AN ASSESSMENT OF REMOTELY OPERATED VEHICLES TO SUPPORT THE AEAS PROGRAM IN THE ARCTIC

Contract N00014-84-C-0180

Science Applications International Corporation

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Contract N00014-84-C-0180
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ACKNOWLEDGEMENTS

Throughout the past 15 years a small cadre of individuals have dedicated much of their time and talent pulling together information on remotely operated vehicle technology. A substantial portion of the study material used to develop this report has been derived from their information data bases and personal communications. Specific acknowledgement and recognition is therefore due the two most helpful individuals, R. Frank Busby and Deam Given. Their assistance and resources significantly accelerated the start-up phase of this study.

Many individuals of the informal "ROV Community" have shown interest in the study objectives and have shared their time and knowledge to provide specific content to this report. There was unanimity among them that ROVs have yet to see their zenith as a useful tool for scientific research and has had little opportunity to show its full potential for supporting scientific research in the Arctic.

Our thanks are extended to our Canadian colleague, Jim McFarland, President, International Submarine Engineering, Ltd. for sharing his first-hand experience operating ROVs and autonomous underwater vehicles (AUV) in the Arctic. His correspondence has been prompt and embellished with photographs of ROVs that have operated under the arctic ice. He shared his future plans for systems that will be dedicated to arctic operations. Dan Johnson (formerly of AMETEK-Straza), and George Clausen, Honeywell-Hydro Products, in addition to providing information and a tour of their manufacturing facilities, offered to help underwrite the cost of publishing the

proceedings of a planned industry, university, U.S. Navy workshop on the potential of ROVs to support scientific research in the Arctic; their offer, and similar offers from others, is deeply appreciated. The visionary engineer Graham Hawkes and marine biologist Dr. Sylvia Earle, Deep Ocean Engineering, Inc. provided their ROV PHANTOM 300 for ocean testing by the authors which was especially appreciated. Assessing the potential of ROV technology through this hands-on experience was invaluable to this assessment study. Howard Talkington and Bob Wernli, Naval Ocean Systems Center provided historical and current information on the Center's continuing development of the U.S. Navy capability in ROV technology for which we were most grateful. The MTS ROV Conference and Exhibition, initiated and organized by Bob Wernli and his Marine Technology Section team, is internationally recognized as the premier annual event for those concerned with this technology. When we needed information on personnel and training we turned to a most cooperative leader in diving and underwater vehicle services, Andre Galerne, President, International Underwater Contractors. He provided his personal philosophy and germain information regarding the curriculum for a remotely operated vehicle pilot/technicial training course that his company created to meet a world-wide need.

The authors took advantage of the time and talent of company spokesman present at the exhibit booths at the Offshore Technology Conference; the Marine Technology Society, San Diego Section, ROV Conference; and the Marine Technology Society and Institute of Electrical and Electronic Engineers/ Ocean Engineering Society. The booth-standers provided an explanation of their respective products and how they might be applied in the arctic regions. Many of the firms visited are identified in the Appendix "Directory". The Proceedings and Conference Records for these annual events over the past 4 years are referenced frequently as they are the primary information exchange avenues used by the "ROV Community".

Dr. Elliot Weinberg, Naval Postgraduate School, Monterey, CA provided an extensive computer read-out of published articles for which we are most grateful. Eleanor Estes performed the yeoman's task of preparing the final version of this manuscript.

EXECUTIVE SUMMARY

The U.S. Navy requirement to assess the performance of acoustic systems destined to support naval operations in the Arctic includes the need to collect environmental data for cold region test site characterization, exercise planning, and operational analyses. New techniques are being sought in the interest of cost-effectiveness and improved data collection to support the spectrum of acoustic systems presently employed and under development

The Anti-Submarine Warfare Environmental Acoustics Support (AEAS) program is responsible for the collection of environmental data adequate for area characterization, exercise planning, and field investigations related to the test and evaluation of a broad range of passive and active acoustic sensors. Classical low-latitude environmental data collection equipment and methods have inherent shortcomings when employed in the Arctic. Accordingly, the AEAS program has a continuing need to identify and acquire more cost-effective new technology support to field assessments of acoustic systems performance in cold, high-latitude regions and to add significantly to its arctic environmental information data base. This study report is the result of an assessment of the support potential that remotely operated vehicle technology offers to environmental data collection and the performance evaluation of acoustic systems under the arctic ice canopy and in the marginal ice zone.

ROV technology research and development has been underway within the U.S. Navy for more than 3 decades and its technology base has served as the principal national resource for the present state-of-the-art systems. It is fortuitous that remotely operated vehicle technology has proven to be so cost effective in the commercial offshore oil and gas industry. ROV technology has been applied commercially in deep water locations, such as the Gulf of Mexico and the North Sea, where it has assumed many of the work functions of the human diver. ROVs have successfully completed a broad range of tasks, often under conditions that would be considered hazardous to human divers. At present, tethered ROVs are fulfilling a large proportion of the undersea support requirements for real-time observation and manipulative functions. Autonomous underwater vehicles are being investigated by university and industrial R&D teams for missions requiring greater horizontal mobility.

ROV technology now offers unique proven capabilities for positioning sensors and instruments in three dimensions for either real-time or delayed data collection. The horizontal and vertical mobility offered by the technology will permit access to areas beneath the arctic ice canopy in an unprecedented way. Several military applications for this technology exist and additional R&D is underway to create "smart vehicles"; the R&D includes investigations into artificial intelligence and robotics.

This study included the development of a world inventory of remotely operated vehicles (approximately 270 different designs) that included their physical characteristics and principal functions. Many state-of-the-art environmental sensors can easily be integrated into an ROV system to provide both real-time and self-recording data sets.

The study effort attempts to answer the following questions:

1. What are the capabilities of current ROV technology to satisfy AEAS environmental support requirements?

2. What are the ROV technology shortfalls, if any, that need to be resolved by further R&D in order to fulfill AEAS requirements?

3. What are the ROV technology trends?

4. What is the status of U.S. and Canadian ROV expertise and manufacturing capability?

5. What published information is available on ROV technology?

6. What actions should be taken by the AEAS program regarding the application of ROV technology to AEAS requirements?

Although this study purposely emphasized the remotely operated vehicle technology support potential to the AEAS program and anti-submarine warfare requirements, it is now recognized that this technology area could immediately serve other warfare areas. A similar assessment should be made when operational requirements are available for other warfare areas.

AN ASSESSMENT OF ROV TECHNOLOGY FOR AEAS

1. INTRODUCTION

The Antisubmarine Warfare Environmental Acoustics Support (AEAS) program is responsible for providing environmental acoustics support for antisubmarine warfare system performance analysis. AEAS responsibilities can be divided into the following:

- the development of system test and evaluation plans,
- site selection of system performance analysis,
- environmental characterization,
- exercise planning,
- measurement, and
- performance modeling programs in support of ASW systems.

AEAS is concerned with the full range of ASW systems (surveillance and tactical).

AEAS is confronted with a new ASW environment in the Arctic. None of the existing operational ASW systems has been designed to function under arctic conditions. New systems are in the design or prototype stages and there are many unanswered questions. In addition, the environmental acoustic data is sparse for much of the Arctic and adjacent seas.

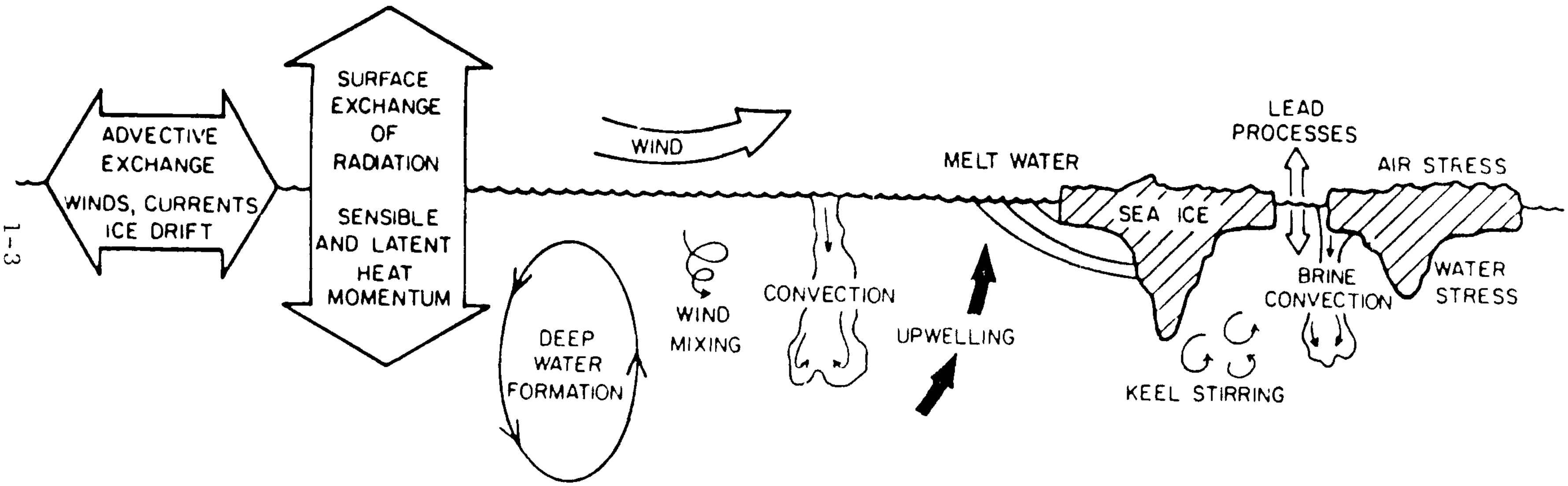
ROV/AUV technology can be applied in a variety of ways to support the AEAS program responsibilities. Probably the most significant contribution can be made in environmental characterization and site selection. But ROV/AUV systems may also be able to play an important role in exercise and measurement programs.

