

*The*  
**CAREER AND TECHNOLOGY EDUCATION CENTER**  
*Features*  
**NAUTILUS**  
*of*  
**TEAM THRESHER**



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Technical Report*



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## Abstract

With the challenges set forth by the Marine and Technology Education center; we, Team Thresher, built this Remotely Operated Vehicle to execute a range of tasks with liveness, while maintaining swiftness and maneuverability. Nautilus has been created to meet all requirements and exceed all expectations. Doing so, we have introduced a new form in structure and ideology to the competition. Our idiomorphic ROV will provide swiftness in sounding, while caring a payload and be gentle enough to finesse objects throughout the task area. Team Thresher's report on Nautilus will explain why and how we built our ROV, the obstacles we faced, and how we overcame them.

## Design Rationale

### ROV Dimensions

- Length – 1.25 m
- Width (With wings) – 54 cm
- Height – 50 cm

### Overview

When it came time to design Nautilus, we decided to challenge ourselves and construct something we haven't seen at competition before. Therefore, we designed Nautilus around the basic submarine shape. This shape allowed for easy movement in water as it is the most hydrodynamic shape we could construct. The design also took into consideration the force of water at 12 meters, with our cylindrical shape and sturdy materials.

### Materials

Knowing that we had to withstand the pressure at that depth we wanted to build Nautilus out of a strong, sturdy. There were essentially two materials for us to choose, the first being PVC. It is inexpensive, easily obtainable, and most importantly, easy to work with; however, PVC is easily damaged. Problems in the past with keeping a PVC structure intact have led us away from this material. In addition, most teams choose to work with PVC, and we decided to challenge ourselves with a material not often found at the competition. This brings us to our second option, metal. Most metals are typically susceptible to corrosion and oxidation. This narrowed our options to copper, aluminum, and stainless steel. Copper didn't come in the necessary sizes for our purposes and can be susceptible to oxidation. Aluminum, on the other hand would be a perfect candidate, but it isn't strong enough for our structure. We had tried to use aluminum because of its malleability and weight compared to a ferrous based metal. While aluminum is less expensive, welding aluminum is a daunting task. To weld our wings together, which are only 10 x 15.25 cm would cost us \$80.00.



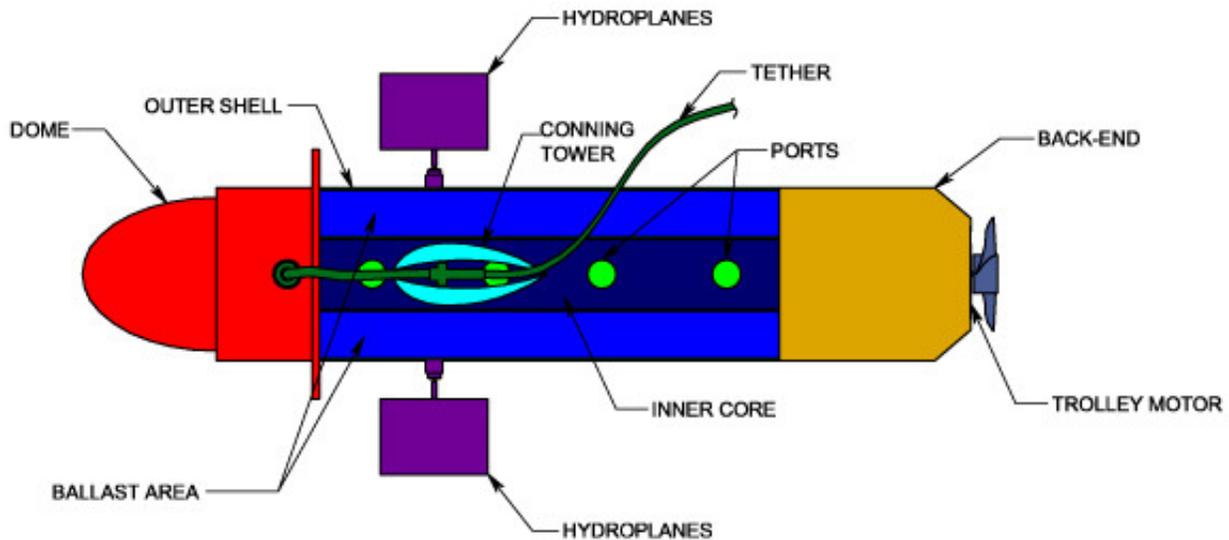
*Construction Materials*

Stainless steel not only provides superior strength, but is also highly resistant to corrosion and oxidation. On the other hand, stainless steel can be quite burdensome not only physically but monetarily. We happened to have a sponsor who allowed us to take his scrape to build Nautilus. We chose stainless steel at a surgical grade of 316L, meaning it is very hard to oxidize because of the increased content of nickel and chromium. Stainless steel also is very hardy and can withstand abuse.

## Structure

Team Thresher chose a design which would eventually lead us to the most difficult task, building it. This radical design is taken from prior observations. If animals could evolve into this shape and the government builds them for warfare then we could build one for an ROV competition. A submarine, we decided, would provide us with the needed room and the complexity to make it desirable to build.

