

## Introducing Students to Ocean Engineering

Thomas R. Consi  
MIT Dept. of Ocean Engineering, Cambridge, MA

### Abstract

Ocean Engineering is a complex multidisciplinary field involving sub-disciplines such as fluids, acoustics, and control systems, that undergraduates either never see or experience only in upper level classes. The problem, then, is how to introduce this subject to beginning students – freshmen who have enthusiasm, energy, and interest but not the necessary background to delve deeply into the subject. To solve this problem we have, for the past 4 years, been running a spring seminar class aimed exclusively at freshmen with the goal of introducing the broad sweep of ocean engineering disciplines in a way that is both engaging and tractable to the students. The core activity of this class is the construction and testing of a simple remotely-operated vehicle (ROV) made out of PVC pipe, toy motors, and other simple components. It is through the discussion and analysis of this vehicle and its various parts that the many facets of Ocean Engineering are introduced to the students. This paper outlines the course and our experiences in teaching it. The paper also describes some of the simple technologies have been developed to enable students to engineer underwater both easily and inexpensively.

### Introduction

Ocean engineering is a difficult field because the ocean is such a harsh environment. Underwater systems (e.g. submarines, instrument packages) are surrounded by corrosive seawater, subjected to enormous pressure, and buffeted by currents. Radio communication is nearly impossible because electromagnetic radiation is absorbed over short distances. Control and communication must be handled through slow acoustic links with surface personnel or computers, or handled by onboard computers as is the case in complex autonomous systems. Space is at a premium in underwater systems because of the cost of underwater housings, especially those resistant to high pressure. This raises significant challenges in packaging of the components and assemblies and necessitates the efficient use of limited power. Some of these engineering constraints are relaxed when marine systems are confined to the surface but other challenges take their place. Chief among these is weather; surface systems such as boats and buoys must be able to survive hurricane conditions and long term temperature extremes.

As a result of the myriad problems associated with marine engineering, ocean engineers often have multiple specialties. They have expertise in more traditional fields like electrical engineering or mechanical engineering plus expertise in the properties of the marine environment and the effects those properties have on marine systems. This multidisciplinary aspect not only makes ocean engineering technically challenging, but also challenging to teach. In particular, it is difficult to introduce the field to beginning engineering students – they seem to have to know so much in order to begin to “get wet”. For the past four years we have tackled the problem of

engaging students in our exciting field through the use of a seminar class that introduces ocean engineering via a hands-on project experience.

The course is entitled “Build a PVC ROV!” (MIT course 13.S36). In it the students learn about ocean engineering by building a small battery powered remotely-operated vehicles (ROVs). The ROV is a vehicle in both the conventional sense of a submarine and, importantly, in the sense of a vehicle for learning in which concepts are introduced as the little machine is built. Course 13.S36 is in the tradition of hands-on type courses that have long been recognized as an important part of engineering education<sup>1</sup>. Hands-on courses connect theory with practice and by doing so help to clarify the theory in the students’ minds. These courses also give the students solid practice in problem solving of the type they will probably encounter on the job. Finally, hands-on courses give the students technical skills (e.g. machining) that they would not have gotten in their core engineering courses. What follows are a detailed description of course 13.S36, some of the technical aspects of the course, and an evaluation of its effectiveness in giving the students a window into the world of ocean engineering.

### **Build a PVC ROV!**

Course 13.S36 – “Build a PVC ROV!” is a seminar course geared toward freshmen students. Seminar courses for freshmen at MIT are designed to offer students some diversity in what is otherwise a standardized set of science and math courses that all freshmen are required to take. Seminar courses often offer an introduction to some sort of advanced topic and whet the students’ appetites for future courses while at the same time helping to keep students interested and motivated while grinding through the fundamentals. The intent of course 13.S36 is well matched with the goals of these freshmen-oriented seminar classes.

Having decided to introduce students to Ocean Engineering at the freshmen level by way of a seminar course, the next topic addressed was the content of the course. For the reasons outlined above we decided to create a hands-on, laboratory course. At that point in the course development we obtained a copy of a remarkable book entitled, “Build Your Own Underwater Robot,” by Harry Bohm and Vickie Jensen<sup>2</sup>. This book describes a number of simple marine building projects designed for high school (and younger) students. Among the projects is a simple and elegant little remotely-operated vehicle made from PVC pipe and toy motors named the Sea Perch. We decided to use the Sea Perch as the core building project of course 13.S36 for three major reasons. The Sea Perch is very easy to build and thus is accessible to students with no prior experience in building things or tool use. Despite its simplicity, the vehicle does display all the properties of a marine vehicle and so can serve to introduce many of the core topics of the field. Finally, the Sea Perch is easy to customize; underwater cameras, motorized grippers and other devices can be developed and added by the students as their skills grow.

