera tilt	1	$34
DPDT switches	5	$79
DPDT switches	3	$48
SPST switches	3	$7
PROPS		**$67**
Concrete base		$20
PVC pipe		$17
Velcro		$30
R & D		**$526**
Prototype frame		$79
Prototype thermometer		$67
Prototype tether		$80
Project boxes		$30
Joy square		$50
Joy sticks		$20
Prototype crab grabber		$50
Prototype camera tilts		$150
COMMUNICATION		**$1,031**
Poster Printing		$800
Newsletter Software		$96
Shirts		$100
Web site expenses		$15
Business cards		$20
TRAVEL		**$9,732**
Travel cases	3	$960
Local travel		
Taxi fare (trips)	15	$600
Subway		$40
Regional travel		
Food		$150
Car rental		$153
Gas		$59
Lodgings		$400
Internationals		
Food (anticipated)		$300
Car rental (anticipated)		$650
Gas (anticipated)		$100
Lodgings		$1,820
Plane fare		$3,300
Vehicle shipping		$1,200

Reflections

Spencer Yamada

I have known all of my teammates from an early age, but this is the first time that I have been able to work with them in a team setting. I have gotten new insights into their psyches that I thought I knew so well, and learned lessons from them that I could not otherwise have learned. I started out thinking that I was the man who had the perfect answer for everything and for everyone, and I couldn't have missed the mark more. The challenges faced individually and as a team showed me my weaknesses and how to improve upon them. The engineering was and always is exhilarating. I love the feeling of building something from nothing, and now, with a team, the experience is even more rewarding.

Joshua Rosenthal

The best thing for me is that our vehicle is much better than the one we built last year. This is mainly because last year we were beginners. We also learned a great deal by participating in the MATE competition. We started from where we left off last year and the improved quality of our vehicle is a measure of all we have learned.

Raph Hubbard

Teaching an ROV class to younger students was great. It was a fundraiser, public-awareness tool, and experience-giver all in one. We based the class on building the kit we developed. In the course of creating a curriculum and planning the details of each class, we really learned a lot. In class, we got practice giving building instruction and engaging presentations on ROV-related topics. The end result was a community that was more aware of and exited about what we were doing and a more experienced team. It was a symbol of the growth of our team.

Aviv Crowell Lang

I have worked on and off with members of the team studying physics, carpentry, and electricity with them. I enjoyed designing the template for the technical report, and finding team colors and clothes for the competition. This is a great group of people, and I'm glad I could be part of the team.

Cole Houston

One of the things I learned the most from this year was asking for sponsorship. It was a difficult job to develop a strategy for contacting companies. First, I wrote to them, but after nobody responded, I started emailing companies. When some companies still weren't responding, I had to call them. I learned the value of persistence and clear communication. I developed my writing and phone skills, and I was able to get valuable work experience.

Future Improvements

Raph fielding questions at a homeschooler science fair.

We greatly enhanced our fundraising this year, but to achieve our future goal of making an even more professional vehicle, we need to improve our ability to raise funds. More funds would allow us to make a proportional control system and afford more expensive components, such as Seabotix thrusters. We have several possible ways to do this.

We designed an ROV kit last year and tested it during the course we taught. The course was highly successful, and we feel that we could market the kit. The Children's School of Science in Woods Hole, MA is already interested in using the kit for its upcoming ROV class. However, we would need to finalize comprehensive instructions and a teacher's manual. Marketing the kit and the course is an exciting possibility, but developing, in essence, a small business, takes a lot of time.

Another possibility arose through the community center where we do most of our pool testing. We are very grateful for their warm support and have helped them out when we can. Once, we did a presentation on the MATE Competition to their resident Explorer group. After seeing the competition that we organized for our class, the Director of the center became interested in hosting an ROV competition at which many New York City Parks Department pools would compete. In this scenario, we would teach staff from participating pools to build our kit so that they could teach participating students. We would also need to work in conjunction with the Parks Department to secure funding for our kits and time. Organizing an ROV competition would be exciting, a great accomplishment, and could help pay some of our bills, but it would take a lot of time.

A third fundraising possibility is to pursue financial grants from foundations and corporations. We have not attempted this yet, in part because we feel funders would be more willing to donate to schools than to homeschoolers. However, NYCHEA, our 501(C3) homeschooling umbrella group, is willing to serve as a fiscal conduit for funds we raise.

We are not yet sure which route we will take. Another option, of course, is to continue in our low budget ways. Next fall one of our members will go to college. Two others will be applying to colleges. We will not have much extra time, so we will need to choose well from among several possibilities.

Acknowledgements

We are excited to have made it this far in the 2008 MATE Competition. However, we are indebted to a multitude of supporters who buoyed us up along the way. We recognize and thank them here.

First, we thank MATE for hosting this wonderful competition at such an affordable price.

Next, we thank PorterCase, MyNewsletterBuilder, Lights Camera Action, Alsco Industrial, Moishe's Moving Systems, Euguene Lemay, Wyatt Houston, Myrtle Alexander, Malcolm Draper, John & Penny Duncklee, Jane Kulesza, and Joe & Leslie Burby, and the Windbiel and Gray families for sponsoring us by donating products and money.

We could not have made it this far without the support of two people who arranged time for pool practice: Domingo DeJesus, who made it possible for us to use the St. Mary's Recreation Center pool, and Erich Ely, who allowed us to use the pool in the Dodge Fitness Center at Columbia University. We also thank Joni Glazebrook, Jim Newman, & Deb Coulombe allowed us to store our tools and build our prototype ROV in their garages over the summer. Dick and Jane Tatlock hosted us during the regionals.

We thank the New York City Home Educator's Alliance for being our sponsor organization.

Special thanks goes to Professor David Vallancourt of Columbia University for giving us advice on our schematic diagram and inspiring us to use rat traps to catch the crabs.

Many thanks go to Dr. Ed Mathez from the American Museum of Natural History for meeting with us to discuss black smokers.

Finally, we would like to thank the families of the team members for their support through the long and challenging work of building an ROV.