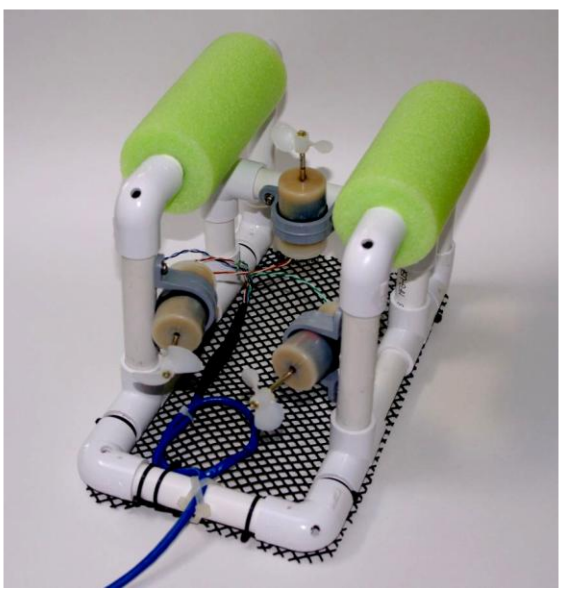
Version 2010-02

SeaPerch
Remotely Operated Vehicle (ROV)

Construction Manual
Standard Assembly Procedures



December 2010

Revolutionary Research . . . Relevant Results

The SeaPerch educational program was created by Harry Bohm and Vickie Jensen and published in their 1997 book "*Build Your Own Underwater Robot and Other Wet Projects*." The initial curriculum was developed by the Massachusetts Institute of Technology, and this version of the SeaPerch Construction Manual was provided under the Office of Naval Research National Naval Responsibility for Naval Engineering (NNRNE) Outreach initiative.

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Introduction

SeaPerch ROV Program Overview

What is SeaPerch?

SeaPerch is an *educational tool* – a *fun, hands-on learning activity* and a *curriculum* that can be enjoyed by a wide range of students, ranging from late elementary school through high school and even introductory college programs. The curriculum is designed to meet many of the national learning standards identified by the United States Government. Often applied at the middle school (or junior high school) level, SeaPerch is challenging, creative, and gets kids excited about science and technology. The SeaPerch program is sponsored through the National Naval Responsibility for Naval Engineering (NNRNE) Outreach effort, with the goal of helping to inspire the next generation of naval architects and marine, ocean, and naval engineers.

A SeaPerch is an *underwater robot* known as a “remotely operated vehicle,” or “ROV.” Students learn best by *doing*, and during the SeaPerch project, they will completely assemble an inexpensive, yet functional ROV, test it, and then operate it underwater. The experience will enable them to explore science and technology both in the classroom and in a pool, or, for some, in natural marine environments.

The ROVs are built from kits comprised of low-cost, easily-obtained components. Students often work in small teams to assemble their vehicles, usually over a period of several weeks. From the classroom activities during SeaPerch construction through in-water application of the ROV, they will have opportunities to learn about various subjects including mathematics, robotics, biology, oceanography, physics, and history, as well as valuable problem solving and teamwork skills.

The SeaPerch program is structured to provide free training to help teachers more effectively lead students through the variety of interdisciplinary activities involved. Within one project, a number of concepts required for their grade level can be efficiently addressed, with the further benefit of exposing the students to additional concepts that may not otherwise be easily covered in their standard curriculum. Mentors from government and industry are often available to support and reinforce the lessons as well as to assist with the SeaPerch construction and application activities in the classroom.

Program History

The SeaPerch Remotely Operated Vehicle (ROV) educational program was inspired by the 1997 book, *Build Your Own Underwater Robot and Other Wet Projects* (ISBN 0-9681610-6), by Harry Bohm and Vickie Jensen. In 1997, Dr. Tom Consi introduced SeaPerch to the Ocean Engineering program at the Massachusetts Institute of Technology (MIT), in order to interest more students in majoring in Ocean Engineering. Realizing the potential of SeaPerch to reach younger students, the MIT Sea Grant (MITSG) College Program created the SeaPerch initiative in 2003, sponsored by the Office of Naval Research. Dr. Chryssostomos Chryssostomidis, MITSG Director, and Brandy Wilbur, Educational Coordinator, were responsible for the effort at MIT Sea Grant.

In late 2007, Office of Naval Research (ONR) tasked the *Society of Naval Architects and Marine Engineers (SNAME)* to research ways of expanding and enhancing the SeaPerch initiative as part of the ONR National Naval Responsibility for Naval Engineering Outreach effort.

Original SeaPerch ROV Manual Development

The SeaPerch Construction Manual was originally developed by MITSG, which modified the instructions for building a SeaPerch from those found in *Build Your Own Underwater Robot and Other Wet Projects* so that the ROV would be simpler and cheaper to build in the classroom. MITSG created a three-unit manual with detailed, step-by-step instructions and a complete list of needed components and tools.

The MITSG SeaPerch manual has been revised several times in recent years as new vehicle components or updated assembly methods were implemented for the program.

Updated Information in This Version of the SeaPerch Manual

Revised Standard SeaPerch Assembly Instructions

This 2010 manual revision builds upon the extensive work of the MITSG developers by utilizing the experience gained through years of SeaPerch program use by educators around the country, incorporating the latest recommended construction techniques, and providing additional information to help teachers and students build and use SeaPerch ROVs. While much of this revision's technical content is aligned with the instructions found in previous versions, its revised graphics and content adjustments are designed to provide additional detail for the more complex construction techniques and to facilitate high-quality reproduction in either monochrome or color. The addition of sign-off boxes for the construction steps will better enable students, teachers, and classroom volunteers to monitor completion progress.

The following summarizes the significant changes from previous manuals:

- Consolidation of safety information and added program background information at the front of the manual, to better enable a discussion of all safety aspects of the project during a classroom session early in the project,
- Revised graphics to clarify electrical wiring and to show recommended construction techniques,
- Minor changes to some recommended construction methods to avoid occasional assembly difficulties that have been identified through experience in a variety of classroom programs,
- Revised numbering for major assembly procedures and for the document's pages to enable easy future substitution of optional or enhancement procedures for standard SeaPerch procedures,
- Addition of separate manual sections for initial testing and ballasting the ROV as well as for use and cleaning of the vehicle,
- Addition of an appendix with troubleshooting hints,
- Addition of a separate construction manual supplement document offering a variety of proven construction options and enhancements, and
- Replacement of the previous Unit 3, for the hand-wired control box, with a new Unit 3 for a printed-circuit-board-based control box. The previous Unit 3 is still available as an option, included in the supplement.

Expanded Testing and Operating Information

Because proper ballasting and pre-deployment testing are essential for successful in-water operation of SeaPerch ROVs, the instructions and other information and suggestions for these activities are now in a separate, expanded section of this manual entitled "Testing and Ballasting the ROV."

In addition, operational recommendations, some helpful hints, application ideas, and post-run vehicle cleaning instructions have been placed in a new, final, manual section entitled "Using the SeaPerch ROV."

Added Appendix Containing Troubleshooting Hints

When the initial ROV testing process identifies a problem, it is best for students to be allowed to try to solve it. However, when help is needed, and before taking drastic steps to change ROV parts or re-wire a circuit, ROV builders should refer to the Appendix, *"Troubleshooting Your SeaPerch ROV,"* which suggests solutions to common problems. This appendix is not necessarily intended to be included in the student copies of the construction manual; rather, it is provided for the teacher's reference and for classroom use at the teacher's option.

Added Supplement for Construction Options and Enhancements

Occasional challenges in obtaining recommended components, special technical requirements, and local budget constraints have inspired creativity and resourcefulness among SeaPerch program implementers, many of whom have found it useful or necessary to identify alternatives for various aspects of their ROVs' construction. In order to provide such needed flexibility while still maintaining a standardized set of assembly instructions that can be fielded nationwide, the manual's format has been updated to enable easy *substitution* of proven and approved procedures to implement construction "*options*," in place of corresponding standard procedures, and *addition* of new procedures for construction "*enhancements*" to add capabilities to the ROV. These optional and enhancement procedures are contained in a separate document, ***"SeaPerch ROV Construction Manual Supplement – Options and Enhancements – Version 2010-02,"*** which may be downloaded from the **SeaPerch website.* It contains a number of alternate and added procedures that have been found to be useful to improve ROV performance, simplify the build process, and/or lower costs.

The supplement's construction *options* result in relatively minor changes to the SeaPerch ROV, such as implementing different propeller mounting techniques, alternate flotation, or a different type of switch. Its construction *enhancements* add capabilities beyond those of the standard SeaPerch vehicle. Examples are addition of a stiffener for the bottom payload net, a payload capture net, or a front accessory attachment fixture. The added procedures for installing the construction enhancements may involve changes to the standard vehicle build instructions, so some will also provide substitute manual pages in addition to the page or pages with the added procedures for installing the enhancements. Some enhancements are also grouped together with options due to the nature of the improvements.

Each option or enhancement section in the supplement includes specific instructions for substituting the changed pages into the construction manual prior to reproduction for student use, to provide a technically consistent manual for use in the classroom. *The supplement's added or replacement pages are designed for use only with this version of the manual, not previous or later versions. Users of the supplement should always verify that its version number matches that of the construction manual before inserting any of its procedures into the manual.*

More options and enhancements will likely be developed from time to time as clever students and their teachers continue to invent and demonstrate new ways to build SeaPerch ROVs. By using the supplement approach and the new page numbering scheme, future new procedures can easily be added to the supplement document and then to individual classroom manuals when needed, without impacting the content of the standard build manual.

Future new procedures will need to go through a short demonstration and approval process before being added to the master manual supplement document that is maintained at the **SeaPerch website* for downloading as needed.

* SeaPerch Website: www.seaperch.org

The SeaPerch Assembly Process

Three Individual Building Units

This manual contains three building units, for the vehicle frame, the thrusters, and the control box. They may be used as a single manual, as assembled here, or they can be removed from this manual and placed into the SeaPerch classroom integration manual at the separate locations indicated therein. In either case, the three unit manuals should always be used *in order*.

Unit 1 is a good confidence-builder for the students who have had little experience working with tools, and it gets the project going quickly. They will measure, cut, and drill pipe and fittings and then assemble the parts with rapid results, as the work in Unit 1 provides a recognizable ROV after just a few class periods.

Unit 2 then introduces basic wiring and soldering skills through the work with the motors for the thrusters. These skills are important for them to have when building the control box in Unit 3.

Finally, Unit 3 involves the students in more advanced wiring and soldering activities and provides an opportunity for them to work with a variety of tools and components used in electrical and electronic technologies.

Recording Progress

The checklist-style boxes next to each numbered step in the manual are intended for the students to write their initials confirming proper completion of each step as they progress through the project. Multiple sign-off boxes are provided whenever a step needs to be repeated, such as during assembly of the three thrusters. Keeping track in this way is important to avoid accidentally skipping steps, but it also greatly helps the teacher and classroom volunteers (as well as other team members, if working in teams), to know how far the student or team has progressed in the building process.

Testing and Adjustments

The last steps in the SeaPerch ROV construction process are to conduct some basic electrical tests, prior to connecting the battery, and performing some simple vehicle checks and adjustments prior to its first operational use. The initial testing in the classroom or lab should help in finding any lingering wiring or thruster-related issues, and the checks recommended before operational use should help to ensure a successful operational experience for all students.

Tools and Materials

Each procedure in this manual identifies the needed components and tools only generically, rather than giving specific descriptions or specifications for each item. Detailed parts, tools, and materials lists are maintained as separate documents for use in procuring the items needed to build the ROVs. This approach allows these assembly instructions to remain applicable even when the specifics of individual components change, such as when a slightly different "12-volt DC motor" is used or when a similar component must be substituted due to availability or cost issues.

SeaPerch ROVs are often built by a team of two or three students. For efficiency during the build process, each team should have its own set of basic tools, including a screwdriver, flush-type wire cutter, needle-nose pliers, wire stripper, and soldering iron. Tools such as standard pliers, cable jacket strippers, pipe cutters, electric drills, and others that are not used on a daily basis can be easily shared among a number of teams. A key aspect of planning for classroom tools is to arrange to obtain enough to ensure that students are not delayed during the build process waiting for availability of needed tools.

Manual Printing Considerations

Please note that this manual is set up for ***double-sided*** ***(duplex) printing****, with a number of extra blank pages inserted to force all procedures to start on the front side of a sheet.* Besides some savings in paper, this approach allows any individual procedure from the supplement (or a future updated version of a standard procedure) to be swapped into the manual as needed without affecting an adjacent procedure or the overall page numbering. To further conserve paper, the *Introduction* section of the manual may be left out of the student copies; however, the Safety Overview should always be included.

The intent, in providing the manual in double-sided format, is to enable easy creation of double-sided student manuals, either by directly printing copies on a duplex printer or by printing a single-sided or double-sided master document to use to reproduce student manuals on a two-sided photocopier (or by a production printing service).

If single-sided reproduction is desired, simply print the manual on a single-sided printer, pull out the blank sheets, and then use that master document to reproduce the single-sided student manuals using a photocopier (or printing service).

Important: If you will be inserting any of the alternate procedures provided in the supplement, you must print the reproduction master manual SINGLE-SIDED, including the blank pages. *Then it can be reproduced either double-sided or single-sided using a photocopier as described above after inserting the optional or enhancement procedures from the supplement.*

Safety Overview

Protective Eyewear

Students, teachers, and classroom helpers should wear protective eyewear at all times when building SeaPerch ROVs. Although some procedures do not usually involve significant eye hazards, the students often work close to others, who at any time may be performing more potentially hazardous steps. Activities such as soldering, cutting, drilling, applying adhesives, and potting thrusters can easily cause materials or parts of broken tools to fly significant distances. Below are some examples.

- **<u>Soldering</u>:** Solder contains rosin flux in its core to help clean the electrical connections and help the solder to adhere to the metal properly. Small amounts of flux can occasionally pop out of the melting solder and sometimes travel far enough to reach the eye of the person soldering, or even someone nearby. Protective eyewear is essential for everyone in the area.

- **<u>Potting Thrusters with Wax</u>:** Melting wax tends to stay in the melting container or where it is poured. However, there is one step in the potting process that can occasionally cause wax to fly a significant distance, often reaching a ceiling, wall, or floor, and it therefore presents a risk for nearby eyes (as well as skin and clothing). This step is the one in which the lid is pushed onto the thruster housing. If performed too quickly, it can result in wax squirting out of the hole in the lid (where the wires pass through). Quick, hard pressing of the lid is common, as students may excitedly put the lid in place before the wax hardens or spills.

  Figure S-1 shows an actual result (held by a forever-committed safety-glasses wearer).

Figure S-1. *Wax Squirted onto a Student's Safety Glasses*

Materials Handing Safety

Builders of SeaPerch ROVs should be made aware of a few potential hazards related to some of the materials used. The following activities require careful handling of materials.

- **Soldering:** Many common types of solder contain lead along with tin and sometimes other metals. Solder should never be placed in one's mouth, and hands should always be washed after working with solder. Breathing the smoke from the melting flux (from inside the solder) should be avoided.
- **Potting Wax:** Bowl ring wax is made from "petrolatum" – basically the same type of material that, when more refined, becomes common petroleum jelly. It is safe to handle when cooled, but quite sticky, and difficult to remove if it solidifies on clothing. Hands should be washed with warm water and soap after handling the wax. Obviously, it must not be ingested. Wearing eye protection, as noted earlier, is essential.
- **Adhesives:** Adhesives, particularly two-part epoxy, "super glue" type adhesives, and PVC primer and cement (some versions of SeaPerch ROVs don't use all of these types) can present hazards to skin as well as eyes. Wearing eye protection and gloves is recommended when working with any adhesives, and hands should always be washed after working with such materials.
- **Protection of Our Environment:** All waste or scrap materials from the SeaPerch ROV construction process should be disposed of properly, in accordance with manufacturers' recommendations and school policies. Recycling of usable excess materials and disassembled vehicles is encouraged for environmental protection and cost avoidance considerations. Most of the ROV components can be re-used in building future vehicles or as spare parts.

Safety While Using Hand Tools

Hand tools such as screwdrivers, pliers, and wire cutters can be used safely when operated as intended. Examples of activities to avoid are below.

- **Screwdrivers:** Screwdrivers should not be used to pry or make holes. Care should be exercised while inserting or removing screws to avoid having the screwdriver tip slip off of the screw head and poke into a body part or damage a table top. The size of the screwdriver tip should be appropriate for the size of the screw.

- **<u>Wire Cutters</u>:** Nothing should be cut with small wire cutters other than copper wire or plastic tie wraps. Never cut pipe or metal fasteners, which could ruin the cutting edges. Be careful when handling wire cutters to avoid being cut or poked by their sharp cutting edges or tips.

- **<u>Needle-Nose Pliers</u>:** Small, thin, needle-nose pliers should be used only to help place wires onto motor terminals (or switch terminals, for some options), as *their jaws can bend or break if used for tightening tie wraps or any prying activity*. Large needle-nose pliers or standard club-nose pliers are better for tightening tie wraps. Needle-nose pliers should also *not* be used for tightening nuts, as the jaws are not parallel like the edges of a nut, so they can easily slip off. Use club-nose pliers or a small wrench instead to tighten the nuts on switches.

- **<u>PVC Pipe Cutters</u>:** The blades on typical PVC pipe cutters can be damaged easily if used to cut anything except PVC pipe, or if used incorrectly. When squeezing the tool to cut pipe, work slowly so that the blade has time to move through the material. Do not twist the tool, and always keep fingers away from the sharp blade. Store the tool in its closed position.

Safety While Drilling

Drilling is perhaps the most potentially hazardous activity involved in the SeaPerch project. Some important safety considerations are as follows.

- **<u>Get Permission to Use Power Tools</u>:** Always get the teacher's permission and adult supervision before using a drill or other power tool.

- **<u>Installing and Removing Drill Bits</u>:** Install and remove drill bits from the chuck of a drill motor or drill press manually, not by energizing the drill motor to spin the chuck closed. Make sure that the bit is inserted straight into the chuck and that it is tight in the chuck before use; spin it briefly to check before drilling.

- **<u>Holding Objects Being Drilled</u>:** Never try to hold an object being drilled in your hand alone. Instead, it should be always be either held in a vise (or clamp), firmly held down by hand onto a solid surface (if that surface will not be subjected to possible damage during the drilling process), or attached firmly to an object that can be safely held by hand. This keeps the object steady, prevents it from spinning and hurting your hand if the drill bit should bind, and keeps your fingers away from the bit while drilling. Never place a body part in the path of a drill bit. Always think about what is <u>*behind*</u> the object being drilled (particularly body parts and tabletops!). If using a drill press, make sure that the object is held firmly and fingers are not near the drill bit.

Safety While Soldering

- **<u>Soldering Uses High Heat</u>:** All soldering involves a very hot soldering iron as well as temporarily-hot electrical connections, which take a few moments to cool after soldering. Do not touch the tip area of a soldering iron, even when it appears to be off or unplugged, as it does not look different when it is hot compared to when it is cold, and it can remain hot for 10 minutes or more after use. Connections should be allowed to cool after soldering before they are moved or touched. As noted earlier, always wear eye protection, even when just in the same area as someone who is soldering.
- **<u>Keep the Soldering Iron in Its Holder When Not in Use</u>:** Great care should be taken to place the soldering iron back into its holder whenever it is not in use for soldering. Never just set it down on a tabletop, where it could burn anything it touches.

Safety While Potting Motors for Thrusters

SeaPerch ROV thrusters are assembled by potting small electric motors in wax. The following safety issues should be reviewed with everyone involved in the potting process.

- **<u>Melting Wax</u>:** The standard SeaPerch wax-melting approach is to warm "toilet bowl ring" wax in a heated pot or a metal container placed in a hot water bath, usually employing an electric skillet to heat the water (and wax). <u>*It is important to always monitor the temperature of the wax or use a water bath (and NOT let all of the water evaporate - keep adding water to maintain it at about ½" to 1" deep). Otherwise, the wax can get EXTREMELY hot, even hot enough to melt the plastic thruster housings*</u>. Fortunately, bowl ring wax has a relatively low melting temperature, but it must still be heated to about 150 degrees Fahrenheit (F) for proper pouring. Although its flash point is over 500 degrees F, the manufacturers usually recommend not exceeding 200 degrees F, so you should try to keep the wax at about 180 degrees F or below (using a thermometer is best, as temperature control knob markings may be inaccurate). Obviously, if the wax is allowed to get too hot, skin burns are possible; more sensitive skin or large quantities of hot wax may cause minor burns. In case of a burn, quickly rinse the area with plenty of cold water and seek medical attention. Care should be taken to prevent getting the hot wax onto skin or clothing. Wearing a protective smock or apron and gloves is recommended. Pour the wax slowly and carefully to avoid spills and potential burns.

- **<u>Watch Out for Squirting Wax</u>:** During the final step of thruster potting, when the lid is placed onto the thruster housing, melted wax can squirt out of the small hole in the lid where the wires pass through. If the lid is pressed quickly into place, wax can even squirt as high as the ceiling or onto nearby walls and people. Placing a paper towel over the lid and pressing slowly is recommended to avoid the wax-squirting problem. Protect nearby walls and floor areas with paper or tarps. Obviously, everyone in the area should be wearing eye protection.

Safety With Electricity and Batteries

The low-voltage (12 volts, direct current (DC)) battery power source used with SeaPerch ROVs is relatively safe and well-proven in students' hands. However, they should be cautioned about potential problems from short-circuits as well as electrical safety issues in general.

- **<u>Battery Short-Circuit Hazard</u>:** Although the battery can be used quite safely when it is connected properly to the ROV, it can be damaged, cause wires to melt, or even start a fire if its positive and negative terminals are connected directly together. That is called a "short circuit," and it will allow the battery to essentially discharge all of its stored energy at once. Besides resulting in sparks when such an improper connection is made, the wire or metal object shorting across the terminal will immediately become extremely hot and may even melt. That could obviously cause burns or ignite an object in contact with the shorting material. Never connect anything between the battery terminals except an appropriate electrical "load" such as the ROV circuitry, through its power cord (with a fuse in the circuit). Be careful to keep the battery terminals covered or away from all wires and metal objects when not in use. Do not connect the ROV circuitry or components to the battery until instructed to do so.

- **<u>Avoid Creating Other Short Circuits During ROV Construction</u>:** When wiring circuits or conducting tests, take care to avoid unintended connections or accidental short circuits. While handling partially or fully completed circuits, ensure that wires do not move and touch together where they should not. Always check the circuitry carefully and conduct the recommended tests before connecting the battery.

- **<u>General Electrical Safety</u>:** When working with electrical circuits with power applied, do not allow any body parts to "become part of the circuit." In other words, do not touch both the positive and negative terminals of a battery with your hands or touch a battery terminal with one hand and part of the circuitry with the other. Make sure that all switches are in their off positions while connecting or disconnecting the battery, and connect just one power wire at a time.

