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A Scientific Application for Remotely Operated Vehicles

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A Scientific Application
for
Remotely Operated Vehicles

University of Rhode Island
Kingstown, Rhode Island

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Fulfillment of Masters Degree in
Marine Affairs

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PREFACE

Remotely Operated Vehicles (ROVs) have opened up new dimensions for the application of underwater technology. ROVs provide an alternate for conducting marine environmental studies, assessing fish populations, and photographically documenting areas of the ocean inaccessible by other means. Yet, despite the well publicized capabilities of ROVs marine scientists have been reluctant to accept this tool as part of their research inventory.

Realizing that ROVs have been designed for the offshore oil and gas industry, scientists are looking at ways to use, or modify, the existing instrumentation to fit their needs. In particular, they are interested in obtaining quality results from still and video cameras, and the ability to collect and recover quantifiable and reproducible samples. Without such capabilities, the "ROV scientist" will be hard-pressed to have his data accepted by his peers.

ACKNOWLEDGEMENTS

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DEDICATION

To my loving wife Susan, for her support, pateince, and inspiration.

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Introduction

Although Remotely Operated Vehicles (ROVs) have been employed in the underwater circuit since the mid - 1900s, their impact upon the ocean community has not been felt until the past decade (Marine Technology Society, 1984). Starting around 1975, the number and types of vehicles have increased dramatically. Early vehicles were surface connected and equipped with thrusters and closed circuit television cameras. Some were additionally equipped with mechanical manipulators which maneuvered within a three dimensional format and derived power from the surface via an umbilical cable.

The vehicles of today fit only a small part of this definition. Present day ROVs can be towed by surface ships in mid-water investigations, while some are in contact with the bottom. Still others have the ability to propel themselves along the bottom using wheels, tracks, and rams. Contrasted with the surface supported vehicles, some ROVs have no phyiscal connection with the surface and are controlled remotely via an acoustical link.

In an attempt to place limitations upon the type of vehicles which can be used by marine scientists, this paper concentrates on two types of remotely operated vehicles. One type of vehicle operates linked to the surface by an umbilical or tether, and the other type of vehicle is free from this tether, but relies upon an acoustical link between the surface to subsurface interface for control.

Manufacturers are now in agreement that the strategy for marketing a straight forward observation vehicle has past (Busby, 1985). What remains is to produce a vehicle that caters to a particular segement of the market, by producing a vehicle that provides the basic transport system which then can be fitted with various forms of work modules. One manufacture states that they had to stop producing high quality "Cadillac vehicles" and had to shift over to the "Ford" and "Chevy" models where higher volume and lower prices would take up the slack (Busby, 1985).

In designing an ROV system, the place to start is with the basic operational requirements. This is followed by the specific task requirements. Next is consideration of the vessel it is to be used in conjunction with. And finally, all of the components should be drawn together and optimized to meet the established requirements.

In order to meet essential demands common to all ROV systems, the following prerequisites should be established no matter what discipline the vehicle is employed in:

1) Safety.
2) Rough weather consideration.
3) Performance.
4) Reliability.
5) Minimum maintenance.
6) Flexibility.
7) Economy.

These seven varibles are discussed in subsequent chapters (Kidera, 1984).

Hypothesis

To allow man to work beneath the ocean safely and effectively beyond certain depths is a costly and limited undertaking. These high associated costs and qualifications have encouraged the development of remotely operated vehicles. The remotely operated vehicle (ROV) industry developed from the needs of the oil and gas community to find a cost efficient, and safe method of replacing man and manned submersibles underwater. It is hypothesized that ROV technology has opened up new avenues for those concerned with ocean research. However, marine scientists have been reluctant to accept this tool as part of their research inventory. The slowness of technological transfer stems from several issues: the lack of quantifiable results; the untried technology; and a lack of awareness.

The objective of this paper is to demonstrate to those involved in ocean research that remotely operated vehicles can meet the specialized needs of science at a reasonable cost. Once this has been illustrated, ROVs will become commonplace to the researcher's inventory.

Reason for Study

Remotely operated vehicles have been used in underwater work for almost 50 years. It was not until the mid-1970s that the full potential for these vehicles was realized. Several factors led to the increased utilization of ROVs, but it was offshore oil and gas developments which have given rise to an industry which can account for over 700 vehicles and is responsible for the full time efforts of thousands.

The learning curve for any new field of technology is frustratingly slow and expensive. Yet, this new technology has maintained its pace within the diving industry to become a useful, economic and viable tool to its main user, the offshore oil and gas industry. The remotely operated vehicle has a place within the marine science community as well. If properly utilized, this type of vehicle can enhance the marine sciences to where its useage will become the norm rather than the exception by the beginning of the next decade.

To have marine scientists except remotely operated vehicles as part of their research inventory, and to have it utilized in such a manner so that it can be cost effective and efficient in the collection of data is a major stumbling block that must be overcome. As with all new technologies, there exists a barrier between the manufacturer and its potential end users. The offshore oil and gas industry has bridged this gap, when they discovered that the ROV could perform underwater tasks safer and less expensive than a man in saturation diving or manned submersibles.

At present there exists a similar technology transfer problem between the marine science communities and the manufacturers and contractors of remotely operated vehicles. This paper focuses on linking these two participants by clarifying the applications of ROVs and establishing guidelines for their use so that ocean research scientists can profit from this new and highly sophisticated tool.

Vehicle Types

The following paragraphs describe the two types of remotely operated vehicles on which this paper will concentrate: 1) Tethered and, free-swimming; 2) Untethered and autonomous in nature. The primary distinction between these two vehicle types is the surface support they receive and where they derive their power.

Tethered

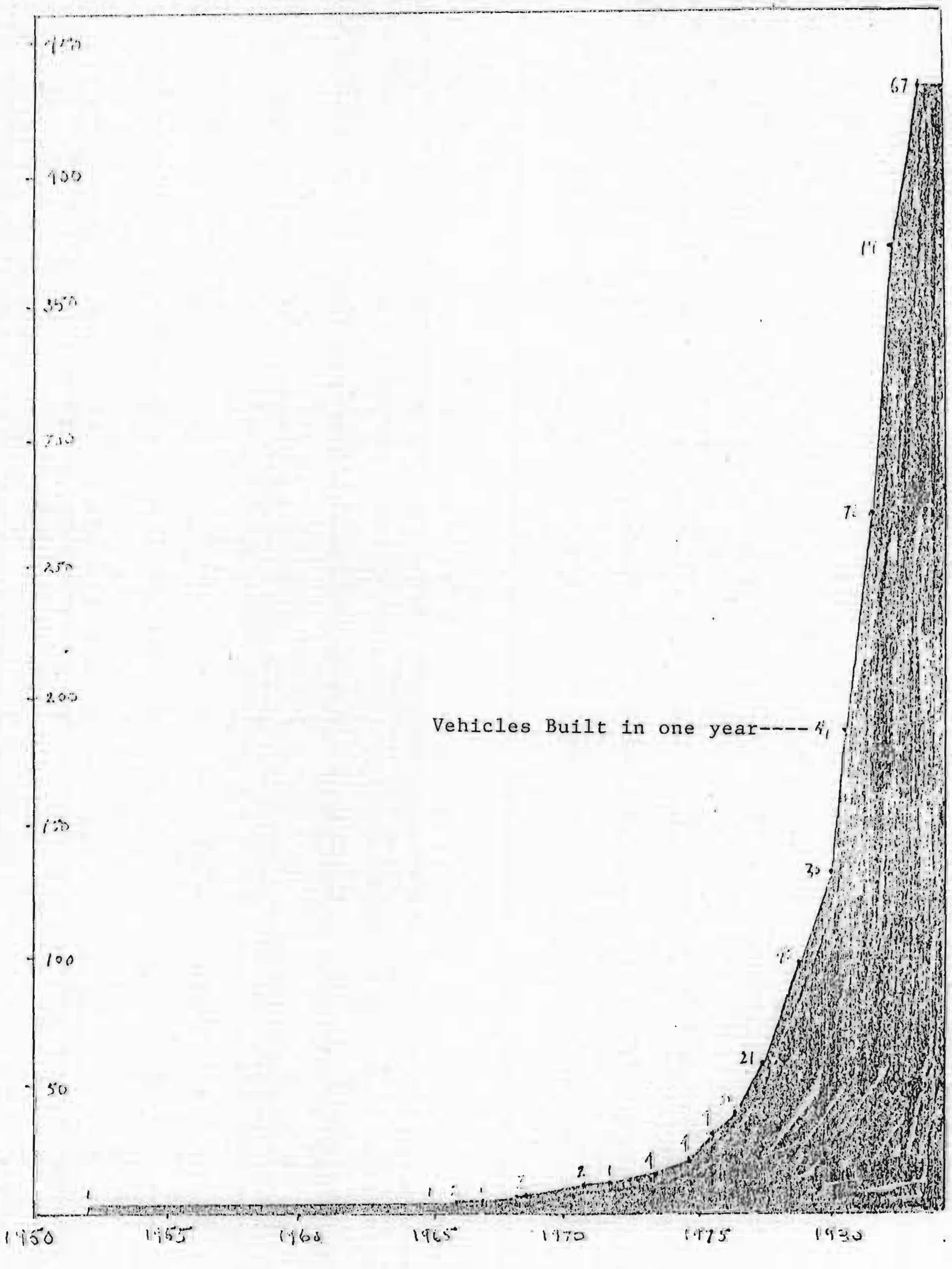
This type of vehicle operates virtually on every offshore oil and gas producing platform, and in virtually any type of environment worldwide. In 1970, there was only one industrial manufacturer of tethered vehicles. During the ROV boom years from 1981 to 1983, there were greater than 27 manufacturers, today there are approximately 12. Four firms, one Canadian and three U.S., accounted for 229 of the 340 industrial vehicles produced since 1975 (Marine Technology Society, 1984). Figure 1. illustrates the tethered, free-swimming ROV growth curve.

Of all the vehicles built from 1953 to 1974, eighty-five percent were government funded and operated. Whereas, ninety-six percent of the 350 vehicles produced within the past eight years have been funded, constructed and bought by private industry (Marine Technology Society, 1984). Figure 2. denotes government or scientific research funded tethered, free-swimming ROV growth from 1950 to 1980 .

The tethered, free swimming vehicle constitutes the majority of ROVs that are in existence today. All have closed circuit television capabilities, maneuver within a three dimensional format, and are connected to the surface, or subsurface platform from which they are controlled.