1.1 Data Requirements

A variety of environmental data are required to support the AEAS program. This might be categorized broadly as data related to sea ice, oceanographic and sea floor conditions. Since sea ice conditions (thickness, concentration, roughness, movement) are largely forced by the atmosphere in most regions, the meteorology becomes another important category.

Recent studies (Thorndike and Colony, 1982) have shown that more than 70% of the variance in ice movement in the central basin can be attributed to the wind. To further establish the importance of meteorology to AEAS interests we note that the ambient noise field in the central Arctic is dominated by sea ice fracturing due to wind stress and/or air temperature changes (Dyer, 1984). The complex nature of the air-sea-ice interaction processes is shown in Figure 1.1.

Table 1.1 presents a comparison of relevant environmental acoustics properties in the Arctic with mid-latitude conditions. It shows that there are numerous system related problems which are unique to the half-channel sound velocity distribution and rough sea ice canopy. While sound paths are very stable in the deep water basins in comparison to open ocean conditions, the upward refracted energy is strongly scattered by the rough ice surface (Buck, 1958 and Dyer, 1984). Near the ice margin the acoustic variability increases significantly over the central basin.



PROCESSES NEAR THE SEA ICE MARGIII
(modified from SCOR, 1979)

Figure 1.1

A COMPARISON OF ACOUSTIC PROPERTIES ARCTIC AND OTHERWISE

PROPERTY	CONVENTIONAL	ARCTIC	IMPACT OF ARCTIC
SOUND VELOCITY PROFILE	VARIABLE WITH DEPTH AND TIME	VERY STABLE, UPWARD REFRACTING	RSR IS PRIMARY PATH - NO DEEP CHANNEL - $\frac{1}{2}$ CZ
NOISE	DRIVEN BY SHIPPING AND WIND	VARIABLE OVER AREA TRANSIENTS AND WIND LOWER UNDER PACK ICE HIGHER IN MIZ	NOISE CONTINUUM IS TRANSITORY IN NATURE. DIRECTIONAL. DI AND SIGNAL PROCESSOR OPERATIONAL PROBLEMS
TRANSMISSION LOSS	SPREAD LOSS AND ABSORPTION	SCATTERING, ABSORPTION SPREAD LOSS	MUCH HIGHER LOSSES - TRANSMISSION FILTER IS HIGHLY FREQUENCY DEPENDENT
SCATTERING - COHERENCY FACTORS	MINOR DIRECT PATH AND SURFACE REFLECTION IMPACT - BOTTOM MAY HAVE LARGE IMPACT	VERY ROUGH ICE AND MIZ CAUSE LARGE SCATTER LOSSES AND BOTH TIME, FREQUENCY AND SPATIAL SPREADS	INCREASES TRANSMISSION LOSS WAVEFORM DISTORTION, SIGNAL DISPERSION, SPATIAL PROCESSING DISTORTION
REVERBERATION	VARIABLE - DEPENDS UPON SCENARIO AND SCATTERER - VOLUME SURFACE AND BOTTOM	MUCH HIGHER LEVEL; LARGER DURATION, SURFACE BACKSCATTER; COHERENT ELEMENTS	AT SHORT RANGES, STRONG INTERFERENCE. MUCH HIGHER FALSE TARGET RATE. SIMILAR EFFECTS AT MID AND HIGH FREQUENCIES
ECHO STRUCTURE	MAY HAVE MULTIPATH AND FREQUENCY DISPERSION	SHORT RANGES ARE SIMILAR TO CONVENTIONAL; LONGER RANGES HAVE MORE SPREAD AND MULTIPATH	ECHO DEGRADATION (WAVEFORM AND ENVELOPE) DUE TO TIME AND FREQUENCY DISPERSION AND GROSS MULTIPATH

Table 1.1

A COMPARISON OF ACOUSTIC PROPERTIES ARCTIC AND OTHERWISE (CONT.)

PROPERTY	CONVENTIONAL	ARCTIC	IMPACT OF ARCTIC
PASSIVE SIGNATURE	MULTIPATH AND DOPPLER SPREAD CHANGE SPECTRUM	BOTTOM PATH SEEMS STABLE - OTHER PATHS HAVE SEVERE TIME AND FREQUENCY SPREAD	REDUCED NARROWBAND PERFORMANCE. BROADBAND DETECTION LESS IMPACTED.
PASSIVE TRACKING	SIGNATURE STRUCTURE DISTORTED BY TIME AND FREQUENCY SPREAD	MULTIPATH, TIME AND FREQUENCY SPREAD MAY BE SEVERE	CORRELATORS SENSITIVE TO SIGNATURE VARIATIONS ALONG MULTIPATHS. LIMITED INTEGRATION TIME AND TIME RESOLUTION.
SPATIAL PROCESSING	SPATIAL SPREADS REDUCE ACHIEVABLE DI MAX RESOLUTION OF 1°H AND 3°V SEEM POSSIBLE	SEVERE SPREADS MAY REDUCE BEAM TO $\sim 3^\circ$-4°H, AND 6°V OR POSSIBLY MORE	IMPACTS UPON DIRECTIVITY INDEX BY LIMITING PROCESSING GAIN; REDUCES SIGNAL LEVEL DUE TO SEVERE SPATIAL SPREAD.

1.2 The Arctic Operating Environment

Figure 1.2.1 shows the Arctic Ocean and adjacent seas. The Arctic Ocean covers an area of approximately 14×10^6 km^2. There are two major deep basins -- the Eurasian (approximately 4000 m) and the Amerasian (approximately 3800 m) which are separated by the Lomonozov Ridge which has a sill depth of approximately 1600 m. About one-third of the ocean is occupied by the adjacent seas -- East Siberian, Laptev, Kara, and Barents -- with extensive continental shelves. The shelf areas play a significant role in the oceanographic and ice conditions in the Arctic as well as the performance of acoustic systems. The shelves in general have a thin sediment cover, and are often underladen by permafrost.

The central Arctic is covered by perennial pack ice with an average thickness of 3 m. During the winter the area covered by sea ice increases over the summer coverage as is shown in Figure 1.2.2.

Sea ice is a highly heterogenesis and complex engineering material. Grown from sea water it contains a percentage of the salinity of the freezing fluid. Newly formed ice may have a salinity of 20%, will be a dark gray color, and spongey. The ice crystals are hexagonal, and are formed of thin platelets and sea water is trapped between the platelets in small brine cells. The brine is highly concentrated (150-250%) and is in equilibrium with the ambient temperature. Any temperature change, therefore, results in a change in the brine volume, and as a result, a change in the mechanical, electrical and thermal properties of the material.