Version 2010-02

Unit 1

SeaPerch
Remotely Operated Vehicle (ROV)

Assembly of Subsystem One
The Vehicle Frame

December 2010

The SeaPerch educational program was created by Harry Bohm and Vickie Jensen and published in their 1997 book "*Build Your Own Underwater Robot and Other Wet Projects*." The initial curriculum was developed by the Massachusetts Institute of Technology, and this version of the SeaPerch Construction Manual was provided under the Office of Naval Research National Naval Responsibility for Naval Engineering (NNRNE) Outreach initiative.

Unit 1 Assembly of Subsystem One *The Vehicle Frame*

Tools and Materials Needed

Tools	Materials	
Eye Protection (Always Worn)	5' (1.5 m)	½" PVC Pipe
Ruler	10	½" PVC Elbows
Marker or Pencil	4	½" PVC Tees
PVC Pipe Cutter (or Saw)	15" (38 cm)	Plastruct H-column
#2 Phillips Screwdriver	2	Floats
Flush Wire-Cutting Pliers	3	Thruster Mounts (1" Conduit Clamps)
Drill (or Drill Press)	6	#6 x ½" Phillips Sheet Metal Screws
¼" Drill Bit	6	#6 Washers (Optional)
3/32" Drill Bit	1	12" x 6.5" (31 x 17 cm) Payload Net
Vise or Clamp	8	6" Tie Wraps (Zip Ties)

Time Needed to Complete Unit 1

Total Construction Time:

Unit 1 usually requires at least 2 to 3 hours to complete, if the required raw materials and components are already sorted into kits for each ROV. When materials must be cut from standard lengths of pipe, rolls of payload netting, etc., plan on up to an additional hour to complete the ROV frame. Have some extra ½" PVC pipe on hand, as pipe-cutting errors sometimes occur.

Typical Allocation of Class Periods:

For standard class periods of approximately 50 minutes each, including any necessary clean-up time, plan for at least three periods to complete this unit.

- 1 period to cut the PVC pipe and drill the holes in the PVC elbows.
- 1 period to assemble and tighten the frame and attach the payload net.
- 1 period to drill holes and attach the thruster mounts.

Procedure 1.1 – Cut the Frame Parts

Tools:

Ruler

Marker (or Pencil)

PVC Pipe Cutter (or Saw)

Materials:

5' (1.5 m) ½" PVC Pipe

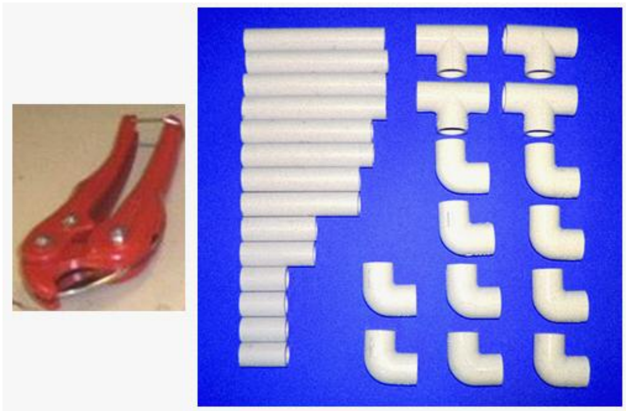

Figure 1.1-1: *PVC Pipe Cutter and Cut PVC Pipe Sections, Elbows, and Tees*

Pipe Cutting Tips:

PVC pipe can be cut in many ways, each of which has its own considerations:

Ratchet Style Pipe Cutters are the easiest and safest option. To open the cutter, pull the handles FAR apart. Then click them closed through the pipe by pumping the handles together and apart.

Non-ratchet Pipe Cutters (flat-blade style, not the roller-blade type) are a cheaper alternative, but more difficult to use. Place the pipe in the cutter, push down LIGHTLY, and turn the cutter around the pipe slowly, applying light pressure, until the blade cuts through all the way. As with all pipe cutters, proceed slowly, giving the cutter time to do its work.

Hack Saws and other hand saws can cut through PVC, but these are the most labor intensive options.

Band Saws are large pieces of shop equipment, and they can be very dangerous. Make sure to get your teacher's permission and supervision before using one.

Construction Steps:

❑ **1.** From a cleanly-cut end of a length of ½" pipe, measure and cut the pieces listed below. Cut the *longest* pieces *first*, in case a mistake is made (smaller pieces may be cut from a longer piece that is accidentally cut too short). You will find the old adage, "measure twice; cut just once," to be the best advice here. Try to cut straight, so that the ends of each piece are square with the sides, but don't worry if they are not perfect.

- ❑ Four Pieces – 5" (12.7 cm) long
- ❑ Two Pieces – 4½" (11.4 cm) long
- ❑ Two Pieces – 4" (10.2 cm) long
- ❑ Two Pieces – 2½" (6.4 cm) long
- ❑ Four Pieces – 1½" (3.8 cm) long

❑ **2.** Write the length on each piece to keep track of cuts and to identify them later.

Procedure 1.2 – Drill the Drain Holes

Tools:

Hand Drill or Drill Press

¼” Drill Bit

Vise or Clamp

Materials:

10 ½" PVC Elbows

Figure 1.2-1: *Drain Hole Drilled in a PVC Elbow*

NOTE: Drain holes are needed in the PVC elbows in order to let air escape and allow water to fill the frame when you put your SeaPerch ROV into the water, and also to allow water to drain when you take the SeaPerch out. Preventing air from being trapped within the frame will enable the vehicle to have consistent, repeatable buoyancy.

Drill Safety Reminders:

Drills can be dangerous pieces of equipment, but they are not difficult to operate properly. Always get your teacher’s permission and supervision before using a drill or other power tool. **Always wear safety glasses when building your SeaPerch ROV (and when using any hand or power tool).**

It is good practice to secure the object you are drilling in a vise or clamp before drilling. This keeps it steady, prevents it from spinning and hurting your hand if the drill should bind, and keeps your fingers away from the sharp drill bit while drilling. Be aware of what is behind the object you are drilling, to avoid extra holes in table tops or in other undesired places! If you do not have a vise or clamp available, push the elbow onto one end of a long (6” or more) piece of PVC pipe, and hold the pipe while drilling the hole. ***DO NOT drill the elbow while holding it in your hand!***

Construction Steps:

☐ **1.** Inspect the PVC elbows to see if they have ¼” holes drilled in them (such as from a previous use). If they all have ¼” holes, skip to Procedure 1.3.

☐ **2.** Secure a PVC elbow in a vise or clamp (or mount it on the end of a 6"-to-12" length of extra ½" PVC pipe, and use the pipe as a handle while drilling).

☐ **3.** Drilling from the <u>*interior*</u> of the elbow outward works best, as the drill bit can easily slip off of the rounded exterior corner of the elbow. If you choose to drill from the outside, drilling a "pilot hole" first, using the 3/32" drill bit, will make it easier to drill the 1/4" hole without slipping. Place the ¼" drill bit in the drill (or drill press), and drill a hole in the corner of the elbow, as shown in Figure 1.2-1.

☐ **4.** Repeat Steps 2 and 3 for other PVC elbows that don’t have the ¼” holes.

Procedure 1.3 – Assemble the Vehicle Frame

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Tools:

None

Materials:

14 Cut Pieces of ½" PVC Pipe from Procedure 1.1

10 ½" PVC Elbows with Holes Drilled from Procedure 1.2

4 ½" PVC Tees

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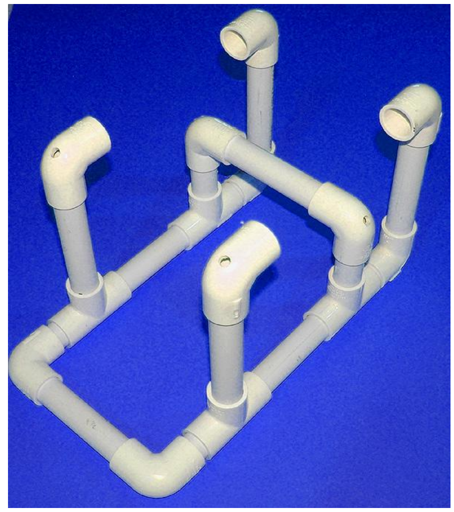

Figure 1.3-1: Assembled Vehicle Frame

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Construction Steps:

☐ **1.** Assemble the frame using the PVC parts as shown in Figure 1.3-2 below. *Do not glue any of the connections.* Orient the elbows that are near the top of the vehicle such that their holes point more upward than downward, to let air escape when the ROV is placed in the water. Orient those at the bottom such that their holes point more downward, to let the water flood in and out easily.

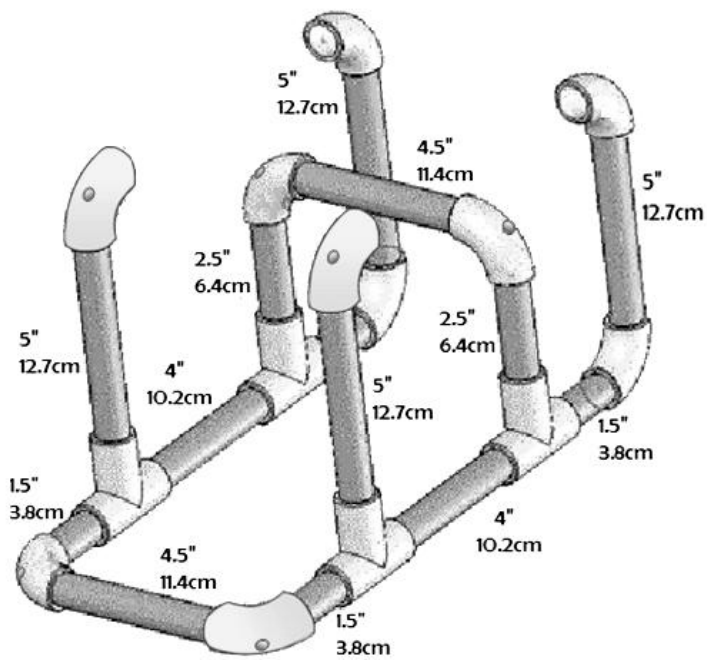


Figure 1.3-2: Frame Assembly

Procedure 1.4 – Install the Floats and Tighten the Frame

Tools:

PVC Pipe Cutter (or Saw)

#2 Phillips Screwdriver (Optional)

Materials:

Assembled Frame

15" (38 cm) Plastruct H-column

2 Floats

PVC Pipe Scraps

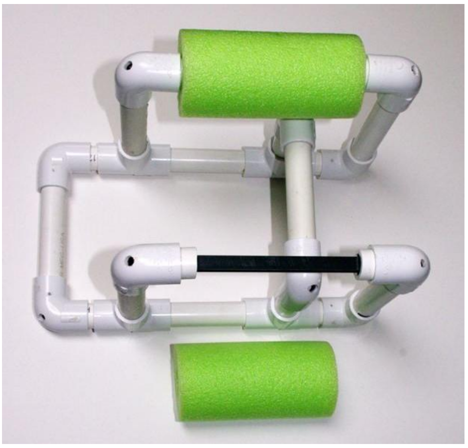


Figure 1.4-1: *H-column Assembly for Floats*

NOTE: Although use of PVC adhesive is not desired when assembling the frame, the pipe sections must still be fit together tightly in order for the ROV to maintain its shape.

Construction Steps:

☐ **1.** Cut the 15" (38 cm) Plastruct H-column into two 7½" (19 cm) pieces.

☐ **2.** Cut four ¾" (2 cm) pieces of PVC pipe from your pipe scraps.

☐ **3.** Insert one of the ¾" (2 cm) PVC pipe pieces into the open end of each of the four PVC elbows on the top of your vehicle.

☐ **4.** Insert an H-column through each of your floats and install the assemblies between each top pair of PVC elbows, as shown in Figures 1.4-1 and 1.4-2.

☐ **5.** With the frame placed on a tabletop, push down hard on all parts of the vehicle frame, from all sides, so that the PVC fittings and pipe sections all fit together very tightly, and so that the H-columns cannot fall out. *Be sure to press HARD, or use the handle end of the Phillips screwdriver to firmly tap on all elbows until the ends of the pipe sections bottom out inside the pipe fittings*. Adjust the sides and the bottom of the frame as needed to square up the vehicle.

Figure 1.4-2: *H-column Float Support Assembly*

Procedure 1.5 – Attach the Thruster Mounts

Tools:

Marker (or Pencil)
Drill
3/32" Drill Bit
#2 Phillips Screwdriver

Materials:

Vehicle Frame
3 Thruster Mounts
6 #6 x ½" Phillips-Head Sheet Metal Screws
6 #6 Washers (Optional)

Figure 1.5-1: *Thruster Mount Placement*

Thruster Mounting Tips:

Two types of common conduit clamps are typically used for thruster mounts, metal and plastic, and they are of slightly different sizes. The better-fitting plastic type are shown in the photo above, but the metal clamps are similar and will work acceptably if the instructions in Procedure 2.8 (later) are followed. For now, don't worry about where, around the circumference of the pipe sections, you attach the three thrusters' mounts. Since we do not glue the joints in the PVC frame, we can change the angles of the mounts later by simply turning the pipe in its joints using a pair of pliers. It is easier to drill and attach the thruster mounts on the back (outside) of the frame… we'll adjust them later.

This is a good time to think about how the angle of the thrusters affects the performance of the ROV. What angles will get you the best forward and backward thrust? What angles will get you the best turning ability? What is the best compromise for your mission needs?

Construction Steps:

❑ ❑ ❑ **1.** Hold a thruster mount against the frame in the three locations shown in Figure 1.5-1, and, using a marker or pencil, mark the vehicle frame through the holes in the thruster mounts. Centering the mounts between the joints on the pipe is more important than placing them at a specific angle around the pipe (they can easily be turned later).

❑ **2.** Using the 3/32" drill bit, drill holes through the six marks on the frame.

❑ ❑ ❑ **3.** Using #6 screws and washers (washers are optional if the heads on your screws are large enough that they will not pass through the holes in the thruster mounts, and if the thruster mounts are metal or hard plastic). *LOOSELY* attach the thruster mounts to the frame. **DO NOT over-tighten the screws and strip the holes in the PVC pipe!!** You will be removing the mounts later anyway to install the thrusters in them.

Procedure 1.6 – Attach the Payload Net

Tools:

Scissors

Pliers

Flush Wire-Cutting Pliers

Materials:

Assembled Vehicle Frame

12” x 6.5” (31 x 17 cm) Payload Net

8 6” Tie Wraps (Zip Ties)

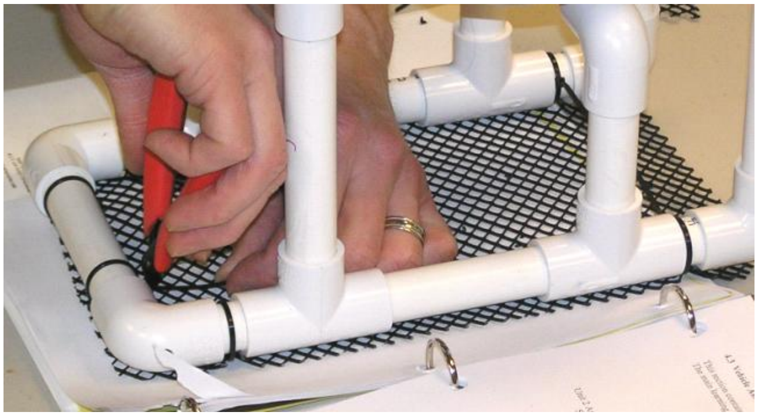


Figure 1.6-1: *Payload Net Attached to Frame*

ROV Painting Tip:

If you wish to paint your vehicle’s frame, do so before attaching the net, and be sure to use waterproof paint. Also confirm that all vehicle pipe sections and fittings are as *tight as possible* and that the frame is *squared-up* before painting, as the parts may be difficult to move after the paint has dried. Painting the ROV should be avoided if parts such as PVC tees and elbows will later be “recycled” for use on another SeaPerch ROV.

Construction Steps:

☐ **1.** Check the frame to ensure that all pipe sections and fittings are pressed tightly together and that the frame’s shape is as shown in the photo on the cover of this unit.

☐ **2.** Place the payload net underneath the vehicle frame and trim it to size with scissors if necessary. Leave as little net as possible extending beyond the edges of the frame. The net is often a bit curved from being stored on a roll; make sure that it is placed under the frame with the *concave side facing up*.

☐ **3.** Attach the net to the frame using about 8 tie wraps (also known as “cable ties” or “zip ties”). Pull them tight using pliers (NOT thin needle-nose pliers, as their tips may bend or even break when twisted!). Make sure the net is tight and flat on the bottom of the ROV.

☐ **4.** Trim off the ends of the tie wraps using flush wire-cutting pliers (scissors usually leave very sharp ends that can easily scratch skin) as shown in Figure 1.6-1.

Congratulations! You have completed the frame for your SeaPerch ROV!

Version 2010-02

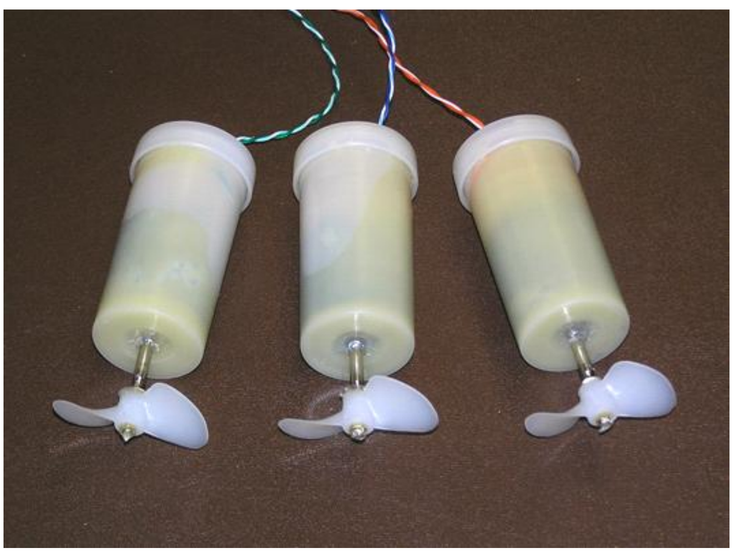
Unit 2

SeaPerch

Remotely Operated Vehicle (ROV)

Assembly of Subsystem Two

The Thrusters



December 2010

The SeaPerch educational program was created by Harry Bohm and Vickie Jensen and published in their 1997 book "*Build Your Own Underwater Robot and Other Wet Projects*." The initial curriculum was developed by the Massachusetts Institute of Technology, and this version of the SeaPerch Construction Manual was provided under the Office of Naval Research National Naval Responsibility for Naval Engineering (NNRNE) Outreach initiative.

Unit 2 Assembly of Subsystem Two *The Thrusters*

Tools and Materials Needed

Tools	Materials	
Eye Protection (Always Worn)	~40' (12 m)	Tether Cable (CAT 3, 5, 5e, or 6)
Potting Holder	3	Plastic Vials or Film Canisters, with Caps
Hand Drill or Drill Press	3	12-Volt DC Motors
3/32" Drill Bit	3	Propellers
1-3/8" Drill Bit (Forstner Preferred)	3	Propeller Shaft Couplers
Small Electric Skillet	6	4-40 Nuts (Brass Preferred)
Metal Cup for Melting Wax	1	Epoxy Pack with Mixing Stick
Pliers	~½	Wax Bowl Ring, and Petroleum Jelly
Wire Stripper	1" (2.5 cm)	Butyl Rubber Tape
Flush Wire-Cutting Pliers	24" (61 cm)	#22 or #24 Stranded Hook-Up Wire, Red
Permanent Ink Marking Pen	24" (61 cm)	#22 or #24 Stranded Hook-Up Wire, Black
Ruler and Scissors	2	Alligator Clips (Red and Black Covers)
Soldering Iron and Solder	1	12-Volt Battery
#2 Phillips Screwdriver	5	6" or 8" Tie Wraps (Zip Ties)
Fine Sandpaper or Steel Wool	1	8" (20 cm) or Longer Wood Block (2x4", "2x6", or "4x4")
		Rubbing Alcohol, Water, Paper Towels, and Electrical Tape

Time Needed to Complete Unit 2

Total Construction Time:

Unit 2 usually requires at least 6 to 7 hours to complete. More time should be allowed for if potting thrusters for a large number of ROVs.

Typical Allocation of Class Periods:

For standard class periods of approximately 50 minutes each, including any necessary clean-up time, plan for at least seven periods to complete this unit.

- 2 periods to test, mark, and wrap the motors for potting.
- 2 periods to solder wires to the motors and prepare the thruster housings.
- 1 period to pot the motors (more for a large number of ROVs).
- 2 periods to mount propellers onto the thruster shafts (and a few minutes, later, after the epoxy hardens, to mount the thrusters onto the frame).

Procedure 2.1 – Build a Motor Potting Holder (If Not Provided)

Tools:

Drill (or Drill Press)

¼" Drill Bit

1-3/8" Spade Drill Bit* (Or a "Forstner" Bit for a Flat-Bottomed Hole)

Permanent Ink Marker

Ruler

**1¼" Bit if Using Standard 35mm Film Canisters for the Thruster Housings*

Materials:

1 Block of Wood, Such as a "2 x 4" (or "4 x 4") at Least 8" (~20 cm) Long

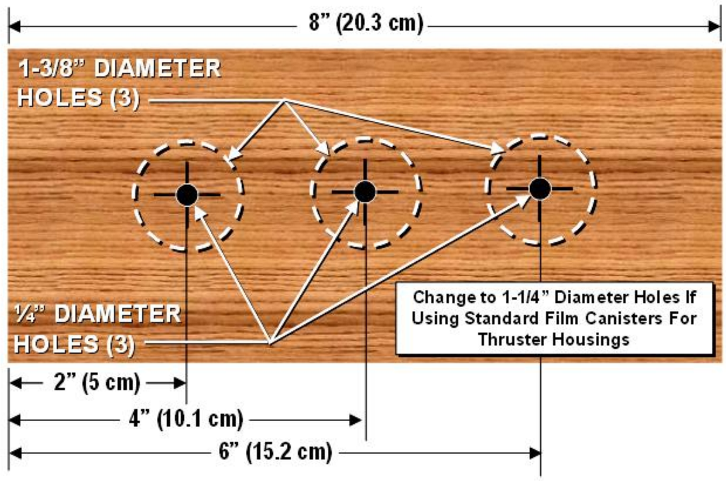


Figure 2.1-1: *Typical Hole Spacing for a Potting Holder*

NOTE: A potting holder of some type is useful in order to securely hold the thruster housings in place while hot wax is being poured, and while it is hardening, during the motor-potting process. Although a cardboard box or other raised surface, with holes at least ½" (13 cm) deep to accommodate the motor shafts, will suffice, a simple wooden holder is easy to build, is reusable, and provides more stable support for the thruster housings than a cardboard stand. High-density packing foam can be used instead of wood if desired, as long as it is a material that can be drilled easily.

