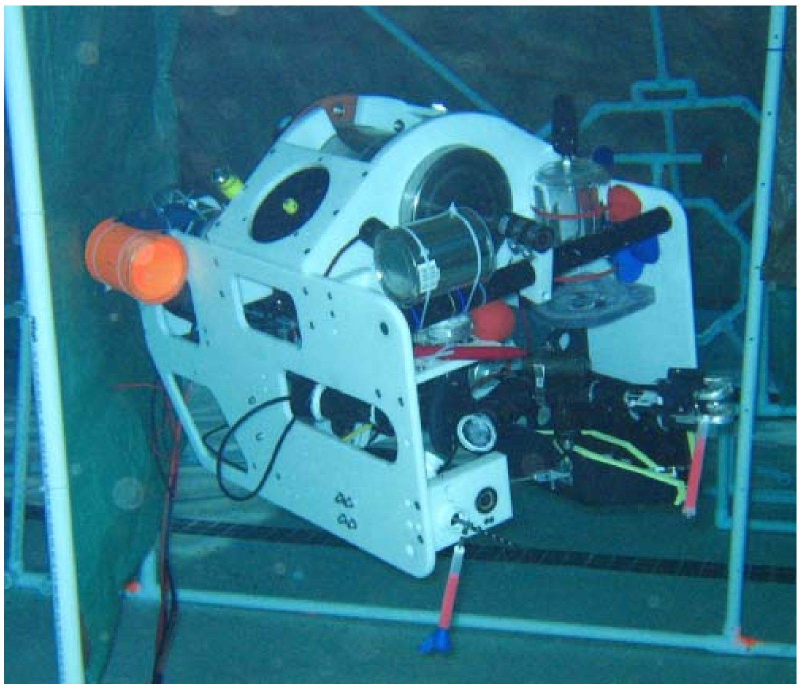
2008 MATE Technical Report

Site 3 Engineering

Jesuit High School Robotics

Carmichael, California



The *Bottom Line* ROV

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Abstract

The developmental process and design of the *Bottom Line*, a remotely-operated vehicle (ROV), by Jesuit High School Robotics, Carmichael, California, is detailed within this technical report. The *Bottom Line* was specifically designed to compete in the 2008 National Underwater Robotics Challenge (NURC) and the Marine Advanced Technology Education (MATE) competition.

As we face two missions with dynamic requirements, our team has constructed a technically advanced, robust ROV suited for the distinct challenges both competitions will present. The *Bottom Line* has design features including a structural frame of 9.53 mm thick high-density polyethylene (HDPE), four custom-built Jesuit J-1 thrusters, and an active ballast control. These thrusters, combined with active ballast control, allow for six degrees of directional freedom. Four high-resolution cameras with built-in infra-red illumination allow for operation during low-light conditions and a two-axis manipulator arm provides our ROV with increased versatility. This year's electronic control module is centered on the Parallax Inc. BS2e BASIC Stamp microcontroller, programmed in C# and PBASIC. All on-board systems on the *Bottom Line* are task-specific, designed and constructed to complete particular mission objectives. For example, sub-systems included on the ROV, a temperature probe, hydrophone and sample collector, serve to accomplish certain goals within the scope of the larger mission.

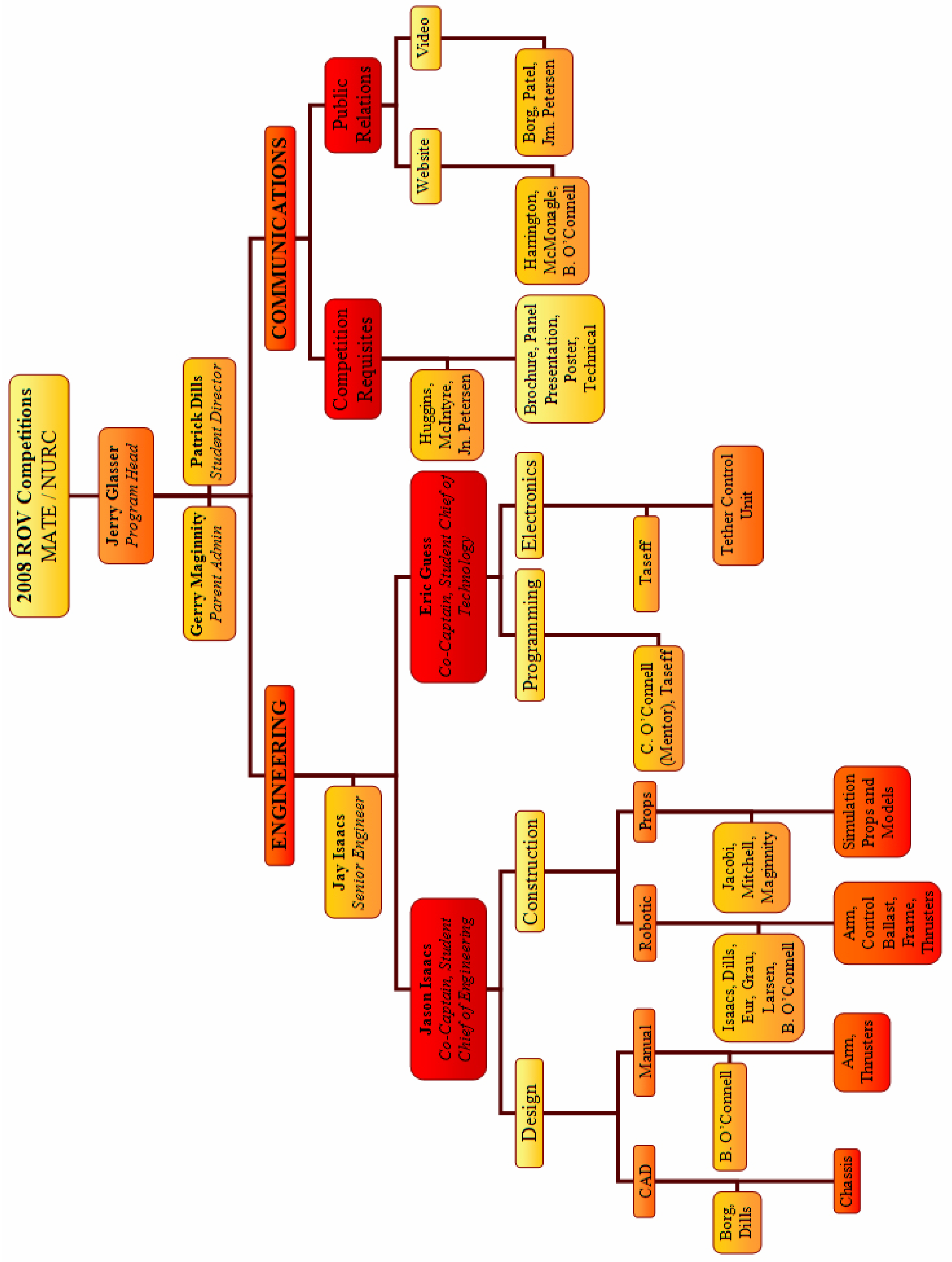
Compared to our entry for the 2007 MATE Competition – the *Thirteenth Hour* – we have made significant improvements in our electronics and mission capability, coupled with weight reducing. This high school team has worked diligently this year on two highly complex mission events.

The Team

This year's Jesuit High School Robotics team is comprised of 19 students from all grade levels (six seniors, three juniors, eight sophomores, two freshmen). *See Figure 1.* We organized our team into two general categories: engineering and communication. These two large categories were then split into smaller functional groups as follows: design, construction, programming, electronics, public relations and required communications projects (e.g. technical report, poster). Each group has both experienced and new team members, thereby allowing for training of inductees. Our dedicated senior members passed on their expansive knowledge of SolidWorks™, design, management, and machining – skills necessary for next year's success.

Scheduling and progress reporting proved to be a weekly challenge. Long-term project scheduling was managed via a Gantt chart. *See Appendix C.* Members posted conflicts beforehand and the team worked around these obstacles. Task lists were posted daily and critical design reviews performed to ensure no absence of resources.

Figure 1: Jesuit High School Team Hierarchy



Design Rationale

Jesuit Robotics is entering 2008's MATE competition with wisdom gained from two previous MATE ROV competitions. Constructing a highly stable and maneuverable ROV is an absolute necessity. We had three primary goals this year: decreasing our overall weight by at least 30 percent while maintaining an acceptable level of thrust, improving our programming and control using a Parallax Inc. electric system, and building a multi-axis arm with a minimum of four degrees of freedom.

Last year's MATE ROV weighed 503 N, with an average linear thrust of 63.0 N. This year's ROV is a trim 268 N and has an average linear thrust of 34.3 N. *See Table 1.* Designing an active ballast control system adds great capabilities to any work class ROV. Our ballast control system delivers 26.8 N of positive buoyancy to the ROV. By reducing our gross weight, adding ballast control, and using the custom J-1 thrusters, we have accomplished one of our primary goals for this year.

Table 1: Comparison of 2007, 2008 ROVs[I]

	Thirteenth Hour ROV, 2007	*Bottom Line* ROV, 2008
ROV Gross Weight	503 Newtons (N)	268 N
Thruster Model	(OTS) MotorGuide™ Thruster T34 Trolling Motor	(Custom) J-1 Thruster
Thruster Forward	96.0 N total	22.03 N each / 44.06 N total
Thruster Reverse	30.0 N total	12.3 N each / 24.6 N total
Average Linear Thrust	63.0 N	34.3 N
Max. Current Draw Thruster (Submerged)	7.00 Amperes (A)	4.50 A
Thrust to Weight Ratio	0.191	0. 164

*All weight was calculated when the item was dry. The 2008 ROV weight in water is -1.5 N of buoyancy.

In accordance with our other goals, the *Bottom Line* ROV's on-board electronics have been replaced this year. We have retired the FIRST (For Inspiration and Recognition of Science and Technology) controller for a Parallax Inc. microcontroller utilizing a Recommended Standard 232 (RS-232) data interface to a PC on the surface. By loading the ROV control software, any PC equipped with a pair of off-the-shelf joysticks instantly becomes a fully operational control platform. Lastly, the *Bottom Line* is equipped with a jointed arm providing two axes of movement. The primary goals for our ROV this year have been met in our design, construction, and operation of the robotic. A custom-built bucket excavator device (BED) has been added to the ROV, designed to excavate lava hold a maximum of three lava samples from the ocean floor. Active ballast control will then be used to compensate for added weight as samples are collected. When closed, the BED secures lava samples for the return to the surface.