Figure 1.2.1. Bathymetry of the Arctic Ocean (from Coachman and Aagaard, 1974)

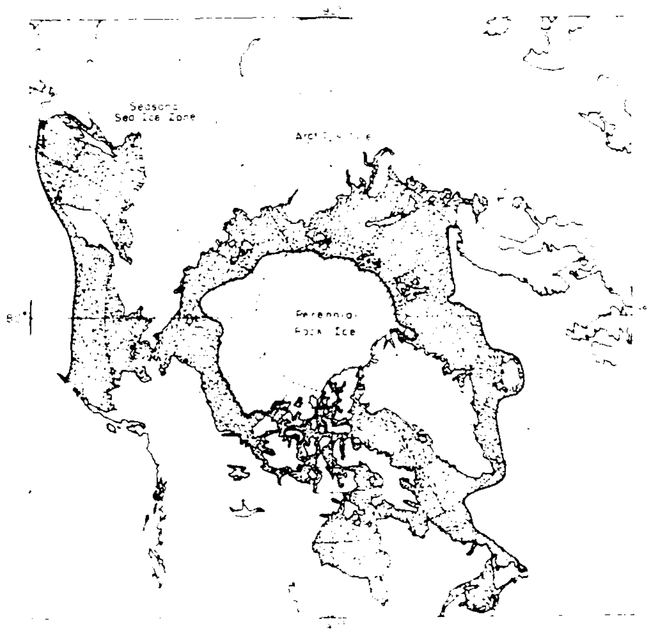


Figure 1.2.2. The limits of the Seasonal Sea Ice Zone in the Arctic showing the extreme northerly and the extreme southerly limits of the ice edge. (from Weeks, 1980)

As the freezing process proceeds the growth is slowed, less salt is trapped in the ice, the crystals grow larger, and become more organized. Since they are hexagonal this means that ice is an anisotrophic material. As sea ice ages the brine drains from the ice and as it becomes less salty, it turns from gray, to gray white, to white, to ice blue and clear. Figure 1.2.3 shows a typical profile of ice crystal structure grown as an undisturbed sheet, and Figure 1.2.4 presents a schematic temperature and salinity profile for ice of various ages and thicknesses. Also shown are the distribution of young modules and the flexural strength. When cold (-20°C) sea ice is very hard (equivalent to mild steel) and strong (particularly in compression). Figure 1.2.4 also shows the flexural strength and Youngs Modules of sea ice as a function of ice salinity and temperature. An appreciation of the strength of sea ice can be gained from the thickness for safely landing various aircraft on the ice in the winter and spring. A Cessna 180 weighing about 3000 pounds requires a thickness of 10 inches; a 26,000 pound DC-3 requires 30 inches; and a C-130 requires 48 inches to support its 145,000 pounds. Clearly, it is not difficult to support heavy loads on the ice, however, it is another problem to locate sufficient runway for fixed wing operations. Furthermore, since the ice is nearly always in motion the integrity of a runway cannot be assured for long periods of time. Finally, we emphasize that sometime in mid May fixed wing aircraft operations from the ice are impossible due to surface ablation.

The ice is in nearly constant motion under the action of wind and currents. Figure 1.2.5 shows the drift tracks of numerous satellite positioned drifting buoys which reveals the major circulation features of the ice and surface layer (Colony and Thorndike, 1984).

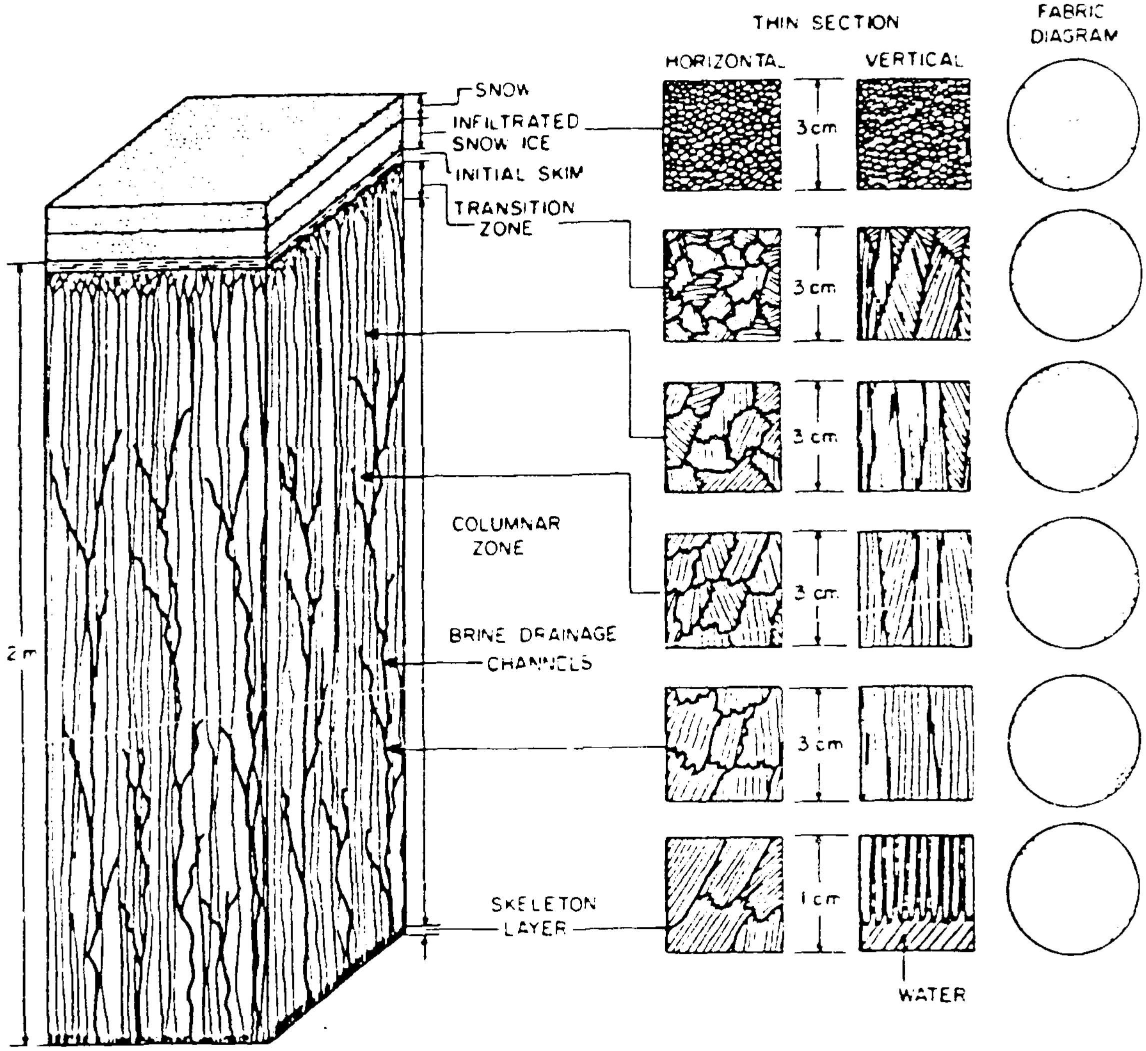


Figure 1.2.3. Schematic drawing showing several aspects of the structure of first-year ice (from Schwarz and Weeks, 1977).

The fabric diagram shows the degree of order in the crystal orientation. The outer circle represents the case of horizontal orientation in the principal axis. The grouping of the points along the outer circle represents a preferred horizontal orientation.

