The MIT Marine Industry Collegium
Opportunity Brief #18

Some Federally Sponsored Research Programs for Unmanned Underwater Vehicles

A Project of
The Sea Grant Program
Massachusetts Institute of Technology
MITSG 80-5

The MIT Marine Industry Collegium

SOME FEDERALLY SPONSORED RESEARCH PROGRAMS

FOR

UNMANNED UNDERWATER VEHICLES

Opportunity Brief #18

Revised Edition

July 7, 1980

Marine Industry Advisory Services

MIT Sea Grant Program

Cambridge, Massachusetts 02139

Report No. 80-5

Index No. 80-605-Eso

PREFACE

This Opportunity Brief and the accompanying Workshop (held on November 1 and 2, 1979) were presented as a part of the MIT/Marine Industry Collegium program, which is supported by the NOAA Office of Sea Grant, by MIT and by the more than 110 corporations and government agencies who are members of the Collegium. The underlying studies were carried out under the leadership of the Principal Investigators named in the report, but the author remains responsible for the assertions and conclusions presented herein.

Through Opportunity Briefs, Workshops, Symposia, and other interactions the Collegium provides a means for technology transfer among academia, industry and government for mutual profit. For more information, contact the Marine Industry Advisory Services, MIT Sea Grant, at 617/253-4434.

Norman Doelling

July 7, 1980

TABLE OF CONTENTS

1.0 A Business Perspective 1

Background
An Overview of Research Programs

2.0 Research in Progress 6

Robot II
NOSC Free-Swimming Submersible
EAVE
Telemanipulators

3.0 Summary 17

REFERENCES 18

Appendix I 19

Appendix II 22

1.0 A BUSINESS PERSPECTIVE

1.1 Background

The need to develop unmanned underwater vehicles stems from two primary concerns. First, using divers for underwater construction, inspection, and repair of offshore platforms and pipelines involves high costs and risks to human life. Robot submersibles capable of performing sensory and manipulatory tasks could remedy this problem. The second need is in oceanographic exploration for foundation studies, environmental surveys, and general research. Appropriately instrumented, unmanned underwater vehicles could possibly provide more data of better quality at lower costs than are available with existing technology.

Research programs at MIT, the University of New Hampshire, and the Naval Ocean Systems Center are currently addressing issues of theory, systems development, and applications of untethered, unmanned, underwater vehicles. This Opportunity Brief reviews these programs that were presented to Collegium members by principal investigators at a Workshop that was held November 1 and 2, 1979.

At the Collegium Workshop, an investigator from the Naval Research Lab also reported on the first trials of the NRL laminar flow vehicle, in the Patuxent River. Some information about the vehicle has been provided by NRL and is discussed in Appendix I.

At the Collegium meeting, a questionnaire designed to help determine future vehicle capability needs was circulated, and the replies are analyzed in Appendix II. The respondents represented oil and oil service companies, operators and manufacturers of remotely operated vehicles, as well as government agencies. Thus, the needs are work oriented rather than just observation oriented. Survey results indicated a strong desire for cooperation among users, manufacturers and researchers in designing and building useful vehicles. Because of the diverse responses, a complete summary and discussion of the questionnaire is included in Appendix II.

1.2 An Overview of Research Programs.

Figure 1 indicates the three government Departments sponsoring work covered in this Brief as well as the institutions, principal investigators, and projects involved.

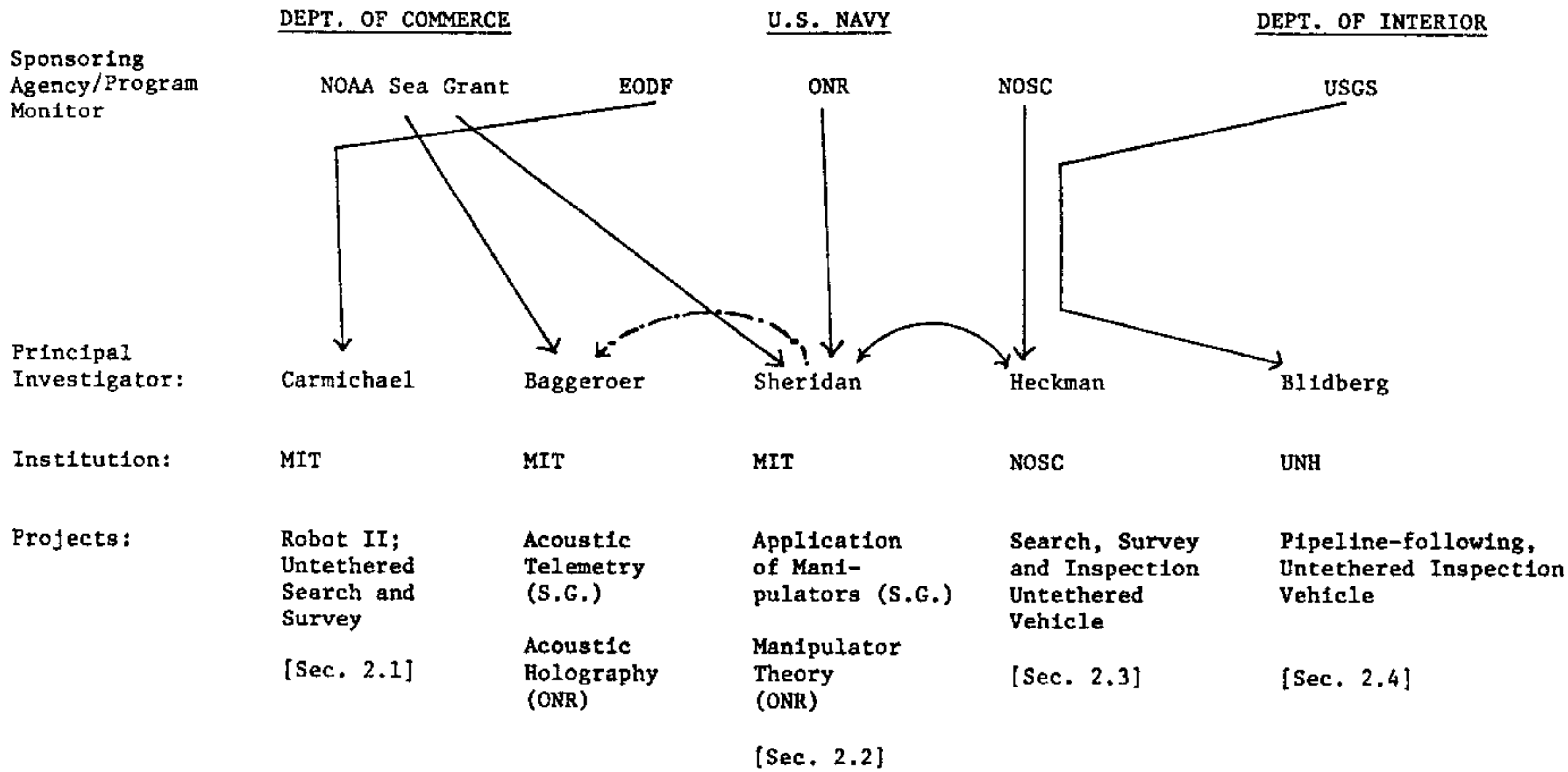
As can be seen, the research programs are tied together formally by contractural interrelations among the sponsors. More importantly, these projects are linked through collaboration among the principal investigators. A common technical problem faces each of the principal investigators and provides a common intellectual challenge: How can humans control vehicles, manipulators, television cameras, sonars and other instruments while those devices are removed from them in space, and perhaps also in time because of communication delays due to the slow velocity of sound in sea water?