The class has a maximum of 8 students to permit close student-teacher interaction and there is an upper class undergraduate who served as a course assistant. There are no tests, the only assignments are readings, and the course is graded pass/fail based on the student’s performance in the lab as judged by the instructor. A simple format is followed for the course; it meets once per week in the laboratory for a two-hour session. Each session opens with a summary of the state of the class – what the class has done, what will be done today, what is planned for the future. That is followed by a brief discussion of the ocean engineering web site of the week.

The web site of the week highlights a site that is either technically relevant to the topic of the day, or it is a site which covers a major aspect of ocean engineering (Appendix 1). Often both goals could be combined with the same site. For example, the NOAA El Niño site was chosen as a prelude to a lecture on sensors because of its extensive discussion of the TAO array of data-acquisition buoys. This site is also a window into the many of ocean engineering-related activities carried out by NOAA. After the web site presentation there is a short, 15 minutes or so, lecture on the engineering topic at hand. For example, a brief discussion of Bernoulli's principle and its relation to propeller function is presented when it is time to add propellers to the vehicles. The remainder of the class is dedicated to constructing and testing the Sea Perch vehicles. Table 1 presents the entire syllabus for the course as given in the spring of 2001, including the web sites, the lecture topics, and activities. As can be seen in this table there are straightforward connections between the various parts of the Sea Perch and the technical subjects that encompass much of ocean engineering.

The Sea Perch ROVs (Fig. 1) are simple to understand, construct, and operate. Two horizontal and one vertical propellers (Dumas model DUMB 1860 model boat propellers, Tower Hobbies, Champaign, IL) move the vehicle. Inexpensive DC brush-type "toy" motors power the propellers and they are waterproofed by placing them in plastic 35mm film cans filled urethane rubber potting compound (Flexane 80 Liquid, model 15800, Devcon, Danvers, MA). The motors and two floats are mounted on a boxy frame made from ½" PVC pipe. The bottom of the frame is covered with plastic netting and acts as a payload bay. The control tether is a 12 meter-long eight-conductor cable that brings power to the motors. Finding a cable with enough conductors that is flexible was something of a challenge. We have successfully used very cheap surplus computer cables as well as more expensive, yet very thin and supple, multi-conductor Mogami cable (model W2789-00-656, Marshall Electronics, Culver City, CA). The tether terminates in a small plastic box that contains an array of switches that permit the user to control the motors. Two DPDT, center-off, switches control the horizontal thrusters and two SPDT, momentary-on, pushbutton switches control the vertical thruster. The vehicle is powered by a 12 V battery; we use sealed lead acid batteries (at least 7 AH). For a detailed description of the Sea Perch see Bohm and Jensen<sup>2</sup>.

Some students had difficulties grasping the Sea Perch chain of control from a pressed switch on the control box to the resultant vehicle motion in the water. We addressed this with a careful explanation that started with the control box and followed the chain of control from the switch closures, to the voltage polarities of the motors, to the propeller rotational directions, to the thrust generated by the propellers, and ending with the vehicle's motions. The control chain of the Sea Perch is a good example of the important area of integration in engineering design and the time taken to make sure it is clear to the students is time well spent.

An extremely important subject that is covered on the first day of class is safety in the lab and in the field. Ocean Engineering presents some of the most potentially dangerous work environments of any field. Most prominent is the juxtaposition of water (often conductive salt water) and electronics – the dangers of electrocution and drowning are very real. This situation is carefully spelled-out for the students: what the dangerous situations are, why they are dangerous, and how to work safely in such situations. To reduce the shock hazard around water all vehicles and electronic equipment are powered with 12 V batteries. Absolutely no 110 VAC

powered equipment is permitted near the water. Fortunately with the availability of low-powered portable test instruments, video equipment, and laptop computers, such a safety regulation is relatively easy to enforce. In addition to electrical and water safety other safety topics covered include: chemical safety, fire, medical emergencies, and the safe use of power tools. During the course both the instructor and the course assistant are constantly alert for potential safety problems and are quick to remind the students to work safely.