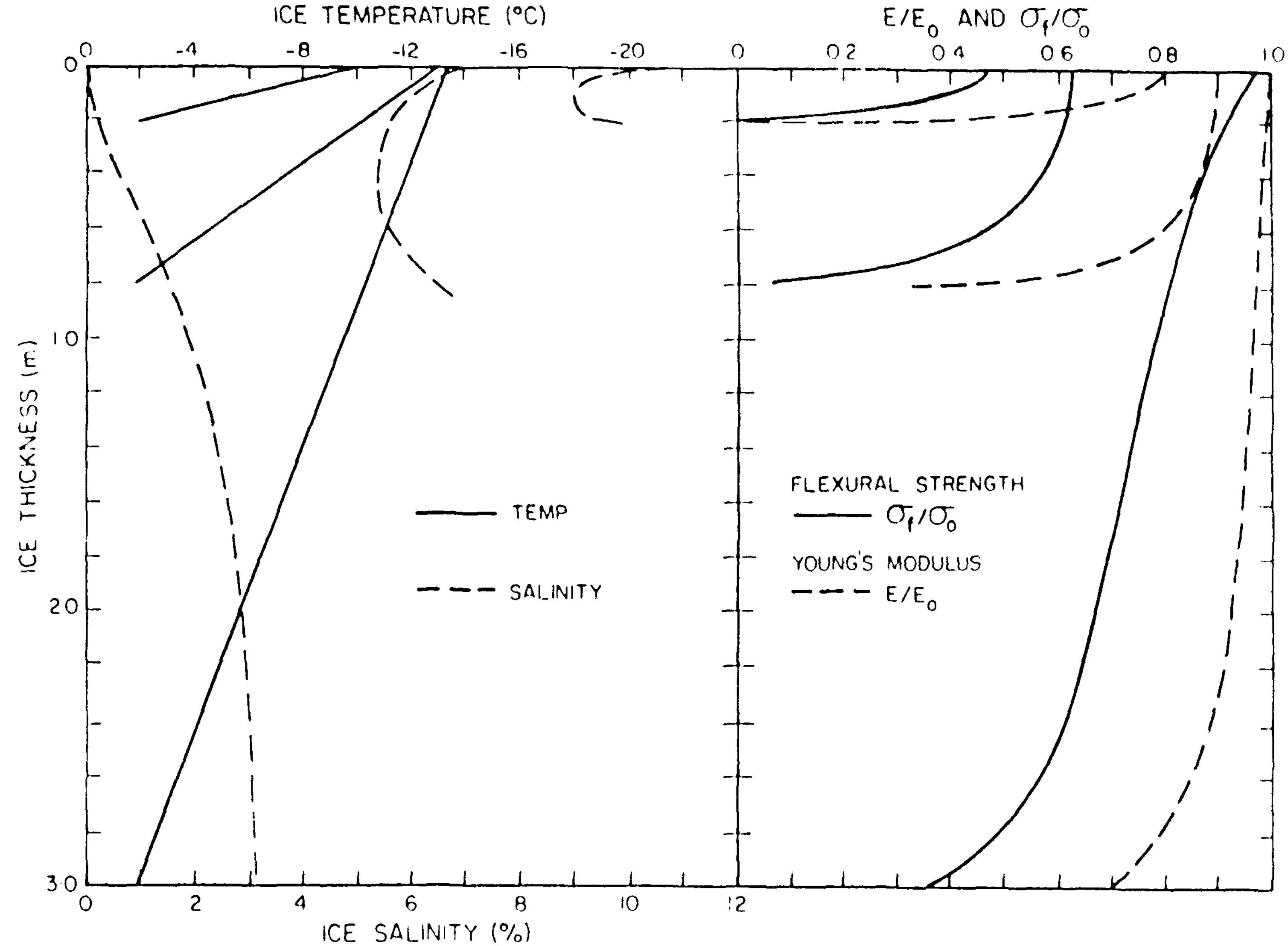


Figure 1.2.4. Representative sea-ice temperature, salinity, E/E_0 and σ_f/σ_0 profiles for 0.2, 0.8, and 3.0 m thick arctic sea ice on c. 1 May. To convert σ_f/σ_0 and E/E_0 to E multiply by 10.3×10^5 N/m^2 and by 10^{10} N/m^2 respectively. (from Schwarz and Weeks, 1977)

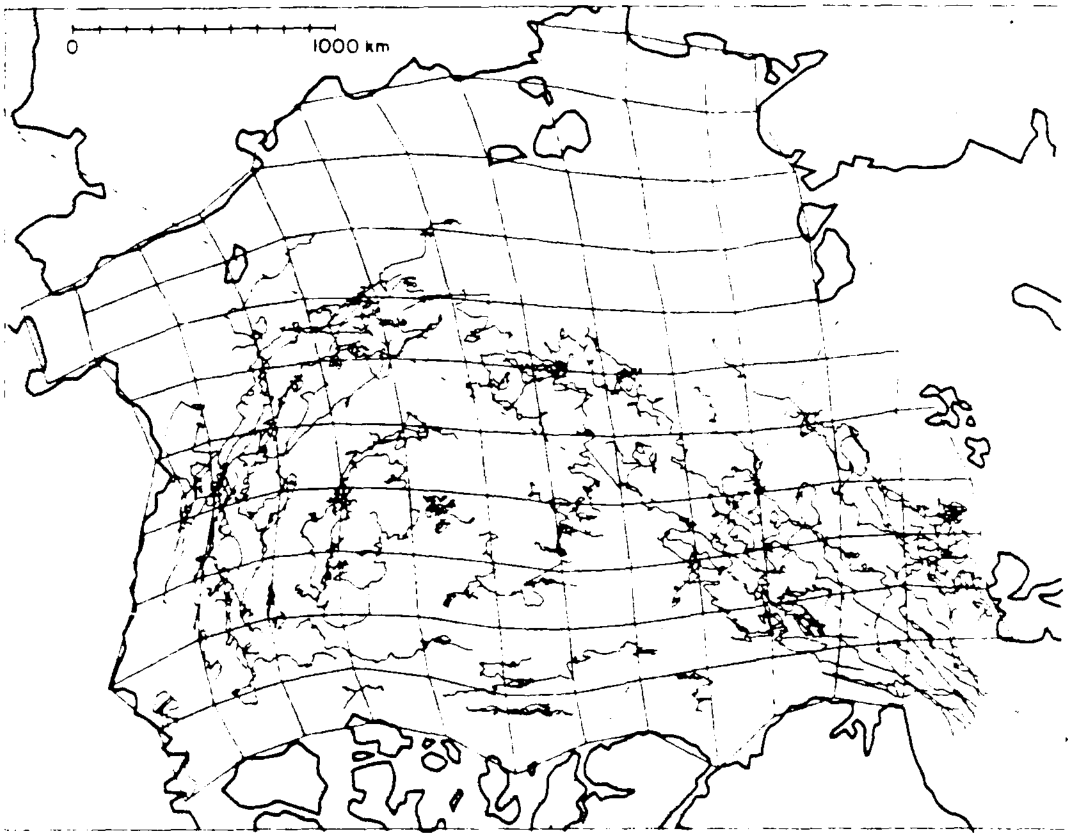


Figure 1.2.5. Trajectories of satellite tracked automatic data buoys 1979-1982 (from Colony and Thorndike, 1984).

Under the stresses in the pack ice the ice breaks and exposes the ocean. Young ice grows quickly (several centimeters in 24 hours) during the winter. Figure 1.2.6 shows growth rate as a function of air temperature. As the forces shift this young ice breaks up to form ridges of ice which may become tens of meters from the top of the sail to the bottom of the keel. Figure 1.2.7 shows the probability density of ice thickness derived from the "upward looking" echo sounder of a submarine along tracks in the Beaufort Sea (Wadhams and Horne, 1978). This reveals a small percentage of thick ice (>3 m) and a small percentage of thin ice (>.1.0 m). Summer brings rapid melting of the ice in the seasonal sea ice zone and the central Arctic where the average thickness ablation is approximately 40 cm.

The central arctic climate can be characterized as a long winter (October to May), and a relatively short summer (June, July and August), with very short fall and spring periods. This arctic condition grades into subarctic seasonal patterns with decreasing latitude in which the seasons become more pronounced. The dominant features of the Arctic are the prolonged periods of darkness in the winter, daylight in the spring and summer, and the cold temperatures. The cold atmosphere accounts for the freezing conditions that lead to the formation of the ice canopy. Winter and summer air temperatures are shown in Figure 1.2.8.

The Arctic is not a region of severe storms since most cyclones are in their dying phase by the time they reach the central Arctic. However, in the subarctic intense storms are common. The most persistent storm tracks are shown in Figure 1.2.9, and observed surface winds for the central Arctic are shown in Table 1.2.1.

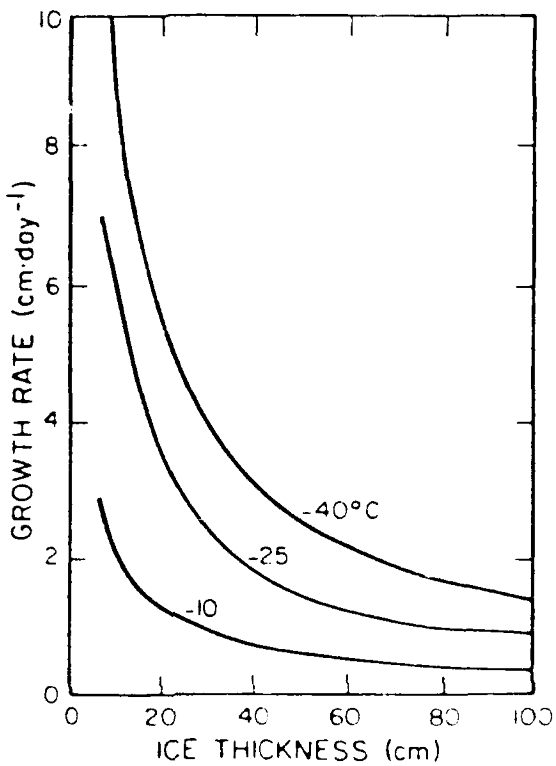


Figure 1.2.6. Dependence of growth rates in young sea ice on ice thickness for air temperatures of -10, -25, and -40°C (from Maykut, 1981).