[I] Testing and data recording supervised and taught and by *Jay Isaacs, Senior Engineer*

Primary ROV Components

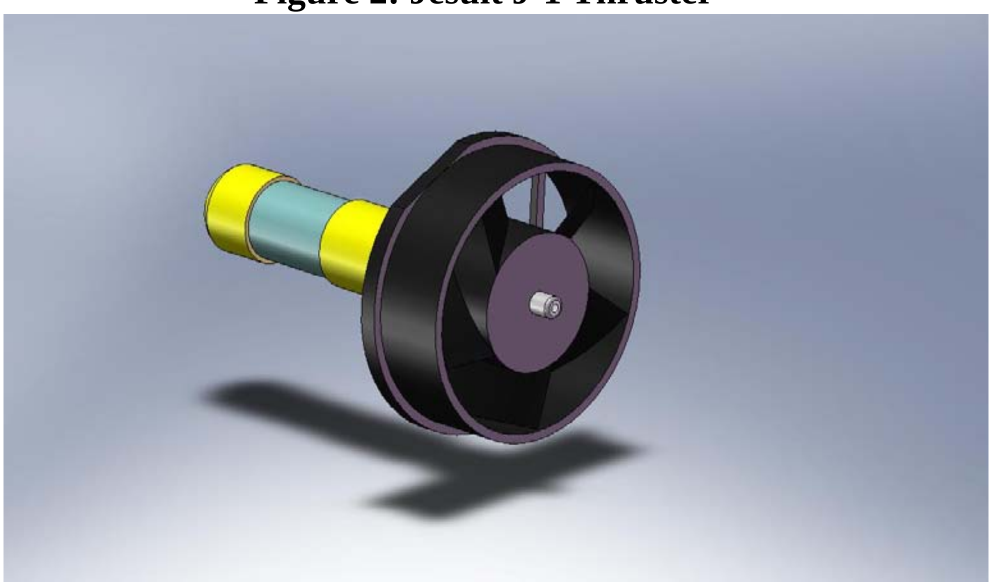
Thruster Development

Testing was performed on many of the modules prior to full assembly. We tested the J-1 thruster units for performance and reliability. *See Figure 2 for a CAD rendering.* Voltage and current were measured and a thrust profile developed in our laboratory test tank using LoggerPro software. *See Figures 3 and 4.* A timing strobe light was used to determine actual propeller revolutions per minute (RPM) once submerged in the tank. This testing caused us to replace our original gearbox motors with a lower RPM motor that had higher torque. The end result was a low loss of RPM and better current draw. As a result of testing, we determined that a 750 RPM motor at 1.2 A was reduced to 600 RPM when submerged (80% efficient), while a 950 RPM motor at 1.6 A had its speed reduced to 660 RPM when submerged (70% efficient).[II]

Extended testing of the J-1 thruster resulted in a critical design change. Thrusters were run for an extended period of time in our test tank to determine the reliability of the rotating shaft seals and assembly techniques. Digital force gauge and ammeters were critical in the development and troubleshooting of the J-1 thrusters. Once in the pool, we attached a digital force gauge to the ROV and performed a Bollard pull. *See references for more information on Bollard pull.*

Forward and reverse thrusts were measured with a digital force gauge and plotted using computer software. We were surprised by the magnitude of difference between the forward and reverse thrust, despite the non-symmetrical prop blades. Though the discrepancy was not visually outstanding, our performance testing proved otherwise.

Figure 2: Jesuit J-1 Thruster



[II] Supervised and taught by *Jay Isaacs, Senior Engineer*

Figure 3: J-1 Thruster Testing, Forward[III]

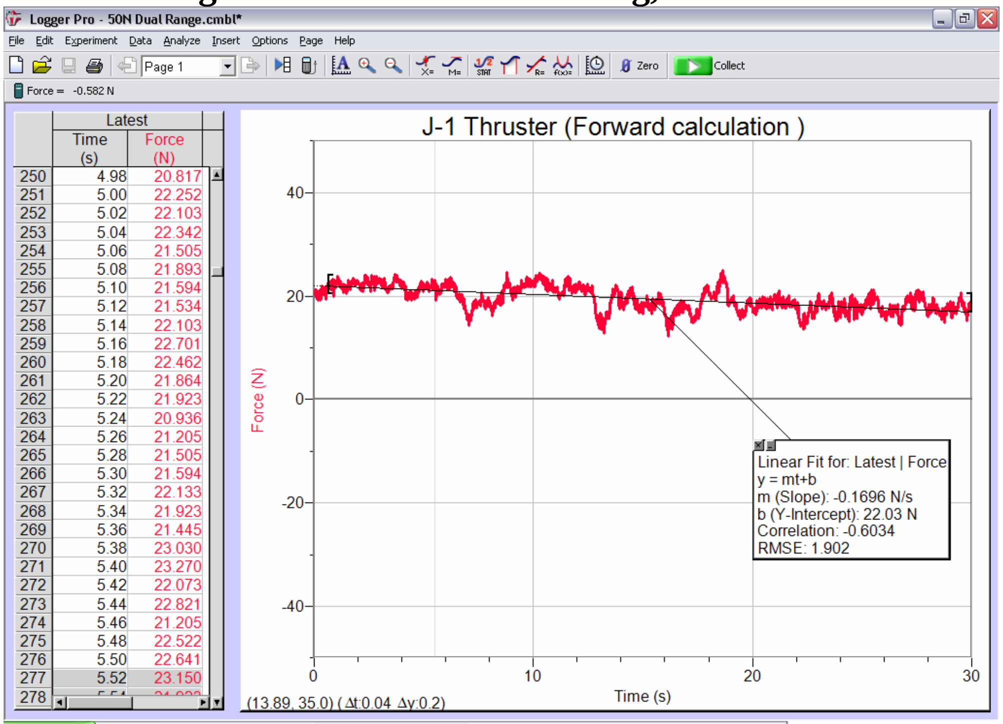
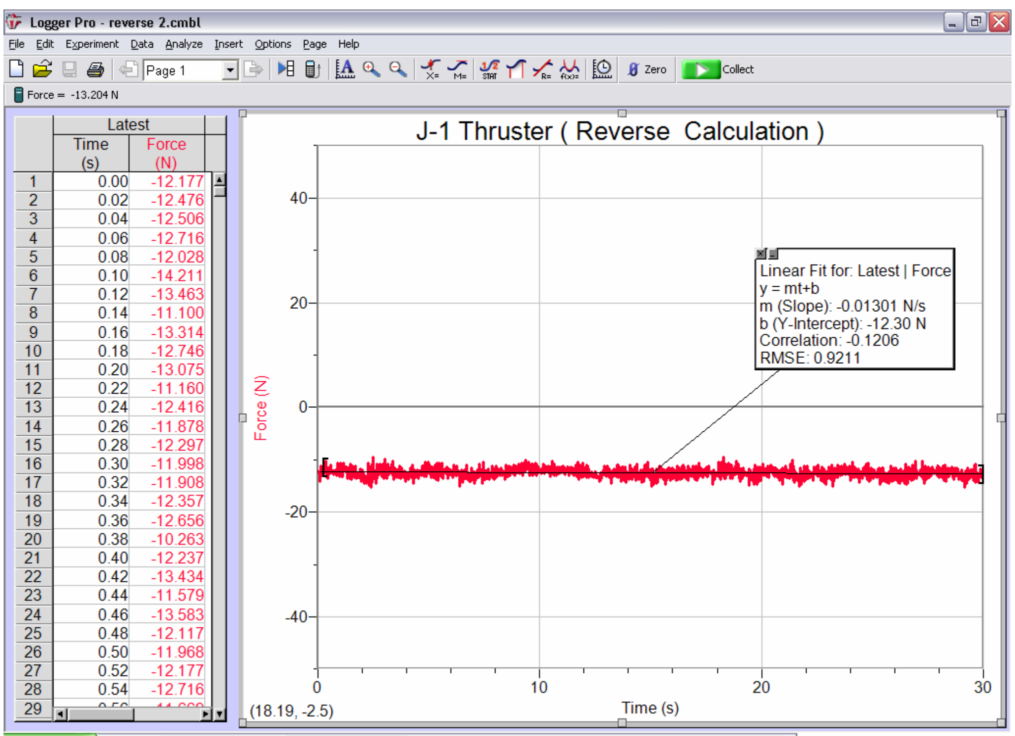


Figure 4: J J-1 Thruster Testing, Reverse[IV]

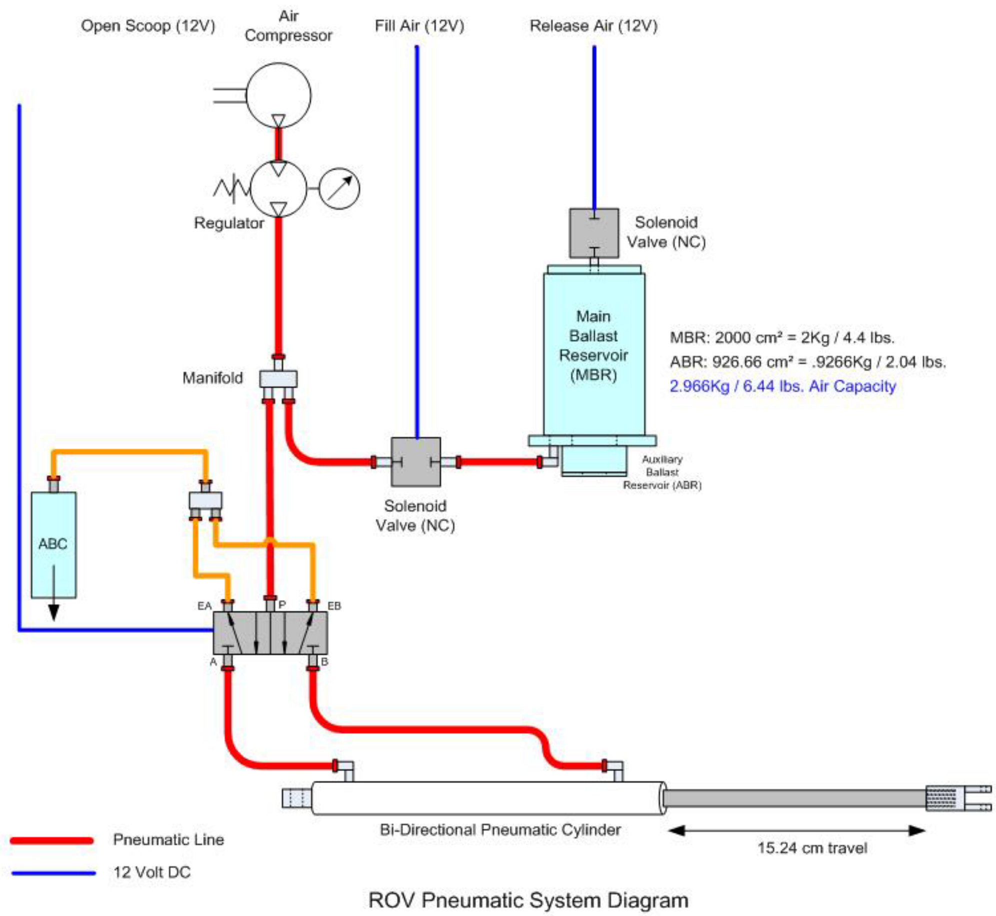


III Image provided by *Jay Isaacs, Senior Engineer*
IV Image provided by *Jay Isaacs, Senior Engineer*