Two additional subsystems are added to the vehicles to broaden the fields introduced to the students and to increase their interest – an underwater video camera and a motorized gripper. The underwater video camera is a small CCD camera enclosed in a waterproof housing. The video signal is brought up to the surface on a coaxial cable taped to the control tether. The video image is observed on a small battery-powered monitor. Illumination is provided by one or two very cheap penlights that are attached to the forward end of the Sea Perch and sealed with electrical tape. Alternatively, more expensive, water-resistant Mini Maglites (Mag Instruments, CA) can be used. A more advanced version of our underwater camera has also been used that has a ring of light emitting diodes around the camera for illumination. The addition of a camera greatly enhances both the functionality and the excitement of the Sea Perch. Students were able to perform well-controlled maneuvers because they could see the actions of the vehicles as if they were riding them. Games can be played, for example, a simple game was devised in which the vehicles pushed pegs into a target at the bottom of the pool. Most importantly, an onboard video camera transforms the Sea Perch into a true miniature underwater exploration vehicle. Course 13.S36 ends with a trip to the New England Aquarium where we run the vehicles off the dock in Boston Harbor. We have baited the vehicles with strips of squid to attract marine creatures, which resulted in very active and exciting underwater scenes. Our cameras were plugged into a multi-channel video switch box and the more interesting scenes were recorded on videotape. The result was a composite tape of Sea Perches encountering sea creatures, each other, and otherwise exploring the deep. Copies of the tape were given to the students at the end of the class and they were, needless to say, very popular.

The second enhancement to the Sea Perch is the addition of a gripper designed to grab underwater objects for retrieval. In contrast to the video cameras, which are given to the students already assembled, the grippers are presented as an engineering challenge. This gives the students an opportunity to apply their newfound knowledge and skills on a simple yet interesting engineering project. At the beginning of the “gripper” section of the course we discuss underwater manipulator arms and grippers and the web page of the week is a commercial underwater manipulator manufacturer. The students are next given a “junk pile” full of motors, solenoids, gears, structural pieces, and other elements that they could use to construct their grippers. We give brief tutorials on how to use some of the more unfamiliar “junk pile” items. The students were then cut loose to design, build, and integrate grippers onto their vehicles. To power and control the gripper a two pushbutton switches are added to the control box that are attached to an extra pair of wires in the tether that connect to the gripper. The results were varied and fascinating. Several students constructed fairly conventional two fingered grippers while some transformed the fingers into two halves of a cup or net. One group created a unique motorized lasso consisting of a round rigid frame that contained a circular wire attached to radially positioned springs. Rotating a gear motor one way caused the wire to contract around

the object to be picked up. Motor rotation the other way relaxed the wire that was expanded by the springs and released the object.

### **Engineering Underwater – On a Budget**

Pressure housings and pressure-rated electrical pass-throughs are very expensive items and can constitute a major fraction of the budget of a small underwater vehicle. Such ocean-rated components are not, however, necessary for many student projects and educational applications where deployments are of very short duration (minutes to an hour or so) and in shallow water (less than 10 meters). The technical details of the underwater video camera used on the Sea Perch will be presented as an example to show how a useful, versatile, submersible system can be made inexpensively from common parts.

The video system (Fig. 2a) consists of a small, cylindrical CCD “bullet” video camera (model V1212-BNC, Marshall Electronics) coupled to a video text display module (model BOB-II, Decade Engineering, Turner, OR). The text display module gets depth information from a BASIC Stamp microcontroller (model BS2-IC, Parallax Inc., Rocklin, CA) that is interfaced to a pressure sensor through a serially connected analog to digital converter (model LTC1298, Linear Technology, Milpitas, CA). The pressure sensor (model 26PCCFA6G, Honeywell Microswitch, Freeport, IL) is a solid-state, 15psi, gage type sensor coupled to the outside via a tube that exits the housing. It senses the difference between the ambient pressure outside and the pressure inside the housing. The signal from the sensor is amplified with an instrumentation amplifier (model AMP04, Analog Devices, Norwood, MA). To reduce fluctuations in the readings the sensor and its amplifier are powered by a 5.00 V reference chip (model REF-02, Analog Devices) that is also used as the reference voltage for the analog to digital converter. The BASIC stamp reads the pressure, calculates the depth in meters, converts that depth to ASCII characters, and sends them to the text display module at a rate of about 4 Hz. The result is an image with a bar of information containing the date, the student’s initials and the depth. The output of the video text display module (image plus information) is sent up a one side of a 12 meter length of dual miniature coaxial cable (model W2947, Marshall Electronics). The other side of the coax cable is used to provide power to the camera system from a 12 V sealed lead acid battery on shore. The dual coax cable terminates topside in a small box with connectors for power in and video signal out. The video is viewed on a small battery-operated video monitor (model V-M45, Marshall Electronics). When used outside a black sheet must be draped across the monitor and the viewer to shield the sun and increase the contrast of the image.