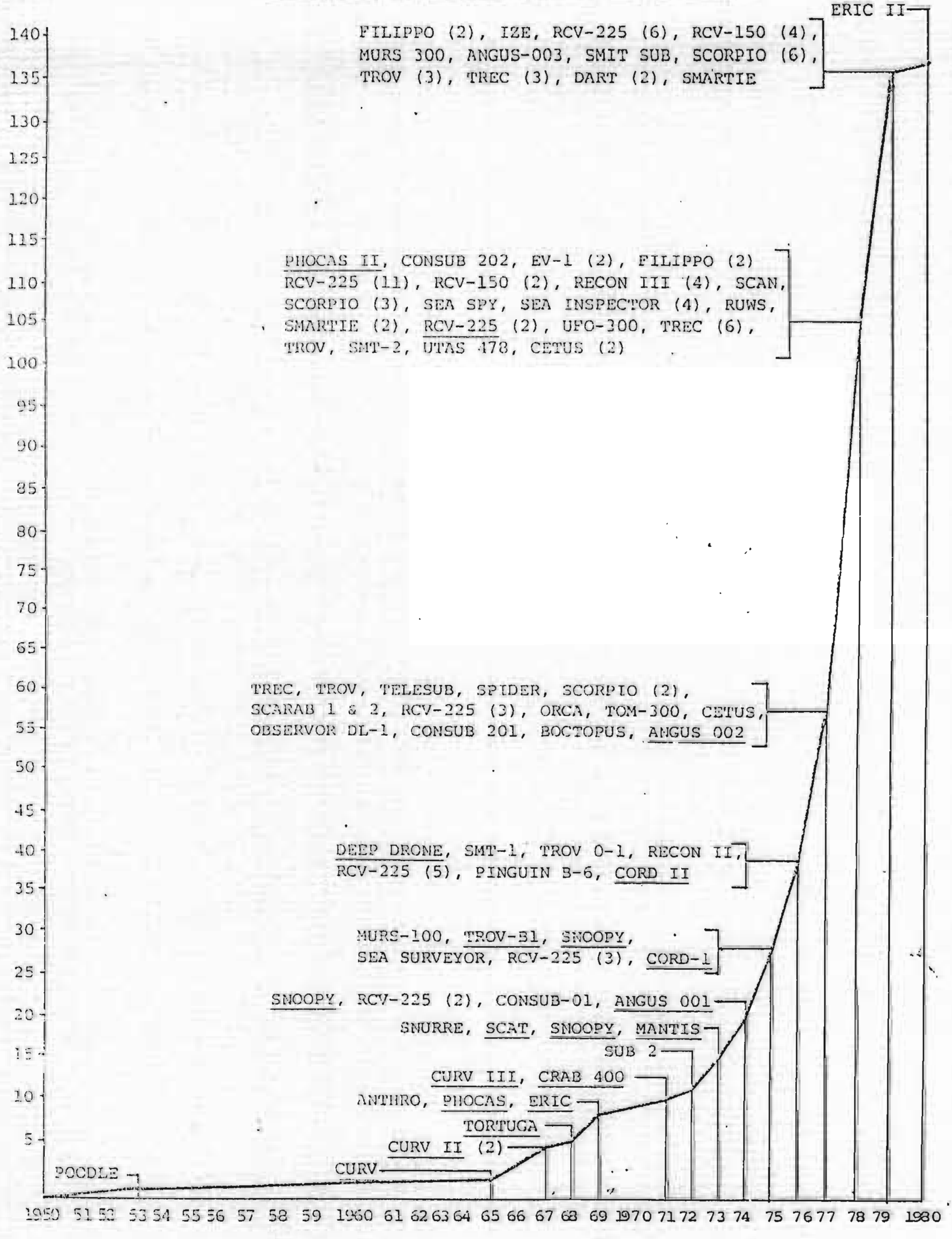
FIGURE 1.

TETHERED, FREE-SWIMMING ROV GROWTH CURVE



* Source: Marine Technology Society, <u>Operation Guidelines for ROVs</u>, 1984.

TETHERED, FREE-SWIMMING ROV GROWTH CURVE



Underscored vehicles denotes Government or scientific/research-funded vehicles)

* Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

This type of vehicle is designed for mid-water use solely, contrasted with the ROV designed for bottom contact. Buoyancy is usually positive, thereby relying upon thrusters for decent. Many of these vehicles are equipped with some form of manipulating system to perform a variety of tasks.

The majority of vehicles in this category operate in depths from 100 to 10,000 feet and range in size from a basket ball to a small car. Operating and maintenance crews vary with the complexity of the machine, but usually range from one to ten, with an average of three.

The basic functions of the umbilical on the tethered free-swimming ROV, is to transmit power to the vehicle. This factor alone places the biggest limitation on the tethered vehicle. The size and length of the tether produces drag, thereby creating a size and power trade off. Other basic functions of the umbilical are to transmit to the operator control of the vehicle, along with navigation and vehicle status. Additional dialogue required by specific tasks, such as sensors, manipulators, actuators, are also transmitted along the umbilical link to the surface.

In addition to the limition previously mentioned, that of power of the vehicle versus the size and length of the umbilical, there exists two other major limitations which can hamper the tethered free-swimming ROV. The reliability of the vehicle is only as good as its umbilical link. As the complexity of the ROV system increases, so does the size and mendability of the umbilical. Many of these vehicles are equipped with some form of manipulating system to perform a variety of tasks.

The remaining limiting factor is that of entanglement. There exists two forms of entanglement, one by the vehicle itself, and the other by the umbilical or tether. Experience has shown that there are also two types of objects in which the vehicle or tether can become ensnarled. One is the ROV support ship or platform from which the vehicle is working from, and the other is the structure or object that the ROV is investigating (Bectarte, 1984).

Untethered

This type of remotely operated vehicle functions without physical connection to the surface. Vehicle operations can be performed in either one of two modes. The first being the vehicle is preprogrammed at the surface, or autonomous in that its tasks are given to the vehicle's microcomputer which then directs the vehicle to the prescribed depths, course, and speed, all of which are carried out without interference from the surface. The second mode of operation consists of control of vehicle depth, course, speed and dive duration via an acoustical link from the surface.

Freed the from tether new opportunties for working and exploring within the oceans are created. With an autonomous or preprogrammed vehicle, depth of operations increases, along with the range and duration of the dive time. Thrusters required will be smaller, and the energy expended will in turn be reduced. Also, the required shipboard handling facilities, which can be massive for tethered ROVs, will also become of modest size.

But what of the technological bottle-neck that exists with untethered vehicles? At present, most of the vehicles of this type are in the developmental stage. The acoustical link pitfall between the vehicle and its support vessel and its implication on the control of the ROV have to be overcome. These are technological demands that must be overcome before this type of vehicle can become a practical and effective alternative to the tethered free-swimming vehicle. Table One illustrates the advantages and limitations of the untethered ROV.

At present, there are only two autonomous remotely controlled vehicles in operation. Epaulard, a vehicle of French design, came into service in 1980 with a development cost of two million dollars. It can operate in water depths down to 6000 meters and carry out observation missions by recording video information which can be stored or retransmitted back to the surface

TABLE 1

ADVANTAGES AND LIMITATIONS OF THE UNTETHERED ROV

	ADVANTAGES	LIMITATIONS
TECHNOLOGY	- No connectors - No cable - Improve reliability	- No real knowledge of acoustic transmission - Narrow band mono channel transmission
OPERATIONAL	- Improved manoeuvrability - No cable induced drag - Vehicle motion independant from support vessel - Openings toward new tasks: - structure inspection in rough profiles - access inside platforms - no depth limiation except for telemetry - work under ice - simplification of handling equipment	- Tasks limited to low power requirements: short mission, low current. - Possible limitation due to use of other acoustic devices. - Visual piloting difficult due to sampling and delay in picture transmission.

* Source: "Comex Developments on Remote Controlled Systems"
Marine Technology Society, Oceans 1982.

in real time by means of an acoustical link (Hyacinthe, 1982).

The second vehicle Spurv II, which operates in a preprogrammed format, was developed for oceanographic research and is operated by the Applied Physics Laboratory of the University of Washington (Nodland, Ewart, Bender, Miller, and Augaard, 1981). Table Two illustrates the present day status of untethered and autonomous remote operated vehicles and their developers.

The History of Remotely Operated Vehicles

The evolution of the remotely operated vehicles industry is still in rudimentary stage, and has not been able to establish the background of knowledge, and engineering experience which can be found in more mature engineering trades such as the automotive and aerospace industries.

Since 1974, over 600 free-swimming tethered vehicles have been constructed. Of these 230 were produced by a single French firm and are used primarily for mine neutralization. The remainder is represented by 40 different types of vehicles through the efforts of 20 manufacturers. The zenith years for ROV construction were from 1981 to 1983 in which 256 vehicles were produced, of these 111 were constructed in 1982 alone.

TABLE 2
UNTETHERED REMOTELY OPERATED VEHICLES

VEHICLE	DEPTH (ft.)	STATUS*	PURPOSE	DEVELOPER
ARCS	1640	Trials	Under-ice Mapping	ISE., Ltd., Port Moody, B.C. Canada
B-1	295	Const	Laminar Flow Feasibility Studies	Naval Underwater Systems Center, Newport, Rhode Island, USA
AUSS	20000	Proto	Search/Identification	NOSC, San Diego, CA USA
CMU ROVER	0	Proto	Feasibility	Carnegie-Mellon University, Pittsburgh, PA, USA
EAVE EAST	3000	Proto	Pipeline/Structure Inspection	Univ. of New Hampshire, Durham, NH,USA
EAVE WEST	2000	Proto	Pipeline/Structure Inspection	NOSC, San Diego, CA, USA
EPAULARD	20000	Oper	Bottom Photography/ Topography	CNEXO Toulon, France
ROBOT SUBMARINE	300	Proto	Bottom Surveys	MIT, Cambridge, Mass., USA
ROVER	984	Proto	Structure Inspection	Heriot-Watt Univ., Edinburgh, Scotland
RUMIC	NA	Constr	Mine Countermeasures	Naval Coastal Systems Center, Panama City, FL, USA
SKAT	NA	Proto	Ocean Research	Institute of Oceanology, Moscow, USSR
SPURV I (2ea)	12000	Oper	Mid-Water Research	Applied Physics Laboratory, Univ. of Wash., Seattle, WA, USA
SPURV II	5000	Oper	Mid-Water Research	Same as above
UFSS	1171	Proto	Search	Naval Research Laboratory, Wash., DC, USA

TABLE 2 (CONT.)

UNTETHERED REMOTELY OPERATED VEHICLES

VEHICLE	DEPTH (ft.)	STATUS*	PURPOSE	DEVELOPER
VERA	NA	Proto	Nodule Collection	C.E.A. & France-Dunkerque Shipyard France
Unnamed	3280	Proto	Structure Inspection and Drilling Support	CSF Thompson Brest, France

*
Proto: Prototype
Constr: Under Construction
Oper: Operational
NA: Information Not Available

* Source: "Operational Guidelines for ROVs"
Marine Technology Society, 1984

Todays ROV manufacturers have decreased to about 12, with an annual output of around 25 to 30 vehicles per year (Busby, 1985).

It is difficult to assess the history of ROVs since the field is so young. However, the oil and gas producing industries can be credited with the development of this underwater technology. In the early 1960s, the diving community was operating with mixed gas dives to 90 meters. The early 1970s produced fully crewed deep bounce saturation diving systems found aboard virtually every offshore drilling operation worldwide (Butler, 1985).