Pneumatic Control System

One of the additions to the ROV this year is a dynamic buoyancy control system. Two single-action valves control air flow into and out of the ballast control vessel with a main capacity of 2000 cm^3 and an auxiliary capacity of an addition 900 cm^3. The pilot can visually monitor the ballast tank. The variable ballast system has a maximum positive buoyancy delta (Δ) of +26.8 N. The buoyancy container has been placed on the ROV to provide both buoyancy and stability. The pneumatic system also provides control for the sample collection device. A bi-direction pneumatic cylinder, attached to the claw, gives the device a fast-action open-and-closure to efficiently collect samples from the ocean floor. *See Figure 5.* The *Bottom Line* has a maximum *net* positive capability of 30N, allowing the ROV to surface rapidly with a significant load.

Figure 5: Pneumatic Control System Schematics[V]



[V] Image provided by *Jay Isaacs, Senior Engineer*

Tether Design

With the power cable being the largest component of the tether, we needed to identify a highly flexible and durable extension cord that would handle our power requirements. We selected a 30.5 m long, 14/3 gauge, 120 Volt, 15 A Husky Brand extension cord, rated at 1800 Watts. With our tether control unit designed to deliver 12 volts at 40 A, for a total of 480 Watts, we are well under the rated capacity of our power cable. Data communication is handled over a Category 5, four-pair data cable. *See Table 3.* Two pairs are reserved for RS-232 signaling with one pair handling National Television System Committee (NTSC) video signals. *See Figure 6.* Two data lines are reserved for future use. *See Appendix A for more information.*

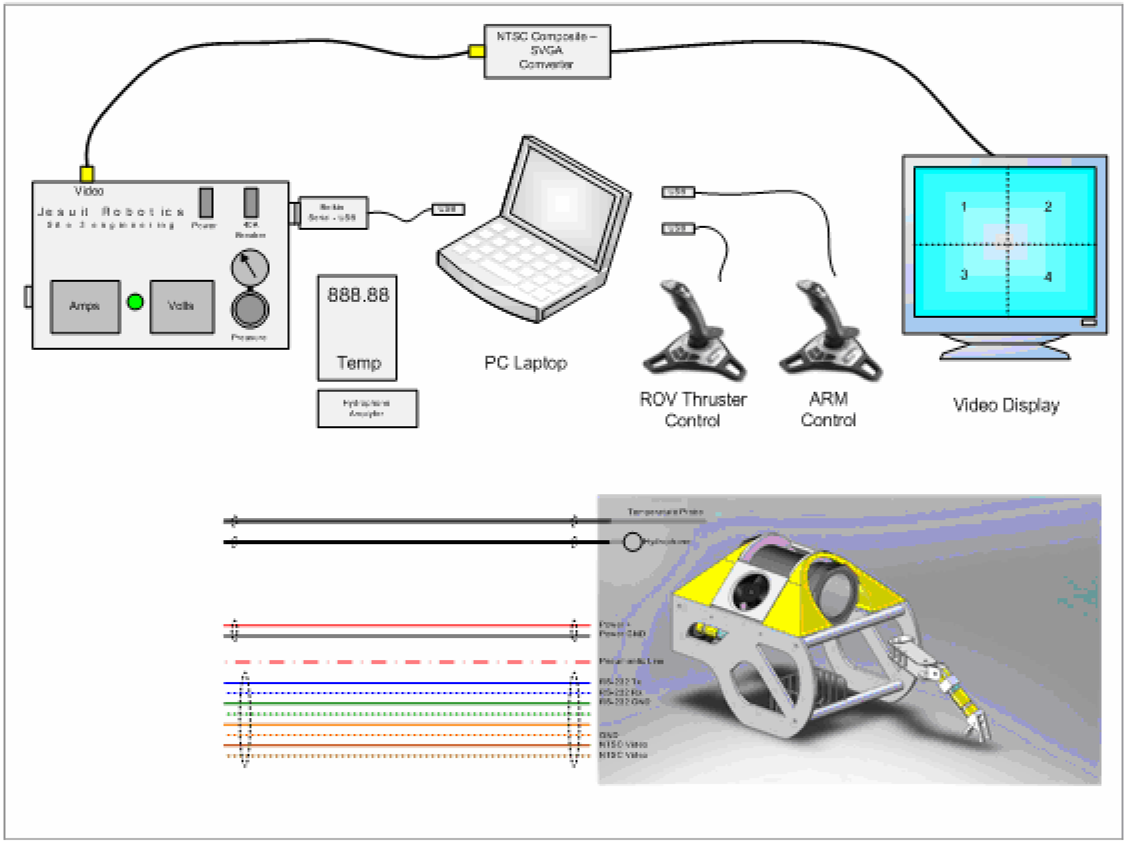
Table 3: RS-232 Signaling Table[VI]

1	RS-232 Tx (Input)	Blue/White
2	RS-232 Rx (Output)	White/Blue
3	RS-232 CTS (Clear To Send)	Green/White
4	RS-232 RTS (Request To Send)	White/Green
5	(Not Used)	Orange/White
6	Ground	White/Orange
7	NTSC Video	Brown/White
8	NTSC Video	White/Brown

Additionally, our tether has a low-density polyethylene (LDPE) pneumatic line rated at 830 kPa at 65 °C. Two additional telemetry components have been added, delivering temperature and acoustic information. A DolphinEAR™ hydrophone and Vernier Software and Technology (Vernier) temperature probe cable add little mass to the tether. Buoyancy comparators were added to achieve neutral buoyancy over the length of the tether.

[VI] Information provided by *Jay Isaacs, Senior Engineer*

Figure 6: Tether Control Unit[VII]



Electronics Control Module

This year we parted from using the FIRST Robotics controller and set out to design a controller module around the Parallax Inc. BASIC Stamp 2e. The BASIC Stamp 2e module has 16 dedicated input/output (I/O) lines with 45 BASIC programming commands. All development this year was done with the STAMP Windows editor running on a PC. All sixteen of the BASIC Stamp 2e I/O interfaces are used for controlling our ROV. RS-232 data communications are transmitted over pins 0 and 1. By not using the built-in serial ports, we have serial communications and can use the built-in ports solely for debugging.

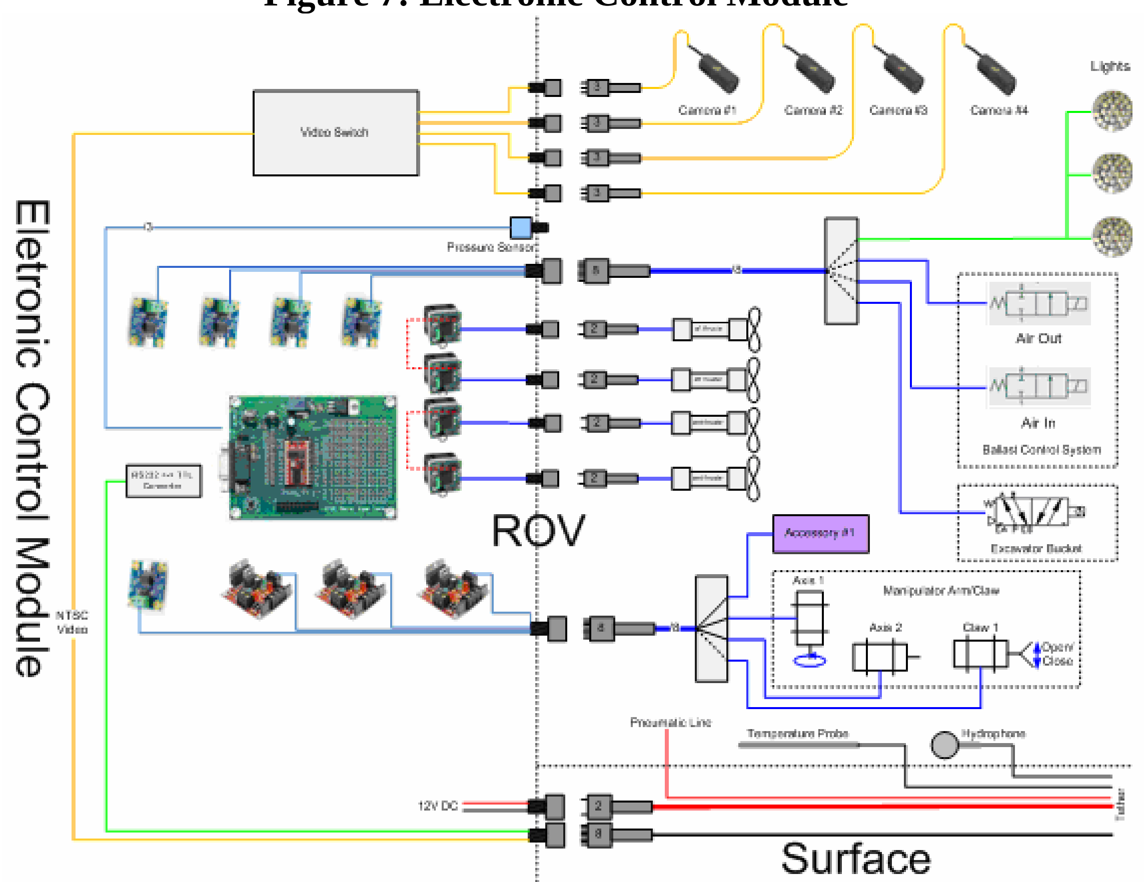
The HB-25 Motor controllers from Parallax Inc. are specifically designed to work with microcontrollers. Each controller only requires one data line to send speed control information. Additionally, two motor controls can be daisy-chained to use a single control line. The HB-25 can handle 25 A of continuous current, making it ideal for thruster control. For motors that need bi-directional control, but much less current, we selected the L289 Motor driver from Solarbotics Ltd. This small package contains a dual H-Bridge, capable of a sustained 2.5 A on each channel, and has been designed to interface directly to a microcontroller.