The CCD camera system has been the topic of a separate mini-course in underwater sensors taught by the author in the MIT Ocean Engineering Dept. The BASIC Stamp microcontroller is very easy to learn and program, it runs a simple version of integer BASIC, and the complete system provides a good introduction to sensors, calibration, and embedded systems. For the mini-course the sensor system was upgraded with the addition of internal and external temperature sensors to compensate for thermal effects on the pressure readings. The camera systems have also been used by students who needed to make underwater observations for other research projects. Nowadays several companies sell inexpensive, shallow-water rated, submersible color and monochrome CCD cameras with integrated light sources (see Appendix 1). While some of these cameras are cheaper than the one described in this paper, they don’t have its depth sensing and data display capabilities. Still, they are useful in educational

applications where there is a need to simply see underwater or when many cameras must be deployed on a limited budget.

A diagram of the underwater video camera in its housing is shown in Fig. 2b. The cylindrical CCD camera was found to fit snugly in a 1" PVC pipe. PVC pipe is a very versatile structural material. It is cheap, available in a variety of sizes, there are many useful fittings that couple to it, is strong, and it is easily worked with hand tools. The pressure housing for the camera consists of a 1" PVC pipe compression coupling that acts as a re-sealable underwater housing. The coupling has two fat rubber gaskets that squeeze around a pipe of the appropriate diameter as the threaded endcaps of the coupling are tightened. There are two short lengths of 1" pipe sticking out of either end. One end contains the camera and is terminated with an acrylic window glued into place. The other end is sealed with a PVC cap (glued in place) that is perforated to permit the passage of the wires and a vinyl tube to the pressure sensor. The PVC cap is partially filled with a urethane rubber potting compound that makes waterproof seals around the tube and the wires. Inside the body of the compression coupling is the video text display module and a circuit board containing the BASIC Stamp and the sensor circuits.

This camera design has proven to be very durable and the cameras have been used in the MIT Pool, the Giant Ocean Tank at the New England Aquarium, and Boston Harbor (down to about 10 meters depth). A more sophisticated housing has also been made that uses a polycarbonate tube, a polycarbonate window glued to one end, and a removable Delrin endcap at the other end. The Delrin endcap has a double O-ring seal, a pipe fitting for the pressure sensor tube and a conventional marine bulkhead connector (model IE55-1204BCR, Impulse, San Diego, CA) for the electrical connections to the video tether. The camera is held in place at the window end of the housing with a short length of pipe insulation and the circuit boards are placed between the camera and the removable endcap. A ring of LED's placed around the camera provides illumination. These housings are more versatile than the PVC pipe housings and they have been used to hold other devices besides cameras. They are, however, significantly more expensive and require more sophisticated machining for fabrication. These housings are good examples of standard pressure housings and they have been used in a mini-course in machining and underwater design co-taught by the author in the MIT Ocean Engineering Dept.

## Conclusions

Course 13.S36, "Build a PVC ROV!" was primarily designed to introduce freshmen to ocean engineering in a hands-on, intuitive way. In this the course was successful; the end of course evaluations consistently showed that the students knew what ocean engineering was all about. This was especially encouraging since many of the students professed to know little or nothing about the subject coming into the course. 13.S36 has also helped recruit students to the major in each of the 4 years that it has been taught – 5 new students out of a total class population of 29 (2 in the first year and one in each of the next 3 years). This is a significant number of new majors given the small undergraduate population of the Ocean Engineering Department (16 students at the time of this writing).