If a motor-potting holder is not already available, one can be quickly constructed by following the procedure below. The holes may be placed in any configuration convenient for placing / removing the thruster housings. If a potting holder is not needed or is already available, skip to Procedure 2.2.

Construction Steps:

❑ **1.** Mark at least three drilling locations in the top of the wood block, as shown in Figure 2.1-1. (If a longer block is used, additional sets of three holes may be added, spaced similarly, for potting multiple sets of thruster motors.)

❑ **2.** Using a 1-3/8" bit*, drill holes at least ½" (1.3 cm) deep for the thruster housings at the locations marked on the block. Drill the holes as nearly perpendicular to the surface as you can, *and be careful not to drill all of the way through the block*.

❑ **3.** If central holes deep enough to accommodate the thruster motor shafts (which will protrude about ½" beyond the bottoms of the thruster housings) were not created by the drill bit in the step above, use a ¼" drill bit to drill a hole about 5/8" (1.6 cm) deep precisely in the center of each of the holes in the block.

Procedure 2.2 – Test the Motors and Mark Their Terminals' Polarity

Tools:

Permanent Ink Marker

Wire Stripper

Materials:

3	12-Volt DC Motors
2	Alligator Clips, with Red and Black Covers
2	24" #22 or #24 Hook-Up Wire, Red and Black
1	12-Volt Battery (Confirm that it is charged to at least 12 volts.)

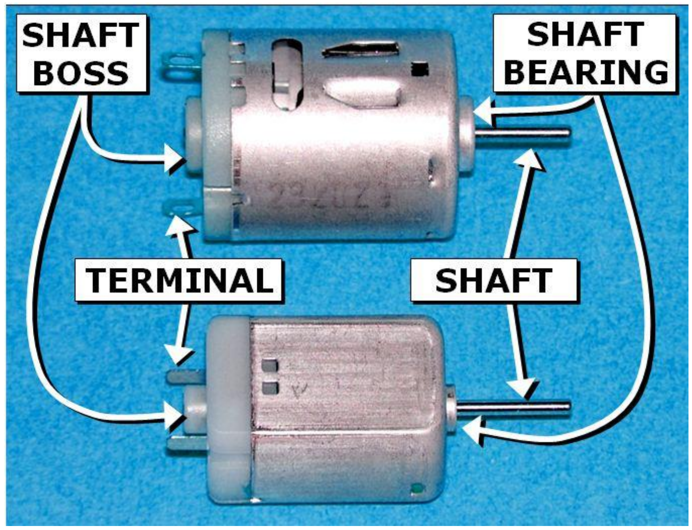


Figure 2.2-1: *Examples of Two Potential Thruster Motors*

WARNING - TO AVOID ELECTRIC SHOCK AND POTENTIAL BURNS:

- ***DO NOT touch exposed wires when making connections to battery terminals.***
- ***DO NOT touch the battery terminals with ANY metal object, especially tools!***
- ***DO NOT CONNECT WIRE OR METAL FROM ONE BATTERY TERMINAL TO THE OTHER!***

NOTE: Small 12-volt DC motors of various types are available for SeaPerch kits, such as those shown in Figure 2.2-1. Some come with wire leads already attached. In that case, the wires must be removed prior to testing the motors and assembling the thrusters. Some mot or shells may have more holes to cover than others. Some have two flat sides, and others are cylindrical. Motor shafts can have different lengths and diameters. *Propellers and shaft couplers must be selected to be compatible with the motor shafts.* Some motor shafts may require a different coupler size or a small bushing, sometimes with a little drilling, to properly attach the propellers.

It is necessary to mark the polarity of the motor "terminals" (electrical connections), even if polarity is already marked on the motors, as you will not be able to see such markings after you prepare the motors for potting by wrapping their shells with electrical tape.

Construction Steps:

☐ 1. Gather the red and black 24" (61 cm) hook-up wires and the two alligator clips to make a pair of test wires (these are temporary; they will be disassembled to make the power cord and your control box in Unit 3).

Procedure 2.2 – Continued

2. Strip about 3/8" (1 cm) of insulation from both ends of the loose black wire, without cutting the copper strands inside. Connect the black wire to one of the alligator clips by twisting the wire strands tight, inserting the twisted wire into the end of the alligator clip nearest the screw, curling the stripped part of the wire clockwise under the head of the screw, and tightening the screw to secure the wire in place (DO NOT SOLDER). Install the black alligator clip cover over the unconnected end of the wire and onto this alligator clip.
3. Repeat Step 2 with the loose red wire and the red alligator clip cover.
4. *IF* the motors have any wire leads soldered to their terminals, use a de-soldering tool (such as a vacuum solder remover or a solder-wicking braid) to remove the wires and any excess solder from the terminals.
5. Cut about 1" (2.5 cm) of electrical tape, and place it temporarily onto the shaft of each motor, wrapping it around the shaft with the end extending out like a flag, to help you see the motor's spin direction when it is energized.
6. Connect the red and black wires to the two terminals on one of the motors (twist them through or around the terminals) and hold them temporarily in place with small pieces of electrical tape (the polarity does not matter).
7. Connect the alligator clip on the black wire to the negative battery terminal.
8. Touch the red wire's alligator clip to the positive terminal of the battery, briefly a few times, and observe which direction the flag on the motor shaft turns when looking into the front (long shaft end) of the motor. The shaft should spin rapidly. If it doesn't, re-check the wire connections. If they are solid and the motor still doesn't spin, or spins slowly, get a replacement motor.
   - If the shaft spins counter-clockwise, the polarity of the wires from the battery is the same as the polarity of the motor terminals (positive battery wire going to the positive terminal of the motor, and negative battery wire going to the negative terminal of the motor). This is the correct polarity for the SeaPerch ROV thrusters, so mark the motor terminal that is connected to the black wire to show that it is the "negative" terminal by using a black marker pen to color one side of that terminal black.
   - If the shaft spins clockwise, the polarity of the motor terminals does not match those of the battery. Mark the motor terminal connected to the red wire "negative" by coloring one side of that terminal black, as above.
9. Disconnect the alligator clip from the battery and the wires from the motor, and remove the tape flag from the motor shaft. Clean any tape residue from the shaft using a small piece of paper towel moistened with alcohol.
10. Repeat Steps 6 through 9 for the other two motors, but *leave the test wires connected to the last motor tested*, as it will be used again in Procedure 2.4.

Procedure 2.3 – Seal the Motors So That Wax Cannot Get Inside

Tools:

Scissors

Materials:

3 12-Volt DC Motors

Electrical Tape

Figure 2.3-1: *A Motor Sealed with Electrical Tape*

NOTE: The purpose of sealing the motors, by wrapping them with electrical tape, as shown in Figure 2.3-1, is to keep the molten wax out of any holes in the motor shells during the thruster waterproofing process. Therefore, EVERY hole in the motor shells must be sealed (except the center area of the two ends where the shaft protrudes from the motor shell), and folds in the tape where wax could pass through must be avoided. The care with which this is done will help determine whether your thrusters will work and how long they will last.

Some motors used for SeaPerch ROVs may be larger than others. To ensure good coverage of the tape and to minimize its thickness, so that the motors will still fit easily into the thruster housings (plastic vials or film canisters) with enough room for the waterproofing wax to flow around them, it is important to perform the wrapping process very carefully to minimize the overall diameter of each wrapped motor.

Construction Steps:

☐ **1.** Make sure the markings placed earlier on the negative terminals of each of the motors have not rubbed off. It is important that you can identify the polarity of the terminals after covering the motors in tape. If the markings are not visible, repeat Procedure 2.2.

☐ **2.** *Study Steps 3 through 5 on the next two pages <u>before</u> beginning the tape-wrapping process.* In those steps you will need to make sure that **ALL** holes are sealed, but *ensure that the motors are still thin enough to easily slide into the thruster housings with enough room for melted wax to flow around the motors.* A common problem to avoid is having the tape around the sides of the motors be thicker near the motor ends than it is for the rest of the motors' sides. Prevent this by cutting the pieces of tape that cover the motor ends so that they are <u>*flush*</u> with the sides as shown in the pictures, and having the edges of the side tapes slightly overlap onto the motor ends (rather than having the end tapes fold over onto the sides of the motors, increasing the thickness there).

Procedure 2.3 – Continued

❑❑❑ **3.** Cover both _ends_ of the motor *first* with several short pieces of tape, and then cut around the motor ends using scissors to remove excess tape (cut at a tilt toward the motor to remove _all_ tape that extends past the edge of the shell) using the process below.

- On the terminal end, gently push each terminal _through_ a piece of electrical tape, instead of trying to tape around the terminals. Use several pieces of tape to fully cover the end of the motor, allowing them to extend past the side of the motor shell. Carefully place each piece up along the side of the motor shaft boss (usually a raised flange area around the rear end of the shaft, in the center of the motor). _Do not_ cover the rear tip of the motor shaft if it is exposed (it is on most motors), which could make the motor run slowly. Cutting two small slits in the edge of the tape, just at the sides of the boss, will allow the tape to fit snugly and flat around the boss area.
- After the tape pieces have been placed all around the end of the motor, cut off all tape that extends past the edge of the motor shell, leaving the end completely covered, except for the boss area. Figure 2.3-2 shows the taping process for the terminal end.

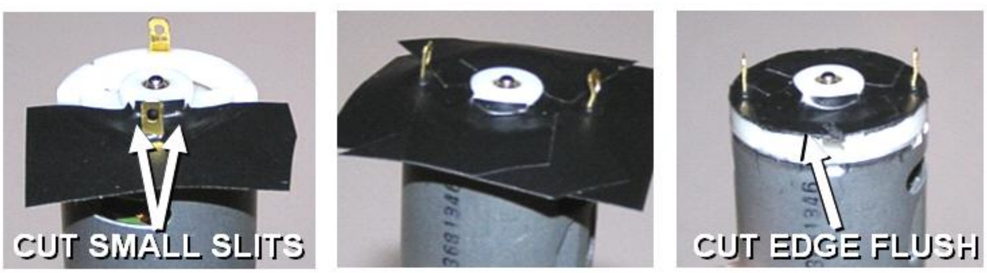


Figure 2.3-2: *Tape Wrapping Process for the "Terminal" End of a Motor*

- On the front (shaft) end of the motor, again place multiple pieces of tape right up to the edge of the shaft bearing. Cut them flush at the edge of the motor as before. Figure 2.3-3 shows the taping process for the shaft end of the motors.

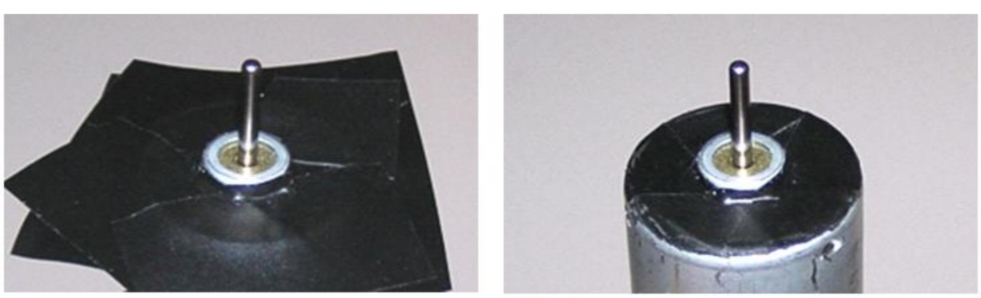


Figure 2.3-3: *Tape Wrapping Process for the "Shaft" End of a Motor*

Procedure 2.3 – Continued

❑ ❑ ❑ **4.** Wrap a longer piece of tape around the sides of the motor. Start at one end with the edge of the tape extending about 1/16" (~2 mm) past the end of the motor, so that it can be folded down to form a good seal. **IMPORTANT:** _Tape only a single layer around the motor,_ overlapping each piece only about 1/8" (3 mm) at its ends. Cut about six small slits around the curved edge of the tape that extends past the end of the motor, to aid in folding it down without wrinkles. Then fold it over the end as smoothly as possible. Figure 2.3-4 shows the final taping process for both ends of the motor.

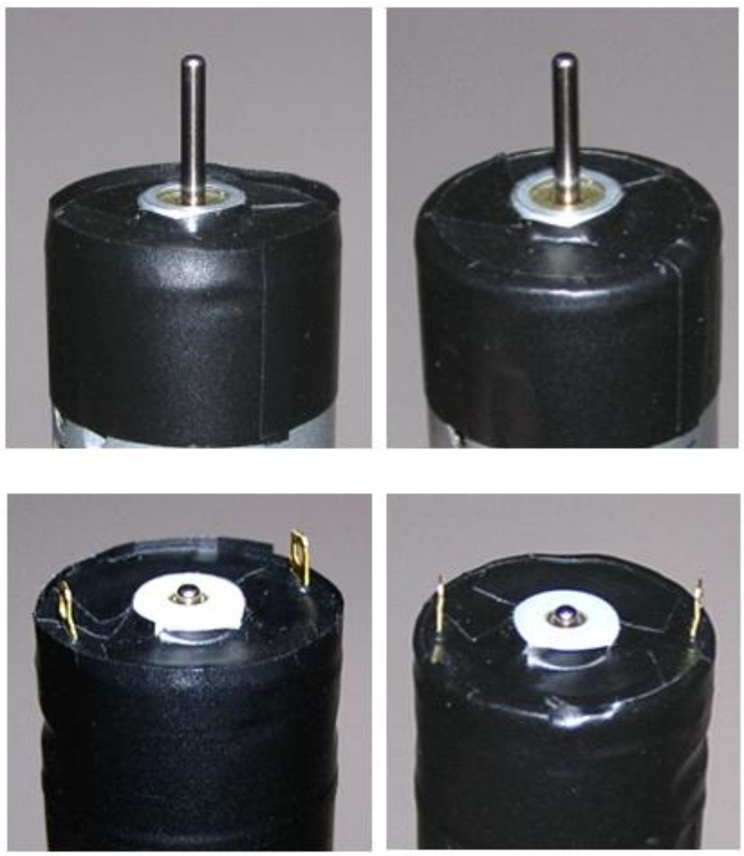


Figure 2.3-4: *Final Tape Wrapping Process for the Motors*

❑ ❑ ❑ **5.** Similarly, at the other end of the motor, place the edge of the tape to about 1/16" (~2 mm) past the end, wrap it around the motor, overlapping slightly as before, and then use about six small cuts around the curved edge to help make a tight seal when you fold the tape over that end.

❑ **6.** **Repeat** Steps 3 through 5 for the other two motors.

❑ ❑ ❑ **7.** Make sure that **ALL** holes in the motors are sealed well by pressing, rubbing, and squeezing the tape with your fingers over the entire surface of each motor shell.

Procedure 2.4 – Drill Holes in the Thruster Housings

Tools:

Drill or Drill Press

3/32" Drill Bit (See Note Below)

12-Volt DC Motor with Test Wires Connected

12-Volt Battery

Materials:

3 Plastic Vials (Or Film Canisters) with Caps

Electrical Tape

Figure 2.4-1: *Drilled Thruster Housing*

NOTE: The standard motors typically used with SeaPerch ROVs have a 0.091" shaft diameter, which matches well with the 3/32" holes to be drilled in the thruster housings (plastic vials or film canisters) to form a good, waterproof seal. However, if you are using a different motor, you should check it to see if the shaft diameter is still 0.091". Many small motors have a smaller, 0.078", shaft diameter. If that is the case, you should substitute a 5/64" drill bit in the procedure steps below that call for a 3/32" drill bit, so that the motor shafts will not be too loose in the holes in the thruster housings. *To get long thruster life, you must create a tight-fitting front seal onto the motor's shaft.*

Drill Safety Reminder:

Always get your teacher's permission before using a drill or other power tool. **Check to verify that you are still wearing your safety glasses.** Secure the object that you are drilling in a vise or clamp before drilling. *Do not drill while holding the object in your hand!*

Construction Steps:

❑ ❑ ❑ **1.** Using the 3/32" drill bit, drill a hole in the center of *each* of the three film canister *caps*. The holes in the caps are where the motor wires pass through, so high precision in hole placement is not essential.

❑ ❑ ❑ **2.** Again using the 3/32" drill bit, *carefully* drill a hole in the exact center of the bottom of *each* thruster housing (see Figure 2.4-1) as follows. This hole is where the motor shaft passes through; it forms the shaft seal, so it is **VERY IMPORTANT** that these holes are drilled with great care. First, scrape any plastic lumps off of the center of the housing bottom with your fingernail or a small tool. Then carefully and *slowly* drill the hole *straight* into the very **CENTER** of the thruster housing. Pull the drill *straight out* to avoid enlarging the hole.

Procedure 2.4 – Continued

❑ ❑ ❑ **3.** Carefully remove any plastic burrs from the hole in the bottom of the thruster housing, which may be left after the drilling process. When using the standard plastic vials, made of a rather soft material, some burrs usually remain in or around the holes after drilling. Burrs may also remain when using 35mm film canisters. It is essential to remove these burrs, as they can make it difficult to get the motor shaft to pass through the hole during the waterproofing process. To clear plastic burrs, remove the 3/32" drill bit from the drill and pass it by hand through the hole, from both directions, a number of times. As the drill bit shaft at the non-cutting end of the bit starts to emerge from the hole, cut or scrape off any burrs that come through with that solid part of the bit. Repeat this process until the hole is *completely clear*.

❑ ❑ ❑ **4.** Polish the holes that you drilled in the bottoms of the thruster housings to the perfect size using the shaft of a running motor, as follows. Locate the motor and test wires that were used in Procedure 2.2, and connect the test leads to the battery (the polarity does not matter). Carefully push the spinning shaft of the motor into the hole and hold it there for a few seconds, until the motor spins freely without slowing down. Do not hold it there too long, or at an angle, as you might melt the plastic and overly enlarge the hole, making the shaft too loose. If that happens, obtain a replacement thruster housing and repeat this procedure.

❑ **5.** After polishing is completed for all three thruster housings, disconnect the test leads from the battery, remove the test wires from the motor, and remove the alligator clips from the test wires. Set the clips, their covers, and the test wires aside for use later, in Unit 3.

Tips on Soldering – Safety and Techniques

Soldering Safety Reminders:

Eye Protection: Always wear safety glasses or goggles when soldering or even when near someone who is soldering (heated flux within the melting solder can "pop" and fly a considerable distance, in any direction).

Solder Hazards: Some solder contains lead, which is poisonous. Never put it in your mouth, and **wash your hands after working with it**. Solder also contains a chemical flux to aid the soldering process. This causes smoke when soldering. Avoid breathing the fumes.

Don't Get Burned: Soldering irons are obviously hot, so care must be taken when handling them. However, care must also be taken when *not* handling them. Make sure that the hot soldering iron is placed securely in a holder or stand when not in use so that it cannot burn you, its own cord, or anything or anyone else in the work area. Always allow the soldering iron to cool completely before maintaining or changing the tip, or returning it to its storage location.

Soldering Technique Tips:

If you have not soldered before, ask your teacher to show you how, and practice on some pieces of scrap wire.

Working With Stranded Wire and Small Terminals: For best results when using stranded wire, always twist the many wire strands together immediately after you strip off the insulation, so that they don't fray and break off (or touch another connection). Then poke the wire through the hole in the terminal on a motor or a switch, *twist* it back around the terminal, and *squeeze* it with needle-nose pliers to make a *good mechanical connection*. It is important to have a solid connection before soldering, both for good heat transfer throughout the connection while soldering and to create a strong solder joint.

Care for Soldering Irons: Always clean the heated soldering iron tip (by *briefly* wiping it on a damp sponge) immediately before (and after) soldering, and "re-tin" the tip with a little fresh solder just before moving to the connection to be soldered. After soldering, quickly **clean** (wipe on the damp sponge) and **re-tin** (apply some fresh solder) the tip. This is essential to keep the tip in good shape for soldering the next connection. Keep it shiny and tinned at all times. *Don't use a file or sandpaper* to clean an oxidized tip; that removes its plating!

Soldering: Besides protecting the tip from oxidation, applying a little solder to the tip of the soldering iron helps to transfer heat to the junction being soldered. Apply heat with the side *of the soldering* iron tip (not the point, which has very small surface area, so it can't conduct much heat) for a few seconds to get the connection up to solder-melting temperature. Be careful not to get it so hot that you melt any surrounding plastic, or the wire insulation. *(Overheating a small toggle switch can actually melt some of its internal components, causing it to fail! – So try to work quickly on each terminal, but wait 10 seconds or so before soldering another terminal.)*

Once the parts are up to temperature, melt some solder onto the connection; not onto the soldering iron tip. As the solder melts, it should flow into the connection. You will usually need to feed about a centimeter or less of thin solder into a typical connection (don't use too much and make the solder joint too big!). After just a second or so, it should flow freely in between the wire strands and over the terminal when the terminal is hot enough. Immediately remove the solder, but hold the soldering iron on the connection for just a second or so longer to make sure that all solder has attained its full melting temperature, and then remove the soldering iron. Try not to move the connection at all until the solder cools and hardens (this takes just a few seconds). If you move the wire before the solder has cooled, the solder will tend to crystallize and make a poor electrical connection.

Keeping Solder Tangle-Free: Although solder frequently comes on a large spool, it is often provided as a smaller coil, either in a box or a tube: If your solder comes as a small coil, be sure to keep it inside the container, only pulling out a few inches of solder at a time as it is needed. This will keep the coil from getting tangled and becoming very difficult to use. It is a good practice to secure the top of a plastic tube of solder using a small piece of electrical tape, so that the solder coil cannot accidentally fall out and get tangled. If you are issued just a short length of solder at a time, such as from a large spool, coil it around a pen or pencil to help keep it from getting lost or tangled.

Procedure 2.5 – Connect the Tether Cable Wires to the Motors

Tools:

Ruler and Scissors

Soldering Iron and Solder

Scissors or CAT 3/5/6 Cable Stripper

Materials:

3 Motors Sealed with Tape

3 Thruster Housings and Caps with Holes Drilled (from Procedure 2.4)

Tether Cable

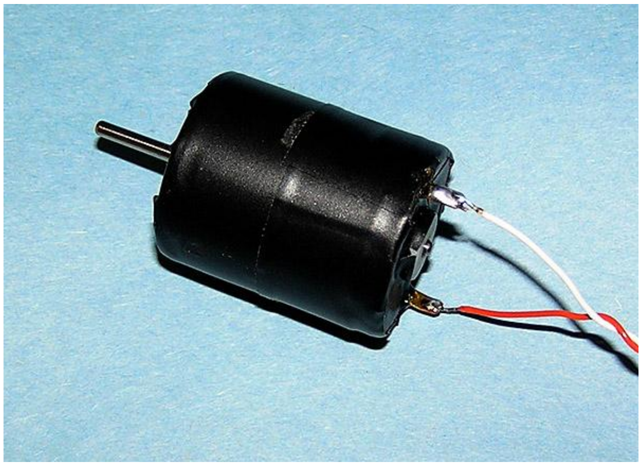


Figure 2.5-1: *Tether Cable Wires Soldered to a Motor*

NOTE: Each motor must be connected to one of the color-coded pairs of wires in the tether cable, as shown in Figure 2.5-1. The CAT 3/5/6 cable types have four wire pairs inside. Three of them will be used for the standard SeaPerch ROV.