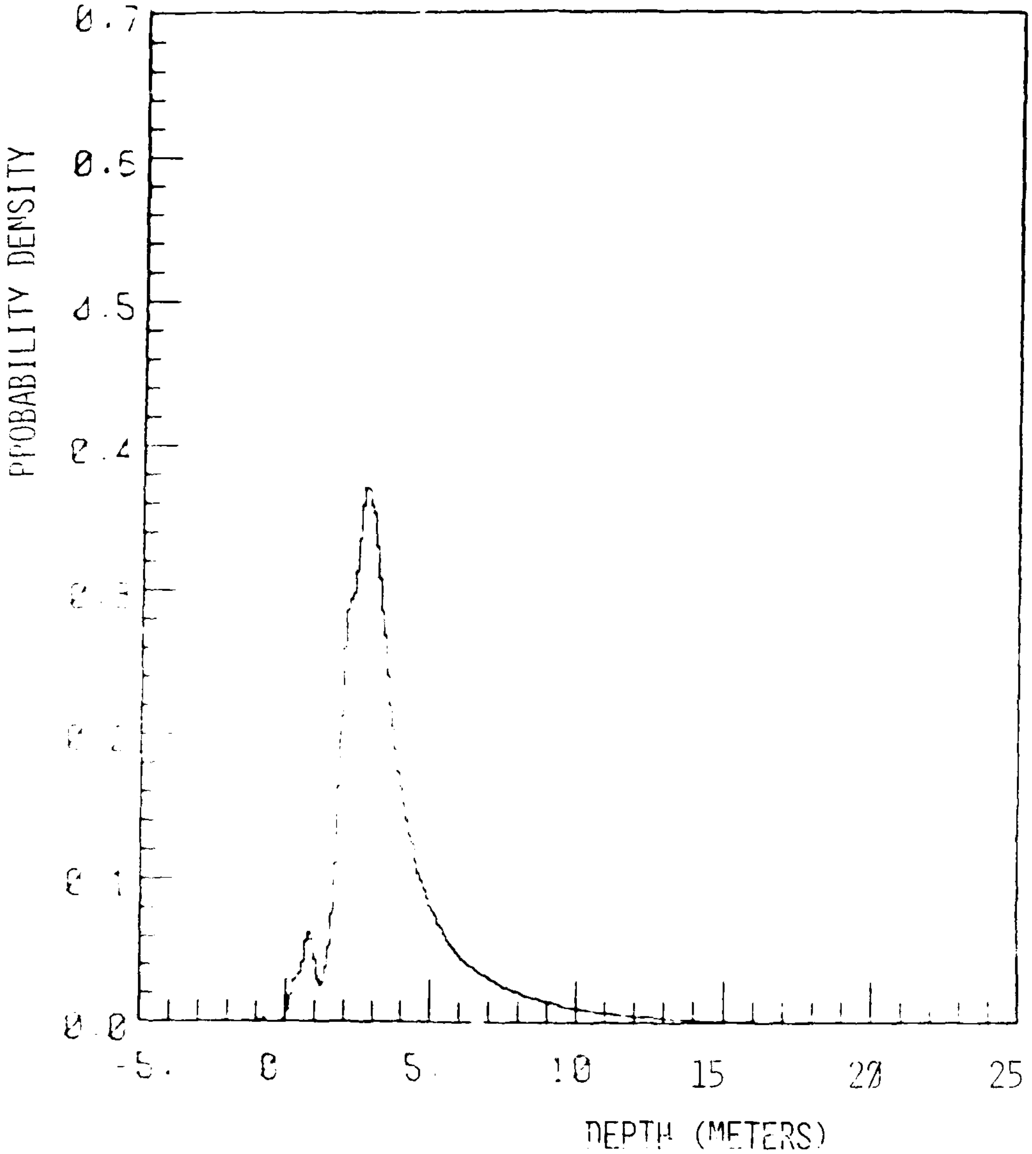
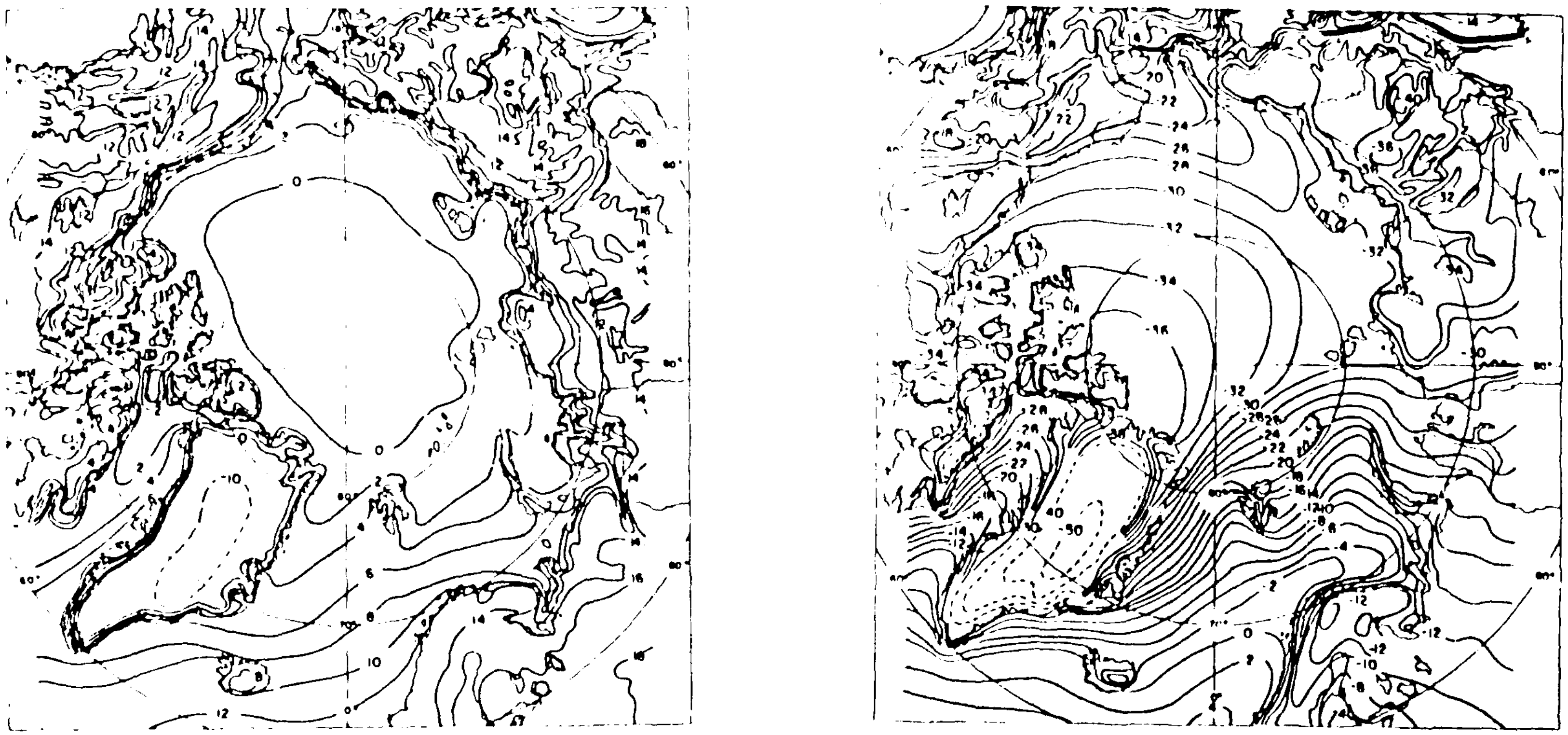


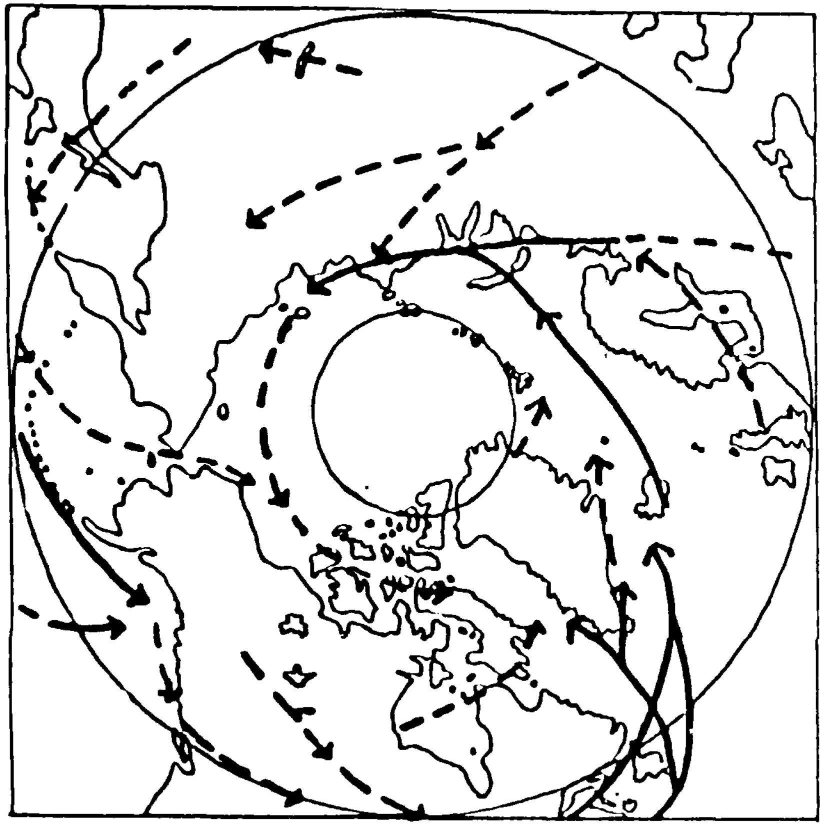
Figure 1.2.7. Probability density function of ice draft, from a 1400 km sonar profile in the Beaufort Sea.