Course 13.S36 also provides students with practical skills (e.g. the use of hand tools, soldering) in the course of building their vehicles. The ability to build something with one's own hands

helps a student develop an intuitive knowledge of what works and what doesn't work in engineering. It also builds confidence in those students with no previous technical experience compared to, for example, a student who builds model airplanes as a hobby. Such inexperienced students frequently have a fear of tools that may be a manifestation of a deeper lack of self-confidence - it is these students that course 13.S36 is especially designed to help. The close interaction between the teacher and the students is critical in helping these students gain self-confidence in building things and, perhaps, in life in general. A less experienced student is closely guided in the steps of building his/her Sea Perch and the minor successes that happen along the way (e.g. cutting a pipe the right length, tapping a hole for a screw) are quickly pointed-out to the student. This succession of small successes leads to the development of a larger self-confidence in the student. The course assistant is also invaluable in guiding the less skilled students, the assistant often helps by simply relating his or her own past experiences of building something as a novice. Course 13.S36 has been particularly successful in preparing beginning students for independent research projects such as those obtained through the MIT Undergraduate Research Opportunities Program.

While the low student/teacher ratio in course 13.S36 has been critical to its success, the course has been successfully scaled-up to accommodate 30 students in the Ocean Engineering Dept.'s Discover Ocean Engineering Program (DOE). DOE is a 3 ½ day program given to incoming freshmen immediately before the official start of freshman orientation. DOE and its companion pre-orientation programs are designed to give incoming students a fun introduction to life at MIT that is less overwhelming than the official orientation program. In addition to these general aims, our goals for DOE are similar to those for course 13.S36 – introduce ocean engineering to students and attract students to the field. The technical core of DOE is the construction of the Sea Perch ROV. This project had to be considerably compressed compared to the seminar course because of the extreme time constraint. To accomplish this some components are pre-built and a more exact step-by-step manual has been written to guide construction. Enough of the vehicle is left to the students to construct so they have a meaningful experience and become exposed to as many construction skills as possible. In addition to the Sea Perch project, DOE has several outings and activities with the Ocean Engineering Dept.'s faculty, graduate students, and staff, all to introduce both MIT and Ocean Engineering to the participants. Five upperclass students act as mentors to guide and advise the 30 new students in the various DOE activities and to serve as sources of information on life at MIT in general. DOE has been very well received by the students and their parents (who learn about the program from their sons and daughters) and the program has raised the profile of both the field and the Department in the minds of students at MIT.

In conclusion we have shown that a simple “toy” underwater vehicle can serve as a window into the many facets of the complex and exciting field of ocean engineering. We have capitalized on this fact and designed a freshmen-level undergraduate course to introduce students to ocean engineering and encourage them to consider careers in the field. In the process of developing and teaching this course we have designed simple and inexpensive devices to enhance laboratory-based ocean engineering education.

### **Acknowledgements**

I would like to thank Prof. Chryssostomos Chryssostomidis, head of the MIT Dept. of Ocean Engineering for advice, encouragement, and support in all of these educational activities. Special thanks to Harry Bohm and Vickie Jensen for designing the Sea Perch ROV and for their marvelous little yellow book. Thanks to Prof. Kim Vandiver of the MIT O.E. Dept for developing the idea of Discover Ocean Engineering; and to Dr. Jerry Schubel of the New England Aquarium for providing access to Boston Harbor for our Sea Perch missions. Thanks also to Mr. Joseph Curcio for designing the advanced underwater camera housing; and to Dr. James Bales of the MIT Edgerton Center for critically reading this paper. Finally, I wish to thank all my students and student advisors in 13.S36 for their input to the course and for making it such a joy to teach.

### **References**

1. West, H., Flowers, W., and Gilmore, D. (1990) Hands-on design in engineering education. *Journal of Engineering Education* 80(5):560-564.
2. Bohm, H. and Jensen, V. (1997) Build Your Own Underwater Robot, Vancouver, BC, West Coast Words.