[VII] Image provided by *Jay Isaacs, Senior Engineer*

A pressure sensor has been integrated into our ROV this year to deliver telemetry data on depth. By attaching the pressure sensor to an analog/digital converter, we are able to translate pressure information into depth. Adding the pressure transducer to our ROV project and interfacing it with the BASIC Stamp microcontroller gave us the opportunity to work with bi-directional data on a serial communication line. We wanted to gain experience in both control and telemetry. Currently, this system is still in the testing phase. This device only requires on and off switching and is attached to solid state relays (SSRs) from Phidget Engineering. Phidget SSRs can switch up to 2.5 A and were selected specifically for their capability to directly interface with a microcontroller. We have used every I/O pin the BASIC Stamp microcontroller has to offer. In order to achieve more telemetry data, which is one of our goals next year, we will either add a second BASIC Stamp microcontroller or a more advanced chip from Parallax Inc.

See Figure 7 for Electronic Control Module. See Appendix B for technical details.

Figure 7: Electronic Control Module[VIII]



VIII Image provided by *Jay Isaacs, Senior Engineer*

Telemetry Devices

The *Bottom Line* ROV has been equipped with a number of telemetry devices to return valuable information to operators on the surface.

Temperature Probe

A rugged, submersible stainless steel temperature probe will accurately measure temperatures from -40 to 135 °C with a resolution of ±0.2 °C at 100 °C from Vernier Software and Technology. The temperature probe uses a 20 kΩ negative temperature coefficient (NTC) thermisistor. The thermostat is a variable resistor whose resistance decreases nonlinearly with increasing temperature. The Vernier LabPro™ interface converts this resistance to °C.

Hydrophone

The ROV is equipped with a DolphinEAR™ hydrophone system. The hydrophone system has two basic parts: the hydrophone and an amplifier. The hydrophone is a specialized pressure transducer which is highly sensitive to underwater sound vibrations. The amplifier increases the weak sound signals so that they can be heard using a set of earphones or delivered to a PC to spectrum analysis. The DolphinEAR™ is calibrated to frequency within the audible range of the human ear. The hydrophone range is sufficient to pick up vocalization of dolphins or whales which generally occur in a range of 300 to 8000 Hz. T*his sensor was utilized in the NURC Challenge and was not removed.*

Mission Strategy

We have engineered our ROV to efficiently perform all required tasks in accordance to our analysis of the mission objectives. Our three specific tasks this year include freeing the ocean bottom seismometer (OBS), collecting three lava samples in the form of 0.91 kg (2 lbs) dive weights, and measuring the temperature of hydrothermal vent fluid. We are not required to complete these tasks in any specific order; therefore, we determined the best course of action, as follows: measure temperature, free OBS, and then retrieve the three lava samples. This order takes advantage of our specific ROV features. *See Figure 8 for a CAD render of ROV and subsystems.* Taking the temperature and freeing the OBS are best performed while our ROV is unburdened and has maximum maneuverability. Once these two tasks are completed, lava samples will be in the clear and easily retrieved by the ROV excavator device. Active ballast control will allow our ROV to compensate for the added weight of the lava samples and easily return to the surface for sample retrieval.

Task #1: *Measure Temperature of Hydrothermal Vent*

We are using a stainless steel temperature sensor – provided to us by Vernier – attached to the frame directly below the arm with a range of -40 °C to 150 °C to gauge the temperature of the of hydrothermal vent fluid.

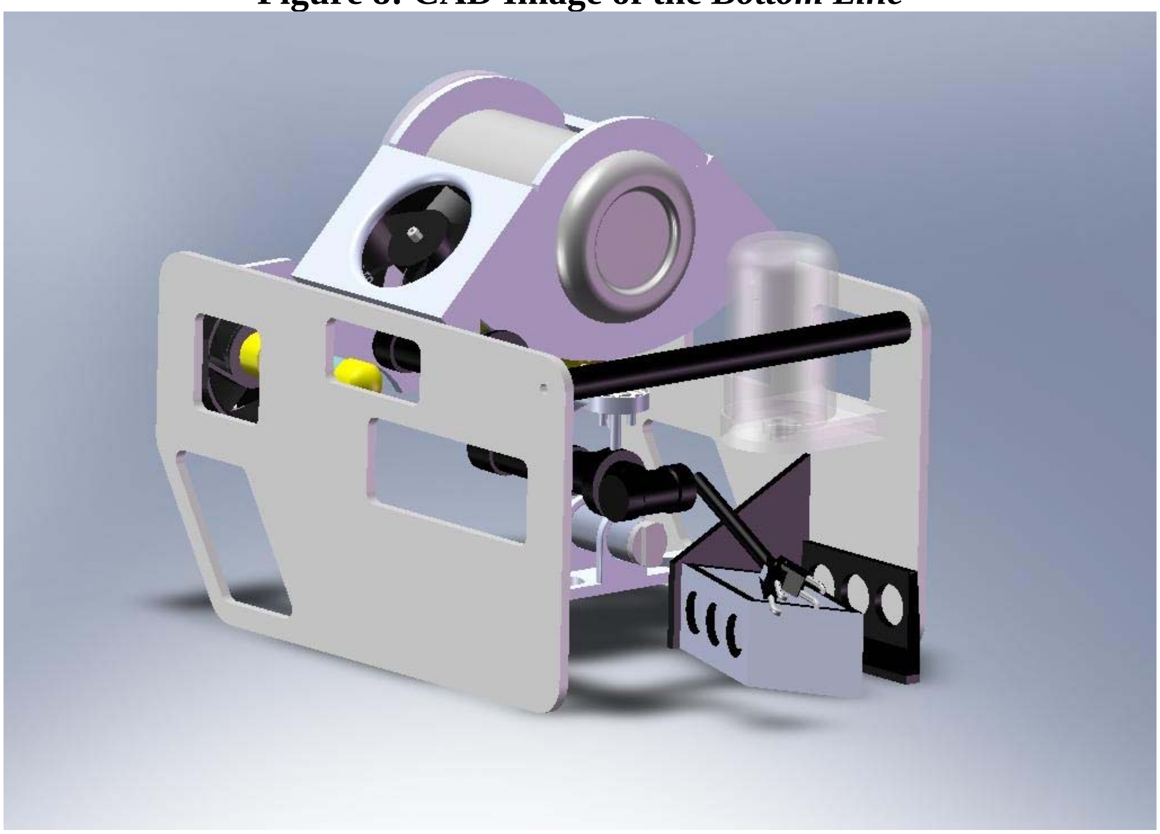
Task #2: *Free Ocean Bottom Seismometer*

The ROV is equipped with a front OBS lifting hook. A combination of our vertical thrusters, active ballast control and lifting look will be used to free the OBS from all lava obstructions. Our strategy is to get the hook on one of the far sides of the OBS so that when vertical thrust is applied, the OBS will have one side lifted from the pool floor, causing the lava samples to slide and fall from the OBS and come to rest on the pool bottom. If necessary, the variable ballast can provide increased vertical movement; additionally, our BED has a specially-designed front end to grab part of the OBS if the claws are unable to operate.

Task #3: *Retrieve Three Lava Rock Samples and Return to Surface*

Finally, we will collect the three lava samples simulated by 0.91 kg dive weights; the BED was designed and created for this task. A large, pneumatic bucket claw that presses up against the floor of the pool and scoops up the samples, the BED is designed to slide all of the samples to one side when collected so that when reopened, no collected samples are lost. Once all the samples have been captured, we will activate the ballast control which will compensate for the additional weight of the samples. A clear top on the BED, with small holes to allow for water flow, keeps all of the samples contained within while surfacing.

Figure 8: CAD Image of the *Bottom Line*



Troubleshooting

This year we took the idea of "taking things back to the drawing board" literally. Using a 3D CAD program in our design phase allowed us to adjust our frame geometry and design easily. We were able to test our ROV with any new revisions in SolidWorks™ in order to minimize the amount of construction changes necessary.

When all else fails, we analyze the ROV system by system, using a meticulous screening process that pinpoints our problem. Each member of the Jesuit Robotics team contributes a unique skill and is an expert in an individual field. When faced with a problem these individuals can disassemble the ROV and analyze their specific systems. Once the problem is found the group turns its attention towards solving that problem and getting the ROV back in the water. This process allows us to make the most of our limited pool schedule.

Major problems arose at the beginning of our design phase. To resolve these issues we used cardboard aided design to try different configurations. Using this alternative to software projections, these models allowed us to experiment with different centers of gravity and various motor mountings. Once these design changes were established, we used SolidWorks™ for basic testing.

Failure Analysis

(When a good motor goes bad…)

Our first major engineering trial came when two of our custom built motors developed leaks. *See Figure 9.* The clarity of the water and the housings which we use hid the water from our view. Anticipating failure for both motors, we decided we had nothing to lose by powering them up. To our amazement, both motors ran for over 30 minutes in our test tank. We disassembled the motors in an effort to determine where the leak could have developed. After dissecting the motor housing and performing additional testing in the test tank, we discovered where the leak originated. Part of our design was to make the rotating shaft seal and nozzle housing removable in order to make maintenance easier. We concluded that the rotational torque from the propeller caused the housing to unscrew from the main housing, allowing substantial leakage. To solve our problem, we have since sealed the gap between the main motor housing and the seal housing with a band of electrical tape.