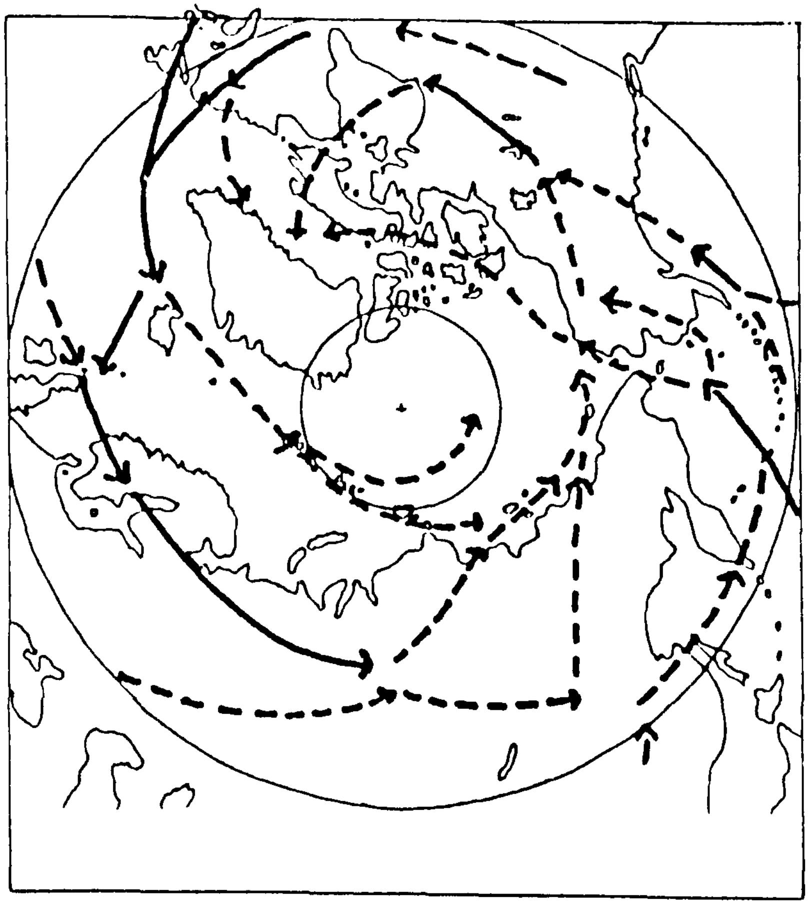
MEAN AIR TEMPERATURE (°C), JULY

MEAN AIR TEMPERATURE (°C), FEBRUARY

Figure 1.2.8. Mean surface air temperature in July and February.



Principal tracks of lows in January.



Principal tracks of lows in July.

Figure 1.2.9. Principal Storm Tracks in January and July.

Table 1.2.1

FREQUENCY DISTRIBUTION OF WIND SPEED OVER CENTRAL ARCTIC OCEAN (PERCENT)

Knots	0	2	4	6	8	10	12	14	16	18	20-28	29-37	38	No. of obs.
J	11	7	8	10	13	12	8	8	6	4	10	2	1	564
F	10	6	11	15	17	15	9	5	5	1	6	0	0	548
M	6	6	8	18	22	15	7	6	4	2	5	1	0	585
A	6	5	15	15	17	15	8	7	5	4	3	0	0	479
M	7	5	11	16	16	15	11	7	6	3	3	0	0	744
J	5	5	9	15	13	15	11	9	6	4	7	1	0	669
J	4	3	9	12	13	16	10	9	9	6	8	1	0	609
A	4	4	7	11	11	15	11	11	8	5	11	2	0	570
S	8	4	9	13	15	15	8	10	5	4	7	2	0	545
O	7	5	9	12	12	12	10	9	7	4	11	2	0	586
N	9	7	10	13	16	15	7	6	6	4	6	1	0	607
D	11	10	14	14	17	12	6	5	4	3	4	0	0	607

The Arctic is characterized by low precipitation (mostly in the form of snow) as shown in Figure 1.2.10, but high incidence of cloud cover particularly as one moves into the subarctic regions (Figure 1.2.11).

These factors combine to create a challenging operating environment for men and equipment. Since the early part of the century the United States and other arctic rim nations have built up a substantial amount of operating experience. The Soviets not only have the largest arctic research and development program (by far), but also the greatest amount of experience in arctic operations (Denner and Sides, 1985). This effort has been driven by the importance of the Northern Sea Route to their economy, northern development, and strategic concerns.

The three major operating factors in the Arctic are the temperature, visibility (darkness, cloud cover or blowing snow) and the sea ice. Taken together these factors pose some significant operating challenges. From the point of view of ROV operations in the Arctic the ice is the primary factor. Temperature and visibility may pose some initial logistical constraints. However, once a deployment platform is in place (ship, submarine, ice camp) ROV operations under the ice should be relatively straightforward. The pack ice provides an extremely stable platform.

1.3 ROV Technology Overview

This report presents an overview of Remotely Operated Vehicle (ROV) technology, its proven capabilities, associated systems and issues for the purpose of assessing the support potential of this technology for acoustic scien-

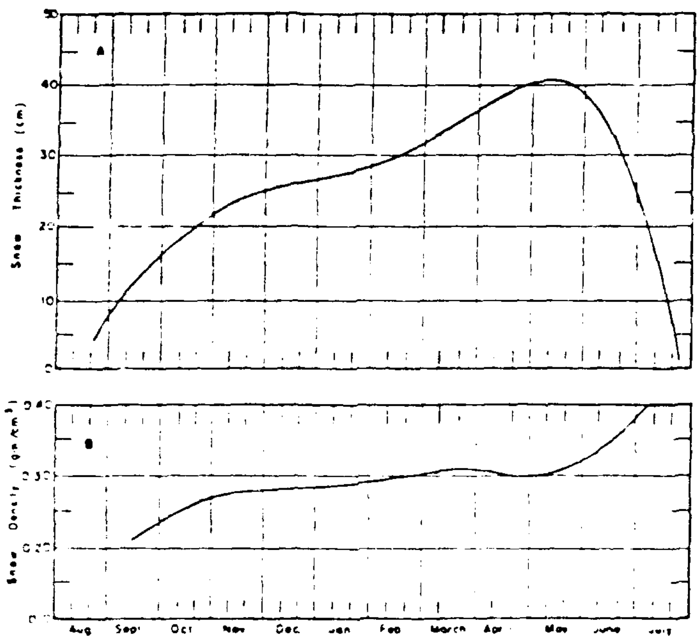


Figure 1.2.10. Average observed snow thickness and snow density from the central Polar Ocean.

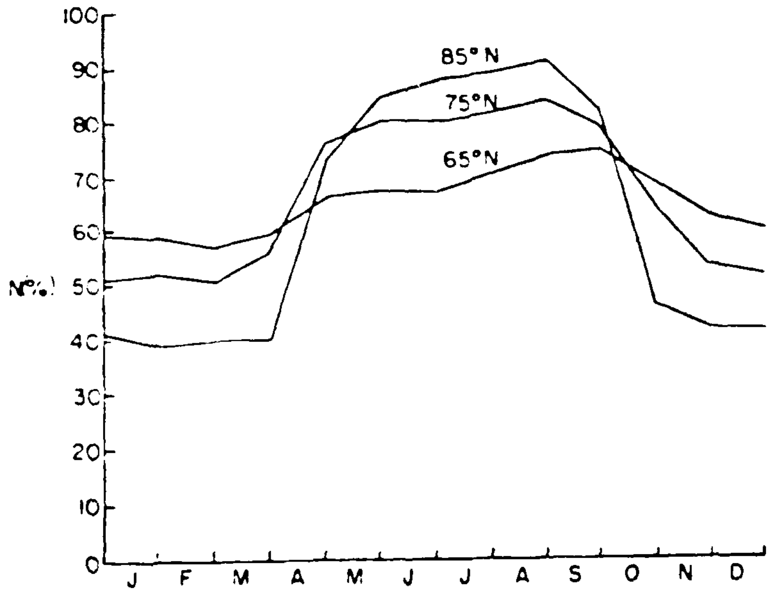


Figure 1.2.11. Latitudinal means of cloudiness.

tific research in arctic regions. In the last 10 years this technology has attained a proven state-of-the-art capability to perform and carry out functions formerly relegated to the human diver. ROVs have also become a commercially cost-effective option for accomplishing a broad range of undewater tasks involved in each offshore oil and gas development phase -- exploration, development, and production.

For the purpose of this report we will consider all types of remotely operated vehicles (autonomous, towed, tethered, and bottom crawlers) under the broad category of ROV. Towed systems have been included in this report as remotely operated vehicles because of the interactive communication links with the vehicle platform and hybrid systems that are being developed. A combination towed vehicle with a tethered free-swimming vehicle carried on-board the towed vehicle is being developed by the Woods Hole Oceanographic Institution (WHOI) and is called the ARGO-JASON. In the summer of 1985 a dramatic feat, the discovery and documentation of the TITANIC at a depth of 12,500 feet showed the versatility of the ARGO-JASON system.