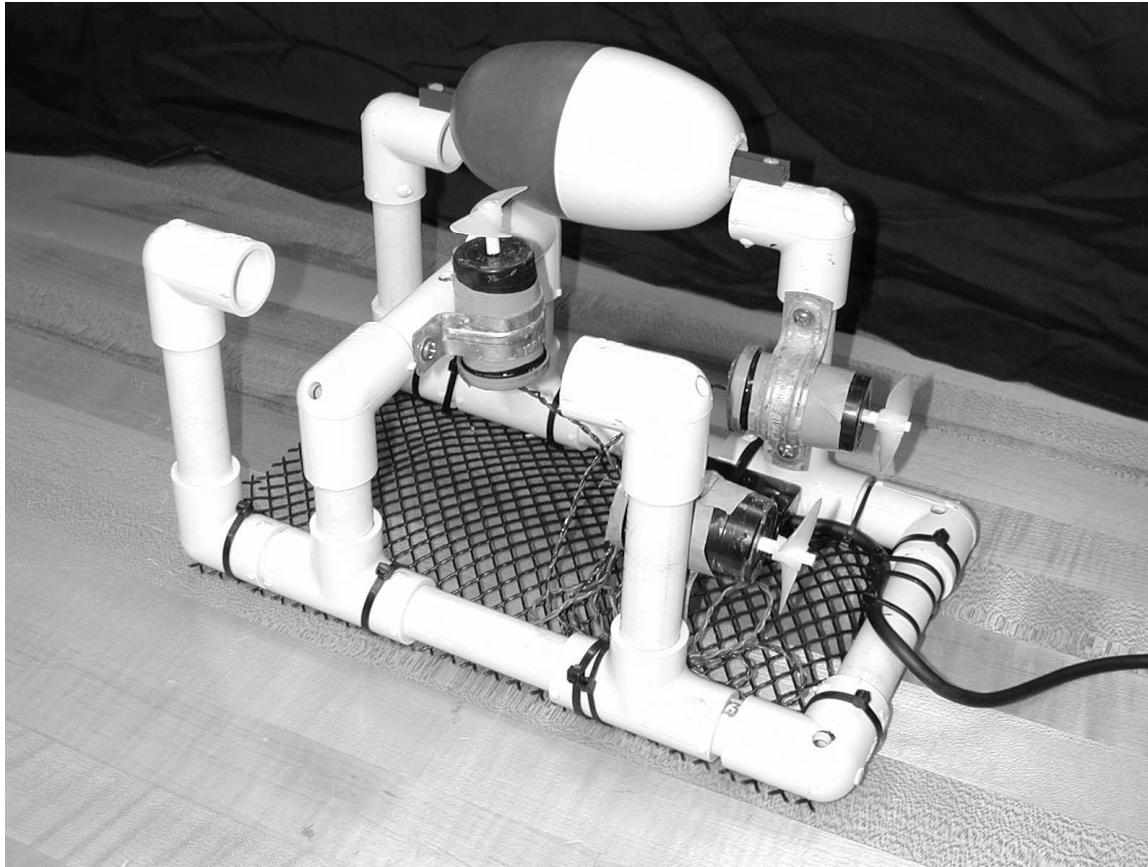
### **Biography**

Dr. THOMAS R. CONSI is a senior lecturer in the Ocean Engineering Dept. at MIT. In addition to course 13.S36, Dr. Consi teaches courses in design and in sensors and measurement. Dr. Consi does research in marine bioengineering and he also develops small vehicles and other little marine systems for research and educational applications.