The middle 1970s gave rise to technological developments where offshore platforms were being positioned in deeper waters off the continental shelf. This turn of events signalled contractors in the operation of manned submersibles for the routine pipeline inspection and platform support.

In 1972, the United States Navy funded the development of the Advanced Maneuverable Underwater Vehicle (AMUV). This vehicle which is still under contract to the Navy is being refitted by Deep Submergence Engineering Laboratory (DSEL) of Woods Hole Oceanographic Institute (WHOI). Existing plans call for AMUV to become the Jason vehicle of DSEL's Argo towed sled, recently famed for its discovery of the RMS Titanic (Smith, 1985).

In 1974, a remodelled and upgraded AMUV became

Hydro Products RCV-125 and is credited with becoming the first successful commercial remotely operated vehicle. The RCV-125 and its predecessor the RCV-225 have been used exclusively for offshore oil and gas platform maintenance. Other larger vehicles of this generation were AMETEK, Straza Scarab, Scorpio and the U.S. Navys Deep Drone. The former was recently used in the search and recovery efforts of Air India's aircraft wreckage off Ireland.

These vehicles have been successful in there application, although they are expensive and difficult to use, maintain and mobilize. Yet, despite these obstacles, the tasks which these vehicles performed would have proven impossible by any other means. As a result, a great number of them became accessible to the market, but unfortunately for the oil and gas community so did the glut. With the market saturated with ROVs and an over abundance of oil, it became uneconomical to operate these vehicles, as it typically takes four years to write off an ROV investment (Smith, 1985).

Oil and Gas

With the increasing installation of deep water platforms in the Gulf of Mexico and off the Southern California coast, along with the growing interest in leasing underwater tracks for oil and gas development in water depths down to 3,000 feet and more, there can be little doubt that underwater contractors will receive more subsea work for their submersibles.

Prior to the development of remote operated vehicles, the oil and gas industry relied solely upon manned submersibles to perform the required work necessary in the deeper waters. Yet, within the past six years manned submersibles have virtually disappeared from the oil fields, due to the rapid development of the remotely operated vehicle. With increasingly affordable ROVs being introduced into the market place each year, offshore contractors have found it more cost efficient to operate and maintain the ROVs as the counterpart to the manned submersible.

Basically there are two main users to the ROV industry: the military and the offshore oil and gas community. The military has never been a significant customer for ROV services. Typically they have always purchased the vehicle and the vehicle systems, and only rarely have they leased the vehicle and its operators (Busby, 1985).

The offshore oil and gas producers constitute the largest consumer to remote operated vehicles and their supporting systems. The type of work in which this industry uses the ROV for can fit into several categories: inspection, monitoring, diver assistance, installation and retrieval assistance, along with cleaning.

Diver assistance is an interesting aspect of the ROV's versatility. It was once thought that ROVs were going to put divers out of business. Conversely the ROV is viewed as a supportive tool, and a wide variety of support applications have been implemented to assist the diver.

Recent interviews with some of the major U.S. ROV manufacturers concerning the state of business has received mixed reactions. Virtually all the manufacturers agreed that the 1981 through 1983 bonanza years are over (Busby, 1985). However, the concensus in the offshore oil and gas industry is that a diverless system will continue to grow, and will succeed in installing subsea equipment which will require inspection or monitoring at some time. When these tasks are required, the conditions which are associated with offshore subsea operations are such that the cost for these operations will be high.

It is here that the remotely operated vehicle and its services will continue to expand. It can be expected that a universal vehicle for subsea work in the oil and gas industry and for the science community will probably never exist. Therefore, a basic design able to accept a variety of work interface modules or tools should be contrived in conjunction with designers.

Marine Science

The United States scientific community has had considerable experience with towed underwater vehicles, in particular Scripps Institute of Oceanography, National Marine Fishery Service, and Woods Hole Oceanographic Institute (NOAA, 1979).

Scientific involvement with free-swimming tethered and untethered vehicles however is extremely limited. Only after the recent discovery by Dr. Ballard, of Woods Hole Oceanographic Institute, of the RMS Titantic did remote operated vehicles receive much attention within the science community. As a consequence of this exposure, the full potential of the remotely operated vehicle, be it tether, untethered, or autonomous in nature has just begun to flourish.

Regarding the suitability of the remote operated vehicle as it applies to marine scientific applications, a number of government researchers have employed one atmosphere submersibles in their research inventory. Yet, it is possible that the tethered free-swimming ROV, or the untethered ROV can perform a number of these tasks without human intervention and less expensively (Rechnitzer, 1985). Today an ROV scientist can carry sensors and instruments to investigate untapped areas within the ocean environment, similar to the manner enjoyed by the first users of scuba. It is only the technology and the techniques used in the collection of this data that has changed, which in turn greatly effects the efficiency of the project. For instance, a detailed geological investigation of the ocean's bottom usually begins with a geophysical survey of a relatively large area, and entails the collection of bathymetric information, seismic profiling, and magnetic and gravity studies. On the basis of this data, a smaller area is selected for more detailed investigations using a towed vehicle. Lastly, ROVs are used to collect detailed information from a very small section within the area of interest. An example of such an exercise was conducted in 1983 off the coast of Oregon, to explore the seafloor topography and bottom fauna of Gorda Ridge. An autonomous controlled ROV, the Epaulard was used to map areas of polymetallic sulfide deposits discovered on earlier submersible missions. Epaulard had the capabilities and performed well enough to where National Oceanographic and Atmospheric Administrative (NOAA) scientists believed that deep submergence studies could be performed at great depths and in cold waters at a reasonable cost (Carnevale, 1985).

CHAPTER TWO
MISSION APPLICATIONS AND SPECIFIC SCIENTIFIC USERS

In the past, the trend was to build remotely operated vehicles as big and as complex as the manufacturers could design. This machine by concensus of the operators, was to be the ultimate "do all" vehicle. The end result was an engineering effort which produced a few remarkable vehicles, but unfortunately they were so complex and expensive that the tasks required could be performed less expensively by using divers.

When considering the potential for ROV systems, one has to take into account what is happening in the industry. Present work is directed towards satisfying specific requirements on a short term basis using known technology (NOAA, 1979). To embark on any program which diviates from present day technology and devise a new generation of vehicles to perform new tasks is risky business. Yet, many of the functions and operations that the marine scientist wants in a ROV system parallels that of the commercially employed vehicle. However, there are considerations which are unique to the ROV scientist. The following list describes six peculiar interests to a scientific ROV system:

1) control and maneuverability over flat and

steeply bottoms;

2) pursuit and capture capabilities;
3) viewing quality;
4) organism detection and location technology;
5) manipulation and sampling effectiveness; and
6) positioning technology (NOAA, 1979).

The application of the ROV to date relies actively on its observational tasks. Undoubtedly, the capability to observe an animal or a natural phenomenon in real time for extented periods is possibly the greatest potential use of the ROV system. Figure 3 illustrates the ROV system configuration versus the tasks required by the marine scientists.

Surveys

Considering the whole field of marine science, the research performed by ROVs can generally be broken down into three categories, near shore benthic studies, open ocean, and deep sea benthic studies. In most cases, the use of ROVs lend themselves well to all three categories. Mid-water employment of autonomous vehicles for establishing the outer edge of the continental shelf, whenever the margin extends beyond 200 nautical miles from the territorial sea baseline, is a good example of survey technique used in conjunction with the 1982 Law of the Sea Convention (Article 76 paragraph 4).

FIGURE 3

SYSTEM CONFIGURATION VERSUS TASK CAPABILITY

SPECIFIC TASK CLASSIFICATION	Manipulator requirements	Generic task classification
Observation	0	Inspection
Small object recovery by grasping	1	Recovery
Small animal recovery by slup gun	1	Recovery
Jetting	2	Recovery
Water filteration for small plant recovery	1	Recovery
Water collection for chemical analysis	0	Recovery
Large object recovery by claw attachment	2	Work
Object preparation and rigging for recovery	3	Work
Component extraction from object	3	Work
Oject installion and maintenance	3	Work

* Source: Author.

The recent example of using a hybrid towed/tethered free-swimming vehicle, the Argo/Jason system renown for the discovery of the luxury liner RMS Titanic offers great potential for geological and geophysical surveys over a wide area, where a broad coverage and specific site reconnaissance is possible (Marine Technology Society, 1984). Additionally, the use of acoustical imagery, which can be described as a forward looking sonar system, is likely to be used more extensively for upgrading future underwater survey techniques.

The qualitative documentation of marine benthic communities or mid-water organisms for basic research or enviromental studies which can be related to some planned seafloor disturbance or development relates to the use of ROVs (Given, and Benech, 1984). It is with the collection of these data that the use of tethered and untethered vehicles offers good justification to the marine scientists.

BEHAVIORAL STUDIES

The use of remotely operated vehicles, in terms of long term observations, offers the marine scientist one of the most valuable tools in their research inventory. By replacing a diver, one loses the advantage of instant start, stop, turn, and a wide visual sweep. But, in the replacement of a diver one gains the ability, through the use of remotely operated vehicles, for long term observations on the movements and interactions of marine organisms. The trade off for the amount of data that can be gathered in a continuous mode with fixed television cameras is a luxury that is not offered to divers or manned submersibles.

An example in which ROVs were evaluated as research tools for assessing the fish population on offshore oil and gas production platforms offers a good illustration of the vehicle's worth. Along the outer continental shelf in the northwest portion of the Gulf of Mexico remotely operated vehicles were appraised in terms of their effect on fish behavior, viewing geometry scale perception, navigation, maneuvering and station keeping capabilities, and quality of data collected by closed circuit television cameras. The data gathered during this study indicated that ROVs could be used successfully in assessing fish population. Furthermore, it was determined that remotely operated vehicles could be more cost effective when compared to manned submersibles or long term saturation diving techniques (Thompson, Pott, Gettleson, Hammer, and Steven, 1984).

Experimentation

Experimentation is probably the most formidable task confronting the ROV scientist. Necessary requirements for vehicle maneuverability and stability, in which the manipulation of complicated instrumentation occurs hundreds or thousands of feet beneath the surface, is complex. Furthermore, the concept of manipulating underwater in a remote fashion and obtaining acceptable and reproducible results is one of the most consequential tests for the ROV scientist.

An area where remotely operated vehicles have been brought to test the theory of underwater robotics is the recent christening of MIT's Sea Grant underwater vehicle, SEAGRANT I (Sheridan, 1985). The vehicle came to the Massachusetts Institiute of Technology with power and propulsions systems, but no sensors or control systems. After designing and installing a camera system, communications between the vehicle's computer and the mother ship and developing telemetry control software, this tethered free-swimming vehicle has been helpful in locating oil leaks, and getting valuable visual records of the environment near sewage outfalls. The effect of SEAGRANT I is a challenging illustration of government, industry, and university cooperation in providing hands on experience for students as well as promoting marine scientific research.