Figure 9: Corroded Motor

Lessons Learned/Skills Gained

Our goals for the 2008 MATE ROV competition were weight minimization and task-specific system design and construction. Through SolidWorks™ prototyping and computer modeling, we were able to begin construction with a set plan. This preliminary process minimized our time spent in the construction phase and helped maximize our testing period. Thrusters provide ample thrust and give the ROV great mobility. An air container at the center of our ROV provides buoyancy control. In general, our design gives us a stable and maneuverable ROV.

This year we effectively used different design and prototyping methods. Our production began as all others do – a sketch on a white board. We then used SolidWorks™ to transfer this design into a fully manipulative and editable 3D image. Having this visual aid allowed us to rotate our rough design on a computer and make changes accordingly. From there we progressed to cardboard prototyping. This phase of our development gave us a more complete spatial arrangement with which we could reposition thrusters, experiment with camera angles, and calculate buoyancy compensation.

The use of prototyping and 3D CAD software allowed us to minimize our design changes to the final system. Not only did these precautionary measures save time, but they also prevented unnecessary material expenditures.

Safety

We implemented safety procedures throughout each phase of development.[IX]

General Shop Safety

- Safety Goggles and Ear Protection
- Scuba experience to acclimate with underwater environs
- Adult supervision at all times
- Weekly meetings included safety discussions
- Proper lab clothing and footwear required
- Fire extinguisher, complete first aid kit, and defibrillator in laboratory
- Proper ventilation when working with potentially hazardous materials

ROV Safety Procedures and Implements

- Cowlings on all thrusters
- Stainless steel, pressure-tested vessel for control modules
- Water-proof SubConn connectors for all interfaces
- All wiring soldered, epoxyed, and double-wrapped
- Strain-relief coil on tether
- 40 A master circuit breakers with "kill switch"
- High-accuracy power management
- Emergency ballast blow in case of total system failure

We are proud of our current safety record, as we have had no incidents or accidents over the duration of the 2007-08 robotics season.

Future Improvements

We have five suggested areas for future improvements:

1.) Convert ROV data control protocol from RS-232 to RS-422. The RS-232 specification sets a technical limit on the distance of the cable between two end point devices. Additionally, there can only be one receiver. By converting over to RS-422, the maximum cable distance is increased to 4000 feet and up to 10 receiving devices can be utilized. *See Table 4.* Having multiple receiving devices would increase the amount of telemetry or microcontroller we could communicate with.

[IX] Guidelines established by *Jerry Glasser, Program Head*

Table 4: RS-232 vs. RS-422[X]

SPECIFICATIONS	RS232	RS422
Mode of Operation	SINGLE-ENDED	SINGLE-ENDED
Total Number of Drivers and Receivers on One Line	1 DRIVER 1 RECVR	1 DRIVER 10 RECVR
Maximum Cable Length	50 FT.	4000 FT.
Maximum Data Rate	20kb/s	100kb/s
Maximum Driver Output Voltage	+/-25V	+/-6V
Receiver Input Sensitivity	+/-3V	+/-200mV

2.) Control circuitry can be added to the quad camera control module (QCCM). The QCCM is used to multiplex four NTSC camera signals into a single NTSC video signal. As a result, only one NTSC video cable needs to be on the ROV tether. At the pilot end, the multiplex video signal is split into four frames on a single screen. The QCCM has the capability of switching between camera signals and single or multiple camera views.

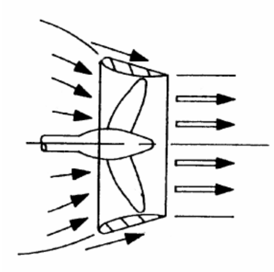
3.) Additional microcontrollers for telemetry data. In adding additional microcontrollers, we can separate the telemetry and control functions of the *Bottom Line*. There are a number of microcontroller modules that can be added to the ROV to provide valuable telemetry data.

- 3-Axis Accelerometer
- Internal Temperature and Humidity Sensor
- GPS Position Module

4.) Pan-Tilt-Zoom Camera (PTZ) system. The addition of a PTZ camera system would allow for the inspection and investigation of areas without requiring the ROV to change position. In areas where maneuverability may be limited, PTZ could compensate.

5.) Design and build more efficient Kort nozzles to increase efficiency of thrusters. Kort nozzles or ducted propellers can be significantly more efficient than un-ducted propellers at low speeds, producing greater thrust in a smaller package. *See Figure 10.* For the Bollard pull, it may produce as much as 50% greater thrust per unit power than a propeller without a duct.

Figure 10: Kort Nozzle[XI]



[X] Information provided by *Jay Isaacs, Senior Engineer*
[XI] Image is public domain and taken from *commons.wikimedia.org*

Mid-Oceanic Ridge

A hydrocarbon[XII] is an organic compound consisting entirely of hydrogen and carbon, as the name suggests. These molecules are one of the earth's most important energy sources, and are crucial for cellular life. Hydrocarbons are considered to be the "building blocks" of life, and are believed to play a critical role in the early stages of evolution. Scientist Giora Proskurowski (*Figure 11*[XIII]) described the generation of hydrocarbons as "very first step; otherwise Earth would have remained lifeless." Some scientists suggest that essential "building blocks" originated from space, or from within the processes that occur within our own earth.

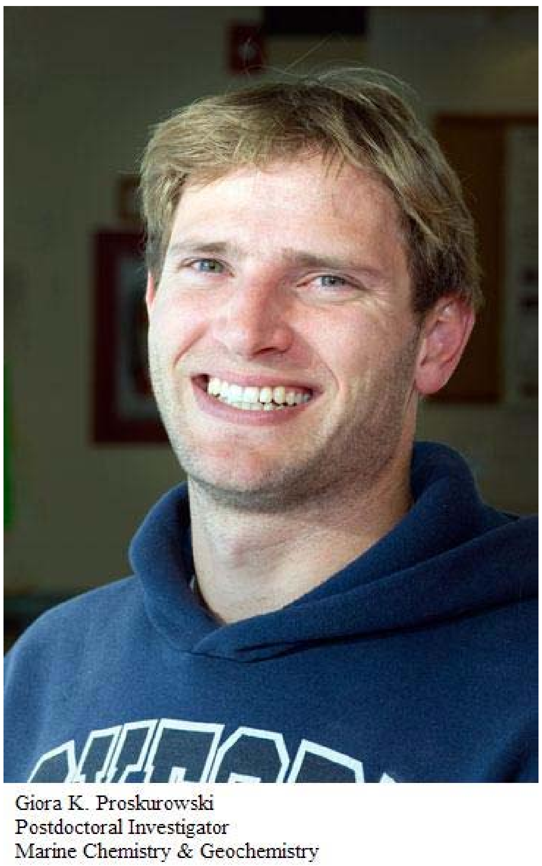


Figure 11: Giora Proskurowski

Figure 12: Mid-Atlantic Lost City Ridge

[XII] *Wikipedia Commons* (http://en.wikipedia.org/wiki/Hydrocarbon)
[XIII] *Woods Hole Oceanographic Institute* (http://www.whoi.edu/cms/images/mediarelations/giora_en_61508_61530.jpg)

At the Lost City hydrothermal vent field in the Atlantic Ocean (*Figure 12*[XIV]), hydrocarbons have been found to be consistently generated through interactions between rocks and saltwater beneath the vent field. The discovery of the generation of these hydrocarbons makes locations similar to the Lost City strong contenders for the location of where life originated. Further research has removed the possibility of the abundance of hydrocarbons found in the Lost City being created by the surrounding biosphere. Proskurowski describes the discovery of the generation of hydrocarbons from a non-biological source as “evidence in our quest to understand the origin of life on this planet and other solar bodies."

The hydrothermal vents found within the Lost City differ from black-smoker vents that were discovered several years ago. The structures formed in the black-smoker vents consist of mixes of sulfite materials, whereas the vents found in the Lost City are almost entirely pure carbonate. The research team used the remotely operated vehicles named Hercules and Argus to undergo their exploration of the Lost City. The water released from the vents of the Lost City is far cooler in temperature than those of black-smokers. This is due to the fact that water from black-smokers is heated by magma, whereas the water in the Lost City is heated by the chemical reactions that occur between the salt water and the mantle rock. These chemical reactions result in the production of ten to one hundred times more hydrogen and hydrocarbons than black-smoker vents. Although more vent fiends like the Lost City have not been discovered yet, Kelley believes that more fields exist, and were far more abundant in oceans of the early earth.

Reflections on the Experience

By Patrick Dills, Student Director

I have grown so much over the last four years. I joined Jesuit Robotics as an inexperienced freshman – without any idea of what I wanted to do – and lacking in practical knowledge of underwater robotics. As I continued to participate through all four years of my high school experience, I learned how to work in a team atmosphere and pass on what I had learned to younger students. My experiences in Jesuit Robotics have given me these all of things.

One of the greatest things the MATE Program has given me is practical experience in construction and machining. I feel this has been an incredibly valuable experience that has put me far ahead of the curve and prepared me very well for the next step of my journey to become a mechanical engineer. Also my experience with the CAD/CAM software, SolidWorks™, was an important skill to develop, as I have seen the program being used by students during all of my college tours.

[XIV] *Woods Hole Oceanographic Institute* (http://www.whoi.edu/cms/images/mediarelations/lostcitry_nr_n3_61533.jpg)

Every year, through hard work and copious amounts of time commitment, I have improved, and along with me Jesuit Robotics. During my first two years, I was exclusively a construction and design specialist. Then during my junior year, I went back to being a novice when I took up the responsibilities of a CAD specialist. Every year I strived to learn something new.

This struggle has benefited me in the long run. It has taught me the creative skills necessary to take an original idea and a valuable tool in the working world. MATE allowed me to network with the working world through my team's attendance at the Underwater Intervention convention in New Orleans, where I got to see that our ROV was similar in many respects to professional ROVs.

I don't regret any of my time spent working in the Jesuit High School Physics lab, and I feel that my time competing in MATE has thoroughly prepared me for my next step in college.