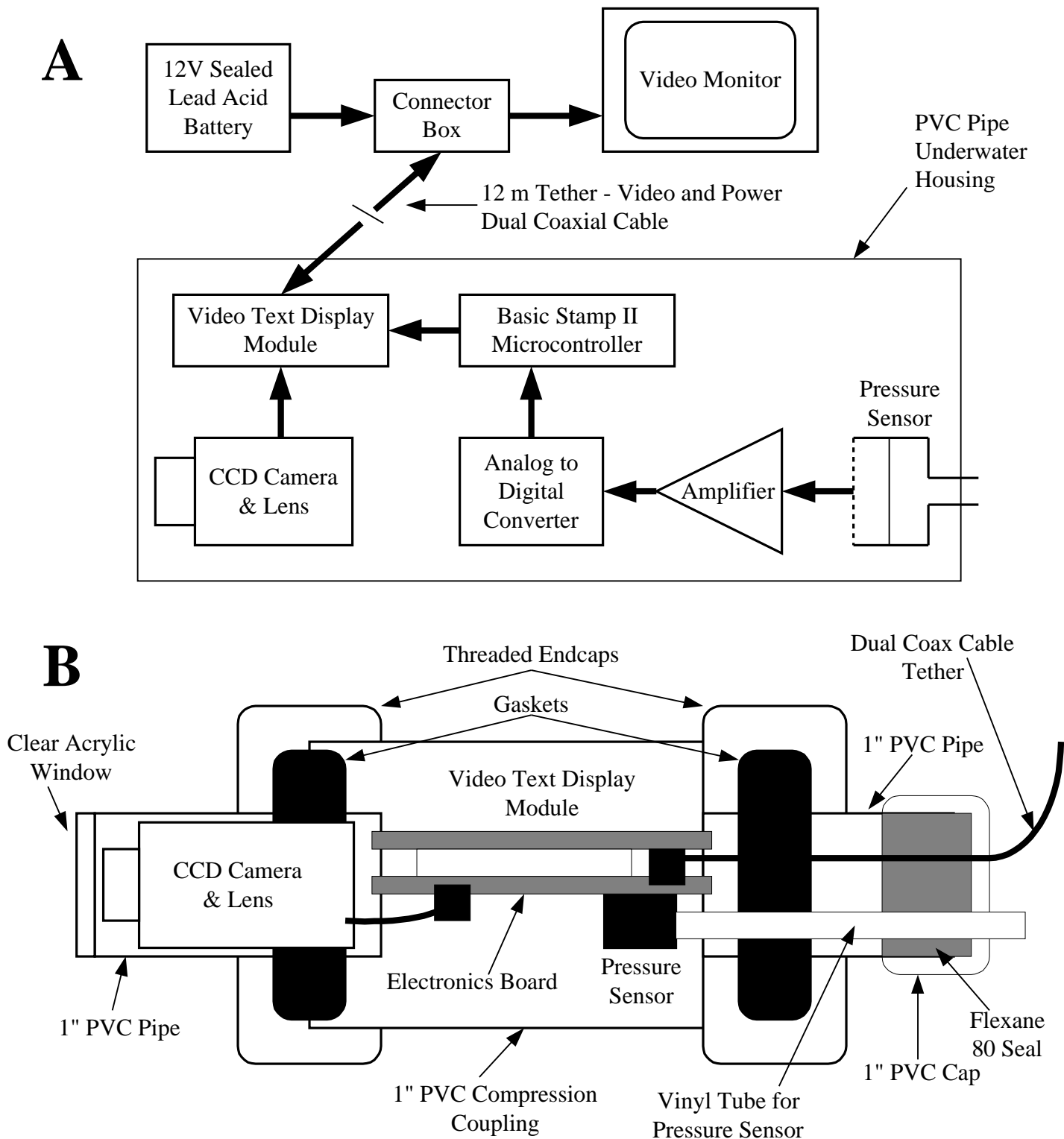


**Table 1. Course 13.S36 – Build a PVC ROV!  
Syllabus for the Spring Semester 2001**

	Engineering Topic	O.E. Web Site of the Week See Appendix I for URL's	Activity
1	Introduction, what is ocean engineering, introduction to ROVs, safety in the lab and in the field.	MIT web sites: Dept. of Ocean Eng. Sea Grant College Program. Program in Science Technology and Society (underwater archaeology group).	Build Sea Perch frame.
2	Basic hydrostatics, Archimedes principle, static stability. Construction techniques.	WHOI Deep Submergence Lab	Build Sea Perch frame.
3	Basic hydrodynamics, Bernoulli's principle, lift and drag, propellers. Construction techniques.	Scripps, MBARI	Build thrusters and control box.
4	Motors and motor control.	Perry Trittech, commercial ROV firm.	Finish thrusters, control box, build tether.
5	Power and efficiency.	Local ROV & AUV companies: Benthos, Webb Research. Duracell for battery info.	Finish construction, assemble vehicle, bench test, ballast and trim.
6	None	David Taylor Model Basin, giant o.e. testing facility.	Test vehicles in pool, measure efficiency.
7	Discuss last week's tests. Underwater video and depth sensing system. Presentation of challenge: pick something up off the bottom of Boston Harbor	The SubCommittee, site for model submarine builders.	Demonstrate video systems, integrate video cameras into vehicles.
8	Discuss gripper designs.	Alstom Automation/ Schilling Robotics, example of a marine manipulator manufacturer. The search and recovery of Gus Grissom's Liberty Bell 7, great example of marine search and recovery.	Demonstration of "junk pile" objects. Students play with devices. Paint vehicles.
9	Discuss gripper designs	The Navy	Work on grippers.
10	Introduction to sensors, the pressure sensor, measuring depth from pressure.	NOAA – El Nino, excellent example of marine sensing and measurement.	Work on grippers, pool available for tests.
11	Microcontrollers and interfacing.	Microcontroller and robotics sites.	Work on grippers, pool available for tests.
12	None	Crittercam and marine animal telemetry.	Test "full-up" system in pool.
13	None	None	Mission to Boston Harbor, run vehicles with video cameras and grippers.
14	Discussion of last week's mission. Discussion of course, students fill-out course evaluations.	NASA-Europa, oceans on other planets!	View video returned by Sea Perches.