Construction Steps:

☐ **1.** On one end of the tether cable, strip off about 15" (38 cm) of the outer sheath, being very careful not to nick any of the inner wires. This can most easily be done with a cable stripper designed for CAT 3/5/6 type cable. If using scissors, use extreme care not to cut the insulation on the inner wires. (Using a knife is not recommended.)

☐ **2.** Separate the four wire pairs in the stripped section, as shown in Figure 2.5-2 (in some tether cables, the wires may not be twisted into pairs). The brown pair is not used in the basic SeaPerch, and can be left hanging for now (do not cut this pair off, as it could be used later for an accessory item, such as a sensor, light, or manipulator).

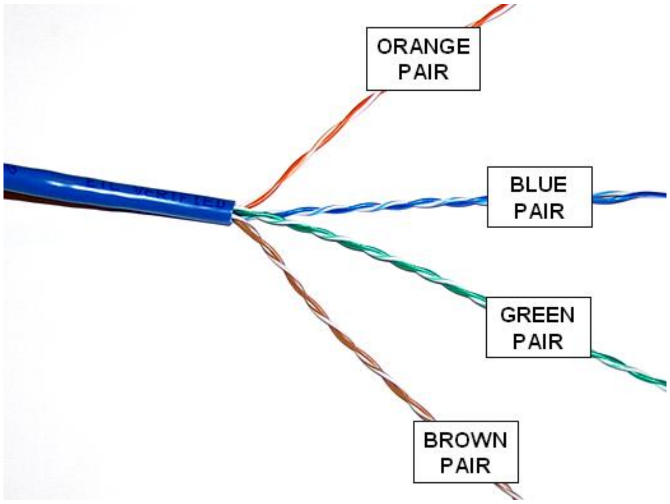


Figure 2.5-2: *Tether Cable's Color-Coded Wire Pairs*

Procedure 2.5 – Continued

☐ **3.** If the wires in the tether cable are not already twisted into pairs, refer to Table 2.5-1 to pair them together by colors ("orange" with "white & orange," etc.). Thread about 3" (8 cm) of each wire pair through the hole in a film canister cap, and tie a knot in each pair, on the inward side of the caps, to serve as a strain relief, as shown in Figure 2.5-3.

Table 2.5-1 – Tether Cable Wire Assignments for Thrusters

POSITIVE (+)	NEGATIVE (–)	THRUSTER
Green	**Green & White Striped**	**Starboard (Right)**
Blue	**Blue & White Striped**	**Port (Left)**
Orange	**Orange & White Striped**	**Vertical (Up & Down)**
Brown	**Brown & White Striped**	**Not Used***

* May Be Employed for Optional Accessories Later

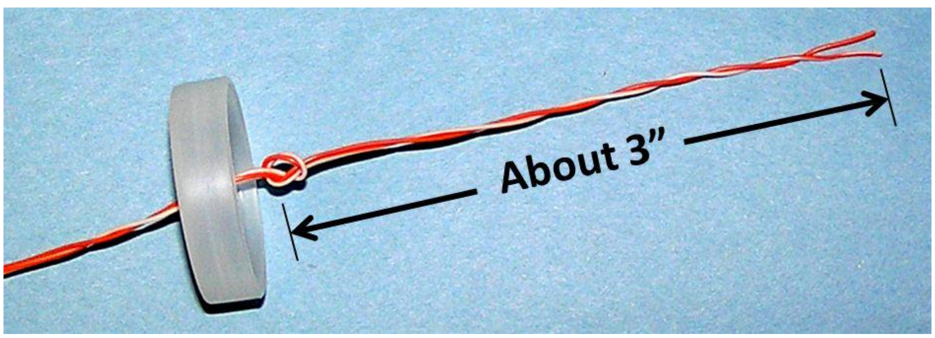


***Figure 2.5-3**: A Motor's Wires Passed Through a Thruster Housing Cap*

☐☐☐ **4.** Strip about ¼" (7 mm) of insulation from the end of each wire, for all three wire pairs (Green, Blue, and Orange).

☐☐☐ **5.** Select a pair of wires and one of your taped motors. Attach the wires to the motor's terminals according to the color code listed in Table 1. **Note that the solid-colored wires of all pairs connect to the positive (+) terminals on the motors, and the color-and-white striped wires of the pairs go to the negative (–) terminals.** Bend the stripped end of each wire through the terminal if there is a hole in it, or all the way around the terminal of there is no hole, and squeeze the wire tight on the terminal using needle-nose pliers, in preparation for soldering.

☐☐☐ **6.** Solder the wires onto the two terminals of the motor, as shown in Figure 2.5-1.

☐ **7.** **Repeat** Steps 5 and 6 for the other motors and their tether wire pairs.

Tips on Wax Melting – Safety and Techniques

Wax Melting Safety Reminders:

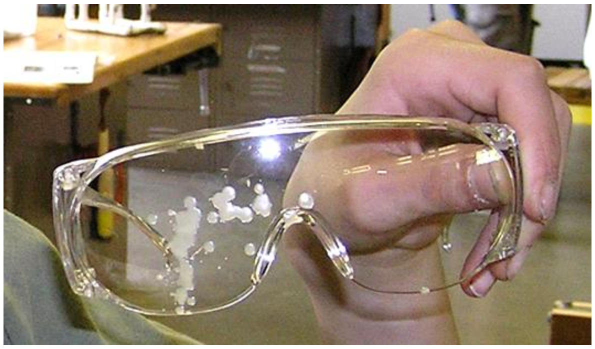
Eye Protection: Always wear safety glasses or goggles when working with potting wax.

Wax Handling: Bowl ring wax is made from petrolatum – basically the same type of material that, when more refined, becomes common petroleum jelly. It is safe to handle when cooled, but quite sticky, and difficult to remove if it solidifies on clothing. After handling bowl ring wax, **wash your hands with very warm water and soap. Do not ingest the wax.**

Don't Get Burned: Bowl ring wax usually melts at a rather low 150 degrees Fahrenheit (F). The wax-melting approach used for SeaPerch ROVs is *either* to melt the wax in an electric heating pot *or* in a metal container placed in a water bath, usually employing an electric skillet to heat the water (and wax). **It is important NOT to let the wax get too hot. For the water bath, never allow the water to totally evaporate (keep adding water to maintain it at about ½" to 1" deep). For the heating pot, monitor the temperature to ensure that it does not exceed 180 degrees F**. (Although the wax flash point is over 500 degrees F, the manufacturers usually recommend not exceeding 200 degrees F.) Obviously, if the wax is allowed to get too hot, serious skin burns are possible; more sensitive skin or large quantities of hot wax on the skin may cause burns. In case of a burn, quickly rinse the area with LOTS of cold water and seek medical attention.

Don't Have a Melt-Down: Too-hot wax, such as from using a hot plate without a water bath, has been shown to actually melt the thruster housings! For this reason, and the safety reasons noted above, use of a thermometer for the wax cup(s) is recommended. If a thermometer is not available, the best advice is to keep the water bath below the boiling point, and adjust the skillet temperature to low or medium, so that the wax just reaches its melting point, or a little higher, about 160 degrees F. The goal is for the wax to be hot enough that it will not harden immediately when poured into the thruster housings, but cool enough to avoid burn hazards.

Watch Out for Squirting Wax: Wax can squirt quite a distance when the caps are pressed onto the thruster housings if the task is done very quickly (wax can jet out of the hole in the cap). Wearing an apron and gloves (latex, nitrile, etc.) during the motor potting process is recommended. *Holding a paper towel over the cap as it is pressed on will help to prevent wax from squirting beyond the area of the housing.* The inside-seal type housings (on some film canisters) tend to squirt wax farther than the outside seal types, but either can be a squirting hazard. The picture to the right says it all; wear that eye protection!



Example of a Student's Safety Glasses Saving the Day!

Wax Melting Technique Tips:

1. To facilitate cleanup, put a drop cloth on the work bench, on the floor below it, and on the wall behind it. When installing caps, stand back to avoid getting wax on you or your (or others') clothes.
2. Start the wax melting early, at least an hour before class time on motor-potting days.
3. Put small weights (such as lead sinkers) in your wax-melting cup(s), to prevent floating in the water.
4. Try to find metal cups with insulated handles that can hang over the side of the electric skillet or other water-bath heating device. This makes handling and pouring much easier than using tongs or gloves on a hot cup.
5. One wax ring will pot about five or six thrusters, but plan on some spillage; have extra wax on hand!
6. Should wax run short, spilled wax can be scraped up from the potting holder, table top, or even the outside of the cooling thruster housings and returned to the cup(s) to be re-melted.

Procedure 2.6 – Pot (Waterproof) the Motors with Wax

Tools:

- Metal Cup(s) and Electric Skillet, or Heated Pot
- Potting Holder
- Scissors
- Apron / Gloves (Optional)

Materials:

- 3 Motors Sealed with Tape
- 3 Plastic Vials (or Film Canisters) and Caps with Holes Drilled (from Procedure 2.4)
- Wax Bowl Ring (~½ Ring Needed Per ROV)
- Electrical Tape
- Petroleum Jelly (Optional)
- Water and Paper Towels

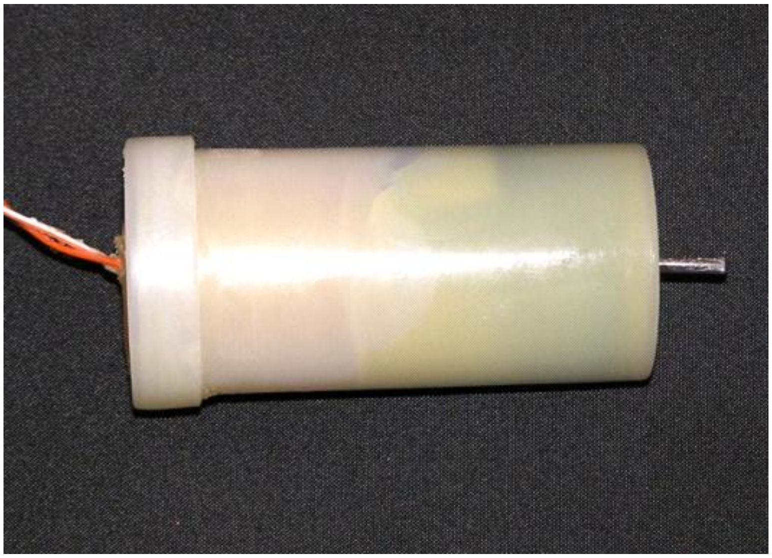


Figure 2.6-1: *Motors Waterproofed by Potting in Wax*

NOTE: Each motor will be potted into its thruster housing using melted wax, as shown in Figure 2.6-1. Wearing an apron and using protective gloves is recommended during the potting process. Review the wax-melting tips on page 2.6-1 before proceeding.

Construction Steps:

❑ ❑ ❑ **1.** Place a *small* piece of electrical tape *loosely* over the hole in the bottom of each of your three thruster housings (vials or film canisters), on the outside of the housings. *The tape should be applied very lightly and with the hole just at the edge of the piece of tape, so that it keeps the molten wax from flowing out of the hole, but still pushes aside easily when the motor shaft pokes through the hole.* Apply the tape as shown in Figure 2.6-2.

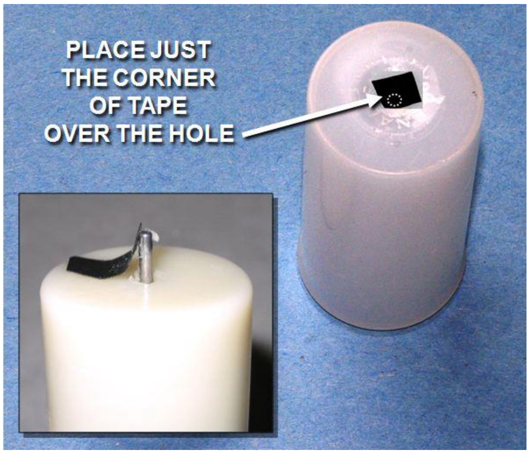


Figure 2.6-2: *Tape Placed Over the Edge of the Shaft Hole in a Thruster Housing*

Procedure 2.6 – Continued

❑ **2.** Your teacher will probably have melted wax ready for your use, using a melting pot like those shown in Figure 2.6-3. If not, see the wax melting tips on page 2.6-1.

Figure 2.6-3: *Wax Melted in an Electric Heating Pot <u>or</u> in a Metal Cup Placed in an Electric Skillet (with Water to Help Regulate the Temperature)*

❑ **3.** Check to see that everyone who is near the wax potting area has put on EYE PROTECTION before anyone begins to work with the hot wax. Wax can squirt quite a distance in any direction when the caps are pressed onto the thruster housings.

❑ **4.** Place the three thruster housings into the potting holder prepared in Procedure 2.1, or other appropriate stand that will allow the thruster housings to sit level for wax cooling while they have the motor shafts protruding from their bottoms.

❑❑❑ **5.** Just before starting the motor-potting process, hold the motor tightly in your closed hand for a minute or so, to warm it up a bit. This will help to prevent rapid cooling of the wax and give you a little more time to get the motor shaft through the hole in the thruster housing.

❑❑❑ **6.** **<u>Optional</u>:** Place a small dab of petroleum jelly at the base of the motor shaft as shown in Figure 2.6-4. This is recommended to help keep water from getting into the motor while in use. Continue warming the motor in your hand, without disturbing the petroleum jelly.

Figure 2.6-4:
Petroleum Jelly Placed at the Base of a Motor's Shaft

❑❑❑ **7.** Carefully lift the wax heating pot, or lift the cup of molten wax from the heated water (if it has no handle, use pliers), and pour about ¼" (7 mm) of wax (not more!) into ***<u>one</u>*** of the film canisters, as shown in Figure 2.6-5.

❑❑❑ **8.** *Immediately*, but carefully, insert the motor into the thruster housing, aiming the shaft at the hole in the bottom, moving it around and pushing GENTLY until the shaft pokes through the hole. It may take a little wiggling to get the shaft to go through, but *DO NOT push so hard that you poke another hole in the bottom*! (This happens more easily than you might think, since the plastic softens when heated by the wax.*) It is essential to get the motor into the housing and the motor shaft through the hole **<u>quickly</u>**, because the wax cools and hardens rapidly when the colder motor touches it.* The wax should push *<u>partway</u>* up around the sides of the motor, but should not fill in above the motor. See Figure 2.6-6.

Procedure 2.6 – Continued

Figure 2.6-5: *Initial ¼" of Melted Wax in a Thruster Housing*

Figure 2.6-6: *Motor Sealed in the Bottom of a Thruster Housing*

Figure 2.6-7: *Wax Filled to ½" from the Top of the Housing*

❑ **9.** **Repeat** Steps 5 through 8 for the other two motors.

❑ **10.** Let the wax cool and harden for several minutes. One end of each motor is now sealed in the wax, so be careful not to push on the motor shafts and break the seals. Once all three of your containers have a motor in them, and have cooled, you will fill them the rest of the way with wax, ***in two steps***.

❑❑❑ **11.** Place a dab of petroleum jelly on the rear tip of each motor's shaft. Do this for all three motors now, as the step is easy to accidentally skip later.

❑❑❑ **12.** Again carefully lifting the hot container of wax, fill ***one*** thruster housing with wax up to about ½" (13 mm) below the top, as shown in Figure 2.6-7. Pour the wax so that it fills in all the air spaces around the motor. Lift your container and look at it from the side to see if you have any air bubbles. Quickly try to get any bubbles out while the wax is still liquid by gently tilting and squeezing the housing.

❑ **13.** Set the canister in your potting holder to cool, and **repeat** Step 12 for the other two motors.

❑❑❑ **14.** Once the wax has cooled, push the caps up to the knots in the wires and coil the wires into the housings as shown in Figure 2.6-8. Make sure that the caps will fit on with the coiled wire in place, and then remove them again in preparation for the final wax pour. Keep the coiled wires away from the top edge of the housing, where they could be pinched.

Figure 2.6-8: *Wires Coiled in the Top of the Housing, Prior to the Final Wax Pour*

Procedure 2.6 – Continued

❑❑❑ **15.** Carefully fill ***one*** thruster housing to the very top with wax, creating a positive meniscus as shown in Figures 2.6-9 and 2.6-10.

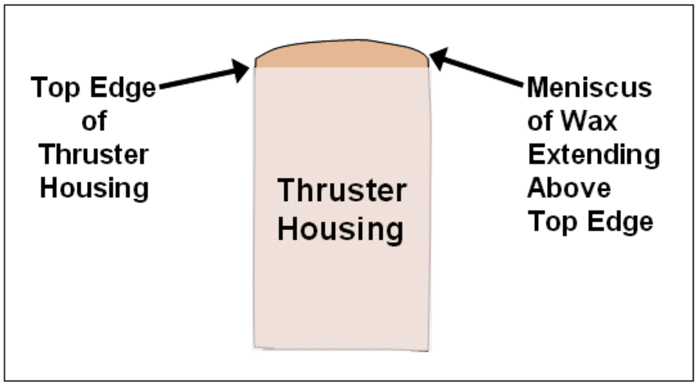


Figure 2.6-9: *Wax Meniscus Should Form at the Top of the Thruster Housing When it is Filled*

Figure 2.6-10: *Filled Housing Ready to Cap*

❑❑❑ **16.** You should hold a paper towel in your hands, over the cap, as you perform this step, to capture any squirting wax (see Figure 2.6-11). Now *quickly,* but carefully, press the cap onto the thruster housing, leaving as little air inside as possible. Be careful not to pinch the wires. Watch out for wax squirting out the hole in the cap! Discard the paper towel, if used. Put the potting holder with this filled housing in a safe place to cool for about 10 minutes, with the wires extending straight out of the lid (not down to the side). Try *not* to move the wires again until the wax has cooled and solidified. Also wait until then to wipe off any excess wax that may remain on the sides of the housing.

Figure 2.6-11: *Using a Paper Towel While Placing the Cap on the Thruster Housing Can Help Prevent Wax from Squirting Onto You or Others*

❑ **17.** **Repeat** Steps 15 and 16 for the other two motors. The potted motors should look like those in Figure 2.6-12 when they have been completed, after cooling. Handle the wires and potted motors *very carefully* throughout the remaining steps in your SeaPerch ROV construction in order to minimize the chance of damage to the shaft or tether wire sealing areas.

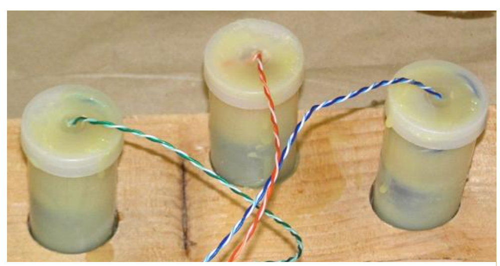


Figure 2.6-12: *Three Motors Potted into Thruster Housings*

Procedure 2.6 – Continued

18. If plastic vials were used for the thruster housings, rather than film canisters (which have snap-on lids), wrap electrical tape around the edge of the lids on all three thruster housings (after wiping off any excess wax), to help hold them in place.

19. **<u>Optional</u>:** If using the standard printed-circuit-board-style control box for this ROV (rather than the hand-wired option), and if a working control box is available for thruster testing, you may perform Procedure 3.2 now to install the RJ45 connector plug on the tether cable, to enable easier testing of the thrusters. If so, skip to Step 22 below, and use the control box switches for the tests (instead of touching the wires to the battery for testing the thrusters).

20. On the loose end of the tether cable (without the thrusters installed), strip off about 4" (10 cm) of the outer sheath, being very careful not to nick any of the inner wires. This can most easily be done with a cable stripper designed for CAT 3/5/6 type cable. If using scissors, *<u>use extreme care not to cut the insulation on the inner wires</u>*. (Using a knife is not recommended.)

21. Separate the ends of the wire pairs about an inch and strip ¼" of insulation off all wires except for the brown / brown-white striped pair.

22. One at a time, test each thruster by momentarily touching the two wires from its wire pair to the two terminals of the 12-volt battery (polarity does not matter).

- *The motor shaft should spin rapidly*, indicating that the thruster is good.
- If it does not spin immediately, or spins slowly, gently twist it in both directions by hand or, if it seems stuck, use needle-nose pliers to turn the shaft, and repeat the above test with the battery.
- If it still does not work, inspect the wires for nicks that may have broken a wire. If a wire has been broken, it can be repaired by stripping about ¼" of insulation from the broken ends and splicing them back together (twist and solder them, and cover the connection with electrical tape).
- If the thruster still does not work, it will need to be replaced by obtaining another thruster housing and motor, cutting the thruster wire as close as possible to the non-working thruster housing, and repeating procedures 2.2 through 2.6 for the new thruster. Alternately, the non-working thruster can be disassembled to see if a wire may have broken away from one of the electrical terminals on the motor. If that is the reason for the failure (rather than wax having somehow entered the motor shell), the wax can be removed from the back area of the housing to allow the connection to be repaired, and then the wax, and cap, can be replaced (Steps 14-16).
- Test any new or repaired thrusters as above to make sure that they spin properly.

Procedure 2.7 – Mount the Propellers Onto the Motors' Shafts

Tools:

Sandpaper (or Steel Wool)

Materials:

- 3 Potted Motors
- 3 Propellers
- 3 Propeller Shaft Couplers
- 6 4-40 Nuts (Brass Preferred)
- 1 Epoxy Packet with Stirring Stick
- Paper Towel
- Rubbing Alcohol

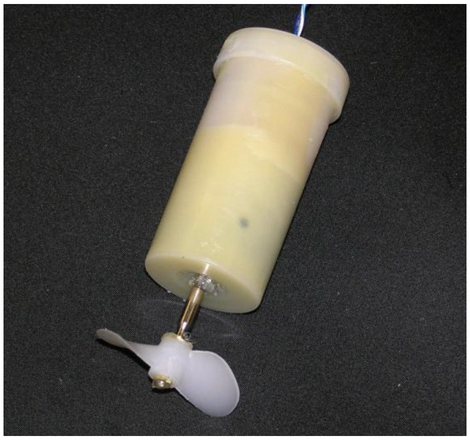


Figure 2.7-1: *Propeller Mounted on a Motor's Shaft*

NOTE: Various propeller types may be used on SeaPerch ROVs. This vehicle will have small boat (underwater) propellers. They fit onto the shafts of the thruster motors, as shown in Figure 2.7-1, using a threaded shaft coupler. It is glued to the motor shaft, and the propeller is held onto the coupler using two nuts and epoxy adhesive. *If desired, you may perform Procedure 2.8 (to mount the thrusters onto the ROV frame) before Procedure 2.7, to reduce the chance of the propellers being jostled about while the adhesive is curing.*

Construction Steps:

☐☐☐ **1.** Wipe the shafts of each of the three motors using a paper towel and rubbing alcohol (or an alcohol pad) to remove any tape residue, excess wax, or petroleum jelly (if used) that may be left after the potting process.