Budget

We budgeted for 2500 USD to construct the *Bottom Line* ROV. A detailed list of expenses is available in *Appendix D*. The total cost of materials was 2991.60 USD. The estimated value of all donated materials and equipment, including SubConn connectors, totals 1200 USD. We saved approximately 600 USD by using 2006-07 ROV spares. We spent more than our anticipated budget due to increased technology risks (for example, student-designed motors vs. commercial purchase) and significant, dynamic testing failures.

References

Bollard Pull
(http://www.hydrocompinc.com/knowledge/whitepapers/HC110-BollardPull.pdf)

Innovations FIRST
(www.usfirst.org)

Jerry Glasser, Program Head
Information, Mentoring

Jay Isaacs, Senior Engineer
Images, Information, Mentoring

NASA
(www.nasa.gov)

SolidWorks™
(www.solidworks.com)

Wikipedia Commons
(http://en.wikipedia.org/wiki/Kort_nozzle)

Woods Hole Oceanographic Institute Article (Main Source for Research Section)
(http://www.whoi.edu/page.do?pid=7545&tid=282&cid=36806&ct=162)

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Lights, Camera, Action Corp. – *ROV camera support*

MATE – *Providing the underwater ROV challenge to Jesuit Robotics*

McMonagle Family – *Monetary donation*

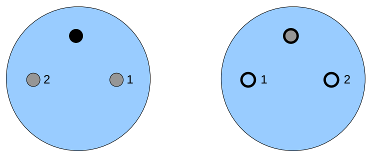
PAC Machines Corp. – *Cabling and waterproofing*

Patel Family – *Monetary donations*

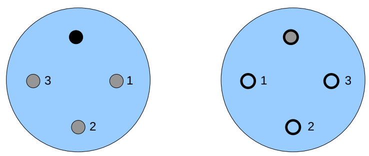
SolidWorks™ – *High school SolidWorks CAD programming*

SubConn Corp. – *Waterproof connectors*

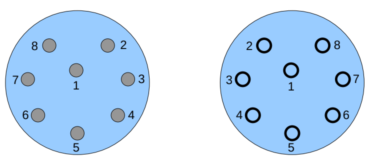
Appendix A: Electrical Schematics[XV]



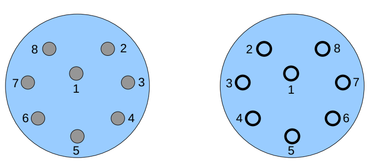
Power Line		
Eletronics Module	**Description**	**Tether/Device**
1	+12 Volts	White
2	GND	Black



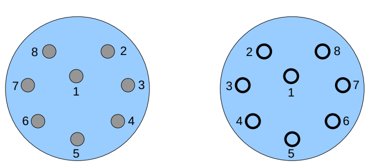
Camera Lines		
Eletronics Module	**Description**	**Tether/Device**
1	NTSC Video	Center
2	GND	Shield/Black
3	+12 Volts	White



Data Communications Cable		
Eletronics Module	**Description**	**Tether/Device**
1	RS232 - Tx	W/Org
2	RS232 - Rx	B/W
3	RS-232 Gnd	W/B
4	NTSC - Signal	Br/W
5	NTSC -Gnd	W/Br
6		Grn/W
7		W/Grn
8		Org/W



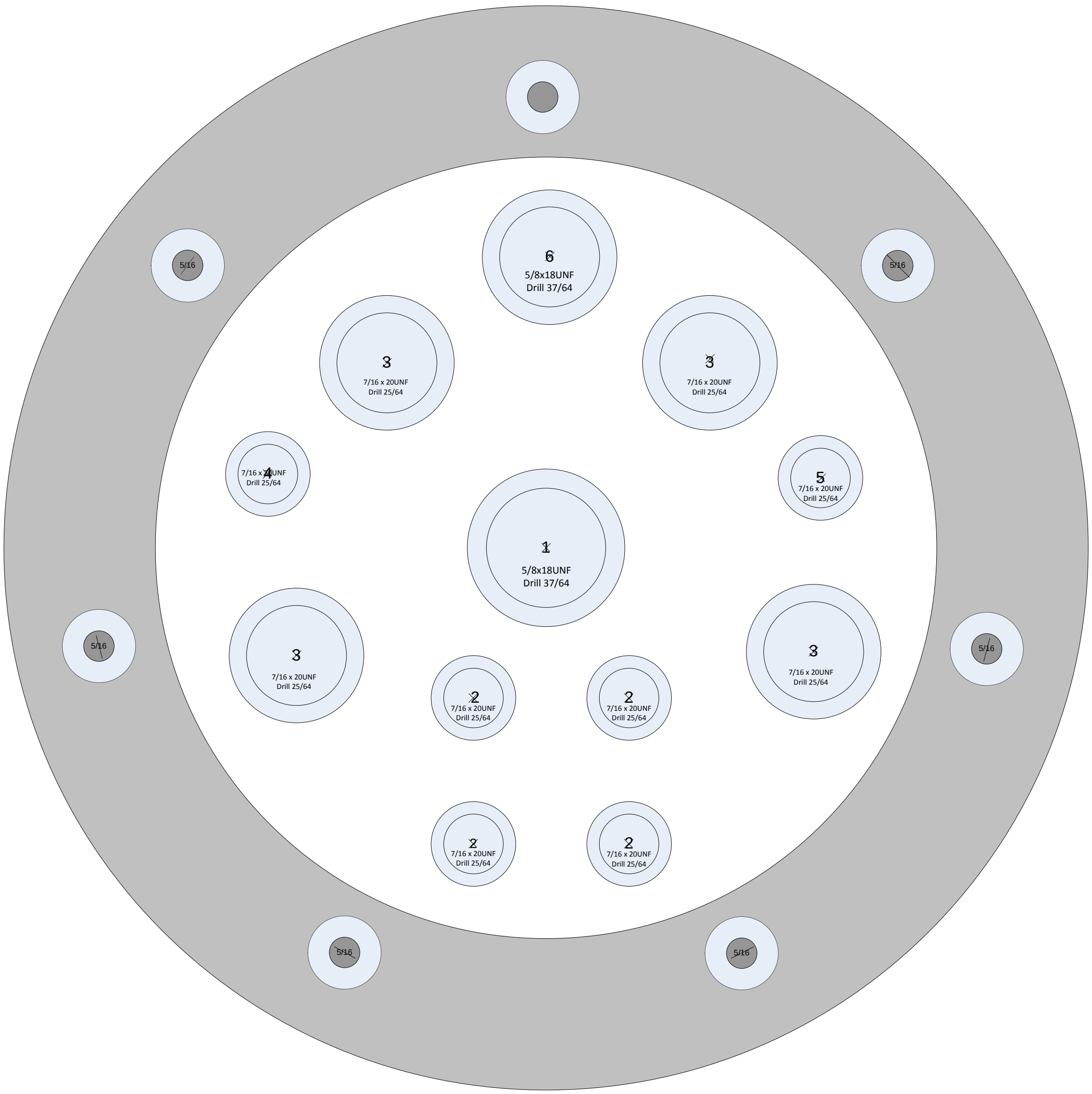
Accessory Line		
Eletronics Module	**Description**	**Control Line**
1	Pneumatic #1 - +12V	Black
2	Pneumatic #2 - +12V	White
3	Pneumatic #3 - +12V	Red
4	Pneumatic - Gnd	Orange
5		Blue
6		Green
7		White/Blk
8		Red/blk



Arm/Manipulator Control		
Eletronics Module	**Description**	**Control Line**
1	Axis 1 - 12 Volt	Black
2	Axis 1 - Gnd	White
3	Axis 2 - 12 Volt	Red
4	Axis 2 - 12 Gnd	Orange
5	Manipulator - 12 Volt	Blue
6	Manipulator - 12 Gnd	Green
7	Lights - +12V	White/Blk
8	Lights - Gnd	Red/blk

XV Images and diagrams provided by *Jay Isaacs, Senior Engineer*

1 Power Connector (Battery 2 Connector)
2 Camera Connectors (Micro 3)
3 Thrusters (Circular 2)
4 Accessories (Micro 8) PN#1 – PN #2 – PN #3 - Lignts
5 Signal Cable (Micro 8)
6 Accessories (Circular 8) Axis #1 – Axis #2 – Axis #3 – Acc #1



Appendix B: Control Systems[XVI]

Control Device Selection	
Device Name	**Function**
Parallax Inc. HB25 Motor Controller	25A bi-directional PWM speed controller
Solarbotics® L289 Motor Driver	2.5A bi-directional PWM speed controller
Phidget SSR	2.5A Solid State Relay

BASIC Stamp I/O PINS Control Functions	
0	L289 #1 H-Bridge Motor Driver #1 Input #1
1	RSS #1 Pneumatic Valve Ballast Air In
2	L289 #1 H-Bridge Motor Driver #1 Input #2
3	RSS #2 Pneumatic Valve Ballast Air Out
4	L289 #1 H-Bridge Motor Driver #2 Input #3
5	RSS #3 Pneumatic Valve Excavation Bucket
6	L289 #1 H-Bridge Motor Driver #2 Input #4
7	
8	L289 #2 H-Bridge Motor Driver #1 Input #1
9	
10	L289 #2 H-Bridge Motor Driver #1 Input #2
11	
12	HB-25 Motor Controller #1 & #2
13	RS232 Rx
14	HB-25 Motor Controller #3 & #4
15	RS232 Tx