Efficient control of a remote vehicle involves such issues as: How can the vehicle sense its operating environment? To what degree can the vehicle operate itself and to what degree must a human operator continuously control or supervise the vehicle? How should the vehicle, via its sensors, tell the human operator about its current environment, its orientation, its velocity, etc.? And how can the human operator efficiently communicate with the remote vehicle to explain what is to be done next?

Dealing with these questions in a useful manner requires contributions from artificial intelligence, control system theory, and man-machine systems theory in addition to ocean engineering and naval architecture. Microcomputer applications and computer programming skills of the highest order are also required.

Figure 1:

Some Research Programs on Unmanned Underwater Vehicles



EODF - Explosive Ordnance Disposal Facility

ONR - Office of Naval Research

NOSC - Naval Ocean Systems Center

USGS - U.S. Geological Survey

Obviously the possibilities for vehicle configurations, missions, control systems, and the like are extremely numerous. In order to make contributions to current industrial needs, it is important to establish a finite set of objectives and applications, and to direct the limited research funds towards a small set of objectives. For this reason, the participation and advice of industrial members of the Collegium has been especially important.

2.0 RESEARCH IN PROGRESS

2.1 Robot II MIT/NAVEODFAC Professor A. Douglas Carmichael

Prof. Carmichael's work at MIT is a substantial extension of work on a vehicle called Robot I, which was begun about five years ago as part of an undergraduate Ocean Engineering laboratory exercise.

Robot I provided some excellent educational opportunities for its student designers, and the experiments carried out with it provided valuable information concerning design performance and problems. The ideas tested and tried in that vehicle have been incorporated or improved upon in Robot II, a new untethered vehicle currently being designed and constructed under the sponsorship of NAVEODFAC. Robot II is an extended search and survey vehicle and therefore is basically a sonar platform with provisions for adding other types of sensor systems. In general, design objectives call for a submersible that will be small, easily transported, untethered, and computer controlled. It is to operate in salt or fresh water and should weigh about 250 pounds so a few persons can handle it without the benefit of special cranes. The design is to be state-of-the-art but will not bear great technical risk. A design goal is to require no adjustments once it is in the water.

The sonar complement will include communication sonar for command and control, a collision avoidance sonar, a bottom-following sonar, a pinger, and most important, a side-scan sonar. Because the side-scan sonar requires extreme lateral stability, special emphasis was placed on designing the control system. The control system was synthesized by a student in the

Aeronautics and Astronautics Department, using optimal control techniques to maintain depth and course with a level attitude. See Reference 2 for a description of the control system synthesis, and Reference 3 for the electronics design.

The operational design goals were established as "maximum weight, 250 pounds; maximum depth, 400 feet; maximum speed, 3 knots with a 25% power reserve; trim and list control, within 0.5 degrees; and low acoustic noise levels to facilitate efficient operation of the sonar systems."

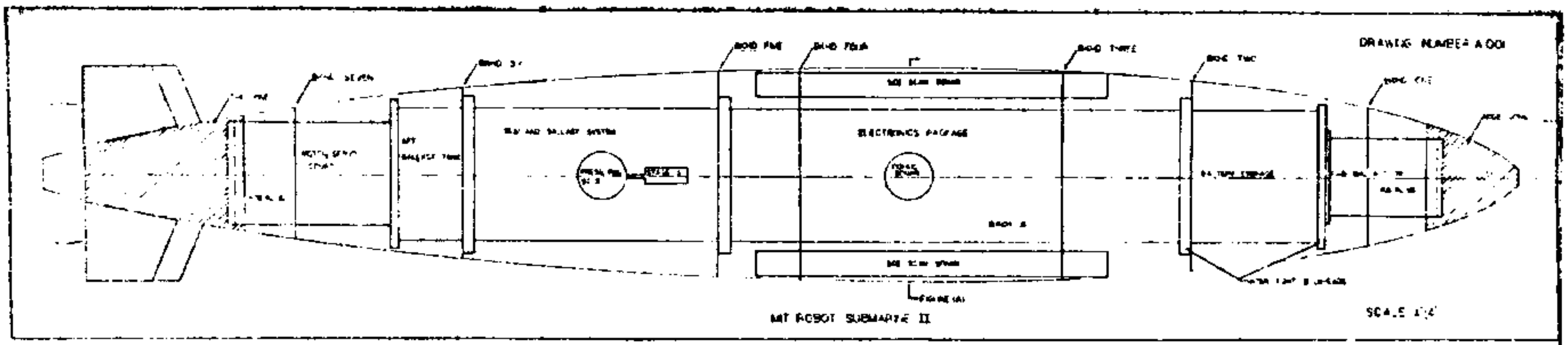
The preliminary configuration is shown in Figure 2.1 (Reference 1). The vehicle is approximately eight feet long and fourteen inches in diameter. Major design innovations are the use of a rubberized fabric similar to that in wet suits as an external protective skin, and floodable tankage systems for automatic ballast and trim.

2.2 NOSC Free-Swimming Submersible NOSC/USGS Paul Heckman

This submersible is one of the latest in a series of NOSC unmanned vehicle systems such as SCAT, Snoopy and the Mine Neutralization Vehicle (MNV). These vehicle systems have generally been controlled directly via cables although, in general, the trend at NOSC has been towards incorporating more of the control system within the vehicle. Thus control systems have progressed from direct control towards supervisory control (See Section 2.4 below). The present vehicle is an untethered robot vehicle preprogrammed via an umbilical cable which is disconnected before the vehicle starts its mission.

Figure 2.1

MIT Robot II



The vehicle is similar in function to Robot II, but is larger (9 feet X 20 inches X 20 inches) and heavier (400 pounds). It has open frame construction and uses canisters to contain the electronics and battery packs. By lengthening the open frame structure, additional electronics or sensors can be incorporated at about 25 pounds more payload for each added foot in length. The system is controlled by an INTEL 8080 microprocessor, with programs written in FORTRAN, PL/M and assembly language. The vehicle is more completely described in Reference 4.

Among the concepts which will be tested and implemented on this vehicle is supervisory control. A microprocessor-based operator interface will be developed to handle operator interactions, freeing the submersible's microprocessor for additional control functions. Colorgraphics will be provided to enable the operator to visualize the pattern programmed into the vehicle, movement of the vehicle, vehicle status information and the like. Two communications links between the vehicle and operator will be tested; first an acoustic link and then a fiber-optic link. A manipulator system, being designed and implemented with assistance of MIT researchers, will be incorporated using a supervisory control system.