☐☐☐ **2.** Use a small piece of sandpaper (or steel wool) to roughen the surface of each of the motor shafts. Then *wipe them again* with alcohol and a clean paper towel (not the one used to remove wax above). *Cleaning the shaft is critical*.

☐ **3.** Look at the propeller and note that the side with the slot (groove) in it is the side that should be placed nearest the motor.

☐☐☐ **4.** Screw a 4-40 brass nut onto each propeller shaft coupler, as far as it will go.

☐ **5.** Prepare your workspace to quickly glue everything, since with many epoxies (including the one specified in the parts list), you will only have about 3 minutes of working time before they get too stiff to use. Lay out the three propeller shaft couplers with a nut on each, the propellers, and the three remaining nuts within easy reach, as shown in Figure 2.7-2, near the three potted motors.

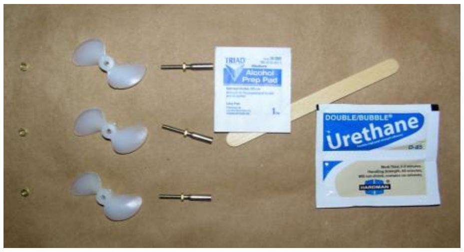


Figure 2.7-2: *Propeller Parts, Ready to Assemble*

Procedure 2.7 – Continued

☐ **6.** Gather the epoxy, mixing stick, and a scrap sheet of paper or cardboard on which to mix the epoxy.

☐ **7.** Mix the epoxy according to the instructions on the package. If you are using the packet specified in the parts list, fold the packet so that the two halves are together. Tear off one end and squeeze all of the contents of both halves onto your piece of paper as shown in Figure 2.7-3. Quickly mix the contents together with the mixing stick until the color is uniform; see Figure 2.7-4.

Figure 2.7-3: *Two-Part Epoxy Squeezed Out onto a Piece of Paper*

Figure 2.7-4: *Stirring the Epoxy Until Its Color is Uniform*

☐☐☐ **8.** Pick up a previously assembled shaft coupler with its 4-40 nut, and use the mixing stick to put a drop of epoxy on the nut, to hold it in place. Put another drop of epoxy on the threaded part of the shaft coupler to hold the propeller, as shown in Figure 2.7-5.

☐☐☐ **9.** Place the propeller onto the threaded part of the shaft coupler, slotted side first; see Figure 2.7-6.

Figure 2.7-5: *Putting Epoxy Onto the Nut and Threads of the Shaft Coupler*

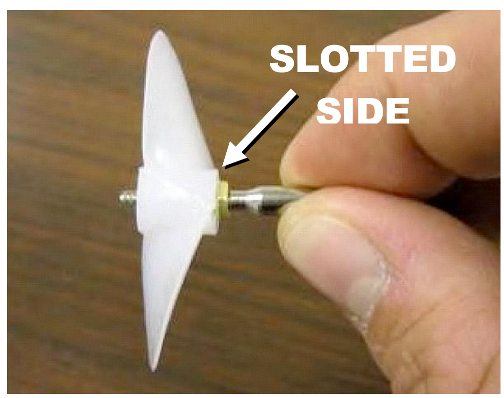


Figure 2.7-6: *Propeller Placed Onto the Epoxy-Covered Shaft Coupler*

Procedure 2.7 – Continued

10. Put a drop of epoxy on the threads at the end of the coupler, and screw the remaining nut on finger-tight, making sure it is held by epoxy. See Figure 2.7-7.

11. Place a drop of epoxy in the hollow end of the propeller shaft coupler and on the tip of the motor shaft, as shown in Figure 2.7-8. Push the hollow end of the propeller shaft coupler onto the motor shaft, but do not let the epoxy or the coupler touch the thruster housing! See Figure 2.7-9. If the coupler has air trapped inside, it may start to push itself back off when you let go. If this happens, give it a quick push back on, and hold it for a few seconds; repeat if needed. You should hear a "pop" when the air finally escapes, and then you can set the assembly down and wait for the epoxy to cure and harden.

Figure 2.7-7: *Nut Threaded Onto Shaft Coupler and Covered with Epoxy*

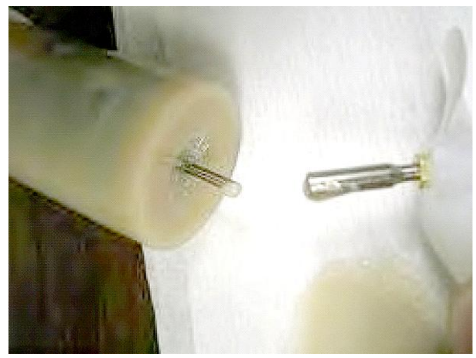


Figure 2.7-8: *Epoxy Placed on Motor Shaft Tip and Hollow End of the Shaft Coupler*

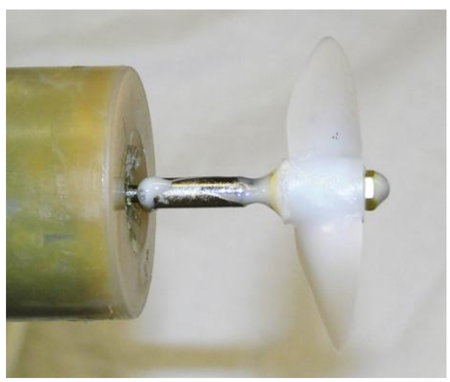


Figure 2.7-9: *Propeller and Shaft Coupler Mounted on a Thruster Motor's Shaft*

12. Repeat steps 8 to 11 for the other two thrusters, ***quickly****, before the epoxy hardens.*

13. Put your thrusters aside and allow the epoxy to harden to handling strength (60 minutes for the specified epoxy) before touching them again. It takes most epoxies about 24 hours to harden to final strength. Do not apply power to the motors or otherwise stress the glued connections until that time has passed.

Procedure 2.8 – Mount the Thrusters Onto the Vehicle Frame

Tools:

#2 Phillips Screwdriver

Pliers

Materials:

3	Assembled Thrusters
	Assembled Frame
	Electrical Tape (Optional)

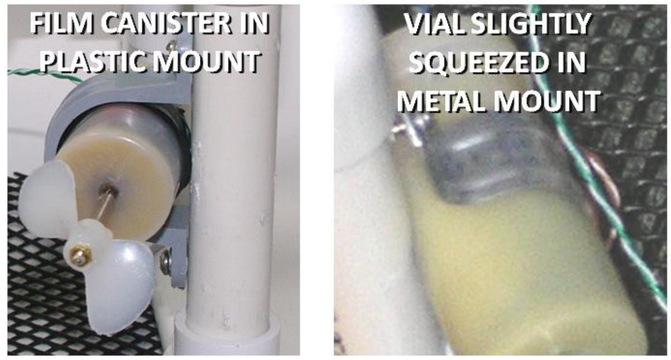


Figure 2.8-1: *Thruster Mounted on ROV Frame*

NOTES:

Epoxy Curing Time: When epoxy adhesive has been used to attach the propellers to the thruster motors (the standard method), *this* procedure should only be performed *after* the epoxy has hardened to handling strength (60 minutes for the specified epoxy).

Thruster Housing Positions: The thruster housings should be positioned within their mounts such that the back end of the motor (estimate where it is inside the thruster if you can't see it) is placed right under the thruster mount. The mounts should not be clamped over the rear of the thruster housings, where there is only wax, nor over the center of the motors, where they might squeeze the motor casings. Placing them over the back end of the motors will best resist the pressure of the tightened thruster mounts.

Accommodating Different Thruster Mounts and Housings: Two types of common conduit clamps are typically used for thruster mounts, metal and plastic, and they are of slightly different sizes. Thrusters that are made using 35mm film canisters for their housings fit best in the metal mounts, and the slightly larger plastic vial thruster housings fit best in the plastic mounts, but either type of mount may be used.

- If using the *35mm film canisters* with the *plastic* mounts, a good fit can easily be obtained by placing about eight or nine wraps of electrical tape around each housing before placing it in the plastic mount (wrap the housing just in the area that is held by the mount), as shown in Figure 2.8-1.
- If using the *35mm film canisters* with the *metal* mounts, the tightness of the thrusters in its mount depends somewhat upon how far apart the mounting holes were drilled. If after tightening a thruster into its mount it is still too loose, remove it, place a few wraps of electrical tape around the thruster housing, and reinstall it.
- If using the larger *plastic vials* with the *metal* mounts, you may need to bend the metal mount slightly or not tighten the screws all the way, leaving a slight gap between the mount and the PVC pipe. This will prevent overly squeezing the thruster housing, which could cause the wax inside to push the cap off.

Procedure 2.8 – Continued

Construction Steps:

☐ **1.** Loosen, or remove, the thruster mounts using a #2 Phillips screwdriver.

☐☐☐ **2.** Place the thrusters in the mounts according to Table 2.8-1. Mount the vertical thruster with its propeller pointing upward, and orient the rear thrusters so that the propellers are not pointed so far outward that they become the outermost part of the vehicle (they could be damaged by contact with other objects).

Table 2.8-1 – Thrusters Identification for Placement on Vehicle Frame

WIRE PAIR COLORS	THRUSTER
Green / Green & White Striped	**Starboard (Right)**
Blue / Blue & White Striped	**Port (Left)**
Orange / Orange & White Striped	**Vertical (Up and Down)**

☐☐☐ **3.** Reattach each thruster mount, with thruster, to the frame, as shown in Figure 2.8-1. It's alright if the thrusters get squeezed a little. Tighten the screws just enough to hold the thruster firmly; they need not be as tight as possible. Be careful not to strip the holes in the PVC pipe. If you do, simply re-drill the holes at another location around the pipe.

☐ **4.** You can now use pliers to gently turn the PVC pipes that the thrusters are mounted on in order to get the thrusters to point in the directions that you want. This is a good time to think about thrust, vectors, and propulsion. How do the angles of the thrusters affect the performance of the ROV? What angles will get you the best forward and backward thrust? What angles will get you the best turning ability? What angles will keep the propellers out of harm's way as the ROV navigates in narrow or crowded places? What is the best compromise for your mission needs? You can always make further adjustments to the thruster angles after you test the ROV's performance in water.

Procedure 2.9 – Waterproof and Mount the Tether Cable

Tools:

- #2 Phillips Screwdriver
- Pliers
- Flush Wire-Cutting Pliers

Materials:

- Completed Frame with Thrusters Mounted
- 1” (2.5 cm) Butyl Rubber Tape
- Electrical Tape
- 5 6” or 8" Tie Wraps

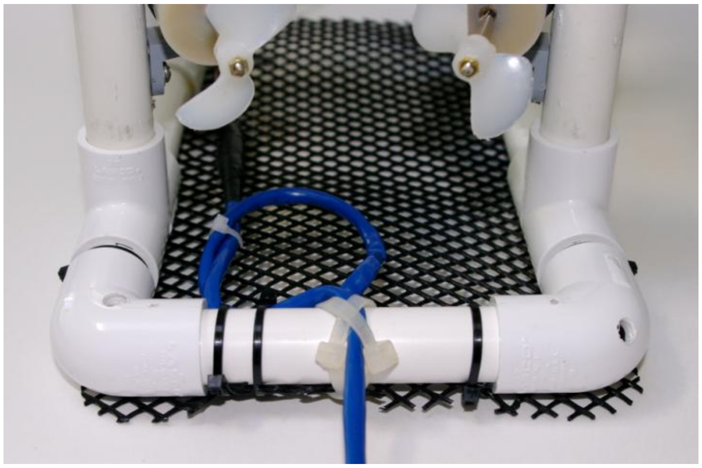


Figure 2.9-1: *Tether Cable Tied in a Strain Relief Loop and Pointing Straight Back from the Center of the ROV*

Construction Steps:

☐ **1.** Locate the point near the thruster end of the tether cable where the four thruster wire pairs emerge from the cable sheath, and bring it out a bit away from the vehicle frame so you can waterproof that opening using butyl rubber tape.

☐ **2.** Locate in your kit (or cut from a roll) a 1” (2.5 cm) piece of butyl rubber tape.

☐ **3.** Stretch the tape to about twice its relaxed length, then wind it among and around the four wire pairs where they emerge from the cable's outer sheath and press it over the sheath opening such that it extends at least ½” on each side of the opening, as shown in Figure 2.9-2. Knead and work it in between the wires well, so that it seals both around and between the wires and forms a smooth seal over the sheath opening, preventing water from getting into the tether cable.

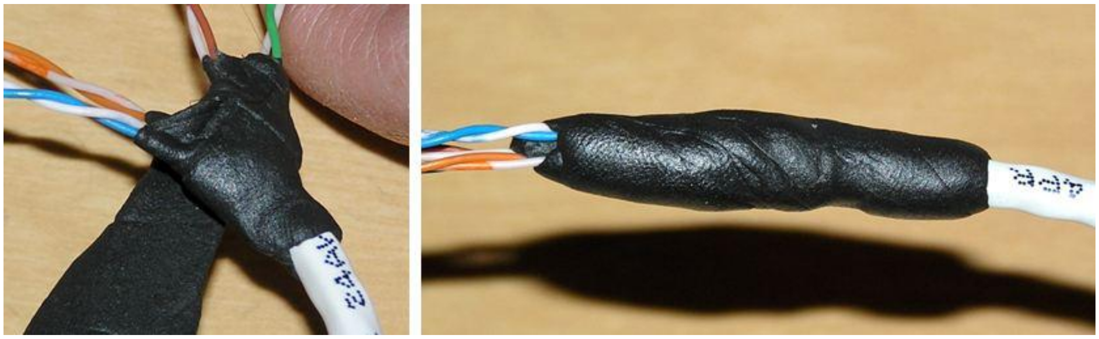


Figure 2.9-2. *Butyl Rubber Tape Wrap to Waterproof Tether Cable Sheath Opening*

☐ **4.** Wrap electrical tape over the butyl rubber tape to keep it from sticking to anything.

Procedure 2.9 – Continued

☐ **5.** After waterproofing the tether cable, **make a loose knot loop** in the cable and **attach it** to the vehicle frame and the payload net with tie wraps **in at least two places**, as shown in Figure 2.9-1. This "strain relief" loop is intended to prevent any pulling on the tether cable from pulling on the thruster wires.

☐ **6.** Install ***two crossed*** *tie wraps over the tether cable* where it passes over the ***center*** of the pipe at the rear of the ROV, as shown in Figures 2.9-1 and 2.9-3. ***This is important*** to keep the tether cable pointing *straight back* from the ROV so that its drag in the water does not tend to pull the ROV more to one side than the other, making it more difficult to turn the ROV in one direction compared to the other.

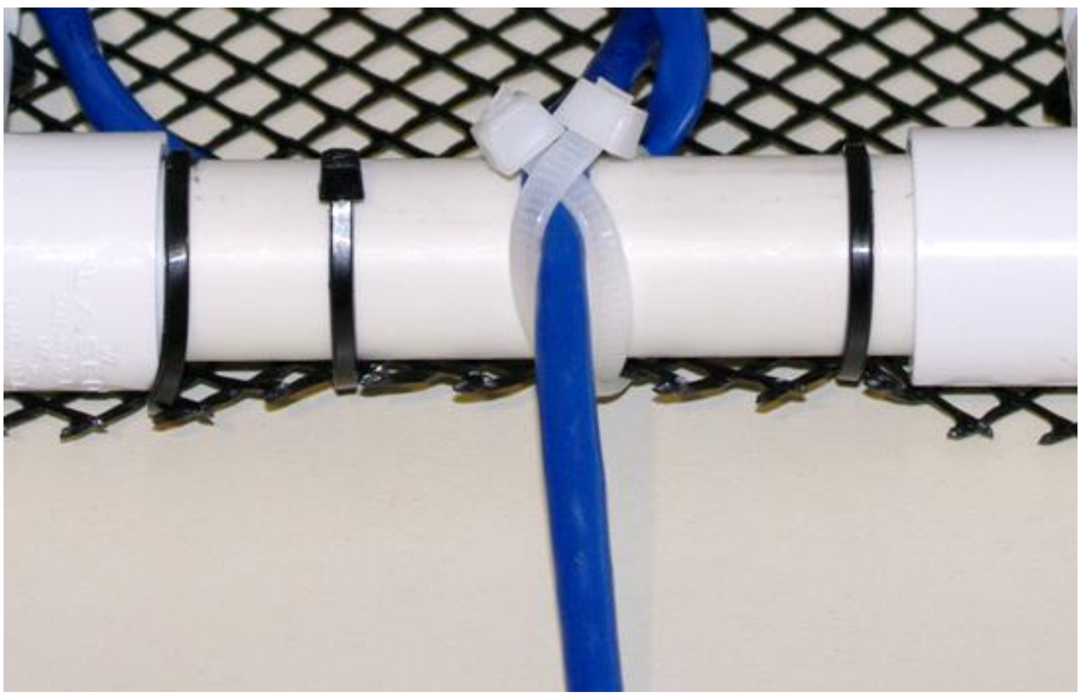


Figure 2.9-3. *Crossed Wire Ties Keep the Tether Centered on the Rear of the ROV*

☐ **7.** Pull all tie wraps tight with pliers, and then use the flush wire-cutting pliers to trim the ends flush. Coil the brown wire pair out of the way and tie-wrap it to the payload net; it may be needed later for accessories or for a thruster wire repair.

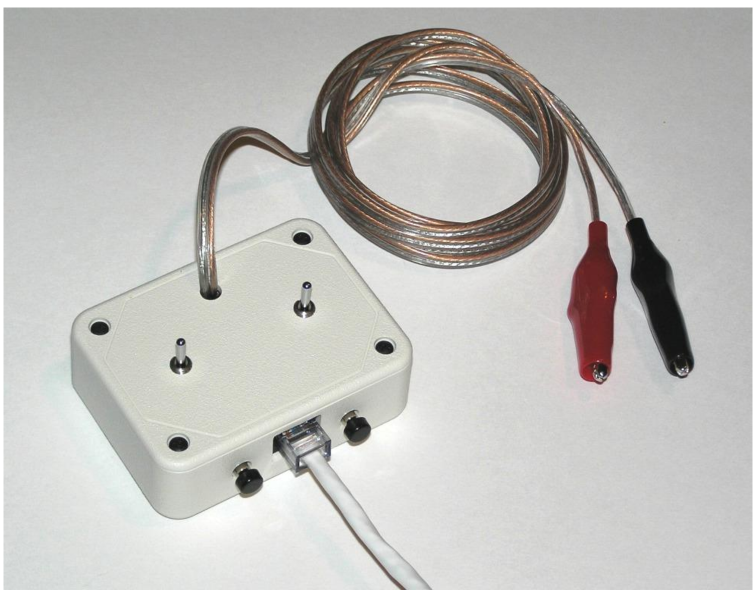
This completes assembly of your SeaPerch ROV Thrusters!

Version 2010-02

Unit 3

SeaPerch
Remotely Operated Vehicle (ROV)

Assembly of Subsystem Three
The Control Box



December 2010

The SeaPerch educational program was created by Harry Bohm and Vickie Jensen and published in their 1997 book "*Build Your Own Underwater Robot and Other Wet Projects*." The initial curriculum was developed by the Massachusetts Institute of Technology, and this version of the SeaPerch Construction Manual was provided under the Office of Naval Research National Naval Responsibility for Naval Engineering (NNRNE) Outreach initiative.

Unit 3 Assembly of Subsystem Three *The Control Box*

Tools and Materials Needed

Tools	Materials	
Eye Protection (Always Worn)	ROV Frame with Thrusters and Tether Cable Installed	
Ruler	1	Pre-Drilled Control Box with Lid & 4 Screws (Black)
Scissors	1	Printed Circuit Board (PCB)
Pliers	4	PCB Mounting Screws (Silver)
Wire Stripper	6' (~2 m)	#18 Speaker Wire (Or Lamp Cord)
Wire-Cutting Pliers (Flush Type Preferred)	2	Alligator Clips (With Red and Black Covers)
Soldering Iron and Solder	1	Fuse Socket
#2 Phillips Screwdriver	1	6.3 Amp Fuse
CAT-5 Cable Stripping Tool	1	12-Volt Battery
RJ45 Connector Plug Crimping Tool	2	Double-Pole, Double-Throw (DPDT), Center-Off, Toggle Switches (Momentary Type Preferred) with Mounting Nuts
	2	Single-Pole, Double-Throw (SPDT) Pushbutton Switches (Momentary) & 2 Caps
	1	Type RJ45 CAT-5 Modular Connector Jack
	1	Type RJ45 CAT-5 Modular Connector Plug
		Electrical Tape

Time Needed to Complete Unit 3

Total Construction Time:

Unit 3 usually requires about 4 hours for students to complete. More time should be allowed if the class is building a large number of ROVs.

Typical Allocation of Class Periods:

For standard class periods of approximately 50 minutes each, including any necessary clean-up time, plan for about five periods to complete this unit.

- 1 period to review the components, explain proper PCB soldering methods, and discuss how the components and circuitry function.
- 2 periods to solder the components onto the circuit board.
- 2 periods to assemble and connect the power cord, install the tether cable connector (if not installed during Unit 2), and finish the control box.

SeaPerch ROV Electrical Circuit Diagram

In this unit, you will assemble the control box for your SeaPerch ROV by mounting components onto a printed circuit board and connecting the tether cable and power cord wires. Below is a circuit diagram (or "schematic") which shows all of the electrical connections that will be made. This diagram is a technical representation to show the components and how they are connected, for the electrical components. Before assembling the control box, you should become familiar with how the components work and how the circuitry operates to cause the thruster motors to spin in each direction. The individual construction procedures in this unit have component photos and illustrations to help you understand what the actual wiring and installed components should look like when assembled.