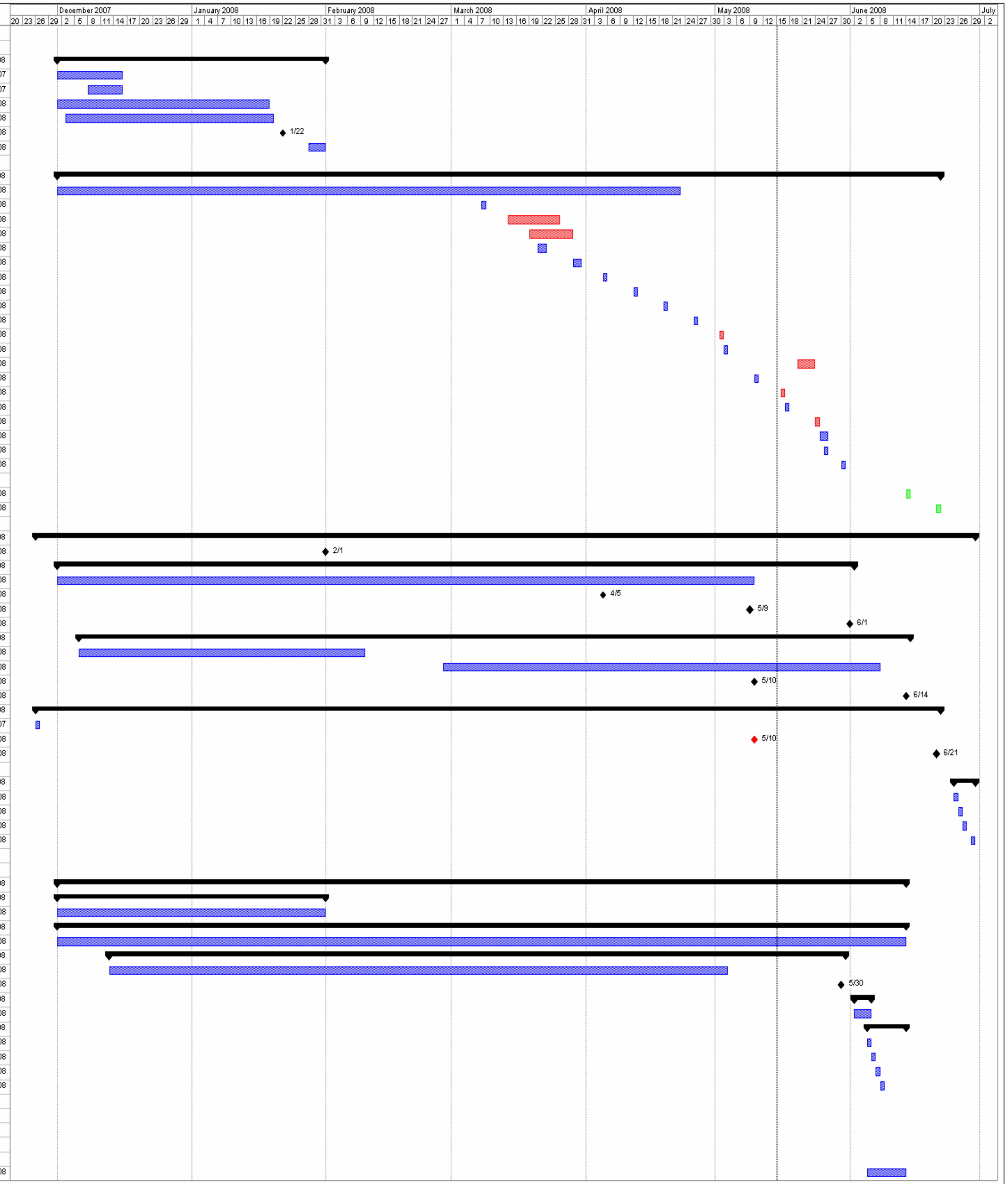
[XVI] Information provided by *Jay Isaacs, Senior Engineer*

BASIC Stamp Microcontroller	
Released Products	BS2e-IC
Package	24-pin DIP
Package Size (L x W x H)	1.2"x0.6"x0.4"
Environment	0° - 70°C* (32° - 158° F) **
Processor Speed	20 MHz
Program Execution Speed	~4,000 instructions/sec.
RAM Size	32 Bytes (6 I/O, 26 Variable)
Scratch Pad RAM	64 Bytes
EEPROM (Program) Size	8x2K Bytes, ~4,000 instructions
Number of I/O pins	16 +2 Dedicated Serial
Voltage Requirements	5 - 12 vdc
Current Draw @ 5V	25 mA Run / 200 µA Sleep
Source / Sink Current per I/O	30 mA / 30 mA
Source / Sink Current per unit	60 mA / 60 mA per 8 I/O pins
PBASIC Commands	45
PC Programming Interface	Serial Port (9600 baud)
Windows Text Editor	Stampw.exe (v1.096 and up)

Swann Quad Video Processor	
Picture Refresh Rate	PAL: 60fps NTSC: 50fps
Resolution	PAL: 720 x 480 / NTSC: 720 x 576
Signal Standard	NTSC/PAL Selectable
Camera Signal Input	4 Channel, Composite 1.0Vp-p75Ω, BNC
Camera Signal Output	Output to Monitor, Composite, 1.0Vp-p75Ω, BNC Output to Quad, Composite, 1.0Vp-p75Ω, BNC Output to VCR, Composite, 1.0Vp-p75Ω, BNC
Output Features	Full Screen/Quad/Freeze/Auto Switch/PIP
Relevant Humidity	≤95%, No Condensation
Sequential Switching Time	1-99 seconds, adjustable skip feature
Channel Name Display	Available
Clock Function	Year/Month/Day Display
Supply Voltage	DC12V
Operating Current (Max)	800mA
Operating Temperature	-10°C ~ +50°C
Dimensions (LxWxH)	142mm x 27mm x 98mm
Net Weight	1.7lbs / 800kg

Appendix C: Build Schedule

ID	Task Name	Duration	Start	Finish
1				
2				
3		49 days?	Sat 12/1/07	Thu 1/31/08
4	Build Crate	13 days?	Sat 12/1/07	Sat 12/15/07
5	Touch up ROV	7 days?	Sat 12/8/07	Sat 12/15/07
6	Business Cards	39 days?	Sat 12/1/07	Fri 1/18/08
7	Portfolio	39 days?	Mon 12/3/07	Sat 1/19/08
8	Ship Crate to New Orleans	1 day	Tue 1/22/08	Tue 1/22/08
9	New Orleans Trip	4 days?	Mon 1/28/08	Thu 1/31/08
10				
11	Weekend Schedule	175 days?	Sat 12/1/07	Sat 6/21/08
12	Regular Session	120 days?	Sat 12/1/07	Tue 4/22/08
13	Saturday 3/8	1 day?	Sat 3/8/08	Sat 3/8/08
14	Mr. G Gone Fishing	11 days?	Fri 3/14/08	Tue 3/25/08
15	Easter Break - OFF	10 days?	Wed 3/19/08	Fri 3/28/08
16	UC Davis First Competition - OFF	2 days?	Fri 3/21/08	Sat 3/22/08
17	Big Weekend Sat & Sun 3/29 - 3/30	2 days	Sat 3/29/08	Sun 3/30/08
18	Saturday 4/5	1 day?	Sat 4/5/08	Sat 4/5/08
19	Saturday 4/12 (Pace Auction)	1 day?	Sat 4/12/08	Sat 4/12/08
20	Saturday 4/19	1 day?	Sat 4/19/08	Sat 4/19/08
21	Saturday 4/26	1 day?	Sat 4/26/08	Sat 4/26/08
22	Friday 5/2 (JHS Senior Ball - OFF)	1 day?	Fri 5/2/08	Fri 5/2/08
23	Saturday 5/3	1 day?	Sat 5/3/08	Sat 5/3/08
24	Finals & AP Finals - OFF	4 days?	Tue 5/20/08	Fri 5/23/08
25	Saturday 5/10 (Senoir Ball St. Francis)	1 day?	Sat 5/10/08	Sat 5/10/08
26	Friday 5/16 (JHS Junior Ball - OFF)	1 day?	Fri 5/16/08	Fri 5/16/08
27	Saturday 5/17 (Pool Practice)	1 day?	Sat 5/17/08	Sat 5/17/08
28	Saturday 5/24 - OFF (Jesuit Graduation)	1 day?	Sat 5/24/08	Sat 5/24/08
29	Sunday & Monday 5/25 - 5/26 (Pool Practice)	2 days?	Sun 5/25/08	Mon 5/26/08
30	Monday 5/26 (Memorial Day)	1 day?	Mon 5/26/08	Mon 5/26/08
31	Saturday 5/30 (Work & Prep NURC Crate ROV)	1 day?	Fri 5/30/08	Fri 5/30/08
32				
33	Saturday 6/14 (Refresh ROV for MATE)	1 day?	Sat 6/14/08	Sat 6/14/08
34	Saturday 6/21 (Crate ROV MATE)	1 day?	Sat 6/21/08	Sat 6/21/08
35				
36	2008 MATE International ROV Competition	187 days?	Mon 11/26/07	Sun 6/29/08
37	Online Registration Deadline	1 day?	Fri 2/1/08	Fri 2/1/08
38	Technical Report	156 days?	Sat 12/1/07	Sun 6/1/08
39	Write Report	135 days?	Sat 12/1/07	Fri 5/9/08
40	Draft Report	1 day?	Sat 4/5/08	Sat 4/5/08
41	Report Final Review	1 day?	Fri 5/9/08	Fri 5/9/08
42	Report Due	1 day?	Sun 6/1/08	Sun 6/1/08
43	Poster Display	165 days?	Thu 12/6/07	Sat 6/14/08
44	Rough Design	53 days?	Thu 12/6/07	Sat 2/9/08
45	Content & Pictures	91 days?	Thu 2/28/08	Sat 6/7/08
46	Poster Finial Review	1 day?	Sat 5/10/08	Sat 5/10/08
47	Poster Print Ready	1 day?	Sat 6/14/08	Sat 6/14/08
48	ROV RTDE MATE & NURC	180 days?	Mon 11/26/07	Sat 6/21/08
49	Design ROV	1 day?	Mon 11/26/07	Mon 11/26/07
50	Proof of Concept	1 day?	Sat 5/10/08	Sat 5/10/08
51	Crate ROV	1 day?	Sat 6/21/08	Sat 6/21/08
52				
53	MATE Competition- SanDiago	5 days?	Wed 6/25/08	Sun 6/29/08
54	Arrivial & Checkin	1 day?	Wed 6/25/08	Wed 6/25/08
55	Setup & Pool Practice	1 day?	Thu 6/26/08	Thu 6/26/08
56	Engineering Pres. & Missions	1 day?	Fri 6/27/08	Fri 6/27/08
57	Missions & Awards	1 day?	Sun 6/29/08	Sun 6/29/08
58				
59				
60	NURC 2008 ROV Competition	168 days?	Sat 12/1/07	Fri 6/13/08
61	Web Site	49 days?	Sat 12/1/07	Thu 1/31/08
62	Site Creation	49 days?	Sat 12/1/07	Thu 1/31/08
63	Team Video	168 days?	Sat 12/1/07	Fri 6/13/08
64	Video Production	168 days?	Sat 12/1/07	Fri 6/13/08
65	Technical Report	144 days?	Thu 12/13/07	Fri 5/30/08
66	Write Report	120 days?	Thu 12/13/07	Sat 5/3/08
67	Report Due	1 day?	Fri 5/30/08	Fri 5/30/08
68	Ship ROC To NURC in Arizona	4 days?	Mon 6/2/08	Thu 6/5/08
69	Crate and Ship ROV to Arizona	4 days?	Mon 6/2/08	Thu 6/5/08
70	NURC - Arizona Trip	9 days?	Thu 6/5/08	Fri 6/13/08
71	Air to PHX	1 day?	Thu 6/5/08	Thu 6/5/08
72	NURC Meet and Greet / Setup	1 day?	Fri 6/6/08	Fri 6/6/08
73	NURC - Competition	1 day?	Sat 6/7/08	Sat 6/7/08
74	NURC - Awards	1 day?	Sun 6/8/08	Sun 6/8/08
75				
76				
77				
78				
79				
80		9 days?	Thu 6/5/08	Fri 6/13/08