Field tests under program control indicate a maximum speed of 1.8 knots and a mission duration of about one hour. The maximum speed can be increased to about 5 knots with the addition of fairings to reduce the drag.

2.3 EAVE UNH/USGS/NOSC Prof. Robert Corell, D.R. Blidberg

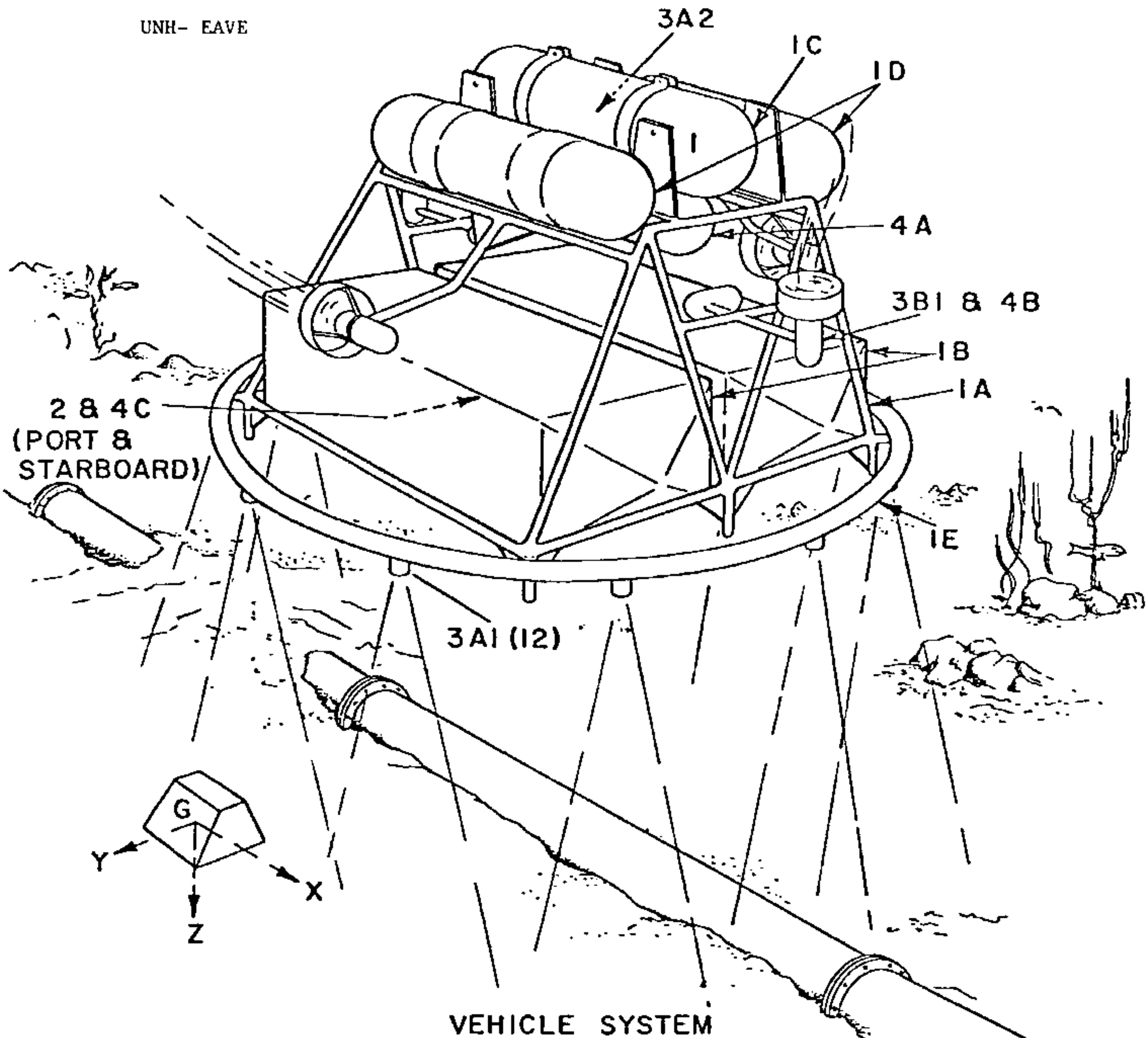
EAVE (Experimental Autonomous Vehicle) is designed to serve as a test vehicle for developing a new technology for inspection of offshore pipelines. It differs from the previously described vehicles in that it has five degrees of freedom for motion; that is, it can move in three orthogonal directions and can rotate about 2 orthogonal axes. EAVE incorporates a dozen sonar transducers which provide input to the navigation and control computers, thus enabling EAVE to acquire and track an exposed pipeline and to maintain a fixed altitude above it. Other on-board sensors such as video, electric current sensors or hydrocarbon sensors, are planned to carry out pipeline inspection.

EAVE'S principal physical characteristics are: Overall length, five feet; width, five feet; height, three feet, eight inches; weight, approximately 690 pounds; speed, 2 knots and operating depth, one hundred feet. The battery system stores about 7.5 kilowatt hours, providing for four or five hours of operation under average conditions. It is schematically shown in Figure 2.3.

The EAVE computer system is built around an Intersil 6100 microprocessor chip, chosen because its instruction set is compatible with the ubiquitous DEC PDP-8 minicomputer family and because the CMOS design uses very low power. The two navigation systems are based upon the use of precision synchronized clocks, with one clock located on board the vehicle

Figure 2.3:

UNH- EAVE



VEHICLE SYSTEM

1. STRUCTURE
   1A. FRAME
   1B. BATTERY CONTAINERS (2)
   1C. ELECTRONICS CONTAINER
   1D. BUOYANCY STRUCTURE
   1E. TRANSDUCER RING
2. ENERGY STORAGE
3. PROPULSION – MANEUVERING
   3A. VEHICLE CONTROL (DECISION MAKING)
      3A1. SENSORS
      3A2. MICROCOMPUTER
   3B. VEHICLE CONTROL (DECISION EXECUTING)
      3B1. MOTOR-PROPELLER UNITS
4. AUXILIARY SYSTEMS
   4A. COMPRESSED AIR
   4B. OIL COMPENSATION
   4C. HYDROGEN ABATEMENT

and the other shore-based or ship-based. In the vehicle tracking mode a clock pulses a sonar transducer on the vehicle. The arrival time of the pulse at each of three receiving hydrophones, that are moored at known locations, is used to compute the position of the vehicle.

The system may be reversed so that the three moored hydrophones are pulsed at the same time. Then the onboard processor would calculate the vehicle position relative to the hydrophones. The position data could then be used as input for the vehicle navigation system. A variation on this system of having a single remote transducer and multiple hydrophones on the vehicle can determine range and bearing to the remote transducer. This variation will be tested and promises to give useful performance as a homing system.