The U.S. Navy Supervisor of Salvage and Submarine Development Group One possesses the principal Navy manned and unmanned assets for search, recovery, and rescue. This in-house experience and capability is under continuous up-grade and represents a valuable resource of knowledge. To date, these organizations have not operated extensively in the Arctic. The discussion herein emphasizes proven ROV capabilities, potential ROV scientific support applications, and illustrations of how that technology might be extended from temperate climates to the Arctic.

ROV vehicles have accumulated a history of significant accomplishments. Since the 1966 nuclear weapon recovery operations off Palomares, Spain, a number of search and recovery tasks have been successfully completed applying steadily improving equipment and procedures. The rescue of the men in the PISCES III from a depth of 1,500 feet by the U.S. Navy CURV III in 1974 was followed by the recovery of the then high technology F-14 aircraft and its SPARROW missiles from the North Atlantic. The ROV SCARAB located and retrieved the flight recorders from the crashed Air-India jumbo jet 6,700 feet beneath the Atlantic. Expeditious location and recovery of the space shuttle CHALLENGER debris involved several ROVs: DEEP DRONE, GEMINI, CORD, SPRINT 101, RECON IV, SCORPIO and ORION. These achievements involved a coordinated effort between manned and unmanned vehicles. The list of recoveries has grown rapidly.

Despite some spectacular scientific accomplishments using ROVs in the U.S. only a few researchers have adopted this technology to their requirements for data acquisition to support their research. Too, there is only limited effort dedicated to the design and development of ROVs specifically for scientific purposes. Nevertheless, germane R&D is underway that will provide improved ROV capabilities, some of which will be applicable to under-ice scientific investigations. Figure 1.3.1 Remotely Operated Vehicle Technology Support Potential, includes most marine scientific research areas. However, ROV technology has neither been extensively tested nor used in arctic regions.

Recent industrial experience with a variety of ROV systems shows that the technology can be successfully applied to a broad spectrum of underwater tasks. It is fortuitous that industrial needs catalyzed the creation of a family of

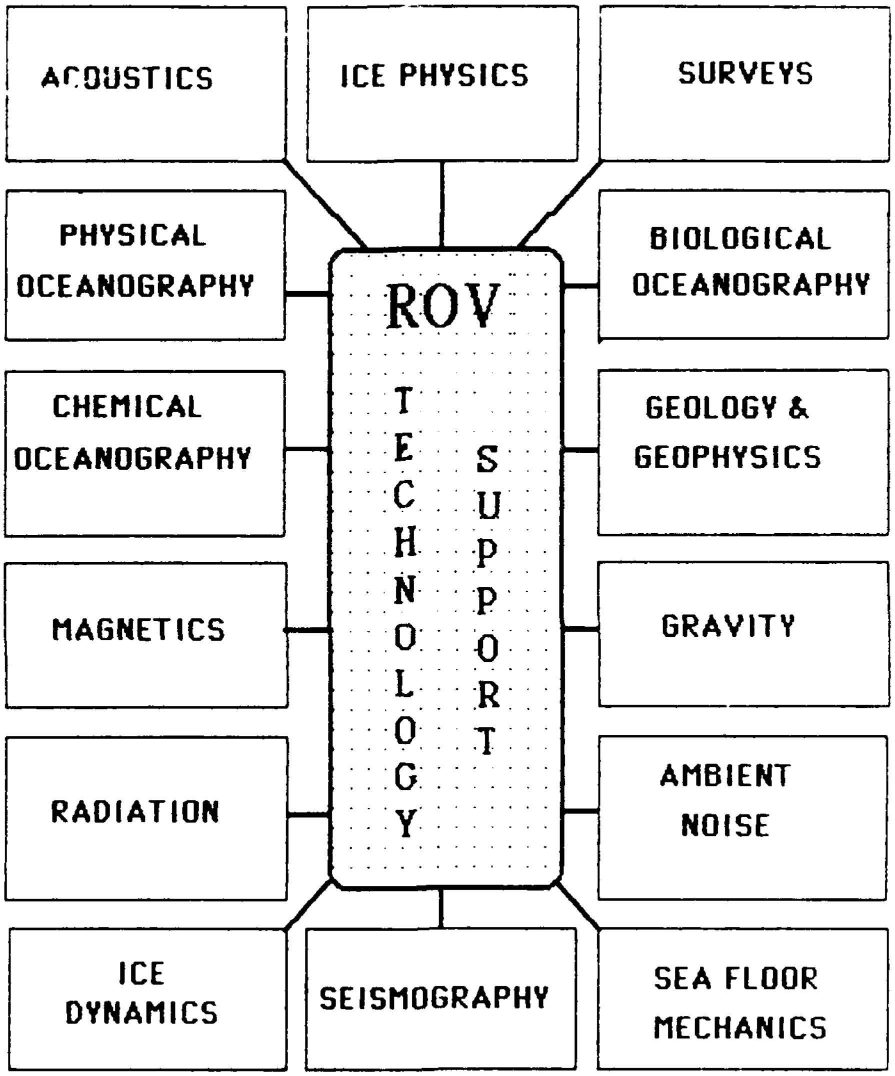


Figure 1.3.1. Remotely Operated Vehicle technology support potential includes most marine scientific research areas.

ROVs with capabilities that are diverse and suitable--without major change--for supporting scientific research activities in polar regions.

Self-contained scientific sensors and instrumentation developed for autonomous long endurance oceanographic buoy installations are readily available from commercial sources. The spectrum of scientific sensors and instruments constitutes a ready supply of data acquisition add-ons to an ROV vehicle. Underwater and atmospheric navigation and positioning systems have been developed and perfected to meet virtually every conceivable type of operation.

Reliability is good, but technician support is required to ensure maximum availability. Surface control stations have been designed, tested, and refined to provide "user friendly" operating and to achieve optimum performance and reliability. Nevertheless, to expedite operator proficiency development, formal training programs are available to prepare personnel to operate and provide technical support. Effort continues to design and develop systems that will provide full replacement for the now required human ROV operator. The primary approach to achieving this objective is through the application of artificial intelligence (a relatively new technology) and robotics.

This report establishes that the technology is at hand to carry out scientific tasks that until recently could only have been accomplished by divers or manned vehicles. These tasks are accomplished for less cost and with no risk to human life. The ROV has the potential to be every bit as effective as a corresponding manned vehicle. Indeed, it could be argued that as a reconnaissance platform the ROV provides superior data since it can be operated for longer continuous periods. The ROV is also cost effective. Acquisition and operating cost per system are less than manned platforms used for the same purpose.

1.4 Objective of This Study

The objective of this study and report is to:

- Conduct an assessment of ROV and related technologies that have potential for supporting AEAS research in arctic regions.
- Prepare a document that provides information that can be used to acquire appropriate ROV technology and ROV compatible sensors and instruments to support AEAS research in the Arctic.

1.5 Definitions

The term "remotely operated vehicle" has been used to describe a wide variety of undersea equipment and system types. There is no generally accepted definition for the term "remotely operated vehicle". However, the tethered free-swimming type is the vehicle type most recognized as an "ROV". There are ROV system variations that include: towed vehicles, bottom-crawling vehicles, autonomous vehicles, and those vehicles that are heavily dependent on contact with the seafloor or some man-made structure. In general, the term refers to any class of unmanned vehicle that derives its guidance from a remote piloting station or from navigation instructions contained within the vehicle's guidance and control equipment. This last class of vehicle is more appropriately described as autonomous self-piloted vehicles. In this report the term remotely operated vehicle (ROV) will be used for tethered free-swimming vehicles and autonomous operated vehicles (AUV). Clarification will be made when any other class of vehicle is mentioned, e.g., towed and bottom crawling.

For the purposes of this report and to provide some distinction for the reader the generic term "ROV" applies to the following four classes of remotely operable vehicles. (Some authors have sub-divided the classes even further.)

1) Tethered Swimming Vehicles. A remotely operated vehicle system that is cable powered and controlled via an umbilical tether cable. Propulsion is integral with a mobile platform equipped with a variety of sensors and manipulators to conduct useful underwater work. The vehicles can be operated in three-dimensions. This type of vehicle is universally known as an ROV.

2) Autonomous Underwater Vehicles. An untethered swimming vehicle system that operates in three-dimensions free of an umbilical cable. Power, propulsion, maneuvering, control, and other features are basically under the pre-programmed control of on-board computer programs. Interactive control and data telemetry is via acoustic link. This type of vehicle is generally recognized and is called AUV (Autonomous Underwater Vehicle) in this report.

3) Towed Vehicles. A remotely operated vehicle system propelled and maneuvered, primarily in two-dimensions, by a surface tow vessel. Vertical maneuvering is achieved by winch lowering and lifting. Acoustic, magnetic, and optical sensors acquire information that is displayed at a surface located console. No generally accepted acronym exists for this vehicle type.