Project: Jesuit Robotics 2008
Date: Thu 5/15/08

Task / Split / Progress / Milestone / Summary / Project Summary / External Tasks / External Milestone / Deadline

Appendix D: Budget Sheet

Tether / Tether Control Unit				
Part Number	**Description**	**Quantity**	**Price**	**Total**
	1400 Pelican Box	1	$69.95	$69.95
320327	Blue Sea 0-50A Meter	1	$89.99	$89.99
320343	Blue Sea Analog 8-16 Volt Meter	1	$39.99	$39.99
	Automotive Toggle Switch 50A 12VDC SPST	1	$4.95	$4.95
551640	Ancor 40 A Breaker single Pole	1	$19.95	$19.95
	Pressure Gauge and Regulator (On hand part)	1	$0.00	$0.00
	12 Gauge Wire	1	$5.95	$5.95
	14 Gauge Wire	1	$5.95	$5.95
	16-14AWG Ring Terminals Package 7	1	$2.95	$2.95
	Liquid Tight Connectors	3	$3.98	$11.94
	RadioShack DB-9 Female Connector	1	$2.95	$2.95
	NTSC to SVGA Video Converter (Existing)	1	$0.00	$0.00
B4383H%	Linrose Super Bright LED (Green) 12v 520mcd	1	$4.49	$4.49
	Husky 14/3 100 ft Extension Cord	1	$26.96	$26.96
2740364	RadioShack PKG4 Shield Phone Jack	1	$3.99	$3.99
	WestMarine Small battery Clips	1	$4.95	$4.95
270-1238	RadioShack 5x20mm Fuse Holder	2	$2.69	$5.38
270-1049	RadioShack Fast Acting Fuses 1 A 1pkg	1	$2.99	$2.99
95-772	Calrad Inline Male Socket Assembly 125VAC/10A	2	$3.98	$7.96
1J-151-05	Pneumatic Tube 1/4 x .160 x 100 ft Red	1	$33.77	$33.77
	Cat 5 75' Data Cable	1	$18.75	$18.75
	DolphinEAR™ Hydrophone (Existing lab Equipment)	1	$0.00	$0.00
	Vernier Temperature Probe (Existing lab Equipment)	1	$0.00	$0.00
	Heat Shrink Tubing 1" @ 5ft Red	1	$19.95	$19.95
168	Greenline Pulling Grip 19mm to 25mm	1	$22.45	$22.45
	Heat Shrink Tubing 1" @ 5ft Clear	5	$19.95	$99.75
		Total		**$505.96**

Bulk Materials				
Part Number	**Description**	**Quantity**	**Price per/sq ft**	**Total**
N/A	3/8" High-Density Polyethylene per sq. ft.	16	$8.00	$128.00
N/A	1/2" High-Density Polyethylene per sq. ft.	8	$10.30	$82.40
N/A	3/4" High-Density Polyethylene per sq. ft.	2	$16.00	$32.00
N/A	1/2" Clear Polycarbonate per sq. ft.	4	$31.20	$124.80
N/A	1/4" Clear Polycarbonate per sq. ft.	4	$13.25	$53.00
N/A	1" 1/2" Clear Acrylic Tube per ft.	6	$3.20	$19.20
N/A	3/8" Black ABS Plastic per sq. ft.	4	$9.45	$37.80
N/A	1/4" Black ABS Plastic per sq. ft.	4	$6.30	$25.20
N/A	1" 1/4" Aluminum Tube per ft.	8	$3.00	$24.00
N/A	1/2" Aluminum Rod per ft.	8	$2.50	$20.00
		Total		**$546.40**

Bulk Materials				
Part Number	**Description**	**Quantity**	**Price**	**Total**
	Mr. Sticky's Glue	10	$9.95	$99.50
	PC11 Two Part Epoxy 1 QT Cans	2	$29.95	$59.90
	ABS Glue	1	$3.75	$3.75
	2.5OZ Solder .032	4	$4.99	$19.96

Bulk Materials (Cont.)				
	Electrical Tape Red-Yellow-Black Rolls	3	$2.95	$8.85
	Type 16 Solvent (Adhesive)	2	$7.50	$15.00
	Stainless Steel Screws/nuts/bolts	1	$250.00	$250.00
		Total		**$456.96**

SubConn Connectors				
Main Power				
Description	Part #		QTY	**Donated**
Battery 2	BHB2F		1	
	DLSB-F	Female Shell	1	
	DSLB-M	Male Shell	1	
	OMB2M		1	
	OM BB	Boot	1	
Camera @ 4 Ballast Control				**Donated**
Micro 3	MCBH3F		5	
	MCDLSF	Female Shell	5	
	MCDLSM	Male Shell	5	
	MCOM3M		5	
	MCOMB	Boot	5	
Signal Cable (tether)				**Donated**
Micro 8	MCBH8F		2	
	MCDLSF	Female Shell	2	
	MCDLSM	Male Shell	2	
	MCOM8M		2	
	MCOMB	Boot	2	
Manipulator Arm Power				**Donated**
Circular 8	BH8F		1	
	DLSB-F	Female Shell	1	
	DLSB-M	Male Shell	1	
	OM8M		1	
	OMBB	Boot	1	
Thruster Power				**Donated**
Circular 2	BH2F		4	
	DLSA-F	Female Shell	4	
	DLSA-M	Male Shell	4	
	OM2M		4	
	OMBA	Boot	4	
		Total		**Donated**

Video Cameras				
Part Number	**Description**	**Quantity**	**Price**	**Total**
LCA-7700-C	LCA-7700 Series Underwater Color Camera w/infra-red LED	2	$233.00	$466.00
		Total		**$466.00**

Electronics Control Module				
Part Number	**Description**	**Quantity**	**Price**	**Total**
BS2E-IC	Parallax Inc. Basic Stamp 2e	1	$54.00	$54.00
27130	Parallax Inc. Super Carrier Board	1	$19.95	$19.95
29144	Parallax Inc. HB-25 Motor Controller	4	$49.95	$199.80
SW-D-QPRO4	Swann Quad Channel Video Processor	1	$98.00	$98.00
	Bi-Directional Speed Controllers	3	$25.45	$76.35
P-VR-DE-SW050	Dimension Engineering 10W Step down adjustable switching regulator	1	$15.00	$15.00
P-VR-DE-SWADJ	Dimension Engineering 5V 1A Switching voltage regulator	1	$15.00	$15.00
P-VR-VregBreakout	Voltage Regulator Breakout Board	1	$9.99	$9.99
C-200-P3052	Phidgets Solid State Relay 2.5 A, 40 Volts DC	1	$18.43	$18.43
MCU-016-172	RS-232 to V TTL Type 1converter	1	$24.50	$24.50
	24 Gauge Hook UP Wire	1	$5.95	$5.95
	Stainless Steel Food Container	2	$12.25	$24.50
	1' x 1' x 1/2" Polycarbonate (Bulk Materials)	2	$0.00	$0.00
	1' x 1' Silicon Gasket Sheet	2	$6.50	$13.00
		Total		**$574.47**

J-1 Thrusters 4 Units				
Part Number	**Description**	**Quantity**	**Price**	**Total**
	BaneBots 27:1 12V Gear Box Motor	4	$45.95	$183.80
	1" 1/4" PVC end Cap	8	$0.55	$4.40
	1" 1/4" PVC Slip / Male Thread	8	$0.55	$4.40
	1" 1/4" PVC Slip / Female Thread	8	$0.55	$4.40
	1" 1/4" Clear Acrylic Tube (From Bulk Material)	4	$0.00	$0.00
	McMaster Carr Liquid Tight Fitting	4	$8.95	$35.80
	Cat 5 Ethernet Cord	4	$7.95	$31.80
	3/8" x 1 ' Stainless Steal Shaft	2	$4.95	$9.90
	PC Muffin Fan	4	$1.00	$4.00
	Harwal Rotating Shaft Seal 3/8"	8	$0.75	$6.00
	3/4" Polycarbonate Circles (Scrap Material)	4	$0.00	$0.00
	10-24 Set Screws	12	$1.35	$16.20
	Aluminum Rod (Shaft Couplers) (From Bulk Material)	4	$0.00	$0.00
	Aluminum Rod (Propeller Hubs) (From Bulk Material)	4	$0.00	$0.00
	Expansion Pins 5/64	24	$0.45	$10.80
		Total		**$311.50**

Pneumatic Control System				
Part Number	**Description**	**Quantity**	**Price**	**Total**
4V210-1/4-1	STC Valve 5/2/1 Four Way Valve 12Vdc	1	$36.24	$36.24
2S025-1/4-1	STC Valve Air, Gas, Liquid, Oil, Water, Two-way Direct Acting, Normally Closed, Stainless Steel Solenoid Valve	2	$30.69	$61.38
	Pneumatic line (Remains from tether)		$0.00	$0.00
	Clear Acrylic Food Container	1	$13.85	$13.85
	Stainless Steel Nuts/Bolts/Screws		$12.00	$0.00
	Pneumatic cylinder and mounts		$6.95	$0.00
	Stainless Steel Spice Container	1	$6.99	$6.99
	1/8 compression / 1/4 NPT fittings	3	$3.95	$11.85
		Total		**$130.31**
		GRAND TOTAL		**$2991.60**