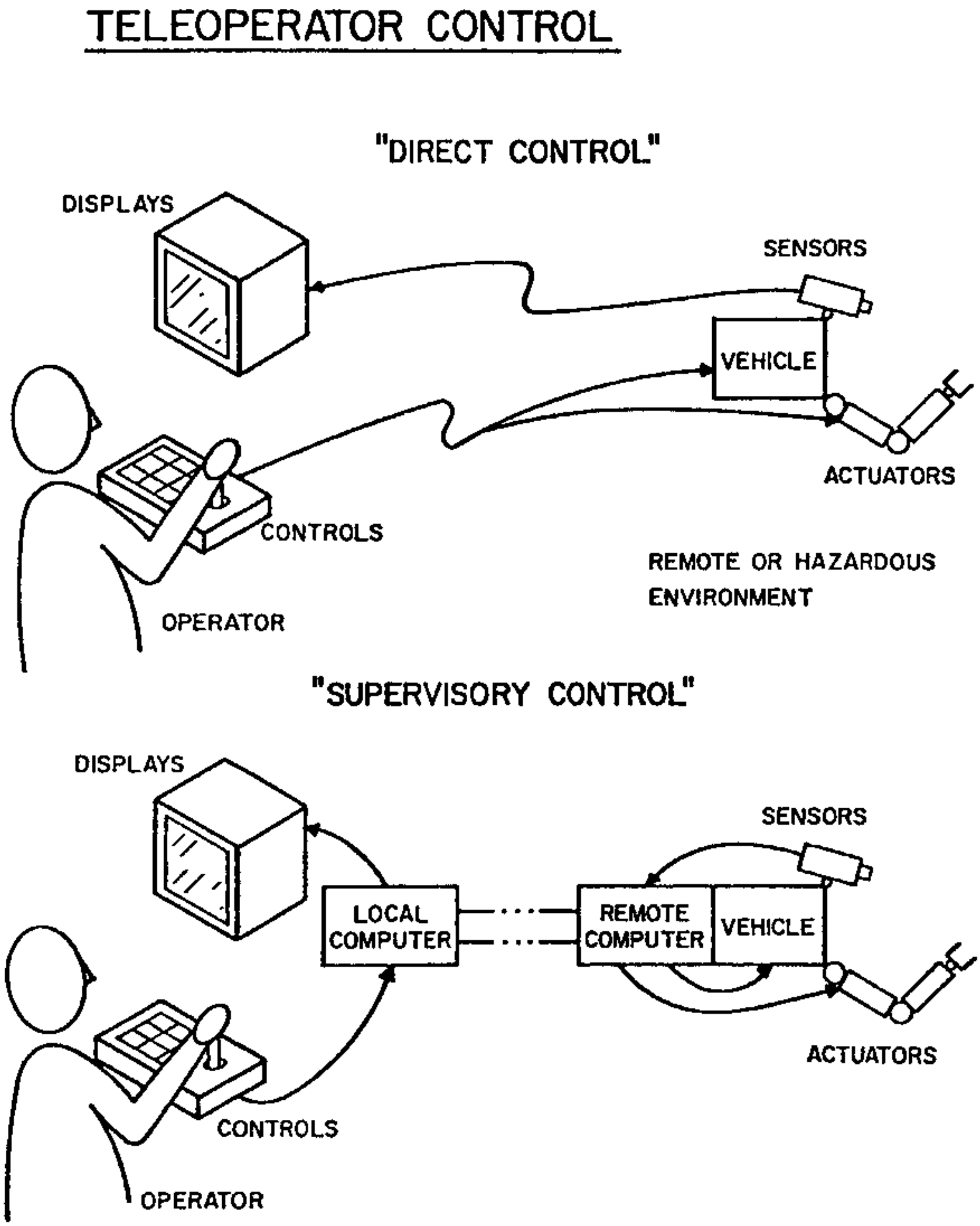
As noted in Reference 4 the vehicle is not intended to be fully autonomous. A communication link which will enable the operator to intervene and control the system and permit the vehicle to report its status is now being tested.

2.4 Telemanipulators MIT/Sea Grant/ONR Prof. Thomas B. Sheridan

Remotely controlled manipulators (telemanipulators) are an essential part of any submersible system designed to do some kind of underwater work. The problems of controlling manipulators remotely (and indeed the problem of controlling any remote device) center on how a human operator communicates with the remote device and how the remote device communicates with the human operator. Even so-called autonomous vehicles require some communication mechanism to tell the human operator where it is, when it's in trouble, etc. Control of telemanipulators is of special interest because it brings out the most difficult problems in man-machine communication systems. One of the more fruitful approaches to the control and communication in the man-computer system has been described as supervisory control. The notion of supervisory control as opposed to direct control is illustrated in Figure 2.4. In this mode the human operator directs the "subordinate computer by planning the actions it should take, directing it how to achieve the desired actions, monitoring its performance, intervening when it gets in trouble and trusting it to accomplish the task without continuous assistance." "Under direct control the operator's control signals are sent directly to the remote manipulator, and sensor information is fed directly back to the operator. Under supervisory control the operator's control signals are relayed through a local computer to the remote computer, which then processes the signals and acts on the information. The relayed signals are not necessarily the raw signals generated by the operator. In fact, the signal is usually a coded instruction of high information density which must be interpreted to be utilized. The operator's input could range from a purely manual analogic command to a highly abstract symbolic command. The remote computer not only interprets the local computer's messages but also acts on the sensor information available to it about its environment. The remote computer only relays information to the operator which is deemed important and necessary for effective supervision - the responsibility for the specific details of control is usually left to the subordinate computer." As Sheridan has said,

Figure 2.4

ONR Telemanipulator



Direct Manual Control and Supervisory Control of a Teleoperator "human supervisors are used in conjunction with robots because the two are complementary: we automate what we understand and can predict, and we hope the human supervisor will take care of what we don't understand and cannot predict." (See Reference 7)

The quotations above are taken from a thesis entitled "Superman, A System for Supervisory Manipulation and the Study of Human-Computer Interactions".* (Reference 7)

It is difficult and perhaps inappropriate to attempt to summarize this work in such a brief note. Some extremely important problems have been worked on and were discussed at the Workshop. The abstract notes:

> A unified theoretical framework of supervisory manipulation has been considered and would give the reader an overview of manipulator and processor selection factors, specific design considerations for the man-computer interface, the control language attributes and implementation factors and control philosophies. Mathematical principles are developed and implemented for dealing with important problems such as relative motion between the manipulator base and the object being worked on. The experiments show that supervisory control can improve system performance for all forms of manual control except master-slave systems with force feedback.

* SUPERMAN is also a computer language for controlling the manipulator system. A note on its derivation seems appropriate. Several years ago a computer language for manipulators was designed at MIT and was given the name MANTRAN as a contraction for MANipulator TRANslator in parallel to the well known FORTRAN for formula translator. It follows that an improvement on MANTRAN for supervisory control must be SUPERMAN.