The shape allows us to partition it off into chambers, much like a nautilus. For simplicity's sake, Nautilus is divided into three main areas: the watertight dome and inner core, the ballast, and the back end. The hydroplanes and conning tower are two other distinct features of Nautilus.



## The Dome & Inner Core

The dome and inner core hold our most valuable devices. They contain 5 Victor Pulse Width Modulators (PWM) and 9 Spike Relays (Fig. 1). These make up half of our control system and if they were to come in contact with water then we would lose all systems and have no way of competing. The dome consists of a parabolic dome welded to a cylinder 23 cm in diameter and 13 cm in height (Fig. 2). A Team Thresher produced flange was then welded on the end, allowing us to remove the dome in order to access the inner core. Our tether enters at the top of the dome, near the flange. This section also houses our power source, two 12V lead acid batteries connected in parallel to give us 14.4 amp hours of service. All wiring throughout

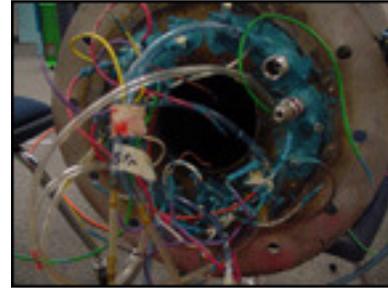
the ROV proceeds through a stainless steel plate which separates the ballast from the dome (Fig. 3). The dome has enough weight in it to offset the back end and keep Nautilus stable.



*Fig. 1 – Dome w/ Electronics*

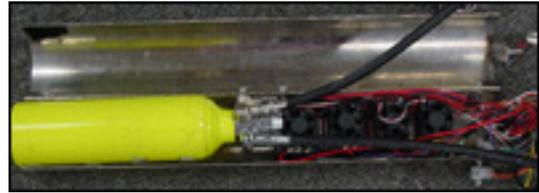


*Fig. 2 – Dome (Outside View)*



*Fig. 3 – Wiring Hub*

While the dome provides us with space for electronics, it was not quite enough. Fortunately, we designed an inner core to give us more space for our PWM's. The inner core is removable from the ballast section of Nautilus, allowing us to make efficient use of space (Fig. 4). The inner core is 61 cm long with a hinge on one side and a handle on one end to allow easy insertion and removal. In addition to the electronics, the inner core also houses a 20.7 Mega Pascal (MPa), or 3000 PSI, scuba tank for all air needs. A vital part of Nautilus, the scuba tank provides air to the ballast system as well as all pneumatics needed for tasks. As a safety feature, the tank can be overfilled by 10%. A 34.5 MPa rated airline is used to fill the tank and a 2.8 MPa rated airline supplies air to the rest of the onboard components. It is then regulated down to .41 MPa (60 PSI) in compliance with competition specifications.



*Fig. 4 – Inner Core*

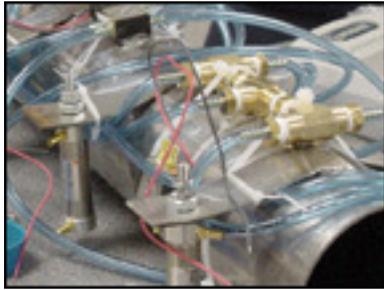
## **Ballast**

In challenging ourselves with the submarine shape, we decided to design our buoyancy system around a submarine's buoyancy concept. However, we made adjustments to the concept to allow our buoyancy system to be efficient, low-maintenance, and economical. As a submarine, our ballast section, which measures 61 cm in length and 23 cm in diameter, is a chamber which exchanges water and air in order to adjust our buoyancy at any given moment (Fig. 5). It is capped at both ends and serves as the centerpiece of the structure, since both the dome and back end are completely detachable. We found that the ballast can hold 20 kg of water allowing us to obtain extremely positive or negative buoyancy when needed. This important capability is one of our major advantages over other ROVs, in that we can rapidly descend and ascend, while still achieving neutral buoyancy when desired.



*Fig. 5 – Unfinished Ballast*

In order for the ballast to exchange water and air, it has four ports on both the top and bottom, equally spaced to provide ample water flow through the ballast. These ports are closed off by rubber stoppers, producing a watertight seal. These seals are pushed and retracted by eight pneumatic cylinders, controlled by two solenoids. These solenoids are connected such that the bottom four cylinders are operated with the same solenoid, enabling them to operate at the

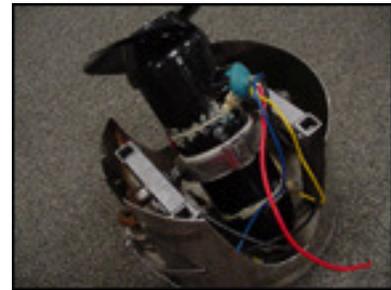


*Fig. 6 – Ballast Cylinders*

exact same time. The same can be said for the top four cylinders. All cylinders are oriented vertically on the sides of the inner core housing, four facing up, and four facing down (Fig. 6). An L-shaped bracket attaches the rubber stoppers to their respective cylinders, allowing them to be controlled only by back and forth movement.

## Back End

The back end of Nautilus houses the main propulsion motor and is completely detachable (Fig. 7). The motor housing is made of a 23 cm diameter stainless steel tube welded to a cap for attachment purposes. The motor attachment is made out of a circular clamp mounted onto a threaded rod for rotational purposes. This rod is housed between two rectangular aluminum braces to keep the rod in place.