**Fig. 1 The Sea Perch ROV, a port side - aft perspective view. The port float has been removed to reveal the vertical thruster. A pair of wires exits each thruster housing and they are spliced to the tether in a small plastic box filled with urethane rubber potting compound, this box is just visible to the right of the port thruster. The 12 meter tether runs off to the right. To the left is the forward payload bay that can house a video camera and/or a gripper. The vehicle is 28.5 cm long, 16 cm wide and 19 cm tall to the top of the floats.**



**Fig. 2. A. Block diagram of the underwater video camera used on the Sea Perch ROVs. B. Diagram of the underwater camera housing using a PVC compression coupling as a re-sealable enclosure, not to scale.**

## Appendix 1. Ocean Engineering Web Sites of the Week

MIT Dept. of Ocean Engineering <http://oe.mit.edu>

MIT Sea Grant College Program  
<http://web.mit.edu/afs/athena.mit.edu/org/s/seagrant/www/mitsg.htm>

MIT program in Science Technology and Society - Prof. David Mindell's Deep Archaeology Group  
<http://web.mit.edu/sts/deeparch/>

Woods Hole Oceanographic Institution Deep Submergence Laboratory <http://www.dsl.who.edu/>

Perry Trittech, Jupiter FL – example of an ROV manufacturer <http://www.perrytritech.com>

Local ROV and AUV companies:

Benthos, North Falmouth, MA <http://www.benthos.com>

Webb Research, East Falmouth, MA <http://www.webbresearch.com>

Duracell – great site for battery information <http://www.duracell.com>

David Taylon Model Basin <http://www50.dt.navy.mil/>

The Sub Committee – model submarine builders site <http://www.subcommittee.com>

Alstom Automation/Schilling Robotics – example of an underwater manipulator manufacturer.  
<http://www.schilling.com>

The search and recovery of Gus Grissom's Liberty Bell 7 Mercury spacecraft.  
<http://www.discovery.com/exp/libertybell7/libertybell7.html>  
<http://www.libertybell-7.com/index.htm>  
<http://www.oceaneering.com/> Oceaneering made the ROV used in the recovery

The U.S. Navy <http://www.navy.mil>

NOAA – El Niño <http://www.pmel.noaa.gov/toga-tao/el-nino/nino-home.html>

Microcontroller, Robotics, and Tiny Video Camera companies:

Parallax [www.parallaxinc.com](http://www.parallaxinc.com)

Microchip [www.microchip.com](http://www.microchip.com)

Motorola Semiconductor Products [mot-sps.com/](http://mot-sps.com/)

Circuit Cellar Magazine [www.circuitcellar.com](http://www.circuitcellar.com)

Robot Information Central [www.robotics.com/](http://www.robotics.com/)

Mondo-Tronics (Robot Store) [www.robotstore.com/](http://www.robotstore.com/)

Microcontroller.com [www.microcontroller.com/](http://www.microcontroller.com/)

Digikey Electronics [www.digikey.com](http://www.digikey.com)

Jameco Electronics [www.jameco.com](http://www.jameco.com)

SuperCircuits [www.supercircuits.com](http://www.supercircuits.com)

Marshall Electronics [www.mars-cam.com](http://www.mars-cam.com)

Crittercam – strap-on marine animal video camera <http://www.nationalgeographic.com/crittercam>.

Animal Telemetry <http://pastel.npsc.nbs.gov/resource/tools/telemetry/telemetry.htm#contents>

NASA – Europa – Oceans on other worlds! [http://www.jpl.nasa.gov/ice\\_fire/europao.htm](http://www.jpl.nasa.gov/ice_fire/europao.htm)