The system was created to provide efficient man-machine interaction. The interface between the operator and the Superman system includes multiple communication channels for redundancy and effective interaction. Whenever possible, tactile, visual and audio signals are fed to the operator. The operator communicates by a keyboard, an analogue-symbolic control panel, a joy stick, and a six degree of freedom master manipulator. Outputs from the system to the operator include graphic and alphanumeric displays, audible warning tones, lights, meters, and force-feedback.

The SUPERMAN language is an explicit language with a constrained programming code to minimize training time. The combination of the language and the interface system defines the capability of the manipulator system. The laboratory system includes provisions for simulating time delays in the communication link between the operator and the manipulator so that the effects of acoustic time delay in the ocean or introduced by limited band width can be experimentally recreated.

As noted in Section 2.2, NOSC is collaborating with MIT to use SUPERMAN concepts on a manipulator system being designed for the NOSC free-swimming vehicle.

3.0 SUMMARY

The system configurations described herein appropriately differ from one another because different missions are foreseen for the various vehicles. There is however a common approach to command and control: all the investigators rely directly or by implication on computer control systems. Microprocessors have become so powerful and so inexpensive that they will be incorporated in all future systems. They are essential for dealing with the other common theme of the research, namely, how can human operators remote from semiautonomous or supervised machines communicate effectively with them to provide appropriate command and control.

The use of multiple microprocessors will allow a modular approach to system building and, one would hope, will allow some standardization of hardware and software. A case in point is in communication systems. Here appropriate microprocessor/transducer modules would permit the system builder to have the sonar equivalent of a standard modem with all of the error detection and correcting activities carried out by that control module.

Although it is probably appropriate for each principal investigator to select the microprocessor appropriate to his needs, it is hoped that a common programming language will be used to develop user software. For example, SUPERMAN is itself coded in FORTRAN so that some degree of machine independence is gained and systems could be built implementing SUPERMAN on other microcomputers. While it's inappropriate to suggest standardization of user languages (e.g. SUPERMAN) at this early date, hopefully some language like FORTRAN or PL/1 will be used as the basic programming language.

REFERENCES

1. Davis, Gerald Martin, Jr, "Design and Construction of the Second Generation MIT Robot Submarine". Master's Thesis, MIT Naval Architecture and Marine Engineering, May 1979.

2. Inoue, Masao, "Control System Synthesis of a Computer-Piloted Submarine". Master's Thesis, MIT Aeronautics and Astronautics, May 1979.

3. Saylor, Michael, "Electronics Systems Design and Control Algorithms for a Robot Submarine", Master's Thesis, MIT Ocean Engineering, 1979.

4. Heckman, Paul and H. McCracken, "An Untethered, Unmanned Submersible", Paper presented at Oceans '79, The Institute of Electrical & Electronics Engineers Inc. and the Marine Technology Society meeting in San Diego, September, 1979.

5. Blidberg, Richard D. and Arthur S. Westneat. "An Unmanned Untethered Inspection Vehicle", Paper presented at Marine Technology '79, Conference in New Orleans, Louisiana, October, 1979.

6. Blidberg, Richard D., E. Eugene Allmendinger, and Nicholas Sideris. "The Development of an Unmanned, Self-Controlled, Free-Swimming Vehicle", Paper presented at Offshore Technology Conference in Houston, Texas, 1978.

7. Brooks, Thurston L., III and Thomas B. Sheridan. SUPERMAN: A SYSTEM FOR SUPERVISORY MANIPULATION AND THE STUDY OF HUMAN/COMPUTER INTERACTIONS. MIT Sea Grant Report No. MITSG 79-20, Cambridge, MA 1979.

8. Johnson, H.A., A. I. Verderese, and R. I. Hansen, "A 'Smart' Multi-Mission Unmanned Free Swimming Submersible", in NAVAL ENGINEERS JOURNAL, April 1976.

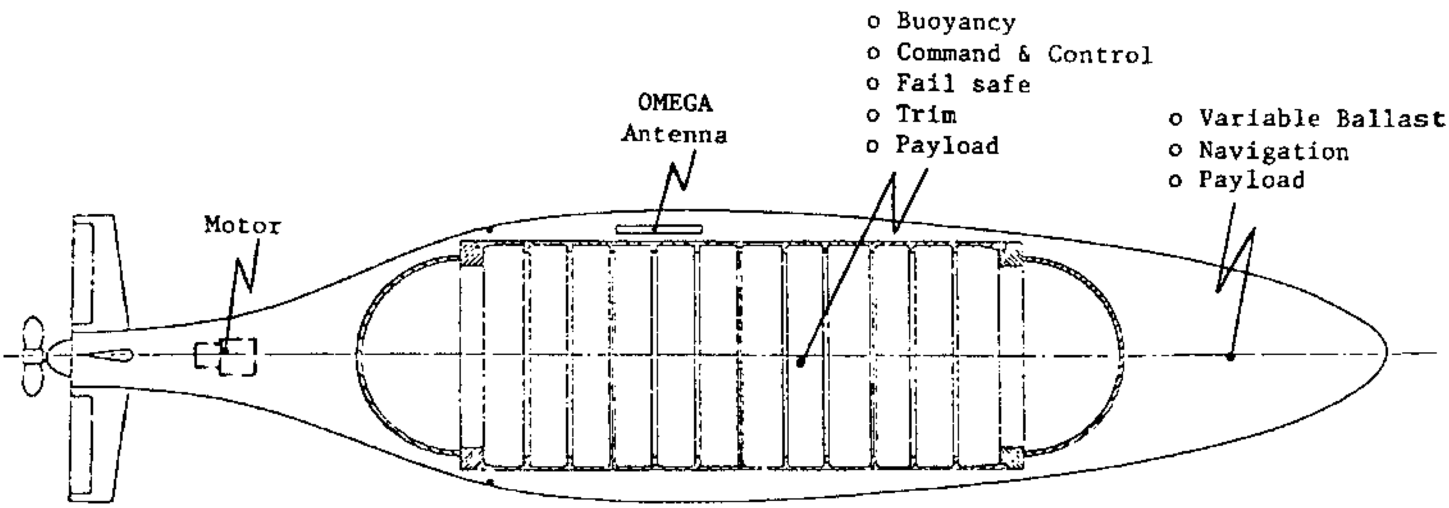
APPENDIX I

NRL Unmanned Free Swimming Submersible Program

During the course of the workshop, Mr. Perry Alers of the Naval Research Laboratory gave an informal presentation on the first field trials of the laminar-flow, unmanned, free-swimming submersible developed by NRL. Preliminary results indicated higher drag coefficients than expected. The high turbulence of the Pautuxent river as measured by a probe on the vehicle was hypothesized as the cause of the high drag.

Design considerations are detailed in Reference No. 8. Figure A-1 gives the approximate configuration and design parameters. Figure A-2 is a picture of the vehicle prior to being launched.