*Fig. 7 – Back End*



*Fig. 8 – Geared Motor*

One of the special features of the back end is the replacement of a rudder system with a geared motor for rotation. Not only would the rudder system lengthen the size of Nautilus, but it could easily be damaged in its exposed position. We instead attached a motor, oriented horizontally near the bottom, which operates a gear system to rotate the trolley motor (Fig. 8). This increases maneuverability, allowing us to rotate Nautilus in place.

The back end also contains a limit switch and a relay. Since the motor has a 180 degree turning radius, an apparatus was needed to stop the motor at center. When the limit switch is triggered, the relay cuts off power to the geared motor that rotates the trolley. The control system can then be triggered to allow the geared motor to resume its rotational ability.

## Hydroplanes

Submarines use hydroplanes, or wings, to keep themselves stabilized and change pitch (Fig. 9). We are using them for the same reasons. They will play an important role in ascending and descending. These wings rely only on water resistance to change the pitch of Nautilus, rather than a propeller. Each wing is rotated with a geared motor and has a rotational capability of 90 degrees. The wings are restricted by physical stops at 45 degrees above and below the center point. A limit switch is used to stop the wing at the center point.



*Fig. 9 – Rotating Wing*

## Propulsion

When designing Nautilus, we chose the most reliable motors for the job. Nautilus contains five propulsion motors. Two of which are up/down motors for tilting purposes. They allow us to make slight vertical adjustments when doing tasks



*Fig. 10 – Adjustment Motor*

(Fig. 10). In choosing the motors we decided to go with something other than bilge pump motors. We were able to find more powerful motors than typical bilge pumps. They are not only economical, but they should be able to handle the extra pressure of 12 meters with a little waterproofing. They are high RPM, with enough torque to adequately power Nautilus through the water. Two more motors are mounted on the far sides of the wings. These motors are used for slight adjustments, due to the fifth motor's immense power.



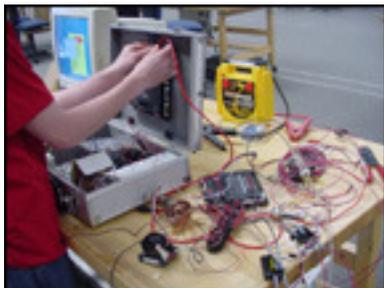
*Fig. 11 – Trolley Motor*

The final motor is a trolley motor, found at any sporting good store (Fig. 11). It is capable of providing 13.6kg of thrust with a two bladed propeller. However, we have since changed the propeller out for a three bladed one, providing Nautilus with 2 kg more of thrust. This extra thrust is very noticeable in the water.

## Control

Opposed to our previous toggle switch control system, we went with the Innovation First control system to provide variable speed. The change was brought on for two main reasons. The first was the complexity of Nautilus. There are simply too many motors to use a single toggle switch for each, since toggle switches require sending down separate wires for each individual motor. This would increase our tether size enormously, decreasing mobility and increasing drag. As a result of using the Innovation First control system, we can provide power from onboard. This cuts down resistance and cuts down response time. This also increases the life of the batteries used because of the decreased resistance. A second reason for the Innovation First control system is the ability to use variable speed on our motors. Our rear mounted trolley motor is great for going distances, but its power can be a disadvantage when completing tasks which require slight movements.

The control has undergone several modifications before implementing. The first being that the control system is not designed for underwater usage; therefore, we had to build a waterproof housing onboard Nautilus. Secondly, because of the nature of the removable housing, we needed to install a new system to power on and off Nautilus, since removing the waterproof dome each time would prove inefficient. This leads us to the voice activation system. This system not only allows us to turn on the control system, but it also provides a security system. The voice activation system allows us to do checks on the motors and buoyancy system. This is a very useful tool that allows us to find problems before hitting the water. However, the most important modification was programming the system itself. The default Innovation First program was useless for our purposes on Nautilus. The controller required reprogramming to take in consideration limit switches, solenoids, and sensitivity of motors.



## Tether

One of the improvements we made this year was the tether. Unlike our previous tether of last year, which contained numerous wires and airlines, we tried to cut down the tether as much as possible. The first thing done was to go with onboard power. This cut down the wires to almost nothing except for a signal cable, three camera lines and emergency power lines. Secondly, we stripped our tether of airlines by going with onboard air. We no longer have to send air down 12 meters, but can get all we need with an onboard scuba tank. As a result of these modifications, our tether has decreased in size from 4 cm to 1.2 cm (Fig. 12). Our current tether is 30 m long. We figured 20 m would be enough to cover most situations; however, we added an extra 10 m of length just in case.



*Fig. 12 – Tether Size*



*Fig. 13 – Tether Joint*

Another important aspect of our tether is placement. It is attached to the Nautilus by way of a pivot joint inside the conning tower (Fig. 13). This central placement ensures that the tether will not get in the way, and a moveable joint ensures maximum mobility. From its point on the conning tower, it runs along the top of the ballast and into the dome.

Tether management is another important issue. With a 30 m long tether, it can be quite burdensome and easily become entangled. For this reason a reel was used to keep the tether in check.