Specific Scientific Users

Despite the fact that science has not been a driving force in ROV technology, there exists a small and active group of marine scientists who see the potential of remotely operated vehicles as a scientific tool (Given, and Benech, 1984). In developing this tool, the logical sequence of events is to accept the fact that the data being accumulated is through a machine interface. The goal should then be to design a machine that suits the work task as best as possible, and then make the man-machine interlink as simple and logical so that operations can be fully mastered, thus assuring quantifiable results.

Biological

The use of ROVs as a successful scientific tool is the main thrust of this paper. It is considered that application of these vehicles within the four disciplines of oceanography (Biological, Geological, Physical, and Chemical) can only enhance the principle investigator's objective, that of data productivity. For the assessment and capture of marine organisms, the employment of remotely operated vehicles are especially well adapted. Investigators, through the use of closed circuit television, can identify planktonic, nekonic or benthic organisms and then utilize a sampling storage device similar to those used aboard manned submersibles.

What makes the remote operated vehicle particularly attractive to the marine scientist is its ability to maintain its station in a variety of environmental conditions. One specialized effort by an ROV in the assessment of herring eggs was performed in September, of 1985 by Dr. David Stevenson. Dr. Stevenson, a biologist on joint appointment with the University of Maine at Oruno, and the Maine Department of Marine Resources deployed the <u>Mini Rover</u> over herring egg beds in the Gulf of Maine. According to Dr. Stevenson, "we had a rough idea of the herring egg bed sites from past field work and fishermen remarks. But, the sites lay too deep and in too strong of a current for safe and efficient use of divers. With the <u>Mini Rover</u>, we were able to identify and photograph beds we knew existed but had never seen" (Middleton, 1985).

Marine scientists have long felt the greatest amount of marine activity is found within the continental shelf region. From water circulation to the migration of fin fish, these areas just off the coast produce a great interest for marine scientists. Yet, despite the relatively shallow water depths, these areas have been inaccessible to most scientific endeavors. ROVs lend themselves well to the open ocean and mid-water sciences as well as to studies of the sea floor and its associated organisms and phenomena. Marine geologists manifested the initial interest in remotely operated vehicles, but it seems to be the marine biologists who consider ROVs as the tool of the future (Given, and Suzanne, 1984).

Geological

As marine technology becomes more advanced and sophisticated, there is a corresponding awareness and belief that this technology is what drives the sciences. Prior to the development of advanced sonar, synthetic lines, and refrigeration, the fishing industry worldwide was in a comparable primitive state. Within the past decade, electronics advanced the marine sciences to such a sophisticated level that it is just beginning to fully realize the real potential of its capabilities in utilizing the oceans resources. One of the most outstanding resources that remains untouched yet capable of harvest through existing technology are the minerals beneath the oceans. Six types of seabed minerals that are recognized include:

1) thick layers of free flowing materials (i.e., oozes muds and clays);
2) superficial mono layers of loose materials (i.e., nodules and fine sands);
3) superficial layers of hard minerals attached to bed rock (i.e., manganese pavements);
4) outcropping masses of hard materials (i.e., metalliferous sulfides);
5) deeply buried masses of ore materials (i.e., nickle sulfides); and
6) hot mineral bearing springs (Cruickshank, and

Rowland, 1981).

Deposits of metalliferous oxides and sulphides associated with manganese rich basalts in the mantle, and other minerals in a variety of forms, from brines to hard rock are found in the deep seabed. Today's technology has made available the exploration and exploitation of these minerals. What is lacking is the need to utilize the concept of ROVs by marine geologists. For example, if ROVs were able to quickly and accurately sample and analyze the ambient waters and superficial sediment, accompanied with precise locations, the advancement of mineral development would save untold millions of dollars. Furthermore, ROVs could be utilized in mining operations, for as mechanization becomes more evolved in terrestrial mining operations, the same heavy earth and rock moving technology could be employed to remotely operated vehicles.

Physical

In terms of present day useage, it is the marine geologist and biologist that enjoy the greatest potential for data collection by the remotely operated vehicle. However, there are applications which the vehicle can be employed in the field of physical oceanography.

The physical oceanographer is particularly interested in the sea-water temperature and salinity for these are charactertistics which help in the identification of particular bodies of water and coupled with pressure they determine the density of sea-water. In connection with these variables, the physical oceanographer is able to gain a greater understanding of ocean structures and their circulation properties, which in turn allow the marine scientist to make a reasonable assessment of the ocean's energy potential and its biological resources.

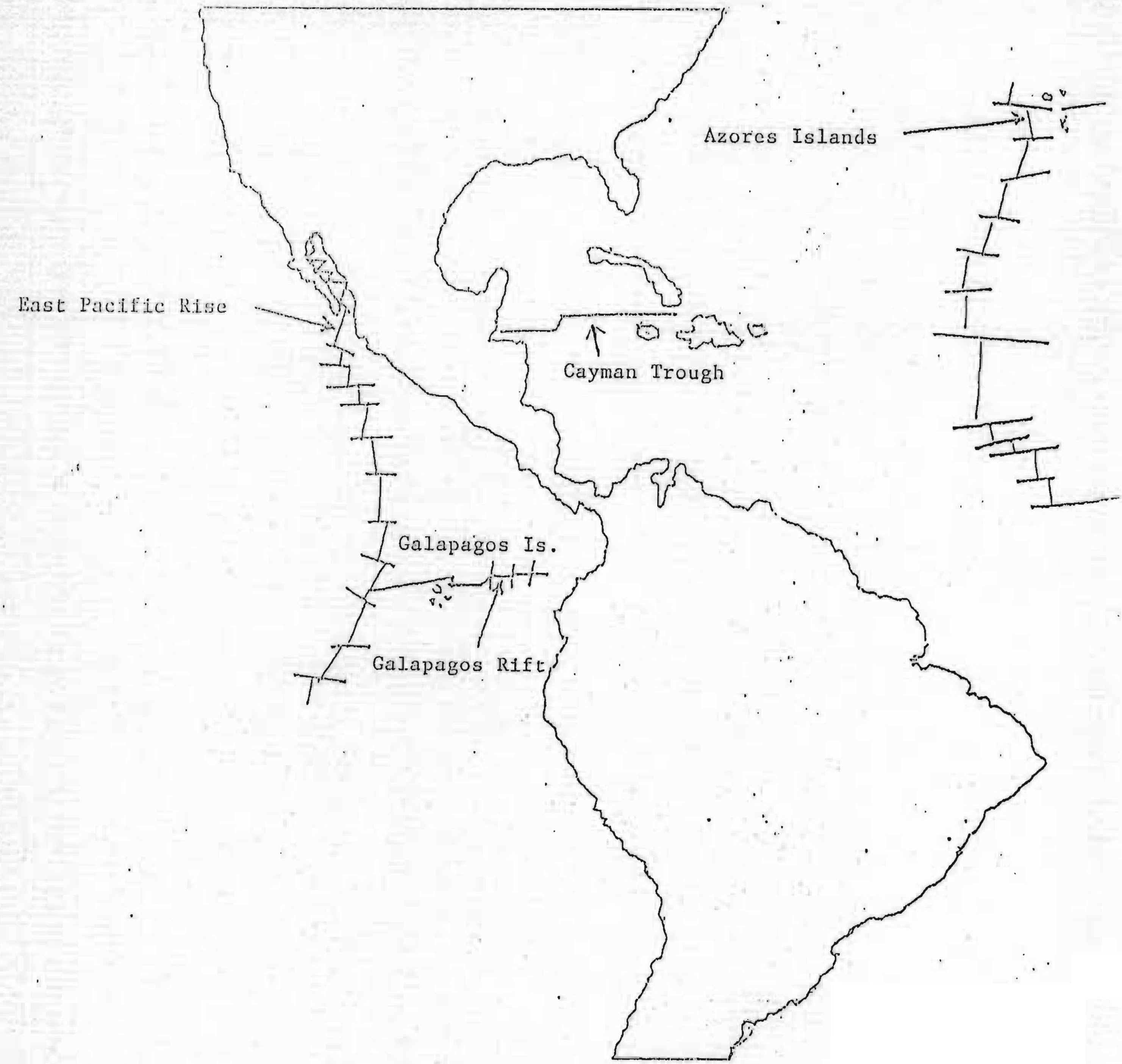
The collection of a data set, in situ by remotely operated vehicles, allows the ROV scientist to determine the density of sea-water as the vehicle travels up and down the water column with the aid of real time visual displays. Technological modification of a vehicle to allow for conductivity, temperature and depth (CTD) measurements would ensure large amounts of data transfer to the surface thereby eliminating the very expensive and time consuming method presently employed today.

Other characteristics of sea-water which would help investigators in the identification of particular water masses are the dissolved oxygen content, and color of the sea. The biological process may change the concentration of oxygen without any movement of the water mass. The detection of the biological productivity and the attenuation of light through the water column as compared to depth can be easily surmised through the use of a camera system deployed on ROVs.

Chemical

The application of remotely operated vehicles in chemical oceanography is probably the least utilized, but could offer the most exciting results due to the recent discovery of hydrothermal springs found along the mid-ocean spreading centers at depths over 2500 meters (See Figure 4). In these regions where there is no light for photosynthesis, ocean water seeps down fractures and is heated by the underlying magma chambers, thus forming the hydrothermal springs. Once the seawater is heated, it rises up to the ocean bottom and dissolves minerals found within crustal rocks. Large biotic communities such as clams and mussels derive their energy from this chemical exchange to produce their own food from hydrogen sulfide gases dissolved in the water of the hydrothermal springs (Thurman, 1983). The potential of chemosynthesis on the biological productivity of the oceans is far from realized and requires much more research. The means by which this data are collected and the ways research are conducted lends itself ideally in the utilization of remotely operated vehicles. The tethered free-swimming vehicle or the untethered autonomous vehicle could conduct real time research within this area at a fraction of the cost

FIGURE 4.



Mid-ocean spreading centers at depths over 2500 meters.

* Source: <u>Essentials of Oceanography</u>

and logistical support than manned submersibles require, i.e. the DSRV Alvin observations made on the East Pacific Rise in 1977.

Present day technology for remotely operated vehicles would require modifications be made in order that samples could be recovered within the hydrothermal springs. It is estimated that temperatures in these regions reach in excess of 300 degrees centigrade. The environmental conditions that the remotely operated vehicles must face, such as the challenge of operating within extreme temperatures bring forth the concept of vehicle design and its surrounding environment.

CHAPTER THREE
ENVIRONMENTAL CONSIDERATIONS

The successful completion of any maritime operation largely depends upon the environmental conditions. These variables include the operating depth that the scientific package is to be deployed, the strength of the currents and their effects upon the instrument, the sea state and swell which the supporting platform is liable to for its seakeeping ability. The primary requirements for any ROV system depends upon knowledge and the effects that the environment will have on the equipment. Although the ROV system is the fundamental concern of the marine scientist, the reliability and economics of endurance of todays research ship and their equipment are also paramount to oceanographers. The following sections on environmental considerations will emphasize the affects between the relationship of the ROV system and its surrounding environment.