Figure A-1:
NAVAL RESEARCH LABORATORY
UNMANNED FREE SWIMMING SUBMERSIBLE PROGRAM



Length overall - 20 feet

Beam - 4 feet

Volume - 125 cubic feet (including 40 cubic feet available for payload)

Range - 125 miles with lead acid batteries

1000 miles with lithium thionyl chloride batteries

Operating Depth - 1500 feet

Hydrodynamics

- o Low Drag Hull (low noise)
- o Designed for 5 knot operating speed (Volumetric Reynolds Number of 2.5×10^6)
- o Volumetric Coefficient of Drag of .007 at operating speed

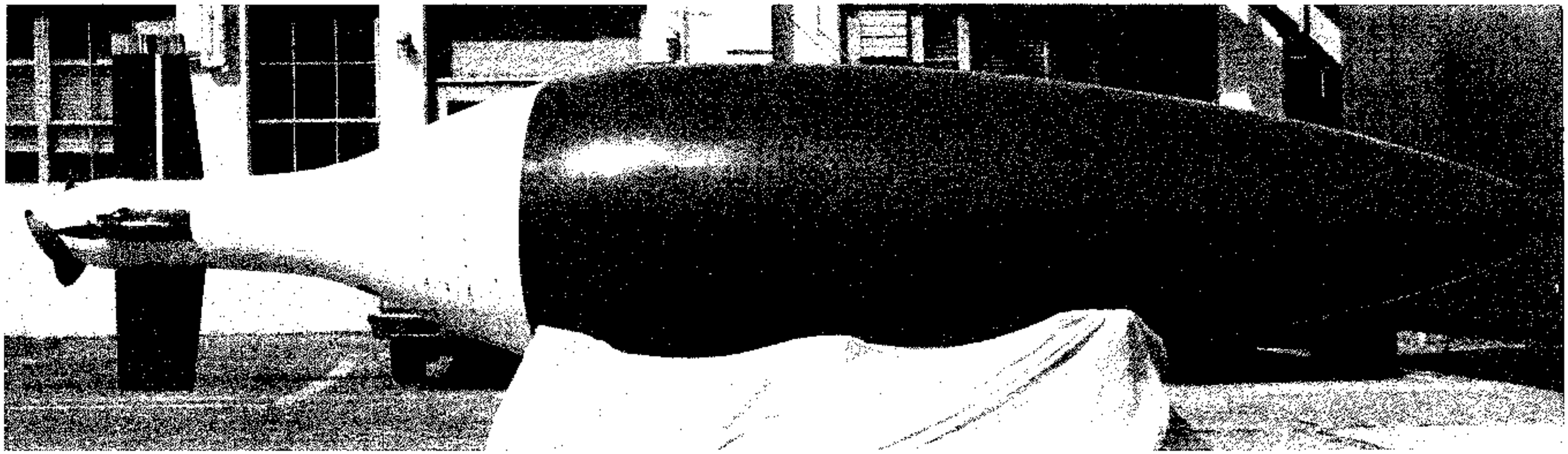
Autonomous

- o Navigation by means of OMEGA integrated with a microcomputer for guidance and control
- o Adaptive to environment

Flexibility - System parameter identification techniques and ease in changing software for closed loop compensation permits changes in performance, hull configuration, and energy device without need for expensive model testing.

Figure A-2

NRL Unmanned Free Swimming Submersible



APPENDIX II

This appendix is a compilation of the responses to a survey presented to the attendees of the Workshop held on 1 and 2 November, 1979. With one exception the responses are from industry and government personnel as opposed to academic. The responses are those of operators and builders of vehicles, oil company users, and government agencies charged with development of such vehicles.

The varied comments can be summarized as follows:

1) Cooperation among researchers, builders, and users is essential to defining tasks and tools needed to design mission oriented, usable, marketable systems.

2) Tethers would be very nice to get rid of but only if we can develop a) adequate power sources and b) adequate communications links.

3) Reliability and maintainability are essential design goals.

4) A remotely operated, untethered work vehicle is a very desirable goal. Its implementation will be a major engineering challenge.

ATTENDEES RESPONSES TO SURVEY QUESTIONNAIRES

In order to obtain a record of ideas, interests and needs expressed at the workshop, attendees were requested to fill out a questionnaire after the conference. The diverse nature of the audience which included designers, operators and users of underwater vehicles provided a broad spectrum of view points. While some general consensus responses are noted, we have incorporated the complete record of comments so that planners, designers, marketers, and users will all have the benefit of the complete responses we received. (The questionnaire is the last two pages of this Appendix.)

Question 1

"In terms of a two to five year time horizon, what kinds of activities do you feel remotely operated systems should be capable of?"

The first question was aimed at obtaining a ranking of importance of certain tasks. Using a scoring system of two for each "Very Important" response, one for each "Important" response and zero for each "Not Important" response, the scores shown in Table I were obtained.

TABLE I

Activity	Very Important	Important	Not Important	Score
Bottom Survey or Inspection	16	6	0	38
Inspection of Structures	17	2	0	36
Inspection of Pipeline/Cables	17	1	0	35
Instrument Placement & Recovery	13	6	0	26
Maintenance Activities	7	9	1	23
Pipeline & Cable Burial	6	10	0	22
Bottom Sampling or Soil Property Measurement	4	13	4	21

In addition, the free-form comments suggested: "Diver Assistance," "Monitoring Construction," "Doing Construction Tasks," and "Cleaning up the Bottom" might also have been important categories. The free-form comments in response to Question 1 were:

-- RCV's are now performing most of the functions listed above to varying degrees. Keeping in mind that 95% of all RCV activity takes place in the offshore oil fields, we must look also at their use as a diver assist device and as a work tool.

-- Monitoring of undersea construction and structure's installation. Clearing fouled or entangled lines.

-- Operation under ice. Operation in areas difficult for divers (cold, deep, swift currents, etc.)

-- Specific work tasks in offshore oil fields, for example: connecting flowlines of subsea production systems: preparation of submarine pipelines for welding; provide underwater services to drill rigs.

-- Placement of explosives.

-- Military applications - important

-- Above reflects our R & D orientation

-- Subsea well heads -There most likely will be a need to change out control units and lines in depth beyond diver capabilities. These could be accomplished by tethered remotely operated systems.

-- Instrument recovery-including tool recovery and very simple positioning or activation/deactivation tasks such as subsea completions.

-- All of the above are important to the future of submersables (unmanned).

-- Debris removal, very important; deepwater drilling support, very important

-- Particularly concerned about deep ocean-- Over 20,000 feet operations of exploratory nature.

-- Advanced methods of controlling oil spills from tankers or from offshore wells.

-- Structural dynamics, risk and failure analyses.

Question 2

"Most (about 95%) of present tasks for remotely operated vehicles are observation, i.e. "see" activities as opposed to manipulation or "do" activities. What are important needs for improving manipulation to make them more widely useful - e.g. agility, control, strength, special tools or power issues - please comment concerning needs as seen from your perspective."

The verbatim responses have been put into four categories that are not mutually exclusive, but which reflect important concerns for making manipulators easy to use.