## Cameras

Three cameras are secured to Nautilus to provide proper visual acuity. The cameras we have selected are waterproofed to 90 feet. They come equipped with four white LEDs, allowing us to see in dimly lit areas (Fig. 14). The main camera is placed inside the dome for driving Nautilus into position. A second camera is mounted beneath the dome for use with the tasks. A third is a rear facing camera, allowing us to see the tether to the instrument package and waypoints.



*Fig. 14 – Camera*

## Tasks

### Electronics Module

First and foremost, the electronics module must be held securely in place. This is accomplished with the use of four partition holders and four pneumatic cylinders, controlled by one solenoid, attached to two aluminum plates (Fig. 15). The partition holders provide a gap for the u-bolts of the electronics module. The cylinder rods then extend through the holes in the



*Fig. 15 – Partition w/ Cylinder*

partition holders and beneath the u-bolts, keeping them from falling out. When the electronics module is positioned correctly, the cylinders retract, allowing the module to release. For a successful drop off, all four cylinders must activate at the same time. One solenoid is used to activate all cylinders, and a timely, successful drop off can be completed.

One of the main problems we see is the descent with the electronics module. The massive surface area of the module produces an immense drag force. In order to cut this resistance down, we can descend vertically, or nose down. This allows Nautilus's dome to cut the water as it progresses down, but it also cuts down the surface area on the electronics module, since the front face is smaller in area than the bottom and top faces. As Nautilus reaches its destination, it will level as it bottoms out, thereby orienting itself horizontally. This puts the electronics module in perfect position for insertion.

### Door

When designing the door opening device, we went with an efficient, simplistic device. A Y-shaped arm was the final design (Fig. 16). The Y-shape allows a greater margin of error. We can quickly position ourselves on the door handle in this way. Once positioned, a cylinder extends, locking the handle inside the Y-shape. The door handle is secured, allowing Nautilus to back up, turn, and quickly release the door handle, without getting stuck.



*Fig. 16 – Y-Shaped Arm*

### Power Communication Probe



*Fig. 17 – Grasping Arm*

For this task we require a device that can easily pick up a cylindrical probe. We designed this device to pick up the probe without using the u-bolt or the ring. Picking up the probe using those items alone would leave the probe dangling and difficult to position. By picking up the probe by its body, we can ensure a secure grasp and easy placement in the port. To accomplish this, a pneumatically operated arm was installed (Fig. 17). The arm is made of three main components, the pneumatic cylinder for extension and retraction out in front of the dome, the cylinder to open and close the arm, and two arched walls that grasp the cylinder nicely. The walls are designed so that when the probe is captured, enough of the probe remains out to place in the communications port.

### Instrument Package

The same device used for the power/communications probe is employed in this situation. Once the probe is secured, the powerful trolley motor is used to quickly reach the waypoints and make all necessary turns. The wings are then used to guide the rope into position by quickly adjusting the height of Nautilus for secure placement inside the waypoints.

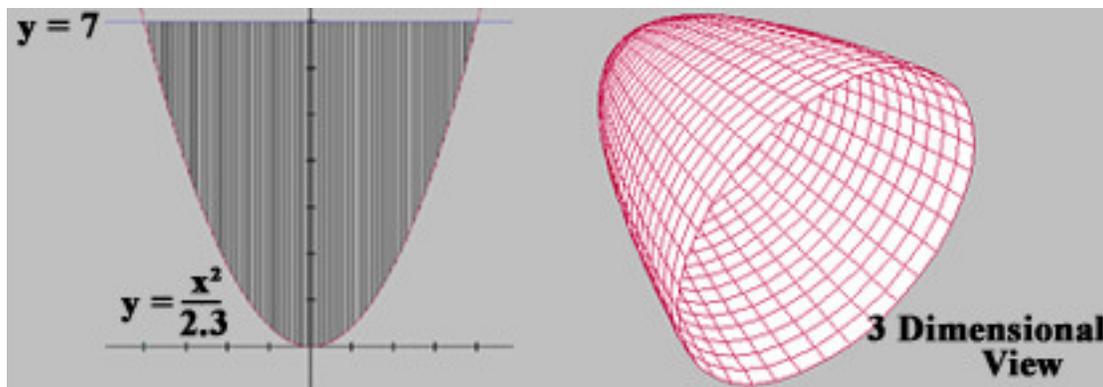
### Ascension

When all tasks are complete, Nautilus can quickly ascend to the surface. Due to the nature of our buoyancy system, we can quickly become positive, allowing Nautilus to ascend rapidly. A solenoid will trigger an airline to begin pumping air inside the ballast, flushing out

water and decreasing density. As the tank empties, the eight ports will close and Nautilus will penetrate the surface. Tests have already confirmed this.