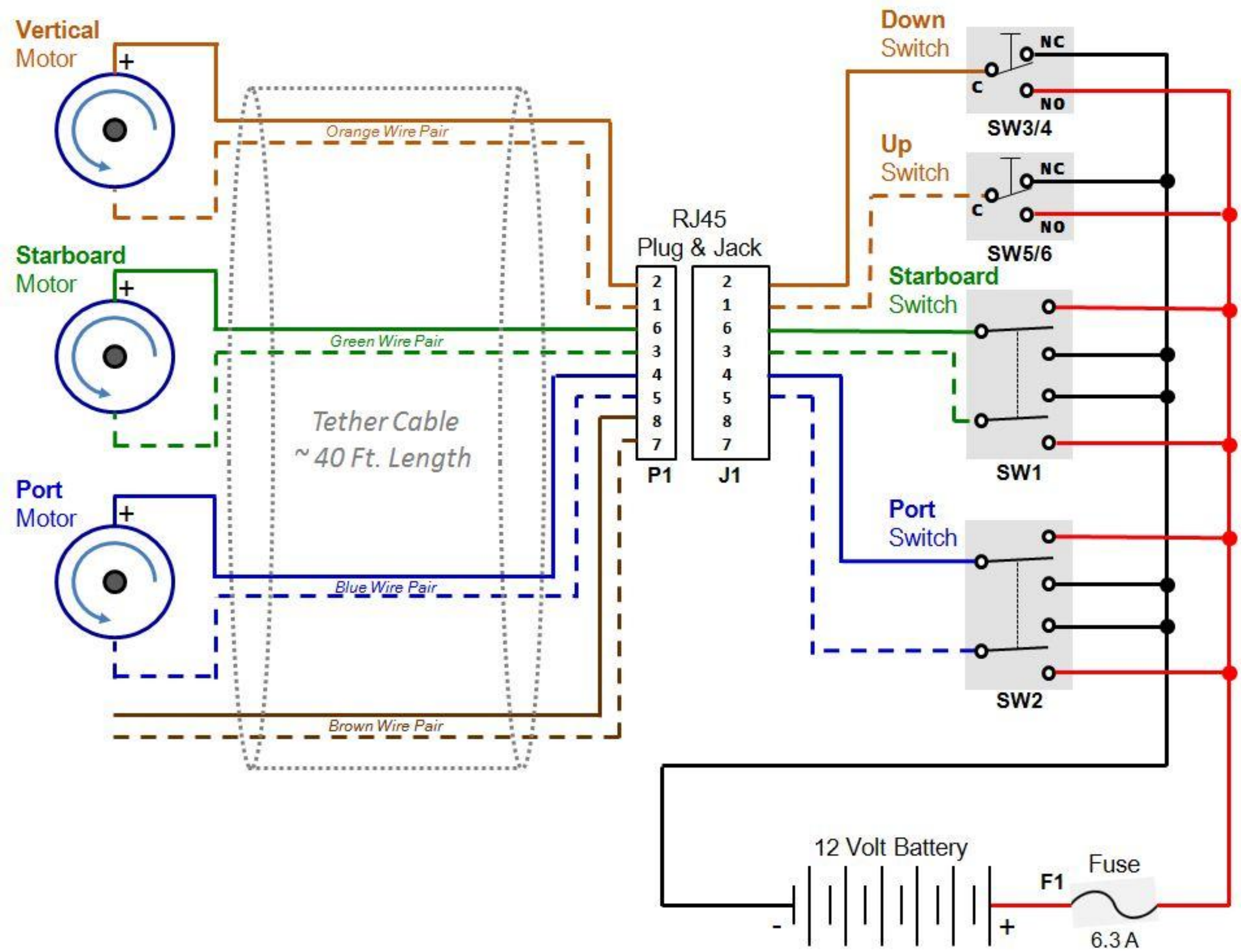


Figure 3.0-1: SeaPerch ROV Circuit Diagram

Procedure 3.1 – Gather the Parts for the Control Box Assembly

Materials:

Qty	Item
	Assembled ROV Frame with Thrusters and CAT-5 Tether Cable Attached
1	Control Box, with Lid and 4 Screws
1	PCB, with 4 Mounting Screws
2	Double-Pole, Double-Throw (DPDT), Center-Off, Toggle Switches (Momentary Type Preferred)
2	Single-Pole, Double-Throw (SPDT) Pushbutton Switches (Momentary)
2	Alligator Clips with Red & Black Covers
1	Fuse Socket
1	Fuse (6.3 Amps)
1	RJ45 Modular Connector (CAT-5) Jack
1	RJ45 Modular Connector (CAT-5) Plug
6'	(~2 m) #18 Speaker Wire (or Lamp Cord)

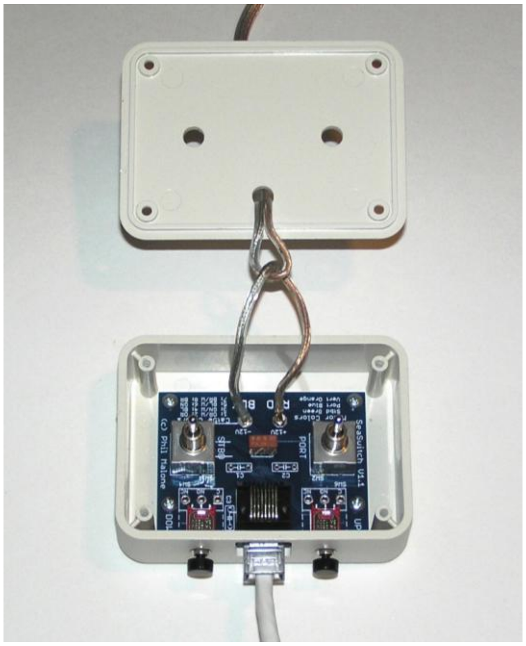


Figure 3.1-1: Assembled Control Box

Construction Steps:

☐ **1.** Gather and identify all parts required for the control box assembly, as shown in Figure 3.1-2. The tether cable shown is the one that is already attached to the thrusters on the ROV frame assembly, completed in Unit 2. If the RJ45 connector plug was installed on the tether cable during Unit 2 work (an option offered there to perform Procedure 3.2 early, to aid motor testing), you will not need to find the RJ45 plug shown.

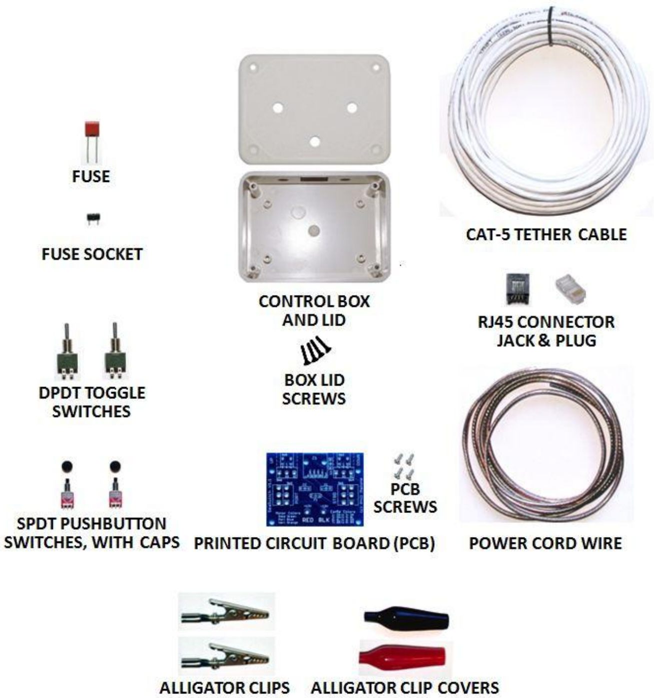


Figure 3.1-2: Electrical Components for the SeaPerch ROV Control Box

Procedure 3.1 – Continued

☐ **2.** Locate the fuse. If its leads are longer than about ¼ inch (6 mm), cut both leads to that length, as shown in Figure 3.1-3.

☐ **3.** Locate the two toggle switches. If they have nuts and/or washers installed on their threaded mounting shafts, remove the outermost nut and the washers; use pliers to loosen the nuts if needed.

☐ **4.** Gather the eight small screws and the hardware removed from the switches, and put them in a safe place (such as taping them to the inside of the vehicle storage tote bag or bin) to prevent them from being misplaced during the assembly process.

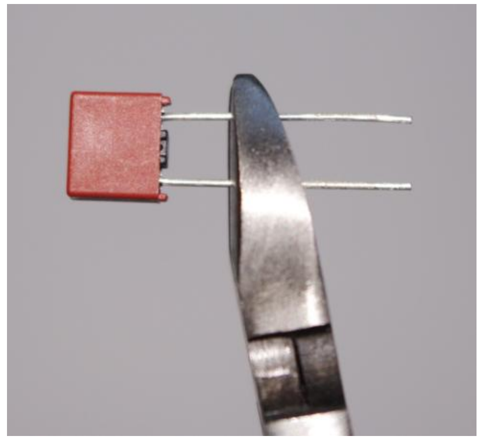


Figure 3.1-3: *Cutting the Fuse Leads to ¼ Inch Length*

☐ **5.** Examine the printed circuit board, and note that it has a component mounting side (which has words and component labels printed in white lettering), and a soldering side (no white lettering), as shown in Figures 3.1-4 and 3.1-5. When installing components in Procedure 3.4, be sure that they are <u>all</u> mounted on the side with the white lettering.

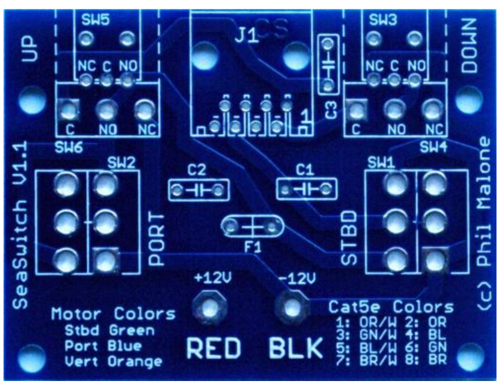


Figure 3.1-4: *Component-Mounting Side of the PCB*

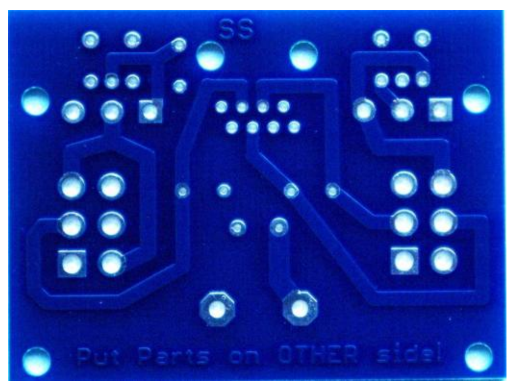


Figure 3.1-5: *Soldering Side of the PCB*

Procedure 3.2 – Install the Tether Cable Connector Plug

Tools:

- Ruler
- CAT-5 Cable Stripping Tool
- RJ45 Connector Plug Crimping Tool
- Wire-Cutting Pliers (Flush Type Preferred)

Materials:

- Tether Cable
- RJ45 Connector Plug

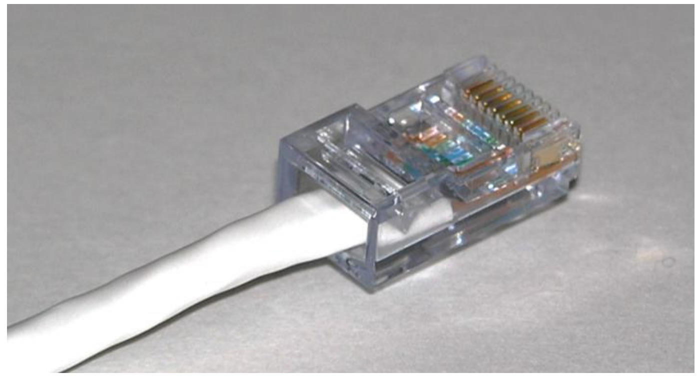


Figure 3.2-1: *RJ45 Connector Plug Installed on the Control Box End of the Tether Cable*

NOTE: This version of the SeaPerch ROV uses standard CAT-5 cable connectors (RJ45 modular plug and mating jack), of the type widely used for Ethernet local area networks, to connect the tether cable to the control box. The key thing to note is that the color-order of the wires that you will install in the RJ45 plug **IS IMPORTANT** to ensure that each switch controls the correct ROV thruster. SeaPerch ROVs use the industry standard "T568B" wire color sequence, the most common color sequence used for Ethernet networks. The wires will not be grouped in the connector by color-pairs as you might expect, so please follow the instructions carefully to get the sequence right.

Construction Steps:

☐ **1.** Locate the unconnected end of the tether cable and the RJ45 connector plug, shown in Figure 3.1-2 (and shown installed in Figure 3.2-1) . Be careful not to tangle the tether cable; it is best to keep it coiled up and secured with a wrap or two of electrical tape, except for about 2 feet of the unconnected end.

☐ **2.** Use a CAT-5 cable stripping tool to gently score and remove about two inches of the outer jacket. Because it is easy to accidentally nick the wires while stripping the jacket, it is best to remove *another* two inches of the jacket using the jacket-stripping pull-cord that is built into CAT-5 cables. Find the thread-like pull-cord among the four wire pairs, hold the wires tightly in one hand, and firmly pull the cord back toward the other end of the cable to split open about two more inches of the jacket, as shown in Figure 3.2-2. Then use wire cutting pliers to *carefully* cut off the split jacket material, the pull cord, and all but two inches of the wires, leaving clean, undamaged wires to use for the connector installation.

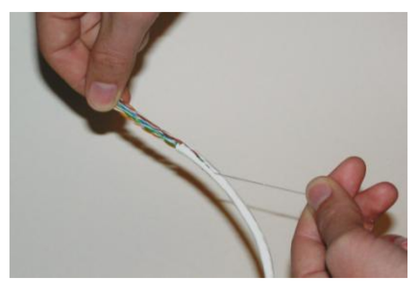


Figure 3.2-2: *Stripping Back the CAT-5 Cable Jacket*

Procedure 3.2 – Continued

3. Separate and untwist the four wire pairs and then carefully straighten out the kinks in all eight wires so that they are smooth enough to be inserted through the RJ45 connector, as shown in Figure 3.2-3.

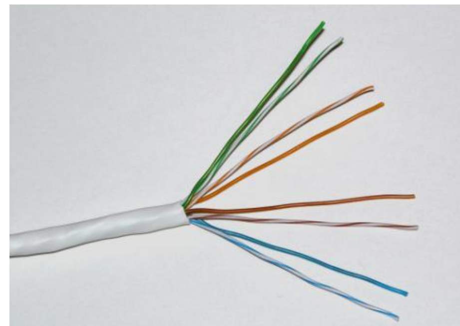


Figure 3.2-3: *CAT-5 Cable Wires Untwisted and Straightened*

4. Review the wire color sequence for the connector, listed in Table 3.2-1. The colors for each pin are also printed (abbreviated) on the PCB, as shown in Figure 3.2-4.

Table 3.2-1 – Tether Cable Connector Wire Color Sequence

PIN	WIRE COLOR
1	Orange & White Striped
2	Orange
3	Green & White Striped
4	Blue
5	Blue & White Striped
6	Green
7	Brown & White Striped
8	Brown

Figure 3.2-4: *Connector Wire-Color Sequence Printed on the PCB*

5. Group all eight wires into a flat bundle, while carefully placing them into the proper color sequence order, starting from pin 1, on the *left* as you look *down* on the bundle, as shown in Figure 3.2-5. Squeeze flat and wiggle the bundle of wires up and down a few times to help stabilize them into a straight, flat group.

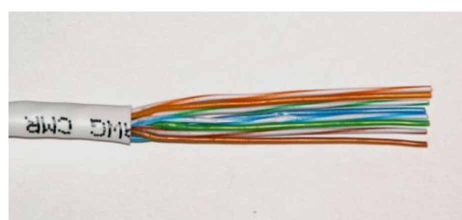


Figure 3.2-5: *CAT-5 Cable Wires in the Correct Color Sequence*

6. NOTE: Some CAT-5 connector crimping tools are designed to both *crimp* the plug and *cut* off any excess length of the wires, all in one operation. *IF that is the type of tool that you have*, skip to Step 7 now. Otherwise, use wire-cutting pliers (or a wire cutter that may be built into your crimping tool) to cut the whole flat bundle of wires, *straight across*, to *exactly ½ inch in length*, as shown in Figure 3.2-6.

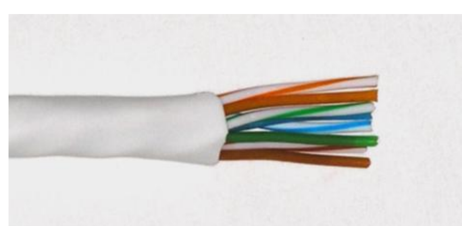


Figure 3.2-6: *CAT-5 Cable Wires Cut to ½ Inch and Ready to Insert into the RJ45 Connector Plug*

Procedure 3.2 – Continued

❑ **7.** With the key tab (or "hook") on the RJ45 connector plug *pointed* *downward*, carefully insert the flat bundle of wires into the back end of the plug, and pass them under the pins in the front of the plug, as shown in Figure 3.2-7. Re-check the color sequence of the inserted wires; you may need to remove and re-insert them a few times to get all eight in with the correct color order. Ensure that the color sequence order is correct before performing Step 8 below, as the connector plug can only be crimped once.

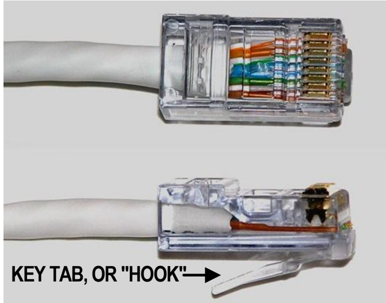


Figure 3.2-7: *CAT-5 Cable Wires Inserted Into the RJ45 Connector Plug*

❑ **8.** Open the handles of the CAT-5 connector crimping tool completely, and, while holding the cable jacket into the back end of the connector plug, insert the plug into the "RJ45" cavity in the tool, as shown in Figure 3.2-8 (note: many crimping tools also have a cavity for another connector type). Then push the cable tightly into the plug while closing the handles, squeezing them very firmly until they stop (or, for ratcheting style tools, through a complete ratchet cycle until the handles open) to crimp the connection. The crimped connector plug should look like the one shown in Figure 3.2-9, with the metal pins inside the plug forced down to connect into the wires and the V-shaped strain relief in the back of the plug pushed a bit into the cable jacket. Remove the crimped connector plug from the crimping tool (press the small key tab on the bottom of the connector if necessary to release it from the tool).

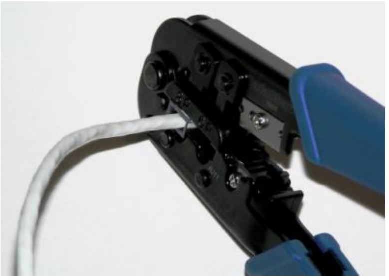


Figure 3.2-8: *RJ45 Connector Plug in the Crimping Tool Cavity*

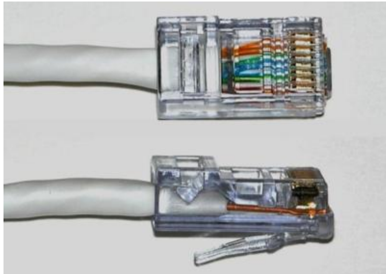


Figure 3.2-9: *Crimped RJ45 Connector Plug*

❑ **9.** If you used a "crimp and cut" style crimping tool for Step 8, and it did not fully trim off the excess wires that extended from the end of the RJ45 connector plug, you should be able to break them off by wiggling them up and down a few times, or use flush wire-cutting pliers to carefully trim them flush with the front end of the connector plug.

Procedure 3.3 – Assemble the Power Cord

Tools:

Soldering Iron and Solder
Wire-Cutting Pliers
Wire Stripper
#2 Phillips Screwdriver
Ruler
Scissors

Materials:

6' #18 Speaker Wire (or Lamp Cord)
2 Alligator Clips (Red & Black Covers)

Figure 3.3-1: *Completed Power Cord*

NOTE: In this step you will assemble the power cord for your SeaPerch ROV, as shown in Figure 3.3-1. *You may be provided with one of several types of 2-conductor wire, such as speaker wire, lamp cord, or a pre-made cord that has alligator clips already mounted on one end (and possibly some other style of connector(s) on the other end). Either type of wire will work, but the procedure is a bit different for the latter type, as indicated in Step 1 below*.

Construction Steps:

❑ **1.** ***IF*** you are provided with a power cord that already has two alligator clips attached at one end, cut off any connectors that may be on the *other* end of the two wires, strip off 5/8 inch of insulation from each, and twist their strands tightly (individually, not together) to prevent them from fraying and breaking. Then **SKIP** the rest of Procedure 3.3 and move on to Procedure 3.4.

❑ **2.** Find the power cord wire (#18 speaker wire or lamp cord), and determine which of its two conductors will be positive and which will be negative. To do this, note that each conductor has its own insulation, and that the two are attached to each other with a thin web of insulation material. Usually the insulation on one conductor is ribbed (like corduroy), and the other is smooth. Often the conductors' insulation is instead marked with white or black stripes, printed information, or other polarity indicators. For some power cords, the insulation is clear but one conductor is silver and the other is copper. See Figure 3.3-2. *For this project, we will call the ribbed, striped, or copper side the positive (+) wire, and the smooth, printed, or silver side the negative (–) wire.*

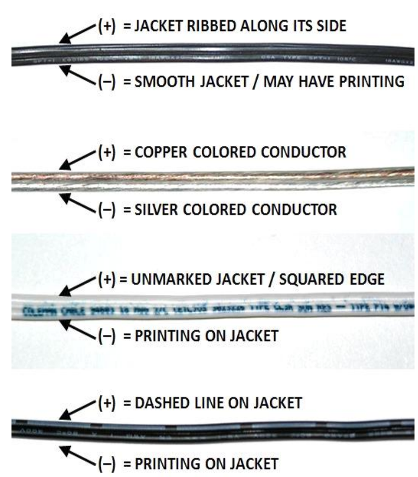


Figure 3.3-2: *Typical Power Cords and Markings to Identify (+) and (–)*

Procedure 3.3 – Continued

☐ **3.** On each end of the power cord wire, carefully separate the two conductors for about 3 inches (7.6 cm). This is best done by snipping the thin web of plastic between the wires with a small pair of scissors or wire cutting pliers. Be careful not to nick the insulation on either of the individual conductors.

☐ **4.** Strip 5/8 inch (16 mm) of insulation off of all four ends of the power cord wire. Twist the strands on each of the four ends (individually, not all together) tightly to prevent fraying and breaking.

☐ **5.** On one end of the power cord, slide the red alligator clip cover (small end first) onto the positive (ribbed / striped / copper) wire; make sure that its large end is nearest the end of the stripped wire so that it will fit over the alligator clips, as shown in Figure 3.3-3.

☐ **6.** Similarly, slide the black alligator clip cover onto the other (negative) wire of the power cord.

☐ ☐ **7.** Attach the two alligator clips to the power cord wires by pushing the wires in through the backs of the clips and up through the holes near the screws. Loosen (but do not remove) the screws, wrap the wires around them tightly in a clockwise direction, and then re-tighten the screws. The connected alligator clips should look like the one in Figure 3.3-4, with most of the wire captured under the screw's head. (You may also solder these connections if you wish, for extra security against pulling loose.)

☐ ☐ **8.** Move the covers over the clips (insert a pencil or other small object into the "mouth" of each alligator clip to make it easier to push the covers over the rear portion of the clip). The assembled power cord should look like Figure 3.3-1. It's other end will be connected to the PCB later, in Procedure 3.5.