A. Tools and Tasks

The first category emphasizes the need for close collaboration between designers and users to design systems to do tasks which need to be done as opposed to general purpose systems which will do all tasks less well, more expensively and less reliably. Good market research is needed, as is close cooperation among all involved parties. Members shared these ideas:

-- The most fundamental "need" has to do with clear definition of the "work" to be done. In the absence of a good definition of the tasks to be accomplished many vehicle systems have been developed that are neither specialized enough to do unique tasks nor versatile enough to handle a range of generic tasks. The technology is, in my opinion, ahead of the communication link between the developers of technology who know what can be done and the operators who know what must be done. At the technical level, however, the most important need has to do with the overall efficiency of the man-machine system. To the extent that the ability of terrestrial man to sense and act upon his physical environment is simulated by real time controls and displays or replaced by vehicle autonomy, the effectiveness of remote work systems will improve. Command and control is the key.

-- I believe the problem is not entirely of technological nature. A lot of progress would be made if: a) tasks were clearly defined; b) operators, vehicle manufacturers and manufacturers of equipment to be manipulated cooperated in the development of vehicle and equipment necessary to perform the tasks.

-- Recommend special tools "tailored" to the tasks rather than complex all purpose hands.

-- Manipulators for deep water use will need to be equipped with specially designed tools, for example, remote pipeline connection and trenching.

-- Special tools should be a design consideration of deepwater well heads, flowlines and systems. Capabilities of RCV's should be considered in design.

-- In underwater work, seeing is not necessarily believing. Very often one has to remove growth, or concrete lagging to inspect. This is a work function requiring special tools. Removal and replacement of components is similarly important.

B. Manipulation and Control

A second and equally important concern is control of the manipulators and the vehicle to which they are attached. Thus while specialized systems are generally recommended, control flexibility, and agility remain a paramount concern. The specific responses were:

-- Ability to operate off of a moving platform; ability to be controlled using a minimum of bandwidth. Ability to observe the manipulator using a minimum of bandwidth.

-- Agility and control are two areas where most improvements are needed.

-- Provide assistance to operator (supervisory control), to relieve tedium and allow longer work hours. Note - manipulators must be jettisonable, in case of fouling - would be nice to have a small cutter on back of wrist or at elbow to allow cutting oneself free of entanglement even if another tool is in the claw.

-- Agility and control are the two items most necessary to carry out these tasks.

-- Not only is agility required but also the ability to hold a vehicle in place.

-- A lot of the manipulator operating problems are solved by using two manipulators - one for holding and one for working. Note that this applies to crabs, lobsters, and such also.

-- Limited manipulation capability is needed to place underwater radiography equipment or explosive charges at particular places on or near underwater objects.

-- Need to develop a stable platform to operate from or the equivalent (such as a reference arm).

-- To perform physical tasks will require pinpoint control and agility. High strength and power requirement should not be required.

-- We are interested in manipulation from a tracked (bottom lander) vehicle. Light weight and extended reach are important factors. Modest lift capability -100 lbs. required.

-- a) Much higher degree of manipulator versitility required at reasonable cost (= more degrees of freedom). Otherwise more complex tasks would require specialized manipulators or tooling, precluding widespread usage of relatively standardized vehicle. b) Master/slave feedback system required having "instanteous" response time. (Requires electronic rather than hydraulic feedback. c) Manipulator platform stability. d) Power applied to manipulator task.

C. Heavy Duty Work Systems

A special case of control and manipulation capability was suggested. These are categorized by an explicit or implicit suggestion that Heavy Duty Work Systems having high forces or torques are needed. Members suggested:

-- I feel that remote subsea vehicles should be designed for substantial tasks on the seabed such as tractor type vehicles for excavation of wellhead cellars in iceberg scour locations. Large crawler type vehicles could be designed to transport reels of subsea control cable and could trench and lay this cable with minimal surface support.

-- Probably the most important task in the area of offshore oil production facilities concerns the maintenance of sea floor equipment. Due to the large heavy nature of this equipment the maintenance vehicles typically need to have the following capabilities:

Heavy payload capability for transportation or replacement parts, typically 1,000 to 6,000 lbs.

Adequate availability of power for heavy lift and torquing tasks.

Deployment and retrieval capability in moderate seas.

Reliable umbilical cables which have good power and signal transmission characterisitcs with good fatigue life.

Adequate self contained control and power capability for preprogrammed recovery sequence in event of loss of umbilical cable.

-- At the present time most envisioned tasks are beyond the capability of manipulator arms due to their lack of adequate strength capability although these are useful devices for assisting the main power manipulator. Arms are employed for such tasks as debris removal and TV camera manipulation for close in inspection. For these tasks lack of manual dexterity is not seen as a major problem.

-- Possible use to make sub sea tie-ins and install tops on existing underwater lines.

-- Control, strength, ability to operate tools/equipment that may be required for inspection, maintenance, and repair.

The need for Heavy Duty Systems was not unanimous. One participant stated, "It is my contention that too much emphasis is being placed on brute strength and size and number of manipulators. RCV's can perform work without physical force if the task is planned properly."

D. Miscellaneous

In addition respondents suggested a wide variety of additional needs for consideration:

-- Am not on the "do" side of submersible development, but consider that control and the concomitant data/info transfer problems are being given plenty of consideration. Should we begin to look at diagnostic requirements now? For example, the application of non-destructive testing devices to structural members under water and the resulting data readout and transmission is not being treated. This is a step beyond seeing that a valve is open or a bolt is sheared, and taking direct action to correct the fault. (I suppose this comes under the category of Special Tools.)

-- There is a need for greater range and depth of submersibles. Also, if the link between tender and vehicle can be anything else but tether, than this would reduce time and money spent.

-- Better sensors needed (optic, sonar, etc.) to increase capability. Speed at an area not important but speed to get to an area more important.

-- Capability of present vehicles as diver's assist in shallow water is generally satisfactory.

-- USGS is interested in inspection and associated physical tasks such as sensor placement and joint cleaning prior to inspection.

Question 3

"Please list technological barriers or hindrances to wider use of remotely operated systems for applications you view as important:"

Owing to the diverse backgrounds of the participants, it is difficult to categorize the responses. We have attempted to put the comments in broad subject areas as indicated below.

A. Reliability

-- The umbilical or tether is correctly singled out as the "weak link" in the tethered unmanned system. Given the present state of the art, the only thing worse than having a tether is not having a tether, and, as a result, suffering the disadvantages of low band width data transmission, relatively large vehicle size, and low endurance. Difficulties in high power density energy sources and high band width wireless communications are the barriers that must be overcome.

-- More reliable connectors

-- Maintenance of the more complex electronics and mechanical devices

-- Rugged reliable configurations that can stand banging around.

-- Biggest problem I see is buying reliable components in small quantities. For example, cable suppliers are not interested in the small quantitites that a year's supply for an RCV manufacturer represents.

-- Electronics equipment of current vehicles is not reliable

-- Problems of acceptance by maintenance companies who are diver oriented.