### Challenge Faced

When designing the ballast system, we wanted to enhance the previous year's system. We also wanted to incorporate the submarine concept. Last years ballast was impressive and efficient for the items used. The inflatable inner tube allowed us to have a wide range of positive to extremely negative buoyancy. However, if inflated too much the inner tube would explode, thus resulting in no buoyancy system. The other disadvantage was that we could quickly inflate the inner tube, but our control system was extremely slow to remove the air. The most important factor for the need of a new buoyancy system was that the inner tube would not easily conform to the submarine concept. For this reason, research was done on the submarine to understand its dynamic buoyancy system. This system was then modified to fit our design. As we discovered, a typical submarine has a chamber, in this chamber water and air are exchanged to change the density of the structure. The change in density allows the structure to sink and float, based on Archimedes' Principle. In order to find the amount of water needed to sink our structure depended solely on the volume of water displaced and mass. To obtain the volume we depended on mathematical formulas, this process is shown below:



- The function  $y = x^2/2.3$  best matched the curve of the parabolic dome
- This was then adjusted to be integrated around the y-axis:  $x = \sqrt{2.3y}$
- The new function was then integrated using the disk method:  $\int \pi(r)^2 * dy$  on the interval (a, b)
- $\pi * \int 2.3y dy (0,7) = 176.9 \text{ in}^3$
- We then converted this number to SI,  $2.9 \times 10^{-3} \text{ m}^3$
- Then we found the volume of the cylinder using the formula  $\pi(r)^2 h$
- The formula produced  $2290 \text{ in}^3$ , which equals to  $.038 \text{ m}^3$
- By adding these two numbers together we an answer of  $.0409 \text{ m}^3$
- We figured that the water displacement from this volume amounts to 41.5 kg

As shown above, we used the formula to calculate the volume of a cylinder, which accounts for most of the ROV's shape, excluding the dome. We then took the volume of the dome, which was done differently due to its parabolic shape. In order to acquire this volume we needed to do a little calculus. As shown we found the parabolic equation that best suited our dome. Limits where then set on the parabolic equation at the maximum diameter of the dome.

The area under the curve was found and finally integrated to find the volume. This was an extremely challenging process, but we obtained the volume. With the volume of water displaced we could find the needed weight of the vehicle. We had obtained the answer as to whether or not the vehicle would sink with the chamber filled with water, and float with air in the chamber. We also knew the maximum weight the vehicle could carry. We had to make sure not to surpass this weight, which provided yet another challenge.

In order to exchange water in air, we had to provide a way to allow water and air in and out of the chamber. We decided that four 3.8 cm ports on the top and bottom would provide ample space for entry and exiting air and water. The ports required a mechanism that would open and close off the ports. The mechanisms chosen to operate the eight ports were eight pneumatic cylinders which were easily obtainable, reliable and efficient. However, since the smallest attainable cylinders were longer than the room given between the core and outer shell, this became a problem. This problem was solved by placing the cylinders on the wall of the core rather than on top as shown in page 6. In making this modification, we had to add angle pieces to the cylinder rods to reach center. At the tip of the angle pieces a rubber seal was attached. When the cylinder rods extend the rubber is compressed, thus sealing the opening.

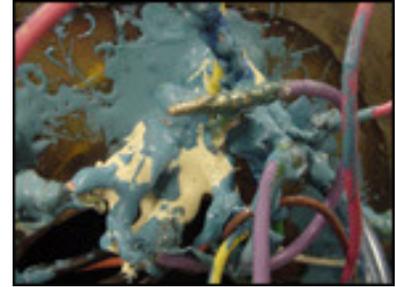
We ran into yet another situation, the angle piece was bending as the rod extended and encountered the outer shell wall. This bending kept the rubber from compressing, causing terrible leaks. The team sat down and went through two possible solutions. The first was to reinforce the angle pieces and the second was to change out the mechanisms. The team decided to reinforce the pieces first due to time, to do this we looked at typical braces, such as I beams and H beams. We analyzed and located the problem with the pieces, and discovered the problem was simply the .3 cm height of the angles. A good example of this is a piece of plywood. If you layout a piece of plywood so that the 1 cm thickness is its height, it can easily be bent up and down. However, if you orient it so that .3 cm thickness is its width and the 1 m width is its height, it becomes extremely hard to bend up and down. So it was concluded that in order to obtain strength, the height of the angle pieces had to increase. We simply installed aluminum L's to the angles and the bending stopped, which in turn compressed the rubber seals providing a waterproof seal. Now, when the top and bottom ports open, water pushes the air out allowing us to sink, when ascending we close the top ports and turn on an airline located inside the ballast, which pushes the water out allowing us to float. The air released in the ballast had to be greater than the water pressure at 12 meters, in order to push it out. The system is complex yet simple and provided us challenging decisions, headaches, and time, all of which we are proud to have encountered and resolved.

### **Troubleshooting Technique**

One of the most nagging challenges in building Nautilus was waterproofing the dome and inner core. For the longest time, water got in no matter how much epoxy we splashed on. After simply applying trial and error and not getting results, we turned to a more methodical approach. We carefully examined the area and came up with several possible solutions. The first was possible pin holes in our welds. While they seemed to be good, watertight welds, no one could tell if they were for sure. We then applied silicon and marine epoxy to all welds in the vicinity of the dome and inner core. After testing, we saw that the water had gone down very little. A second approach was taken. After carefully examining the wires, we noticed spaces between the



wires themselves and their insulation. We then applied connectors to the ends, essentially waterproofing them completely (Fig. 18). After taking this approach, we discovered the water level had indeed gone down, but there was still the matter of a couple centimeters. Our final attempt involved placing a camera inside the dome to check for leaks. This proved to be the last as we noticed the leak and promptly fixed it. Our thought-out, methodical approach to waterproofing the dome and inner core proved a success.