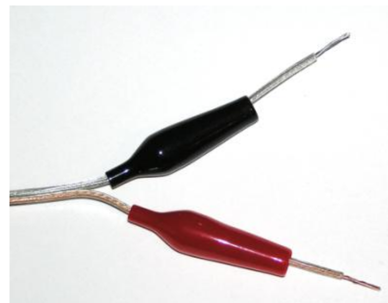


Figure 3.3-3: *Alligator Clip Covers Installed on Power Cord Wires*

Figure 3.3-4: *Wire Properly Connected to an Alligator Clip Screw*

Procedure 3.4 – Install the Printed Circuit Board Components

Tools:

Soldering Iron and Solder
Needle-Nose Pliers
Wire-Cutting Pliers
#2 Phillips Screwdriver

Materials:

1	Control Box and Lid with 4 Screws (Black)
1	PCB with 4 Screws (Silver)
1	Fuse Socket
1	6.3 Amp Fuse
1	RJ45 Modular Connector Jack
2	DPDT, Center Off, Toggle Switches (Momentary Type Preferred)
2	SPDT (Momentary) Pushbutton Switches

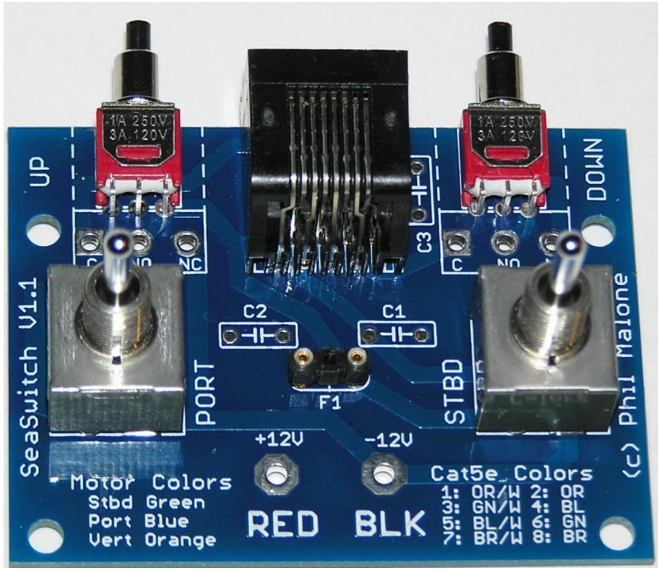


***Figure 3.4-1:** Components Mounted on the Printed Circuit Board*

PCB and Component Soldering Tips:

◆ When soldering, ***always wear eye protection!*** ◆ Be sure that the components are placed firmly against the PCB before soldering them; although it is possible to make corrections later, it can be difficult. ◆ Clean the soldering iron tip before EVERY soldering step, and then touch solder to tip of the soldering iron to "tin" it briefly before starting to solder a component. Keep solder on the tip between uses. ◆ While soldering, touch the solder only to the "pad" (the round contact on the PCB) and the component wire or pin, *not* to the soldering iron tip. ◆ Touch the iron's tip only on the pads, not the board. ◆ Heat each connection for a few seconds before applying solder so that the solder will flow completely over the pad as well as the component wire that passes through the hole in the pad. However, do not overheat the pads, as they might lift off of the board or it may become scorched; several seconds of heating is usually enough. ◆ When done soldering, remove the solder from the pad first, then the iron. ◆ When soldering the switches, pause a few seconds between each connection, so that plastic parts inside the switches don't overheat and possibly get damaged. ◆ After soldering each connection, let the solder cool for several seconds before moving the PCB, so that the solder will form a good conductive connection. They should be shiny, not rough or dull-looking; if they don't look shiny, simply reheat them and keep them still while cooling. ◆ Use just enough solder to cover the connection; too much can cause the excess to bridge between closely-spaced connections. Check for solder bridges after soldering each component.

Construction Steps:

❑ **1.** Review Figures 3.0-1 and 3.4-2 to understand the circuit diagram and identify the components that will be installed on the PCB. You will start with smaller ones first, and then move on to the larger components.

Procedure 3.4 – Continued

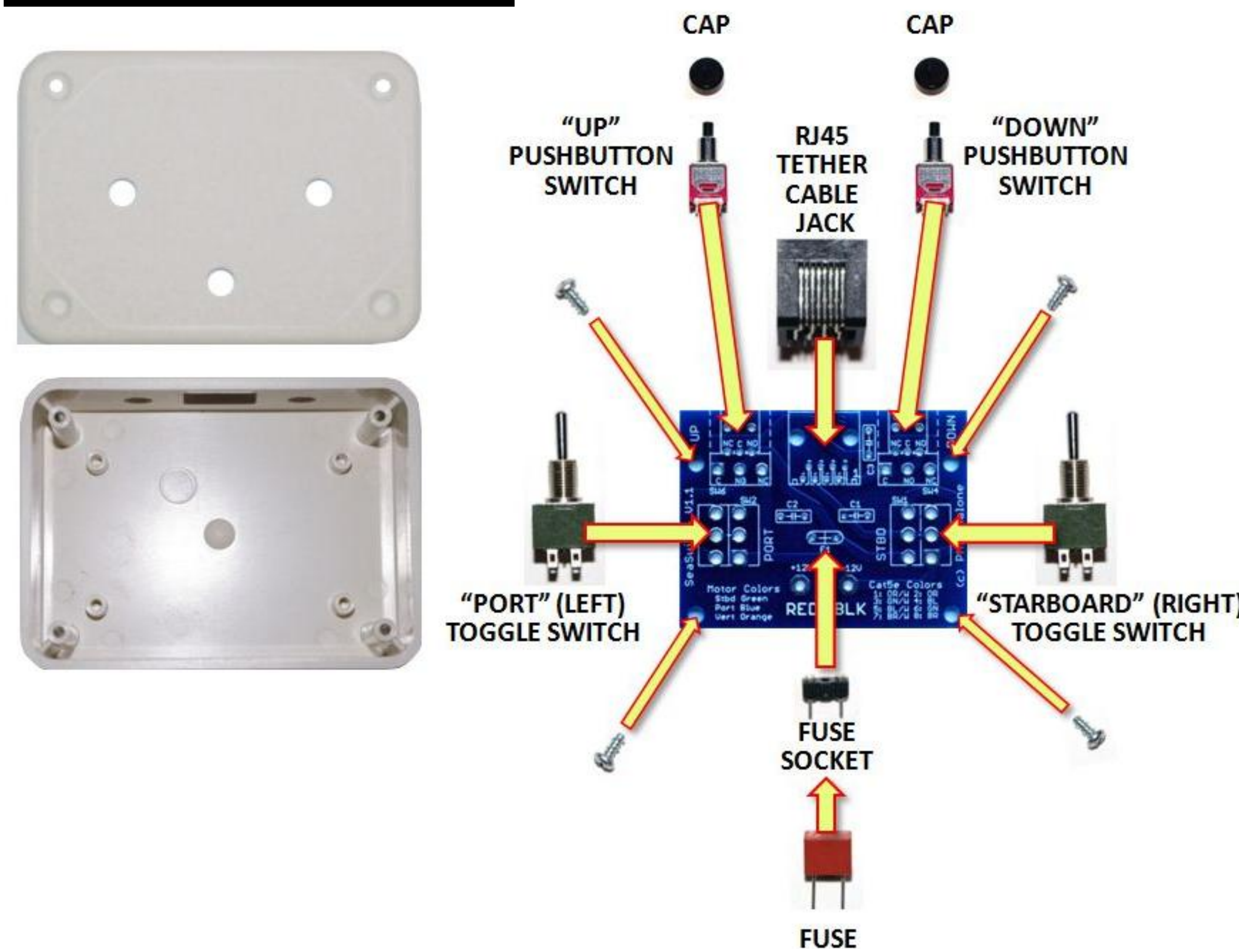


Figure 3.4-2: *Components Required for the Control Box PCB Assembly*

☐ **2.** Locate the **fuse socket** (the smallest control box component). It goes in the middle of the board, at the location labeled "F1." Place its two pins through the holes at the F1 location, as shown in Figure 3.4-3 (remember, ALL components go on the side of the PCB that has the white lettering). Flip the board over, while holding the socket in place, and solder the connections. Melt only about 1/4 inch of solder into each connection, let them cool for a few seconds before moving anything, and make sure that there are no solder bridges between the connections. Remove excess solder if needed using a clean soldering iron tip.

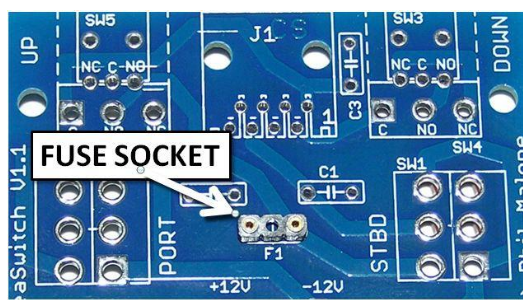


Figure 3.4-3: *Fuse Socket Installed at the Location Labeled F1*

Procedure 3.4 – Continued

- [ ] **3.** Place the pins on the two **pushbutton switches** through the pads in the PCB at the locations labeled "SW3" and "SW5," as shown in Figure 3.4-4, after making sure that their pins are all straight (perpendicular to the switch body). While holding the switches in place, flip the PCB over and place it on a tabletop. Press down on the PCB to hold the switches FLAT against the board (in order for them to fit properly through the holes in the box), and solder the five connections on each switch. The solder connections should look similar to those in Figure 3.4-5.

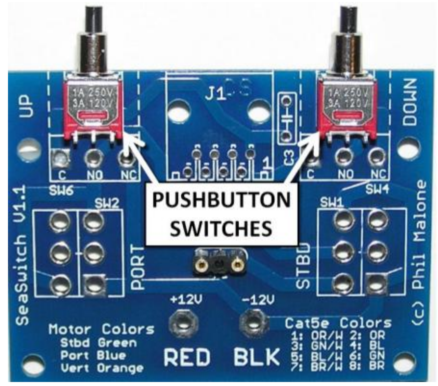


Figure 3.4-4: *Pushbutton Switches Installed in the SW3 and SW5 Locations*

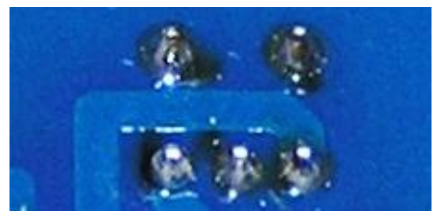


Figure 3.4-5: *Pushbutton Switch Solder Connections*

- [ ] **4.** Find the two **toggle switches** and the **control box lid**. Place the switches in the SW1 and SW2 locations on the PCB, as shown in Figure 3.4-6. It is important to keep the switches flat against the board while they are soldered into place, so that they will be straight when the control box is finished. A good way to ensure this is to use the control box lid to hold the switches while soldering. Simply put the toggle handles through the two center holes in the control box lid (they may be a bit tight), install a switch retaining nut on each switch, and tighten the nuts finger-tight. Then, while holding the PCB against the back of the switches, turn the assembly over and place it across the open top of the control box, as shown in Figure 3.4-7.

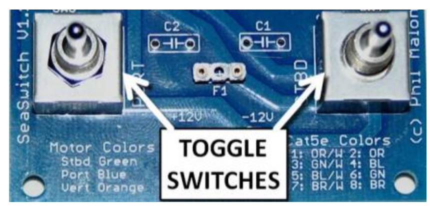


Figure 3.4-6: *Toggle Switches Installed in the SW1 and SW2 Locations*

- [ ] **5.** The PCB will probably be rather loose on the back of the toggle switches, so hold it down flat while soldering the <u>first</u> of the 12 switch connections, to make sure that it will be tight against the switches. Note that the larger terminals on the toggle switches will each require more solder than was needed for the smaller switches. Solder the remaining 11 connections, taking care not to overheat the switches (wait a few seconds between connections, or alternate between the two switches). Then remove the nuts and the lid.

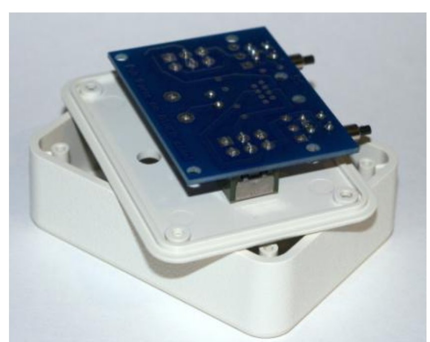


Figure 3.4-7: *Toggle Switches Held Straight by the Control Box Lid During the Soldering*

Procedure 3.4 – Continued

- [ ] **6.** Check to ensure that the small pins on the bottom of the **RJ45 connector jack** are not bent, and then place them through the holes in the PCB at location J1, as shown in Figure 3.4-8. After confirming that all pins are properly through the holes, press down on the jack to snap it into place. Place the PCB back on top of the control box and solder the eight pins, being careful not to use too much solder, which might create solder bridges between the closely-spaced connections.

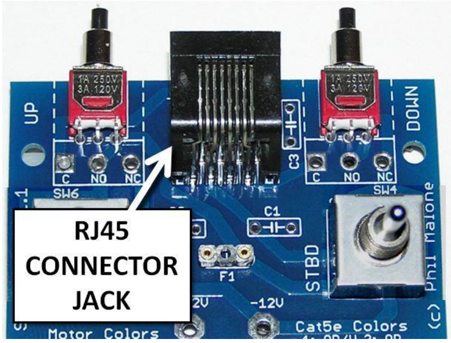


Figure 3.4-8: *RJ45 Connector Jack Installed at Location J1*

- [ ] **7.** Re-examine all of the solder connections on the PCB as a final check for solder bridges or connections that don't seem to have enough solder. Re-solder them if needed. The soldered side of the completed PCB should look similar to the one shown in Figure 3.4-9. You may see a little extra solder flux remaining around some of the connections, but they should all be shiny, and there should not be any solder bridges creating unintended short circuits.

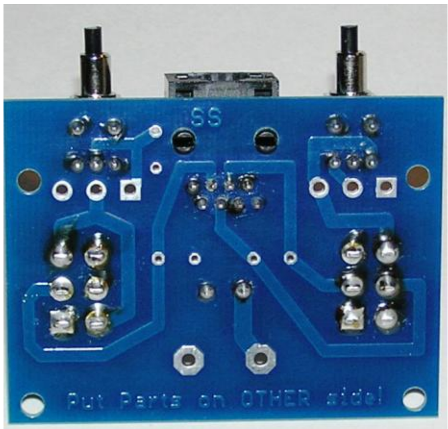


Figure 3.4-9: *A Typical PCB After Soldering All Six Components*

Procedure 3.5 – Connect the Power Cord

Tools:

Soldering Iron and Solder

Wire-Cutting Pliers

Materials:

PCB with Components Mounted

Assembled Power Cord

Control Box Lid

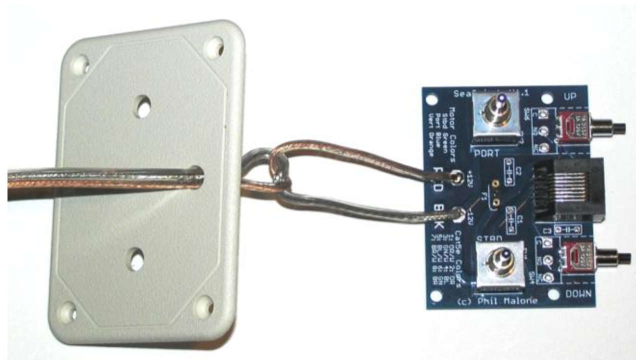


Figure 3.5-1: *Power Cord Passed Through the Box Lid and Connected to the PCB*

Construction Steps:

❑ **1.** Twist the strands of the two power cord wires, and *pass them through the hole in the control box lid*, from the top side. Then tie a knot in the two wires, about one to two inches from their ends, on the underside of the lid, as shown in Figure 3.5-2.

Figure 3.5-2: *Power Cord Passed Through the Hole in the Box Lid, and Knotted*

❑ **2.** Re-twist the strands of each of the two wires so that they can pass through the solder pad holes in the PCB easily without fraying. Then place the positive (ribbed / striped / copper) wire into the "+12V" (RED) power wire hole in the board, and the negative (smooth / printed / silver) wire into the "–12V" (BLK) power wire hole, both entering the holes from the component side of the PCB, as shown in Figure 3.5-3. Bend the wires over to help hold them in place, or get someone to assist in holding the wires in place during the soldering process.

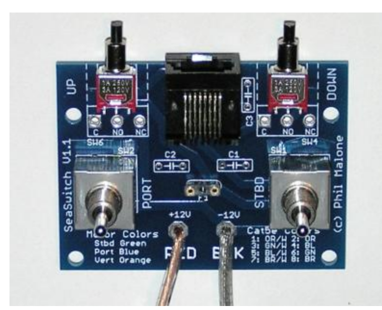


Figure 3.5-3: *Power Cord Wires Through the Holes in the +12V and –12V Pads*

❑ **3.** Solder the two power wires, making sure to use enough solder to make good, solid electrical connections that are held firmly in place, and then snip off the excess wire using wire cutting pliers. Snipping the excess wire ends is optional, as they will only touch the bottom of the plastic box, but it is a good construction practice.

Procedure 3.6 – Finish the Control Box

Tools:

#2 Phillips Screwdriver

Materials:

Control Box

Completed PCB with Lid and Power Cord Attached

4 Silver PCB Screws

4 Black Control Box Cover Screws

1 Fuse

2 Pushbutton Switch Caps

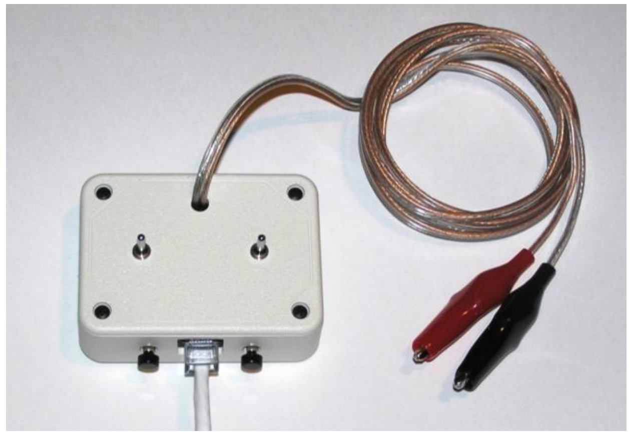


Figure 3.6-1: *Completed Control Box*

Construction Steps:

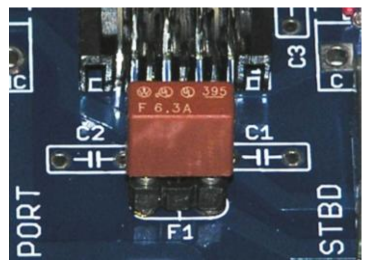


Figure 3.6-2: *Fuse Installed in PCB Fuse Socket*

1. Install the **fuse** into the fuse socket located in the center of the PCB. Press its leads tightly into the socket, as shown in Figure 3.6-2.
2. Examine all PCB connections one more time. Look for, and fix, any missed or loose solder connections, short circuits from wire strands or solder bridges between connections, or missing components.
3. Place the PCB into the control box, passing the pushbutton switch actuators carefully through the two holes in the front of the box, and secure the PCB into the box using the four small silver screws.
4. Press the two **pushbutton switch caps** onto the actuators, as shown in Figure 3.6-1. They may require firm pressure to snap them securely into place.
5. **Optional:** You may conduct the open-switch electrical tests described in the following section, "Testing and Ballasting the ROV," now if desired; however, if Step 2 was performed well, the test can wait until after completing assembly.
6. Install the lid onto the control box, carefully folding the power cord wires inside the box as the lid is lowered into place. Secure the lid with the four black screws.
7. Connect the tether cable's RJ45 connector plug into the RJ45 jack on the control box. However, **DO NOT connect the battery** until the electrical testing in the following section has been successfully completed.

***CONGRATULATIONS*, you have finished the construction of your SeaPerch ROV!**

Now it's time to get it ballasted and tested!

Testing and Ballasting the ROV

Time Needed to Complete Testing and Ballasting of the ROV

Combined Testing and Ballasting Time:

Initial electrical testing usually requires much less than 1 hour, unless the vehicle does not function properly, in which case several hours may be required to resolve the problem(s). Ballasting experimentation and mounting of the final ballast weights usually requires about 1 to 2 hours. With large numbers of ROVs, more time should be allowed if in-water test space and troubleshooting resources are limited.

Typical Allocation of Class Periods:

For standard class periods of approximately 50 minutes each, including any necessary clean-up time, plan for at least four periods to test the ROVs and ready them for in-water use.

- 1 period to perform initial electrical tests, check the operation of the thrusters and control box, and make minor adjustments.
- 2 periods to review buoyancy concepts (conducting a hands-on "buoyancy lab" session is recommended), determine the amount of ballast needed, and install the weights.
- 1 class period for troubleshooting and problem solving, which is usually needed for at least a few ROVs per class.

Initial Electrical Testing

Testing Before Connecting the Battery:

Conducting a few quick short-circuit tests **BEFORE connecting the battery** can avoid blowing the fuse (or even melting wires), if there is an undetected problem with the ROV's wiring. The following tests are recommended.

Open-Switch Test:

Connect an ohmmeter (multi-meter) or continuity tester across the two power cord wires, where the battery would normally be connected. With all switches in the "off" position, there should be no continuity indicated, and an ohmmeter should read infinite resistance. If there is a continuity indication or if any less than infinite resistance is measured, there is a short circuit somewhere in the wiring, likely in the control box. Solve this problem before connecting to the battery, or the fuse will likely be blown immediately.

Closed-Switch Tests:

With the continuity tester or meter still connected (and making sure that the tether cable is plugged into the control box, if using the printed circuit board version), close each switch, one at a time, to check for continuity through the thrusters. A typical thruster has some electrical resistance, but little enough to allow a continuity tester to indicate continuity. An ohmmeter should show a relatively low resistance, typically from about 10 to 50 ohms. Conduct this test for each pushbutton switch (if used) and for the two “on” throw positions of each toggle switch. Check also with combinations of switches closed at the same time. If the resistance ever reads near zero on an ohmmeter, that indicates either a shorted thruster or another short-circuit wiring problem in the control box or tether cable. Solve the problem before connecting battery power to the ROV.

Testing for Proper Thruster Operation:

After passing the tests above, it is finally time to connect the ROV to its battery. Connect the two power leads (the alligator clips, or the quick-disconnect terminals on some versions) to the appropriate positive and negative terminals of the battery. Then, close each switch, one at a time. The propellers should spin *counter-clockwise* (looking into the end of the shaft) whenever the controls are switched to “forward” for the horizontal thrusters and to “down” for the vertical thruster. Then check the opposite directions. If any thruster spins in the wrong direction or does not spin properly, see Appendix A, “Troubleshooting Your SeaPerch ROV” for some common solutions. Students should try to solve the problems on their own before using that aid, at least until running out of ideas!