Depth

Future operations of ROV systems will undoubtedly operate at increased depths. This is due, in part, to the sophistication of technology which has a tendency to drive science, and an increased desire by the oil and gas communities to explore for resources in deeper waters. The more advanced ROV systems have depth capabilities of 3,000 feet. These capabilities are not restricted by present day technology, but rather by what is demanded by the users. Hence, the ability of an ROV system to reach a determined depth is a question of design. If increased depths of operations are desired, a revised system of underwater components would have to be developed which could withstand the increased water pressure. Today's market for an ROV system does not call for deep water capabilities, however that does not mean that the technology is not available. The United States Navy has several deep ocean programs underway which involve depth capabilities to 20,000 feet, such as the STSS and AUSS systems (Marine Technology Society, 1984). In the future when private firms find it feasible to undertake deep ocean mining, ROV systems will be required to reach even greater depths. The point at issue is that in today's market it is not possible to take an off the shelf ROV system and operate the vehicle at any depth.

When considering a ROV system for deep water deployment, several design enigmas must be kept in mind. One, is as the system increases in operational depth the size of the umbilical must also increase, unless an autonomous, or untethered vehicle is used. Additionally as the length of the tether increases, the specification on the cable and its effect upon the handling system must be considered. This leads to a vicious cycle. For instance as depth increases, cable drag increases, leading to a decrease in the vehicle's footprint or electronic capabilities. Therefore, an increase in power must be supplied to the vehicle in order for it to accomplish its given task. This in turn leads to an increase in the cable diameter which produces greater drag, and requires a further increase in power.

Another consideration with increased depths is the overall time of the operation. The time required for an ROV to transcend depths reaching 20,000 feet and back again greatly effects the efficiency of the operation. Those who monitor the underwater system, the sea kindliness of the supporting platform, and the weather window of the operation all contribute to the success of the operation.

Another factor which must be added to the depth equation is the cost of the project. As the ROV scientist goes deeper with his investigations, costs associated with underwater components, power supply systems, handling systems, umbilical lengths, and the charter cost of the research vessel must be taken into account. Concerns about safety and reliability along with probability of success must also be added.

Another factor which merits mentioning, as it pertains to the handling system and in association with increased depths, is that the tethered ROV can be classified as a spring mass system (Marine Technology Society, 1984). Depending on the overall characteristic of the handling system, it is possible to enter a stage in depth where the dynamic attitude of the cable changes. This dynamic change in cable characteristics is referred to as "snap loading". It occurs when there is a transition into deeper waters and cable tension goes from positive to negative or slack. Thus when tension is taken out due to the dynamics of the system and snap loading occurs, stress is placed upon the cable. To compensate for this undo stress and possible damage to the cable itself, articulated winch arrangements can be introduced into the system to decouple the ships motion from the ROV. It is this marshalling of the ROV system in holistic terms that can increase the reliability of the vehicle and its potential for successful collection of scientific data.

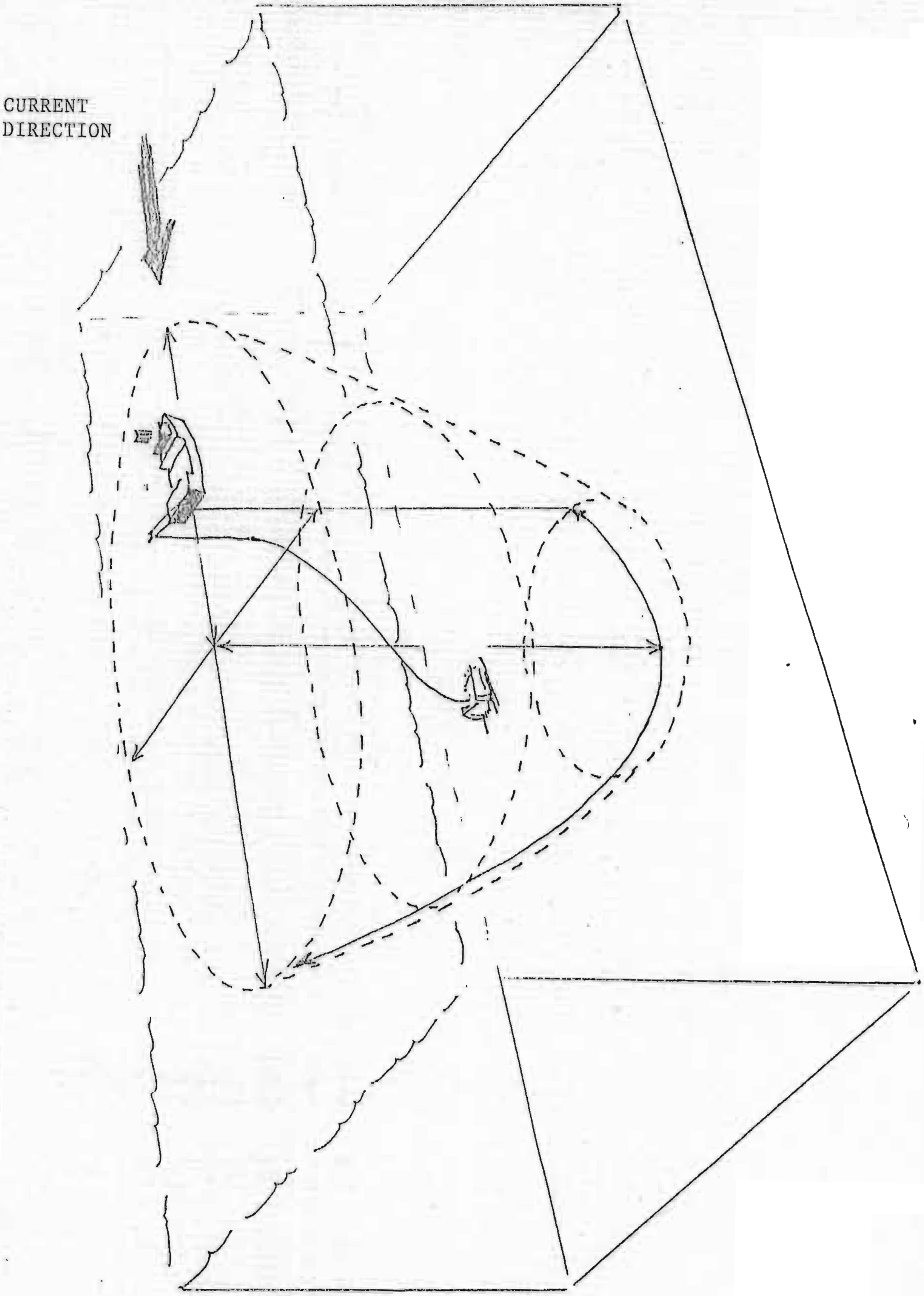
The caveats associated with increased depth for ROV operations will augement the complexity and costs to the scientific user. Ocean currents however, decrease as depth increases, and these currents have the greatest affect upon the ratio between cable and the power trade off.

Currents

Ocean currents have the most laborious effect on the ROV system and its supporting platform. There are little data on deep ocean currents, but the general belief by oceanographers is that deep ocean currents are less than 0.25 knots (Marine Technology Society, 1984). Furthermore, most ocean currents are predictable with the tidal period as the variable component. This differential in tidal velocity is true in deep oceans as well as shallow and near shore environments. Surface currents are the most troublesome for ROV operations, making vehicle launch and recovery and station keeping ability for the support vessel inconsistent (See Figure 5).

Underwater currents have a dynamic effect on the vehicle and its supporting components. The relationship that exists between the supporting tether and its diameter, to the amount of power transmitted to the vehicle to overcome the induced drag is the greatest obstacle that the tether free-swimmming ROV system has to conquer. An example of induced drag to power transmission can be expressed by: a ROV is experiencing an increase of current from one to two knots. The power increase to overcome this drag is not one of 50 percent, but an increase of twice the drag (proportion to the square of the velocity) and requires three and one half times the power (proportion to cube the velocity) (Marine Technology Society, 1984).

FIGURE 5.



* Source: Author.

Sea State and Swell

The operation of remotely operated vehicles from a support vessel is assured of motion from the air-sea interface. This movement may be minimal at times, but within a matter of minutes the support platform could experience an increased sea state resulting in a pitching deck of ten to twenty feet, with rolling factor of ten to twenty degrees. Therefore, limitations on ROV operations will vary with the seakindliness of the support platform, but generally range from a sea state zero to a factor of six (See Table 3).

Concerns with an increased sea state include the storage and securing of the ROV and its supporting components enroute to the site of operations, as well as preparations for prelaunch and safety considerations during launch and recovery. The awareness of increased dynamic loads placed upon the tethered vehicle and the supporting hardware must also be realized as the supporting vessel heaves in a growing sea state. It is at this stage that the greatest potential for accidents occur.

In order to minimize the adverse affects on ROV operations while experiencing increased sea states, full considerations should include: the launch and recovery system; the maneuveribility of the support vessel; and the proper training of crew.

TABLE 3

SEA STATE CHART

Wind and Sea Scale For Fully Arisen Sea						
Sea-General		Wind			Sea	
Sea State	Description	(Beaufort) Wind Force	Description	Range (Knots)	Wave Height Feet Average	Significant Range of Periods (Seconds)
0	Sea like a mirror.	0	Calm		0	—
	Ripples with the appearance of scales are formed, but without foam crests.	1	Light Airs	1-3	0.05	up to 1.2 sec.
	Small wavelets, still short but more pronounced. Crests have a glassy appearance and do not break.	2	Light Breeze	4-6	0.18	0.4-2.8
1	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white caps.	3	Gentle Breeze	7-10	0.6	0.8-5.0
					0.88	1.0-6.0
2	Small waves becoming longer; fairly frequent white caps.	4	Moderate Breeze	11-16	1.4	1.0-7.0
3					1.8	1.4-7.6
					2.0	1.5-7.8
					2.9	2.0-8.8
4	Moderate waves, taking a more pronounced long form; many white caps are formed. (Chance for some spray.)	5	Fresh Breeze	17-21	3.8	2.5-10.0
					4.3	2.8-10.6
5					5.0	3.0-11.0
	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray.)	6	Strong Breeze	22-27	6.4	3.4-12.2
					7.9	3.7-13.5
6					8.2	3.8-13.6
					9.6	4.0-14.5
	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of wind. (Spindrift begins to be seen.)	7	Moderate Gale	28-33	11	4.5-15.5
					14	4.7-16.7
7					14	4.8-17.0
					16	5.0-17.0
	Moderately high waves of greater length; edges of crests begin to break into the spindrift. The foam is blown in well-marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh Gale	34-40	19	5.5-18.5
					21	5.8-19.7
					23	6.0-20.5
8					25	6.2-20.8
					28	6.5-21.8
	High waves. Dense streaks of foam along the direction of the wind. Sea begins to "roll". Spray may affect visibility.	9	Strong Gale	41-47	31	7-23
					36	7-24.2
9					40	7-25
	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility affected.	10	Whole Gale	48-55	44	7.5-26
					49	7.5-27
					52	8-28.2
					54	8-28.5
					59	8-29.5
	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the waves are blown into froth. Visibility affected.	11	Storm	56-63	64	8.5-31
					73	10-32
	Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	12	Hurricane	64-71	>80	10-(35)

* Source: "The Practical Navigator", Bowditch, 1980.