*Fig. 18 – Waterproofed Connectors*

### **Improvement for Next Time**

There is always room for improvement, nothing is perfect, which brings us to the one major improvement Team Thresher would like to make for next time. The tether has greatly been reduced in size in the past years on the ROV's, but eliminating the tether completely would be a major advantage. Like on all ROV's tethers provide unwanted drag and are susceptible to getting caught on items on the ocean bed. By implementing wireless transmission as opposed to a tether, we would lose of all tether drag, increasing mobility and operational range. Team Thresher has already begun research on wireless transmission through water. The Innovation Control system transmits a 900 MHz signal, after some research; we found that the 900 MHz was too high of a frequency; we needed a much lower frequency. The reasoning behind this is as follows. With a high frequency the water molecules get excited and absorb the signal, causing the signal to die out. Secondly, the signal goes from air to water, two different mediums, with a different index of refraction causing the signals to refract and reflect. However, by implementing a floating device that would take the signal from air and retransmit the signal downward to the ROV we would get a more effective transmission. This would be a more efficient signal because when the signal is shot straight down into the water, no refraction occurs. Since the Innovation First control system transmits a frequency that is too high, there are two options. The first would be to build a control system with the desired frequency. The second option would be to purchase or build a device which would lower the frequency until it reached the controller, were it would be received and converted back so that the controller would accept the signal. This idea offers many advantages and would be much more economic than the use of fiber optics. The converting transmitter, the second transmitter and the receiving converter would be the only necessary parts. The idea requires more time and research, but could be easily accomplished.

### **Lesson Learned**

One important lesson we learned while designing and constructing Nautilus was the compatibility of different metals, or lack thereof. Stainless steel was typically the metal of choice; however, aluminum was sometimes more practical. It may have been more readily available, lighter, or just plain easier to use. There were a few occasional instances in which we wanted to weld aluminum to stainless for extra support. Unfortunately, the team learned that this is not possible, and we had to stick to more conventional measures such as screws and bolts.



*Fig. 19 – Aluminum/Steel Connection*

Welding was an important skill learned by a couple team members during construction. Our welding jobs were first completed by experienced professionals, but as time went on, the



skill was picked up by the team. One member's borrowed welding machine became a valuable asset, as it was used often. In welding, one important lesson was learned. Stainless steel must be heated so extremely that it has the tendency to warp. This became somewhat of a problem as the flange became slightly distorted, losing its flat watertight seal. Welding can be a valuable skill when working as an ROV pilot. It may be necessary to fix a broken frame while out at sea to avoid costly journeys to shore. While likely not used often by ROV pilots, any skill necessary to fix an ROV can be priceless.

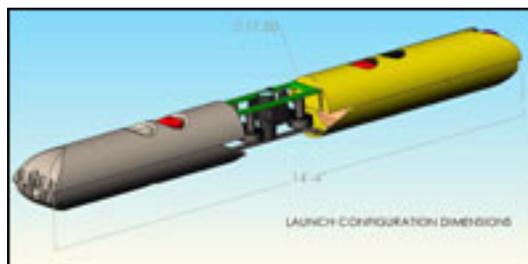
### Related Technology

A very hot subject lately has been that of global warming. In order to make future predictions, data must be meticulously gathered from all parts of the globe. Underwater ROVs can play a large role in such a type of data collection. One such ROV is known as Spray. This venture across the Atlantic starts in Greenland and ends on the coast of Spain. Spray has the ability to measure temperature, salinity, and can even tell scientists about ocean currents in the way it deviates from its path [1]. Researchers hope to deploy hundreds more worldwide, maintaining a constant presence in the world's oceans.



*Spray*

Another ROV shaped much like Nautilus was set to hit Antarctica in March of 2005. The \$700,000 ROV is submarine shaped and set to measure temperature, salinity and 14 other conditions beneath the frozen continent [2]. A group of Northern Illinois University professors hope to study how the underlying ocean melts the ice of Antarctica. This just shows that advances in unmanned submersibles can provide researchers with new information on the subject of global warming.



*Antarctica Exploration*

[1] Popular Science – Posted April 19, 2006

<http://www.popsci.com/popsci/whatsnew/84462eaf4766a010vgnvcm1000004eecbccdrerd.html>

[2] ROV.org Press Releases – Posted March 29, 2005

[http://www.rov.org/pressreleases/mar\\_2005.cfm#Mar29](http://www.rov.org/pressreleases/mar_2005.cfm#Mar29)

### Acknowledgments

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ROV Budget -- Nautilus  
 School -- CATE Center  
 Mentor -- Quenton Hensley