-- Acceptance of these advanced systems by operators

B. Navigation, Station Keeping

-- Finding, identifing, and returning to the worksite (navigation & positional manuevers)

-- Station keeping by the support platform

-- The tether, station keeping, the work capability

-- Accurate & low cost naviation capability that doesn't require placement of reference instruments.

-- Maneuverability around structural members of offshore platforms.

-- Deployment, station keeping and retrieval of large heavy payload vehicles in moderate sea states.

C. Communication

-- Light weight, strong, low drag, wide bandwidth, EMI protected cables

-- Ability to transmit and/or store data with fidelity, reliability & bandwidth

-- Communication capability for untethered vehicles

-- Real time communications link

-- High bandwidth capacity back up communication links for use in the event of main umbilical failure.

D. Control

-- entire area of telecontrol of manipulators, tools, etc., using limited bandwidth channels.

-- Manipulator control. Supervisory control as developed by MIT appears very promising. How reliable is it and when is it available for use by the industry?

-- Effective power transfer - control

E. Power Sources

-- long-endurance (high energy-density) power sources

-- Power for untethered. Li Primary batteries are not the answer unless costs drop 2 orders of magnitude.

-- Storage capacity and weight of on board emergency power batteries.

F. Cables

-- Stronger more abrasion resistant, positively bouyant tether cables

-- Fatigue life of power and signal umbilical cables.

-- Mundane as it may sound, reliability and maintainability are the two greatest problems associated with the majority of remotely operated system.

G. Launch and Retrieval

-- launch and retrieval systems for free swimmers, esp. for use in higher sea states

-- Launching and handling system improvements

-- Surface Handling, and lack of large enough market for special components.

H. Motors

-- direct current, efficient motors and speed controllers

-- More efficient and reliable motors.

I. Miscellaneous

-- Small light weight gyro

-- All the pieces of the technological puzzle exist. It will take several years to put them together to perform real inspection tasks underwater.

-- Imaging in turbid water

-- Silt or Turbidity Supression around worksite

-- Dependance on reasonably clear water for good viewing of the work area

-- Underwater systems (well heads, flowlines, etc.) are not designed with RCV's in mind. Time will eliminate this problem. Power and time requirements will limit use of free-swimming RCV's. I believe there is little restriction to wide use of "see" activities. Most likely the greatest barrier here for effective use is lack of initial engineering planning.

-- Control of high degree of freedom devices at reasonable cost; elimination of tether at reasonable cost.

-- Most importantly-Lack of any applicable technology in industry today! There is a need for more research money.

-- Cost is important factor in shallow water - divers are cheaper.

-- Problems of vehicle insurance inhibit use in high risk situations

-- In our context, the availability of a reliable tethered vehicle for 20,00 feet ocean depth that can be operated from an oceanographic ship in the manner that "Deep Tow" is operated.

-- Tolerance and precision

Question 4

"Would you be interested in participating in future workshops involving government, industry and academic researchers and users of remotely operated vehicles, perhaps a two or three day meeting similar to the Underwater Mining Institute?"

Of 24 respondents, 23 were in favor of a similar future workshop (the 24th made no comment). Three respondents felt the one-evening one-day format was excellent. Specific comments included:

-- Such workshops would act to break us all out of the little islands we find ourselves in. Plenty of opportunity to exchange ideas and techniques and needs without upsetting any proprietary apple carts.

-- Would be useful.

-- I found the workshop at MIT very informative and valuable. The JPL workshop was also very valuable.

-- One day meeting is great. Two-three days is not justified.

-- The MIT Workshop #18 was just right. (Implies "no" ?)

-- I feel these meetings are worthwhile as information exchanges.

-- It would promote interaction which is desperately needed.

-- This would be helpful if a greater emphasis could be placed on commercial applicability.

-- I think the "evening before day" meeting just held is very appropriate.

-- Workshops should speed up the answers and results that Offshore construction and maintenance now needs.

Question 5

"We're considering forming a steering committee consisting of representatives of government research sponsors, manufacturer and industry users to coordinate government/industry/academic research and development activities. Would you (or a colleague) be available to serve on such a group?"

Evidently the idea of an ad hoc informal steering committee was well accepted. Seventeen of the respondents answered affirmatively. Three answered negatively, two were equivocal, and two did not respond. We are pursuing this idea at present and will welcome suggestions and ideas.

Additional Comments

-- You guys did a good job. First Class!

-- This was good meeting. A good mix of attendees, and well scheduled talks.

-- Many thanks - this was a fine conference.

-- Thought the meeting was excellent exchange of information. I'd be interested in seeing the compiled results for questions 1,2 & 3 of this form.

-- Please send summary analysis & would appreciate list of attendees.

-- Workshop #18 was very well done indeed. Thanks again for giving me the opportunity to attend.

-- I would like to see a summary of the responses. By the way, I found a copy of Superman report here in the Sea Grant Office and have found it quite interesting & helpful.

-- My interest & activity re unmanned underwater vehicles concerns Navy applications, thus I really can't comment on the above commercial applications. Nevertheless - would it be possible to obtain the following:
1-Leads (phone numbers) to the authors of the reference list on page 19 of your working draft
2-An attendee list for the 1 November meeting

-- Here is my form without a great deal of comment. Higher power/density batteries will constitute an important impetus to development of untethered vehicles. Please send me a copy of the summary analysis.

TO: Attendees of MIT/Marine Industry Collegium Workshop #18
"Some Federally Sponsored Research Programs for Unmanned Underwater Vehicles"

FROM: Norman Doelling

The research you've heard described ought to be valuable to future commercial remotely operated underwater systems. To help all of us plan, coordinate and direct our work, your comments and suggestions are valuable.

1. In terms of a two to five year time horizon, what kinds of activities do you feel remotely operated systems should be capable of?

Activity	Very Important	Important	Not Important
Bottom Survey or Inspection			
Bottom Sampling or Soil Property Measurement			
Pipeline & Cable Burial			
Instrument Placement & Recovery			
Inspection of Structures			
Inspection of Pipeline/Cables			
Maintenance Activities			

Other - Please comment: ____________________

____

____

____

2. Most (about 95%) of present tasks for remotely operated vehicles are observation, i.e. "see" activities as opposed to manipulation or "do" activities. What are important needs for improving manipulation to make them more widely useful - e.g. agility, control, strength, special tools or power issues - please comment concerning needs as seen from your perspective:

____

____

____

____

3. Please list technological barriers or hindrances to wider use of remotely operated systems for applications you view as important:

____

____

____

____

____

4. Would you be interested in participating in future workshops involving government, industry and academic researchers and users of remotely operated vehicles, perhaps a two or three day meeting similar to the Underwater Mining Institute? YES__________ NO__________

COMMENTS:

____

____

____

____

____

5. We're considering forming a steering committee consisting of representatives of government research sponsors, manufacturers and industry users to coordinate government/industry/academic research and development activities. Would you (or a colleague) be available to serve on such a group? YES__________ NO__________ COMMENTS:

____

____

____

____

____

NAME____

ADDRESS____

November 2, 1979