It is the launch and recovery of the ROV system that creates the greatest potential for vehicle damage as the sea state increases. Thus, due reqard must be given to the complete system. Vehicle design should be made compatible with the launch and recovery mechanisms, be it either a dedicated system or one that is placed aboard a vessel of opportunity. The most effective method for the over the side launch and recovery is by utilizating an A-frame or a knuckle crane. Even with these devices, the interrelationships between the sea, swell, currents, and wind, along with the maneuvering capabilities of the support vessel must be fully understood for successful ROV operations.

Weather

The physical features of the ROV system are invulnerable to weather, yet weather can have serious affects upon the cost and efficiency of the operations. Variability in weather introduces an element of uncertainty. For example, the launch of an ROV under ideal weather conditions does not guarantee the recovery of the vehicle under similar conditions. Therefore, the possibility of adverse weather conditions must be made part of the planning procedure. Different aspects of weather conditions, ice, wind, fog, and precipitation all effect ROV operations in different ways. Primary concerns are of increased wind and sea conditions which will affect the station keeping ability of the support vessel and in turn effect the ROVs ability to maintain station. Therefore, the design of the support vessel and its ability to operate within adverse weather conditions is paramount to the success of ROV operations.

CHAPTER FOUR
SUPPORT FACILITIES AND TOOLS AND SENSORS

In the planning and implementating of a ROV operation, it should be understood that the vehicle system must be considered holistically. The handling system (i.e. winches, launch and recovery mechanisms) along with the vehicle and the personnel required to operate it must be considered as one; be it either through a ship of convenience, or a ship which is dedicated to the remotely operated vehicle.

Surface Vehicle Support

The ultimate productivity of a ROV system is largely determined by the vessel or vessels that will be used in conjunction with. University research vessels usually range from 50 to 300 feet in length. Such vessels may be flexible in their supporting activities or extremely limited. Components such as winches, handling systems and motion compensating sub-systems may be part of the vessel system, or part of the vehicle system. The actual situation is an important design criteria.

Ship of Opportunity Versus Ship of Dedication

There exists two types of operations in which the ROV system can be employed. The ship of opportunity is a system where the remotely operated vehicle and its supporting infrastructures are installed temporarily. In the dedicated system, the support platform is devoted to the ROV system and its accompaning components. The factors in determining which system to employ are the cost and duration of the operations.

In exercising a ship of opportunity, the over-all cost will be considerably less, however there is a trade off in the efficiency of the total system. The intergration of the navigation and control systems, coupled with the reliability of underwater positioning systems would not be as sophisticated as with a permanent installation. Mobilization and demobilization costs must also be taken under consideration.

On ships of opportunity, the utilization of the ships superstructure for handling the ROVs places severe restriction on the type of vehicle employed, especially if larger ROVs are considered by the researching scientist. In addition, with the use of arbitrary cranes or A-frames, dangerous situations could arise and reduce the weather window for operations. To circumspect this problem, the ROV package should include a mobile handling system, i.e., a motion compensating knuckle crane.

A purposely built and dedicated ROV support vessel or a ROV support package including personnel has the advantage over the ship of opportunity, in that the support vessel and its associated handling gear is just as much a part of the ROV system as the vehicle itself. The ability to launch, recover, track, and provide the necessary servicing and maintenance is perhaps the most important marketable factor in ROV operations (Askew, 1984).

Handling System

The most critical period in the launch and recovery of the ROV system is when the vehicle passes through the air-sea interface. It is here that the greatest dynamic loads are experienced, and if improper handling techniques are employed, damage to the vehicle and supporting infrastructure can occur. To protect the vehicle and its cable, the handling system should have a method of shock absorption. Ideally, the initial pickup should make contact with the vehicle below the waters surface (Kidera, 1984). The distance between the vehicle and the attachment point on the handling system should be as short as possible, thus minimizing the pendulumization effect associated with the sea state.

The are two strategies in the handling system for ROVs, deployment by a crane or by an A-frame. The crane has the advantage of being able to cover the greatest deck area, and is merited with its marketability since it may be included as a package item. Furthermore, cranes offer greater flexibility in the launch and recovery process. A-frames on the other hand offer the highest rigidity, especially for a given deck space. What ever system employed, either crane or A-frame, the rating should be in accordance with the appropriate classification society regarding load factors.

There are several tactics used in the handling system for launch and recovery of the vehicle system. A "pick-up hook" is used when the tether is of medium construction, thus allowing the vehicle to be winched in or hand tended. In this approach, simple cranes are used, often those of opportunity. Launch or recovery with a "grabit" or "go-getter" is when the device runs down the umbilical and latches onto a pick-up mechanism atop the vehicle. This approach is generally used on dedicated cranes (Marine Technology Society, 1984).

Due to weather conditions and their effect upon the support vessel, motion compensating of the ROV may be required. One technique which is often used is to place floats to the tether, whereby a decoupling effect is achieved between the surface forces and the vehicle (Marine Technology Society, 1984). Another method which can become complex and expensive includes the use of active and passive winch systems. There are several considerations which should be examined when choosing a winch system. The most obvious is that of line pull, a factor characteristic to the weight of the vehicle. Another important issue is braking. There should be two methods for applying the brakes to the winch system. First, a method used during normal operations, and secondly, an automatic engagement during an emergency situation, such as a rapid drop in oil pressure. The winch factor and its braking abilities is an additional further consideration that merits attention in designing a system as a portable package.

Personnel Involvement

The ROV system must be designed as a total system. The vehicle, its tether, the handling system, motion compensating winches, along with the personnel involved must be designed as an integrated package. If the ROV scientist is to be successful in applying innovative technology to his research, the functions of all personnel associated with the equipment and its maintenance must be of the highest quality. This is especially true if the vehicle system is owned and operated by the researching institution.

Pilot Training

The objective of ROV pilot training is to introduce a program in which the most elementary skills of offshore operations will be experienced. This includes a sense of how a vehicle will react in currents, the use of cable handling, underwater navigation, inspection and sampling techniques, along with the application of sonar, tracking systems, and bottom surveys. Justification for ROV pilot training can be measured in two ways: the cost efficiency of ROVs within a given work task, and the effect of training in achieving cost efficiency (Evensen, 1984). It is estimated that the value of ROV services and their supportive systems in the North Sea area is 120 million dollars per year (Evensen, 1984).

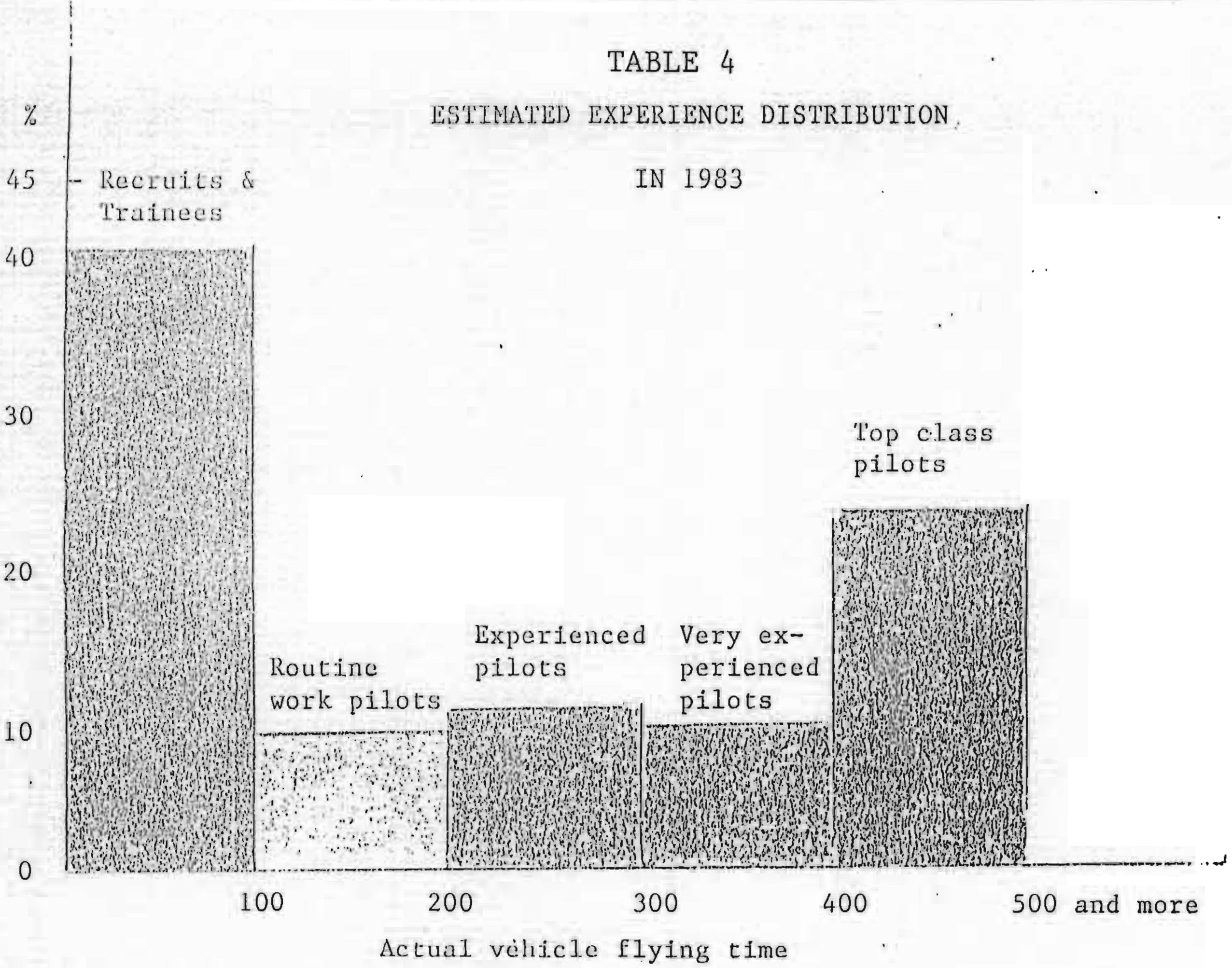
What is the present competance level of the ROV pilot? The average situation in 1983 was that a team was usually made up of three members, one good pilot, one pilot with average ability, and one which lacked experience. To complicate the formula, it is estimated between now and 1990 the number of remotely operated vehicles will increase by 50 percent (Evensen, 1984). Traditionally, experience has been gained by on the job training, similar to the trends used in manned saturation diving. The difference of a fairly good pilot in ROV operations and a top class operator will have to come with experience. Table 4 presents the estimated experience distribution in 1983, and the estimated experience to be achieved by 1990.