Period  
 From: 7/1/2005  
 To: 5/26/2006

Income / Expense

Date	Description	Income	Expense	Unit Cost	Quantity	Quantity Cost	Balance
9/4/2005	Donation (James Phelan)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	\$100	1	\$100	\$100.00
9/6/2005	Trolley Motor	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$100.00)	1	(\$100)	\$0.00
9/8/2005	W.W. Diving Donation	<input checked="" type="checkbox"/>	<input type="checkbox"/>	\$850.00	1	\$850	\$1,050.00
10/1/2005	6CFT Tank w/ Din Valve	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$160.00)	1	(\$160)	\$890.00
10/1/2005	Cochran 1st stage Din	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$190.00)	1	(\$190)	\$700.00
10/1/2005	Acorn Gauge	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$60.00)	1	(\$60)	\$640.00
10/1/2005	HP Hose (custom)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$40.00)	2	(\$40)	\$600.00
10/1/2005	HP Connector GD	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$60.00)	2	(\$120)	\$480.00
10/1/2005	LP Hose (custom)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$40.00)	4	(\$160)	\$320.00
10/1/2005	80CFT HP Tank	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$190.00)	1	(\$190)	\$130.00
10/1/2005	Trans Fill Whip	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$80.00)	1	(\$80)	\$50.00
11/8/2005	Donation (Technip)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	\$1,500	1	\$1,500	\$1,550.00
11/18/2005	Gearmotor (Beetle B104)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$37.99)	1	(\$37.99)	\$1,512.01
12/1/2005	Cylinders (NCJ2F16-100)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$32.38)	1	(\$32.38)	\$1,479.63
12/2/2006	Cameras	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$152.90)	3	(\$458.70)	\$1,020.93
1/10/2006	Misc Epoxy and Silicone	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$58.56)	1	(\$58.56)	\$962.37
1/10/2006	Misc motors	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$72.18)	1	(\$72.18)	\$890.19
1/10/2006	Cylinders (NCJ2F16-100)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$28.65)	8	(\$229.17)	\$661.02
1/25/2006	Gearmotor (Beetle B104)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$36.24)	2	(\$72.48)	\$588.54
2/1/2006	Donation (Boyer)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	\$200	1	\$200	\$788.54
2/14/2006	Manifold & Tubing	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$76.37)	1	(\$76.37)	\$712.17
2/20/2006	Spray Paint	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$7.76)	1	(\$7.76)	\$704.41
2/22/2006	Stainless steel hinges	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$29.04)	1	(\$29.04)	\$675.37
2/22/2006	Donation (Boyer)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	\$1,000	1	\$1,000	\$1,675.37
3/2/2006	Batteries	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$43.53)	1	(\$43.53)	\$1,631.84
3/3/2006	12 Guage Wiring	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$39.58)	1	(\$39.58)	\$1,592.26
3/3/2006	CAT 5 (30 Meters)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$23.84)	1	(\$23.84)	\$1,568.42
3/3/2006	SMC Airlines	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$63.98)	1	(\$63.98)	\$1,504.44
3/3/2006	6 Inch Pnuematic cylinders	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$30.00)	2	(\$60.00)	\$1,444.44
3/3/2006	PMW Controllers	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$339.44)	1	(\$339.44)	\$1,105.00
3/3/2006	Pnuematic solenoids	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$32.72)	10	(\$327.20)	\$777.80
3/23/2006	Welding	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$100.00)	1	(\$100.00)	\$677.80
3/28/2006	1 5/8" Steel Tube (12")	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$10.00)	1	(\$10.00)	\$667.80
3/29/2006	Misc	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$31.63)	1	(\$31.63)	\$636.17
4/4/2006	Misc	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$40.08)	1	(\$40.08)	\$596.09
4/19/2006	Task Materials	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$23.31)	1	(\$23.31)	\$572.78
4/26/2006	Small Johnson Motors	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$6.48)	3	(\$19.45)	\$553.33
5/2/2006	Misc	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$32.76)	1	(\$32.76)	\$520.57
5/8/2006	Cylinders (NCJ2F16-100)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$27.07)	5	(\$135.34)	\$385.23
5/10/2006	Cobalt Drill set	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$55.03)	1	(\$55.03)	\$330.20
5/10/2006	Tool boxes	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$139.97)	1	(\$139.97)	\$190.23
5/22/2006	Rubber Materials	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$16.91)	1	(\$16.91)	\$173.32
5/26/2006	Aluminum Angle	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	(\$39.57)	1	(\$39.57)	\$133.75
5/15/2004	2004 Innovation First Sys.	<input type="checkbox"/>	<input type="checkbox"/>	\$2,249	1	\$2,249	\$133.75
5/15/2004	Monitors	<input type="checkbox"/>	<input type="checkbox"/>	\$150	3	\$450	\$133.75