Ballasting and Trimming the ROV

Understanding Neutral Buoyancy:

ROVs work best when they are nearly neutrally buoyant, with a slight positive buoyancy to enable them to slowly return to the surface should they fail. An ROV is neutrally buoyant in water when the force exerted by its total buoyancy (due to the vehicle’s own buoyancy plus any added flotation materials) pulling it toward the surface is the same as its total weight (due to the vehicle’s own materials plus any added ballast materials) pulling it down by gravity. By being neutrally buoyant, not tending to sink or rise, the ROV can move through the water based only upon the power applied from its thrusters. However, the total mass of the vehicle compared to the power of its thrusters is also an important consideration. Even a massive ROV that has lots of flotation matched with lots of ballast can still be neutrally buoyant, but that large mass may also be difficult to move using the relatively small thrusters employed for SeaPerch ROVs. The general goal for adding flotation and ballasting is to keep the ROV reasonably nimble and responsive to its thrusters, whether moving about horizontally or lifting a payload vertically. Minimizing the ROV’s *total mass* as well as its *in-water drag*, which is addressed in the next section, will help in meeting this goal.

The buoyancy of an object is dependent upon the type of water that it is in. An object floats when it weighs less than the water that it displaces. Denser water will make a given object relatively lighter, so it floats more easily. Thus, objects have more buoyancy in saltwater than in fresh water. Saltwater density can change with depth as well. Therefore, the ballast may need to be adjusted for different ROV operating locations and depths.

Participating in a "buoyancy lab" class session (with hands-on experimentation to better understand buoyancy, the effects of flotation and ballast materials, and neutral buoyancy in particular) can be helpful prior to attempting to ballast and trim a SeaPerch ROV.

Ballast and Trim Considerations for SeaPerch ROVs:

The standard cylindrical foam floats or fixed-buoyancy net floats that are often used for SeaPerch ROVs have a significant amount of buoyancy that must be counteracted by adding quite a bit of ballast weight to the ROV, typically up to about ten ounces or more for a basic ROV without sensors or other accessories. Other types of floats bring different ballast needs, but all SeaPerch ROVs must have some added ballast in order to achieve neutral buoyancy. *Note that when using foam floats, their physical size will often decrease with increasing depth (over about five feet of depth), due to increasing water pressure; this results in reduced displacement and thus reduced buoyancy at depth. For example, when the ROV sent to the bottom at the deep portion of a swimming pool (often 12 feet or more in depth), it may no longer be able to return to the surface easily. <u>For this reason, it is best to have the ROV ballasted to be more positively buoyant while at the surface when using foam style floats</u>.* This will also enable the foam-float-equipped ROV to more easily bring payloads to the surface.

Trim refers to adjustments to the ballast and flotation of the vehicle to make it level in the water. The ballast and flotation materials should be placed around the vehicle in such a way that it is not tilted much side-to-side or front-to-rear. Being level in the water will enable the vehicle to pick things up off the sea (or pool) floor as well as turn left and right without also changing depth. Standard SeaPerch floats are in fixed positions on the ROV, so proper trim is best achieved by minor adjustments to ballast placement, after neutral buoyancy is attained. For ROVs with PVC tube floats, front to back trim may be adjusted by sliding the floats forward or backward, but ballast adjustments are still needed for side-to-side trim.

Students should experiment with different types of ballast materials, but always using items that can be placed in water without damaging them (or the water). Certain types of metals rust or corrode easily in water (fresh water, pool water, or salt water), so ballast materials should be chosen wisely. Also, for ballast to do its job well, it should not move around, which can change the ROV's trim and even its dynamics as it accelerates and decelerates. Therefore, bags of materials (which can also create excess drag) and suspended weights are not good choices for ballast.

Ballast items can be attached to the ROV in various ways, such as using tape, tie wraps, or fasteners such as screws or clamps. The weights can be attached to the frame or to the payload net; however, it is best to *keep the front center area of the net clear* to enable the ROV to pick up items without interference.

Students should also consider how the tether cable affects ballasting and trim, for different operating depths. At deep depths, or if a camera cable is paired with the standard ROV tether cable, added flotation may be needed on the cable to enable the ROV to surface.

Initial In-Water Testing in the Classroom, Lab, or Pool

Buoyancy Check:

A quick check for positive buoyancy can be made by pushing the ROV to the bottom of a tank or even a large bucket (making sure to get all of the air out of the pipes) and letting go. A properly ballasted ROV should very slowly rise to the surface. Most initially pop up like a cork. If it just sits on the bottom, it's time to re-evaluate ballast already installed and/or check the floats to make sure that they have not leaked. Students should iteratively adjust ballast and recheck their ROVs until near-neutral buoyancy is achieved.

Trim Check:

After attaining neutral buoyancy, it is helpful to quickly check that the ROV sits level in the water. Simply hold it at a depth somewhere between the surface and the bottom, let go, and observe it for a moment, before it floats to the surface. If the trim needs adjustment, this is the time to do it, usually by redistributing the ballast weight. If movable floats are used, they can also be adjusted slightly, moved toward the front or back of the ROV to adjust its trim.

Thruster and Control Test:

Beyond getting the SeaPerch ROV properly ballasted and trimmed, the in-water test provides an opportunity to make sure that its thrusters can push it straight and predictably, that it can dive and surface, and that the controls work reliably. This can be accomplished in a swimming pool, a small water tank, such as a water trough, or even in a bathtub. By placing the ROV on the surface at one end of the tank or tub, there should be enough running distance to observe whether it will run in a generally straight line when both horizontal thrusters are switched on in the forward direction at the same time.

Similarly, a foot or two of depth is sufficient to determine whether the ROV can pull itself from the surface to the bottom and back. The goal of the initial test is to identify any thruster speed or mounting angle problems before testing in open water. Plus, the test gives the builder a great feeling of accomplishment (*the realization that the ROV really works!*).

Tether Cable Check:

Prior to operational use, all ROVs should be checked for proper tether cable attachment at the rear of the vehicle. If the ROV would not "fly" straight in the test above, an improperly attached tether cable could be the reason. Tie wraps crossed in an "X" over the tether cable in the *center* of the lower rear pipe section usually indicates proper attachment, to keep the vehicle-end of the tether cable pointing straight back from the ROV. The strain relief loop's attachment should also be checked in this process.

Propeller Check:

Before operating the ROV in water, always conduct a simple test to make sure that the propellers won't easily detach from the thrusters' motor shafts. Whether they were installed using the standard adhesive process or using an optional method from the supplement, give each propeller a gentle tug -- not so hard as to try to pull it off of the motor's shaft, but with enough force to make sure that it does not come off easily. If it does, repeat Procedure 2.7.

Thruster Angle Adjustment:

As noted in Unit 1, the angles at which the horizontal thrusters are mounted will affect the thrust, stability, and maneuverability of the ROV. Students should experiment with different thruster angles to find a configuration that provides both good forward thrust and good turning ability. The angles are easily changed by twisting the pipes on which the thrusters are mounted.

Battery Charging:

Make sure that the battery is fully charged before taking the ROV out for an operation. The battery should also be recharged immediately after use, as lead-acid batteries will last much longer if they are not left discharged.

Post-Test Cleaning:

Always make sure to rinse your SeaPerch ROV thoroughly with fresh water when you have finished operating it in a swimming pool (or a natural marine environment). Pay special attention to the motor shafts, as they are often the first places to rust. Clean all seaweed or other foreign materials off of the vehicle, particularly the motor shafts, and rinse it well with fresh water. Spraying the shaft area of each thruster with a protective agent such as WD-40 after each use will help to lengthen the operating life of the vehicle.

The SeaPerch program website at http://www.seaperch.org contains valuable information and educational resources. Additional information is also maintained at the MIT Sea Grant website, http://seaperch.mit.edu.

Enjoy Using Your SeaPerch ROV!

Using the SeaPerch ROV

Safety Precautions

Safety is an essential consideration when working around water. Besides the risk of ROV operators falling into the water, electrical safety precautions should be observed. All ROV operators (pilot and tether manager) as well as water-side observers should exercise caution and stay aware of the movement of others while near the edge of the pool, dock, or other water-side location. Even simple inattention to what is going on in the area while focused on operating an ROV can lead to unexpected "dips." Wearing a personal flotation device is recommended if operating the ROV from a pier that extends into deep water or from a boat (as is often required by law).

Even though the ROVs operate on low voltage direct current, it is a good idea for people handling the ROVs' electrical controls, batteries, and related systems to keep their body parts out of the water. Keeping the water surface free of disturbance also makes the ROVs and their maneuvers much easier to see.

Batteries are heavy, and if one is pulled off a tabletop by a tug on the ROV's power cord, it can cause an injury (such as if it is dropped on a foot), as well as damage to the battery. Be careful in placement of the battery; consider keeping it on the ground or pool deck.

Environments Suitable for Using a SeaPerch ROV

SeaPerch ROVs can be used in fresh water or saltwater, in man-made pools or natural marine environments. However, ballasting as well as post-operation cleaning requirements are different for the two types of environments. Due to the differing water densities, adjustments to the total ballast, and thus often to ROV's trim, are usually needed when moving from one environment to the other. For deep water use, the foam floats should be replaced with solid (non-compressible) floats. Two options for alternate flotation are noted in the SeaPerch ROV Construction Manual Supplement.

After operations in either pool water or saltwater, the ROV should always be rinsed thoroughly with fresh water; however, use in natural marine environments may require biologic material or sediment to be removed as well, even from inside the ROV's pipes.

Piloting the ROV

Vertical Motion (Diving and Surfacing). A properly operating SeaPerch ROV should be able to submerge or return to the surface under its own power, and a submerged ROV should slowly return to the surface when the thrusters are off. When operating at deep depths, the weight of the standard tether cable, if not compensated by flotation materials, can make it difficult for the ROV to return to the surface. In that case, re-ballasting with a bit more positive buoyancy can help.

Horizontal Motion (Underway Maneuvering). The ROV should move directly forward when both horizontal thrusters are energized. It should be able to move toward the port (left) or starboard (right) with nearly equal power when the tether cable is straight behind the vehicle. Should the tether cable be tending far to the right or left, due to the position of the ROV relative to the operators, it may seem to move better in one direction than the other. It should turn and move forward somewhat when only one thruster is energized in the forward direction, and turn faster with less forward motion when the other thruster is simultaneously energized in the opposite (reverse) direction. When both thrusters are energized in reverse, the ROV should move backward; however, the tether cable (then being pushed instead of pulled) can more noticeably affect ROV dynamics when it is operated in reverse. When underway at deep depths, the drag of the tether cable can also affect ROV performance. Sometimes the horizontal thrusters simply run at different speeds. This can obviously affect the way the ROV moves forward as well as its ability to turn. If the difference is significant, changing a thruster (by cutting the wires and splicing in and mounting a spare thruster) is relatively easy and can greatly improve ROV performance. SeaPerch thrusters are fairly powerful for their size, and they can even seem almost too powerful at times, such as when delicate maneuvers are needed. Using “momentary contact” toggle switches, which quickly return to the off position automatically when not being engaged, can be helpful in making minor adjustments to the ROV’s position. With ROVs, precision maneuverability is a more important factor than maximum speed. In fact, an ROV that can dart about too quickly may have a more difficult time performing some types of underwater work.

Mounting-Angle Effects of Horizontal Thrusters. The angles at which the ROV’s horizontal thrusters are installed, relative to the centerline of the vehicle, can affect both forward motion and turning capability. The ROV frame creates drag in the water, so its thrusters (if not placed at the ROV’s center of mass, or thrusting directly toward that point) will cause the vehicle to rotate about that center of mass. The effect of a thruster can be quite different depending upon where it is placed on the ROV and at what angle it is pointed. The ROV’s motion will be the result of the combination of the forces from all three thrusters, so it usually won’t maneuver much like a wheeled vehicle does on the ground. Operators should experiment with their ROV and try different angles for the horizontal thrusters as needed in order to achieve predictable maneuvering capabilities.

Courteous and Careful Piloting. When multiple ROVs are in the water together, the importance of paying attention to ROV movements increases, particularly when non-momentary switches are used for the horizontal thrusters (which can make it easy to leave thrusters energized longer than desired). An ROV can travel significant distances, possibly into the path of another, in just a few seconds, so good attentiveness is essential when they are underway. An ROV should never be allowed to run into another ROV ("bumper-cars" fashion), which could damage the propellers or other vehicle parts. Operators should always pay close attention to the locations of their tether cables, to avoid getting them tangled with the tethers of other ROVs. Similarly, when moving through openings or around obstacles, the ROV's pilot and tether manager should plan for the fact that they will usually need to bring the ROV back out the way it went in.

Post-Run Cleaning and Maintenance of the ROV System

Post-Run Cleaning. The ROV should always be rinsed thoroughly with fresh water after use. Pool water as well as saltwater can be corrosive to thrusters and other metal parts. Biologic or other materials picked up in natural marine environments can be damaging and difficult to clean off later if left to dry on the ROV. In addition to rinsing the vehicle and cleaning off any debris, it is helpful to submerge it in a tub of fresh water and run the thrusters for a few moments, to better clear corrosive materials from the motor shafts. Immediately treating the shaft areas with a protective material such as WD-40 spray and allowing the vehicles to dry before storage is recommended. Even if the ROV will be disassembled to have its parts reutilized for future ROVs, having clean parts that are free from corrosive materials and contaminants is important. In such cases, the used thrusters can provide valuable spares, so they should be cleaned carefully.

Battery Maintenance. The lead acid batteries normally used with SeaPerch ROVs should be kept in a fully-charged condition for maximum service life. Always recharge the batteries with the recommended charger and charging method soon after use, and then keep them "float" charged if possible while in storage, with a charger designed for that purpose. This is particularly important when they won't be used again for many months. The batteries can last for a number of years if maintained properly.

APPENDIX A

Troubleshooting Your SeaPerch ROV

Things to Try Before Re-Wiring the ROV or Changing ROV Parts

Solving Directional Control Problems:

Sometimes SeaPerch controls are found to be reversed, such as the port switch controlling the starboard thruster. Sometimes one or more thrusters operate in the reverse direction from that intended. The hints below may help in troubleshooting the problem(s), and, in some cases, offer simpler solutions than tearing into the control box or thrusters to redo the wiring.

- **Port and Starboard Switches Operate the Wrong Horizontal Thrusters**. Simply swap the horizontal thrusters by loosening their mounts and trading them (port / starboard), or check the tether's RJ45 plug wire order; re-install if needed.
- **A Horizontal Thruster Runs in Opposite the Direction Intended**. Check the tether's RJ45 plug wire order and re-install it if needed, or simply learn to operate the control switches in their reversed orientation.
- **The Vertical Thruster Runs in Opposite the Direction Intended**. Re-mount the thruster upside down in the thruster mount (*but be careful that it will not interfere with any payload being handled by the ROV*), or check the tether's RJ45 plug wire order and re-install it if needed.
- **A Thruster Runs in Only One Direction, or Does Not Operate**. First, check the tether's RJ45 plug wire order and re-install it if needed. If the plug is good, a switch may have failed due to overheating during soldering (there are plastic parts inside many switches, and they can melt from too much heat). Try the control box with another ROV, if available, to determine whether the switch is working. Or, open the control box to test the suspect switch using an ohmmeter (for continuity when actuated) or a voltmeter (for 12 volts when actuated). Carefully de-solder and replace the switch if it has failed.
- **The ROV Always Seems to Turn More Easily to the Left or the Right**. Check to see that the tether cable is mounted on the ROV in the *center* of the pipe on the rear of the vehicle, and that the *crossed tie wraps* are in place to keep the vehicle-end of the tether cable pointing straight back from the ROV. Then check to see that the thrusters are mounted at about the same angles relative to the centerline of the vehicle. Also, check to see that the horizontal thrusters are both running at about the same speed. If a thruster is not working or is running slow, it can easily be replaced with a spare by cutting the thruster’s wire pair about 4” from the thruster and splicing on a good spare thruster.

Solving ROV Operational Problems:

- **<u>The ROV is Very Slow in Diving</u>**. First check to see if any air is trapped within the pipes. Then check the ballast to confirm that none of it has fallen off. Re-ballast for neutral buoyancy if necessary.
- **<u>The ROV is Very Slow in Surfacing</u>**. Check to see if the payload being handled by the ROV is too heavy. Also, make sure that the floats have not taken on water. Note that a significant problem can occur when using foam-type floats. If such an ROV works fine in shallow water but does not surface easily from deep water, the problem is likely caused by the foam floats compressing due to increased water pressure at the deep depth. This results in less water displacement by the floats, thus less buoyancy. Using less ballast can help, or operate in water depths of about five feet or less. For deeper depths, use one of the optional floats identified in the *SeaPerch ROV Construction Manual Supplement*.

Solving Thruster Operational Problems:

- **<u>Thruster Works in Air, But Not in Water</u>**. If a propeller spins fine in air, but the thruster doesn't work when in water, it's propeller may not be properly installed. For glued-on propellers and shaft couplers, which may be slipping on the motor shaft (when they don't fall off entirely), superglue or hot-melt glue can be used for quick repairs. For pressed-on propellers (Option 7), the styrene bushing may have been over-reamed. In that case, simply re-install the propeller with a new bushing. For soldered-on propellers (Option 11) that slip, first make sure that the outer nut is tight. If it is, try re-heating the shaft area of the threaded coupler to solve the problem; otherwise solder on a new coupler and reinstall the propeller.
- **<u>Initial Operational Problems</u>**. Sometimes SeaPerch thrusters do not work properly due to problems in the waterproofing process. Frequently, a thruster seems to be frozen when first energized after the potting process, and then it works fine after simply being spun a few revolutions by hand (or using pliers if the shaft won't turn by hand), possibly freeing up the shaft from being stuck on the wax seal or due to foreign material in the seal area. *<u>Always try hand-spinning the thruster before replacing it</u>*.
- **<u>Wax Intrusion Problems</u>**. If wax leaks into a motor, it usually does not work at all, but sometimes such motors work intermittently, possibly with some wax on brushes or other internal parts. Turning the thruster shaft back and forth while repeatedly energizing the thruster for about one second at a time can sometimes get a thruster working.
- **<u>Failed Thrusters</u>**. If a thruster simply won't run, or runs slowly, it can be replaced with a spare thruster. Always have a few spare thrusters (and plenty of extra fuses) available to support in-water ROV operations. As noted above, the thruster wires can be cut a few inches from the failed thruster, and then a replacement thruster can easily be spliced to the tether cable wires.

- **Thrusters that Don't Run After Post-Operation Storage**. If the thrusters are not rinsed and protected properly after in-water use, they may not operate when tried some time later. This might be due to rust or corrosion in the shaft seal area or water leaks into the motor. Later cleaning and lubrication of the thrusters might bring them back to service, but the best way to avoid this problem is to always follow the cleaning recommendations in the "Using the SeaPerch ROV" section of the manual after every in-water ROV use.

APPENDIX B

Optional Construction Hints

Guidance to Provide to Students as Needed to Simplify the Build

Pipe Cutting Template:

Some SeaPerch ROV builders may need a little help in planning how to cut their frame's pipe pieces to make efficient use of the raw pipe stock provided.

When the pipe is provided in one-foot-long sections, as in typical SeaPerch ROV kits, the diagram in Figure B-1 will likely be useful while performing Procedure 1.5, *Cut the Frame Parts.*

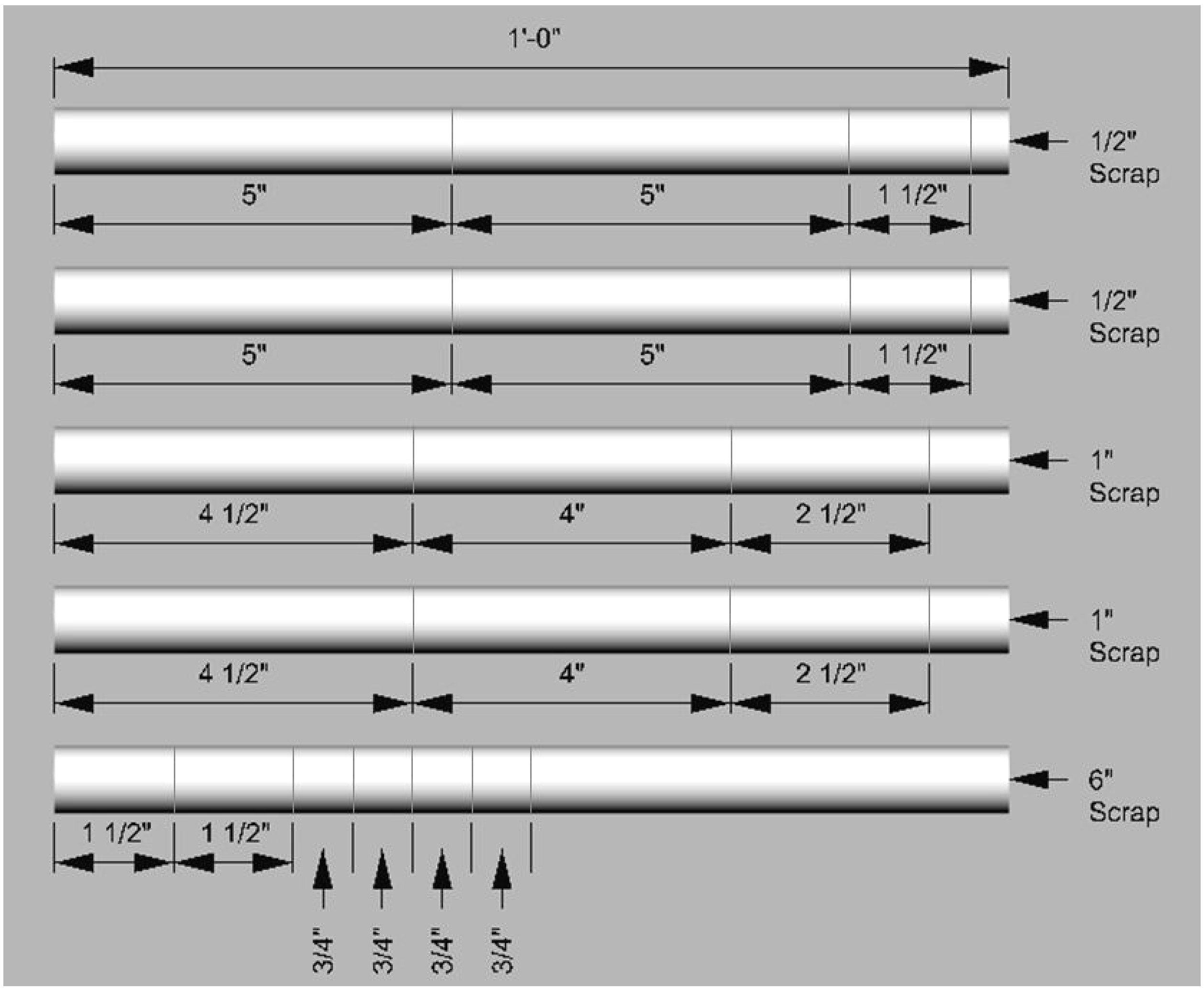


Figure B-1: *Pipe Cutting Guide*