The fact that the future will call for more and more diverless systems as well as skilled workers to

TABLE 4

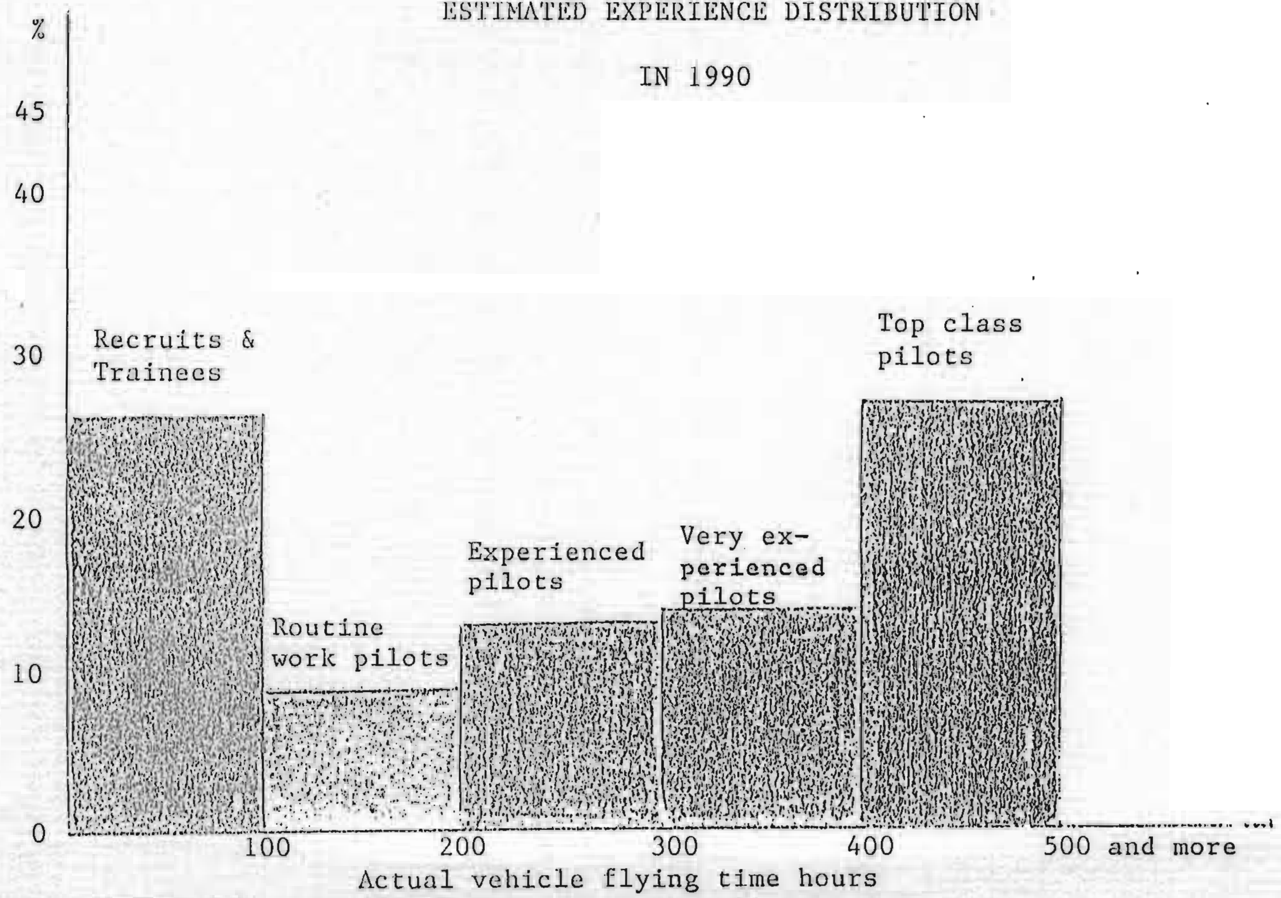
ESTIMATED EXPERIENCE DISTRIBUTION

IN 1983



ESTIMATED EXPERIENCE DISTRIBUTION

IN 1990



* Source: Norwegian Underwater Technology Center, 1984.

operate them is a challenge to the system. ROVs are superior in cost efficiency and allow no practical alternative to the researching scientist who wishes successful and quantifiable results in a diverless system.

Tools and Sensors

Although remote operated vehicles have been used almost exclusively within the offshore oil and gas industry, there are many tasks that are applicable to ocean research. Taking relevant samples and measurements by remotely operated vehicles can only enhance the successful recognition that is needed in order for this technology to become the state of the art in ocean research. To differentiate the various tasks that the remotely operated vehicles can accomplish, it is beneficial to indentify the two regions in which the vehicle operates; those directed towards the water column and those that are aimed at the oceans bottom, or sea floor.

Mid-Water

Wcolumn, there has been some interest generated toward suspended matter which adds to the attenuation of the environment as well as to sediment on the sea floor. The most logical method for collection is a series of pumps and filters. Additionly, sediment traps can be placed upon the ocean bottom to catch raining particles or "sea snow" as they descend down the water column. Remotely operated vehicles can act as a platform for a system of pumps and filters, as well as adding in the placement of sediment traps.

The use of remotely operated vehicles, as it pertains to chemical properties of seawater, may promote existing sampling devices. As previously mentioned, conductivity, temperature, and depth (CTD) are measured by rosettes of remotely actuated sampling bottles hung on a wire from the researching platform. The ROV could enhance investigations by being coupled with the rosette and assist in the identification thermalclines, and euphotic zones.

An area where the ROV would certainly excel would be in the sampling of the chemical characteristics of the hydrothermal activity located along the oceans spreading centers. Special pumps and sampling bottles would have to be adapted to cope with the extreme tempertures (300-400 degrees C) as well as precautionary measures to the vehicle against the possible corrosive solutions exiting from the corridors of the vents system (Marine Technology Society).

Remotely operated vehicles offer the marine biologist the greatest opportunity in an alternate sampling techniques. With the potential to travel up and down the water column, an ROV can identify and collecte different species of plankton without the physiological limitation placed upon man, or the high cost associated with the manned submersibles. Collection techniques would incorporate already existing mechanisms, Niskin bottles for water samples, and a system of pumps and filters for capturing small organisms for later shipboard analysis. Intermediate sized organisms such as Gelatinous Zooloplankton could be collected using a slurp gun type of arrangement, thus preserving the animal which would of otherwise have been crushed if collected by towed nets.

Seafloor

The organisms that dwell on the seafloor can be broken down into two categories, those that lodge on the hard substrates, and those that reside within the soft substrates. To collect animals that inhabit the harder substrates, manipulators equipped with a scraping device would be fitted onto the vehicle. Animals that are not firmly attached to the harder substrates would be gathered using methods similar to midwater collection.

The organisms found within the benthic community could be collected by intergrating the manipulator with a coring device, thus allowing the scientist to identify and collect in situ. For those animals located within the sediment, slurp guns could be used for gathering without the risk of damage to the organisms (Marine Technology Society, 1984).

Remotely operated vehicles could offer a new technique in the measurement of the geotechnical properties of the seafloor and its sediment. With the use of acoustics, and their absorption into the sediment, the density, the grain size, and porosity of the seafloor would be disclosed (Marine Technology Society, 1984).

Cameras and Manipulators

Part of the unfriendliness of the underwater environment is the uncertainty associated with the orientation of organisms or the objects to be studied. Therefore, perhaps the most significant tools in the ROV inventory are camera systems and manipulators. Optical systems that allow ROV scientists to fly the vehicle and identify and collect samples have become state of the art on off the shelf vehicles. The manipulator system, which is important for discrete sample retrieval, takes on a "Jekyll and Hyde" character of spatial correlation, in that the operator loses sense of touch and control when operating the arm. What is needed is a force feedback system which would allow for greater control and sensitivity (Butler, 1985).

CHAPTER FIVE
ECONOMIC FACTORS

The principle factor governing the use of remotely operated vehicles by the scientific community is economics. As with any new research instrument, ROVs have to meet the criteria set by the end users, this is the enigma of technological transfer. If remotely operated vehicles can meet these standards at a cost that is less than methods presently employed, then the marketability of the technology will increase within the scientific sector.

To understand the economic principle behind remotely operated vehicles as it pertains to the ROV scientist, it is necessary to achieve an accountability of how the vehicle fared with its key user, the offshore oil and gas industry. ROVs are commonplace in the offshore oil and gas industry. While dozens of firms participate in this activity, the majority of the business remains with five companies: Hydro Products, International Submarine Engineering, AMETEL, Straza Division, Perry Oceanographics, and Gay Marine (Offshore Services and Technology, 1981). The above companies have cornered the market by having the foresight in developing a commodity which revolutionized the offshore diving industry. However, a report from one of the major operators states that all his equipment (30 vehicles) are working, but business is stagnant. A daily rate of $3500 per day was obtainable a year or two ago, where now $2200 to $2500 per day is the expected return in the Gulf of Mexico. Straight forward observation vehicles are getting $1400 per day, and in the North Sea daily rates for the same vehicle are reported at $800 to $1000 (Busby, 1985). There are several reasons for this drop in price; more vehicle competition, a strong dollar in terms of foreign competition, and a decrease in offshore activity as the price of oil declines (Busby, 1985).

The objective of this section is to consider the costs and other variables that the ROV scientist has to take into account when chartering an ROV system.

Successful completion of any scientific project requires a clear understanding between the user and the contractor. Vehicle tasks and expected results should be defined. Conditions should be set where each item is clearly stated and included in a written contract, i.e. liability and risk, estimated time of operations, total estimated price, insurance, legal aspects, and mobilization and demobilization of the research vessel. The stipulations of the contract will be elaborated further on in this section.

When a marine scientist wishes to charter an ROV for a specific task, he will send a proposal to an ROV operator. In a hypothetical case, the assumed operator shall be an academic research institution with the ability to charter an entire ROV package and its supporting research platform. The proposal requests the operator to respond to a given work task and to itemize the costs in a specific manner. It should be noted that the proposal can be tailored to fit specific work requirements, i.e. equipment necessary to perform given work tasks (manipulators, slurp gun, acoustical instruments), or any special conditons which might exist, i.e. high currents, hazardous zones (hydrothermal vents), and or extreme depths. As stated earlier, the management of a successful ROV operation requires a clear understanding of procedural guidelines, thus allowing both parties to recognize the extent of their responsibility.

Risk and Liability

The extent of risk and liability should be clearly defined between the operator and the client. As this is an assumed condition between a researching institution and a scientific user, a contractual agreement may or may not be necessary, however this does not preclude the need to establish a clear line of accountability.

Examples of agreements follow.

The operator agrees:

1) to pay off all claims for labor, material, and supplies furnished by the operator;

2) to pay all carrier's charges;

3) to allow no liens upon any property of the client;

4) to comply with all laws, State, Federal, and International;

5) to protect, indemnify and save client harmless from and against all claims, demands, and causes of action, suits, other litigation...on account of personal injuries of death or damage to property; and

6) to protect, indemnify and save client harmless from any loss or damage to property, equipment or materials, owned or furnished by client when such loss or damage is caused or results from the negligent act or omission of operator.