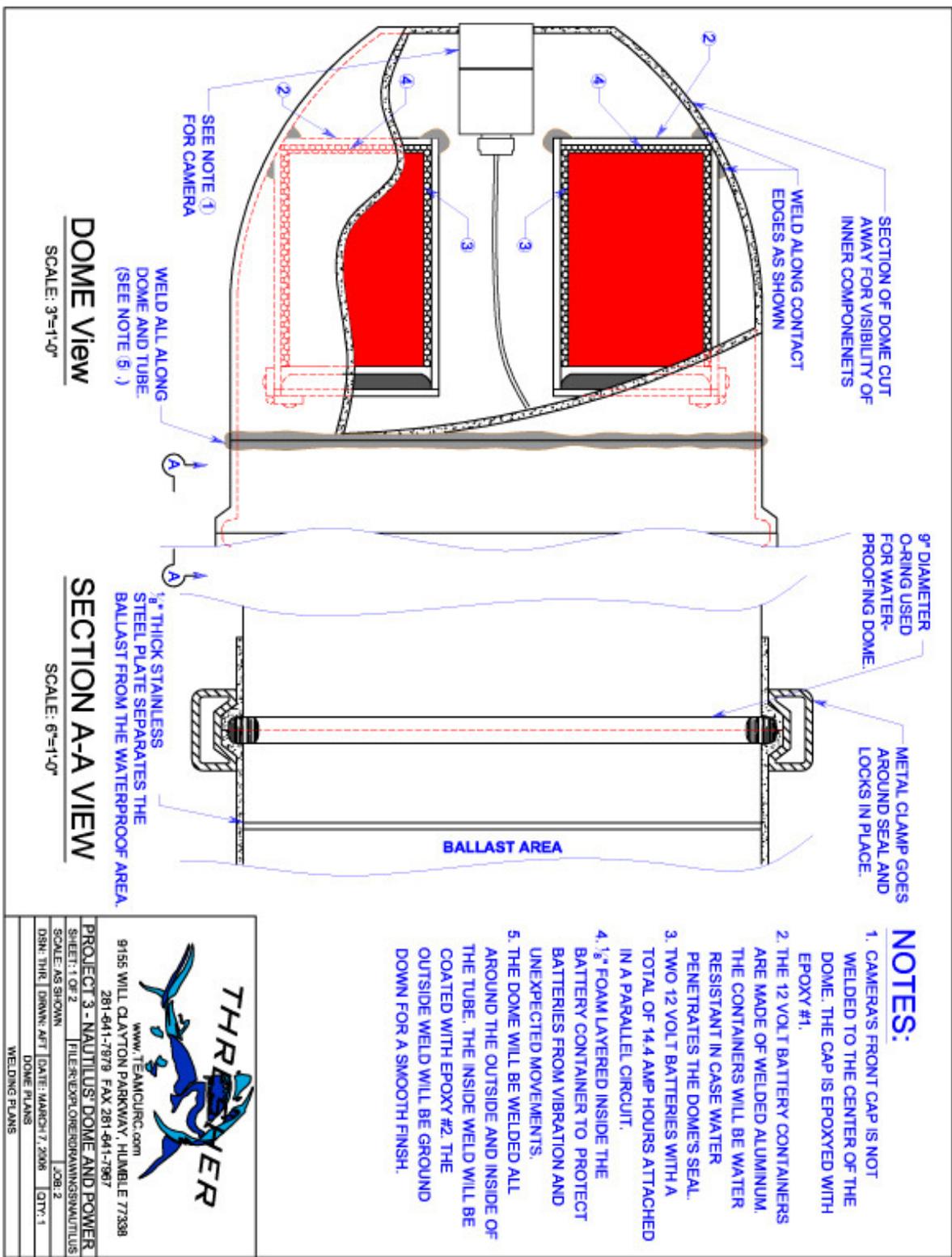
**TOTAL :** \$6,415.25

**Actual Spent On Rov :** \$3,716.00

Donated By Imaging Inc.	Voice Activation Components	\$300	1	\$300
Donated By Boyer Inc.	Stainless Steel Materials	\$300	1	\$300
Donated By Baro Company	Limit Switch	\$150	1	\$150
Donated By The C.A.T.E	Hotel Rooms (2 days)	\$200	3	\$600
Donated By The C.A.T.E	Meals	\$15	10	\$150

TOTAL AMOUNT FOR DONATED ITEMS \$1,500





**NOTES:**

1. CAMERA'S FRONT CAP IS NOT WELDED TO THE CENTER OF THE DOME. THE CAP IS EPOXYED WITH EPOXY #1.
2. THE 12 VOLT BATTERY CONTAINERS ARE MADE OF WELDED ALUMINUM. THE CONTAINERS WILL BE WATER RESISTANT IN CASE WATER PENETRATES THE DOME'S SEAL.
3. TWO 12 VOLT BATTERIES WITH A TOTAL OF 14.4 AMP HOURS ATTACHED IN A PARALLEL CIRCUIT.
4. 1/2" FOAM LAYERED INSIDE THE BATTERY CONTAINER TO PROTECT BATTERIES FROM VIBRATION AND UNEXPECTED MOVEMENTS.
5. THE DOME WILL BE WELDED ALL AROUND THE OUTSIDE AND INSIDE OF THE TUBE. THE INSIDE WELD WILL BE COATED WITH EPOXY #2. THE OUTSIDE WELD WILL BE GROUND DOWN FOR A SMOOTH FINISH.

**DOME View**

SCALE: 3"=1'-0"

**SECTION A-A VIEW**

SCALE: 6"=1'-0"



**THRYSMER**

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 281-641-7878 FAX 281-641-7987

**PROJECT 3 - NAUTILUS' DOME AND POWER**

SHEET: 1 OF 2 FILE: R:\EXPL\ORNDHAM\NAUTILUS  
 SCALE: AS SHOWN JOB: 2  
 DSN: THR | DRAWN: AJT | DATE: MARCH 7, 2008 | QTY: 1  
 WELDING PLANS