The contractor agrees to carry the following insurance coverage (contractor being a State funded research institution):

1) Workmen's Compensation and employers' liability insurance with limits of liability less than...

2) Endorsements to the Workmen's Compensation and employers' liability policy extending the policy to provide, when applicable;

3) Federal Longshoreman's and Harbor Workers' Compensation Insurance extended to the Outer Continental shelf;

4) Extension of Coverage to provide employers'

liability under Admiralty jurisdiction including the Jones Act and;

5) extension of territorial limits to include the areas of transportation and operation of agreement.

The areas of risk play a vital role. The operator generally assumes full responsibility to damage, and or destruction to tools and other equipment resulting from any cause while in use on the clients/ROV scientist equipment (Marine Technology Society, 1984).

Total Estimated Price/Job Cost

The marine scientist requires the research institution to calculate the costs of conducting a project, supported by the ROV system. Expenses that the researching institution must consider for a total cost are: 1) capital equipment (research vessel and ROV package); 2) insurance coverage; 3) maintenance; 3) salaries (direct and indirect); 4) fringe benefits and; 5) overhead and general administrative costs. These expenses determine the daily rate of the researching system, however this hypothetical case is utilizing an academic institution whereby money would be subsidized from a researching grant.

Estimated Time of Operation

The ROV scientist has to make an estimation of the total time required to complete the project. This time should include the best estimation of weather that can be expected, resulting down time, and the time needed for mobilization and demobilization of equipment.

Insurance

Insurance can be a complicated issue when considering at what point and to what degree the ROV system should be insured. The following situations are relevant when taking into account the position of the operator in regards to insurance:

1) during commercial transport;
2) during transport from truck to vessel;
3) when the system is in stand-by condition or in the stored condition;
4) during all phases of underwater operations, or are there exceptions, i.e. depth, latitude, hazardous conditions;
5) the amount of the deductible;
6) should insurance cover new equipment coming from the manufacturer, and if so are the spare parts insured or only capitalized items and;
7) should personnel and liability insurance

> should be carried under workmen's compensation or does the Jones Act apply to the scientist and their application to the vehicle (Marine Technology Society, 1984).

One caveat, however should be registered here. Some insurance marine policies have equipment floaters attached to them for the rate value of the object being insured. Otherwise the premium paid on a $100,000 ROV system would range between $1,000 to $1,500 per year (Ocean Insurance Group, 1985).

Legal Aspects

The legal position, as it pertains to the shipment of remotely operated vehicles and or their components from the United States to foreign countries, can be an involved procedure. The ROV and its supporting components are considered high technology, and the nature of the work that the vehicle system can perform may be considered to have some military value. Thus, circumstances in which marine scientists find themselves when applying for permission to conduct ocean research within the waters of a coastal state may be complex. For instance, which departmental branch of the government has the authority to allow the export of such technology, Department of Defense, Department of Commerce, or the Department of State? All have vested interests in the performance of the ROV system, however, there is no clear cut lines for authorization (Marine Technology Society, 1984). Nevertheless, the technology and its supporting components are subject to review before export.

Mobilization and Demobilization

The marine scientist is expected to incorporate into the estimations of cost the necessary period required to onload and or discharge scientific equipment from the researching vessel. This port duration usually lasts three days. One day to discharge the equipment, one day to onload, and one day to verify its performance. In addition, the science party is required to inform the marine office of the researching institution of any specific support required, i.e. ships superstructure or any required deck space. In the final analysis, from the marine scientist's point of view, the remotely operated vehicle fills a particular market gap. If credibility of the vehicle system can be achieved in the field where safety, cost, and reliability are obtained, then the acceptance of this innovative technology will be passed along.

CHAPTER SIX
ANALYSIS

Introduction

The purpose of the following analysis is to gain insight from marine scientists for the utilization of remotely operated vehicles, as it pertains to underwater research. The aim in this investigation is improve the qualitative research methods presently employed by our ocean research community.

In conducting this survey, a random selection of established scientists were interviewed within the four disicplines of oceanography. The interviews were restricted to those scientists in residence at the University of Rhode Island Graduate School of Oceanography, not out of bias, but rather out of convenience. The analysis utilizes a holistic method of research. After the theme or problem was stated to the interviewee, the formation of research questions were put forth, and a systematic analysis of each question was conducted. This holistic method approach was chosen for it's value; in that the selection of statements adopted increased the chances for stimulating an insightful theory development (Borum and Enderud, 1980).

Analysis

Seven questions were posed to each of 14 marine scientists with an accompaning of number available responses to select from. Each response was recorded and assigned a percentage share. In some instances, questions were answered with more than one response. If such was the case, each multiple response was assigned it's own percentage share.

The questions were as follows:

1) Your principle discipline of oceanography is:

Biological Geological Physical Chemical Engineering

2) Could you use an ROV system to enhance your professional achievements? Yes or No.

3) How will ROV technology be adopted by members of the science community?

-when ROV data corresponds to direct observations.
-when the ROV scientist has his data accepted by his peers.
-when the ROV system demonstrates it can do the job equal to or at a cost lower than the methods presently employed.

4) What does the marine scientist want in a basic ROV system?

-manipulators
-T.V. and Video
-positioning technology
-collection technology
-versatility

5) What could expand ROV useage by marine scientists?

-word of mouth
-published results of research and commercial projects
-peer pressure

-successful field applications.

6) What is holding science back from utilizing ROV technology?

-cost
-lack of awareness
-logistical support
-lack of confidence in the system

7) What can the ROV builders and contractors do in order to make themselves aware of what marine scientists need in an ROV system?

-published reviews
-conferences
-field demonstrations.

The responses to Question One illustrated that out of the 14 scientist interviewed, 43 percent were marine biologists, 21 percent were marine geologists, 21 percent were physical oceanographers, and 14 percent were ocean engineers. The high percentage of biologist accounts for a wide variety of specialization within this discipline of oceanography. For example, a host of scientists were interviewed whose principle interests ranged from marine mammals to phytoplankton. These scientists were considered valid recipients for ROV technology.

Responses to Question Two revealed that 93 percent agreeed that the use of an ROV system could indeed enhance their professional achievements. However, seven percent responded negatively. This overwhelming positive reaction indicates a high potential acceptance for increased useage of remotely operated vehicles which can support the marine sciences.

In reaction to Question Three, 93 percent answered that ROV technology would be adopted by members of the science community when the system demonstrated that it could do the job equal to or at a price lower than methods presently employed. This response is of course relative to the scale at which the marine scientist conducts his investigations. However, with decreasing cost and increasing technological achievements the ROV system's cost curve will narrow the gap compared to different research methodologies. The remaining seven percent of the respondents felt that ROV technology will be adopted when it corresponds to direct observations. This was refected in the responses to Question Four.

Sixty-four percent of the respondents to Question Four, felt that T.V. and video systems were basic to a ROV system. Hence, direct observations are of a paramount concern to the marine scientists. Fourteen percent felt that all the available responses to Question Four were basic to an ROV system. On the other hand, only seven percent felt that collection technology was basic to the system, and seven percent felt that versatility was of basic importance to the ROV package.

Question Five indicated that 43 percent of those interviewed responded that published results of research and commercial projects would expand ROV useage. An additional 43 percent felt that successful field applications would increase ROV useage. Seven percent were of the opinion that all four available answers would increase ROV useage, and 7 percent did not respond at all. It appears that field applications and documentation of such applications are necessary for the expansion of ROV useage. This line of thinking follows the recent discovery of the RMS Titantic by Dr. Robert Ballard of Woods Hole Oceanographic Institute with the remotely operated system, Argo and Jason.

Responses to Question Six showed that 50 percent of those interviewed were of the belief that the cost of ROV technology was the major contributing factor limiting its increased utilization. Fourteen percent felt that it was the lack of awareness, and 21 percent reacted to both cost and lack of awareness. These responses reinforce the expandability of ROV technology through published results and successful field applications. A lack of awareness and cost seem to parallel that of published results and successful field applications. Of the remaining responses to Question Six, seven percent of those interviewed felt that it was the lack of confidence in the system which was holding marine scientist back from greater ROV utilization, while the remaining seven percent did not respond.

Twenty-nine percent of the respondants to Question Seven were of the belief that published reviews by the science community would increase the awareness of ROV contractors and manufactures to the needs of science. Thirty-six percent felt that field demonstrations by ROV contractors and builders would canvas the needs of science within the ocean community. Fourteen percent responded favorably to conferences, while an additional 14 percent reacted to all three possible choices. Seven percent did not respond to Question Seven.

In trying to bridge the technological transfer of the ROV system from contractors and builders to that of the ocean science community, it appears that actual field demonstrations are necessary. Hands on experience to the ROV system by marine scientists will open up new avenues of opportunity for ROV manufactures in creating a second market front. The remaining two alternatives, that of published reviews, and conferences have to date been tried without much success.

CHAPTER SEVEN
SUMMARY AND CONCLUSION

During the past twenty years the United States Navy has been a pioneer in the development of unmanned underwater vehicles. This technological development, through such programs as CURV III, (cable-controlled underwater recovery vehicle), RUMS, (remote unmanned work system) and WSP (work system package) has been transferred to the oil and gas industry. As a result, the use of remotely operated vehicles can be credited as a safe, and cost effective alternative to man and unmanned submersibles.

Further use of remotely operated vehicles as a means of research technology will improve the marine scientist's ability to obtain data. This rationalization is manifested by those within the ocean research community.

One of today's vehicles has the potential to meet the demands placed upon them by marine scientists. A typical off the shelf ROV can be controlled and maneuvered by a relatively unseasoned individual. Each vehicle on the market today has pursuit and capture capabilities, with state of the art in viewing quality. Organism detection and positioning technology along with manipulation and sampling effectiveness can be applied to most vehicles with relative ease and expense.

Recently, ROVs assisted divers in the recovery of the solid rocket boosters of the space shuttle Challenger. The nuclear power industry is using ROVs to inspect the internal systems of reactors, a hazardous job once performed by divers. However, the application of ROVs as a work system is still in its infancy in the field of ocean research. The question, then is, what is holding the scientific community back from adopting this new form of technology? Can it be the cost of the vehicle and its supportive system? At present, there are two firms which offer an ROV package for less than $50,000. This cost is comparable to the equipment found within most marine laboratories. Could it be vehicle portability or logistical support? It is possible for two people to handle and operate an ROV system from a 16 foot support platform. Could it be lack of awareness? To date, there have been three Marine Technology Society ROV Conferences, the Proceedings from each has lacked support by the scientific ocean community.

How does one resolve this dilemmna in the transfer of technology? A publication is needed which periodically canvases all ROV operations and provides information concerning the performance, and or any innovative modifications to the vehicle and its supporting systems. By maintaining contact between the developers and the users, two services will have been provided: a critique of vehicle performance, and the status on research and development activities.

It is through increased awareness and exposure that a solidarity amoung marine scientists in the use of remotely operated vehicles will take shape. With the establishment of a consenus, the lag time in transferring the state of the art technology will diminish.

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