4) Bottom-Crawling Vehicles. A remotely operated vehicle that operates via a tether umbilical cable and in two-dimensions on the seafloor. The vehicle receives power and control from a surface support platform. These vehicles have a substantial payload capacity for sensors, manipulators, tools, and other equipment useful for seafloor measurements, installations (including trenching and burial of pipe and cables), maintenance and repair. No generally acceptable acronym exists for this vehicle type.

There are a number of major components common to a complete ROV system:

1) A remote control station.

2) A remote power source (using either the main power supply of the surface ship or an ROV dedicated power plant).

3) An umbilical tether cable. (The autonomous vehicle is an exception.) The umbilical cable usually provides power, a communications link, data telemetry, and serves as the strength member for launch/retrieval. Communications and data telemetry to and from an AUV is accomplished via an acoustic link.

4) A launch/retrieval system (crane/boom, traction winch, storage winch, and in some instances, a deployment cage.

5) An underwater vehicle.

6) Tools, sensors and instruments to conduct specific missions.

This report contains information (Appendix 1) on more than 268 different types of ROV (the world-wide total fleet of vehicles numbers somewhere near 700). Appendix 2 provides a directory of suppliers, and Appendix 3 provides a comprehensive breakdown of specifications. Appendix 4 provides a list of recent relevant publications.

2. ROV TECHNOLOGY HISTORY AND TRENDS

The history of modern ROVs spans just over three decades. The pioneer vehicle in this class was created by Dimitri Rebikoff in 1953 who converted his normally manned operated diver transport vehicle PEGASUS into a tethered cable controlled vehicle. At that time he field demonstrated the vehicle for both military and academic scientific researchers but, despite their declared interest in applying this technology, the marine community did not make a buy. Little progress in commercial ROV development took place until 1975. Industrial demand for an alternative to human diver services stimulated the market opportunities for both domestic and foreign sales. Since 1975 the world fleet of ROVs has grown dramatically. Military applications and procurements of ROVs and AUVs will spur the development of additional units in the coming decade. Already mine neutralization vehicles are being developed and produced in substantial quantities--particularly by France. The majority of non-military vehicles have been custom designs to meet unique functional requirements of offshore oil and gas companies. Only a few manufacturers have enjoyed multiple sales and a production run of a given model.

The introduction of the tethered swimming ROV with a television camera gave the technical personnel, responsible for offshore drilling and production, their first opportunity to see what was happening hundreds of feet below the surface. The surface-bound engineer could monitor the operations continuously. Communication with the diver while observing the situation provides a valuable tool for the responsible engineer. The "flying eyeball" is perhaps the key feature of

ROVs applied in the offshore oil industry. Along with a good view of the work site, other innovations have been added to the ROV, particularly manipulators and tools that they can operate. There has been a progressive development of ROV systems -- sensors for expanding the view area, non-destructive testing devices, documentation systems, and acoustic navigation and location systems. Many diving operations are now routinely observed and supported by an ROV. Vehicle systems can handle all drilling support in deep water and a great part of it in shallower depths.

Commercial AUV applications have been limited. The relatively new technology "artificial intelligence and robotics" is being explored for underwater applications, particularly in AUVs. The level of automation research and development to meet the industrial manufacturing requirements far exceeds that available for underwater applications. However, technology transfer from the manufacturing field to underwater AUV will likely occur. Several experimental AUVs are under development that incorporate artificial intelligence. These are dubbed "smart fish" to reflect the on-board environmental assessment and decision-making that will take place in an on-board computer. After analyzing a given situation the AUV will take action on its findings.

2.1 Tethered Free-Swimming Vehicles (ROVs)

During the last decade substantial improvements, largely driven by the offshore oil industry, have taken place in the design, development and practical application of unmanned tethered free-swimming vehicles. However, the industry need to conduct cost-effective exploration, field development and, finally, production was satisfied, in part, in the remotely operated vehicle technology base established by the Navy.

From 1957 to the present the U.S. Navy has conducted in-house ROV research and development. The Navy has also funded university ROV and AUV developments. Most of the vehicles have been developed as working test beds that incorporate a broad range of technologies considered potentially valuable to military operations. The longest continuous record of ROV/AUV developments has been at the Naval Ocean Systems Center (NOSC), San Diego. The Center draws a significant historical experience base from developments at the Naval Ordnance Test Station (NOTS), Pasadena/China Lake, CA. Although NOSC is the current lead laboratory for ROV/AUV developments much of the early history credit appropriately belongs to NOTS. The initial Navy requirement for ROV technology was the need to recover valuable high technology experimental torpedoes and other new Navy ordnance that sank during field trials on the test ranges operated by the NOTS and the Naval Torpedo Station, Keyport, WA.

The following paragraphs describe some of the systems that have been built:

- MERMUTT III. In 1957 the Navy took delivery of its first torpedo recovery ROV, MERMUTT III, manufactured by VARE Industries, Inc. MERMUTT III was designed to be a search and recovery vehicle with a depth capability of 1,200 feet. The vehicle was 18 feet long, 4 feet 8 inches wide, 3 feet 9 inches high, weighed 1,000 pounds in air, had a positive buoyancy of 30 pounds, a submerged speed of 3 knots and a hovering capability in a 1 1/2 kt current. It was equipped with a television. This system became the property of NOTS and appears to have been the precursor of the progressive in-house upgrades of this design that became CURV (Cable-controlled Underwater Vehicle).

- SOLARIS. The SOLARIS (Submerged Locating and Retrieving/Identification System) was similar to MERMUTT III and was developed for the same purpose to depths of 650 feet. It was an open frame structure fitted with television, lights, an echosounder, and either a toggle-action claw to recover torpedoes, a general purpose claw, a cable claw (for cable repairs), or an explosive magazine, and a stud gun. The vehicle was designed and fabricated for the Naval Torpedo Station, Keyport, by the Vitro Laboratories. Although the vehicle successfully located and retrieved a dummy target from 650 feet it did not pass the established performance specifications test.

- SORD. The SORD (Submerged Object Recovery Device) was built by the Naval Undersea Warfare Engineering Station, Keyport, in 1965 for weapon systems recovery from its underwater test ranges. The system has an open metal frame that supports a television camera, flood lights, directional hydrophone, magnetometer, a mechanical latching device for ordnance or object retrieval, and a washout pump that can remove six meters of sediment overburden to expose the object to be recovered.

- SPURV. The SPURV (Self-Propelled Research Vehicle), an AUV, was designed and developed by the Applied Physics Laboratory, University of Washington. It underwent its initial testing in the Dabob Bay, 3-d acoustic test range on 25 November 1959. It was designed to cruise under its own power to depths of 10,000 feet, at a speed of 6 knots, for 5 to 10 hours depending on the type of battery used. Its primary payload was oceanographic instrumentation--100 to 200 pounds. The function of the research vehicle was to obtain information on ocean bottom topography, and to record oceanographic and geophysical data at great depths and over long distances. Its development was sponsored by the Office of Naval Research.

- TORTUGA. In the sixties several experimental testbed ROVs were conceived at NOSC and fabricated by a commercial firm (Hydro Products, San Diego). Among the first was TORTUGA. It was purposely sized small to improve test improved maneuverability ideas and to allow close observational access to spaces inaccessible by the larger designs. Several versions of TORTUGA were fabricated and evaluated. An early design using water jet propulsion lost out to more effective propellers.

- ANTHRO. The ANTHRO took its name from its anthropomorphic features and was build by Hydro Products following NOSC specifications. It was developed to evaluate a concept wherein the vehicle would mimic the motions of a human head attempting to scan and interpret an unfamiliar scene. The technique was termed "head coupled" television and involved slaving the vehicle (with its included televion camera) to the operator's head that was covered by a master control helmet. Binaural audio inputs were included to determine if such augmentation would improve the operator's ability to locate and identify a target. In addition, the operator's control station chair was instrumented to match the roll, pitch, and azimuth changes in synchrony with the vehicle. Vehicle depth was controlled by servo-controlled vertical thrusters that automatically maintained a desired depth.

- SCAT. The SCAT (Submersible Cable-Actuated Teleoperator), as originally configured, was built to serve as a testbed for evaluating head-coupled television. It was subsequently modified to serve as a light-duty inspection/work vehicle capable of operating to a depth of 3,000 feet.

- SNOOPY. SNOOPY is the smallest in a series of NOSC developed light-weight, portable ROVs. It carries a television camera with a 250 watt mercury vapor light source. Its primary function is optical viewing to a depth of 100 feet.

- NAVFAC SNOOPY. The NAVFAC SNOOPY (Navy Facilities Command SNOOPY) is a small ROV designed for ocean construction support. Its primary uses are optical survey of proposed seafloor construction or implantment sites, monitoring and documentation of diver operations, and general undersea inspection and documentation.

- LARP. The LARP (Launch and Recovery Platform), another NOSC design, is a unique ROV that is normally operated by scuba divers to a depth of 130 feet. From 130 feet to 200 feet the system is cable controlled from the surface.

Its function is for the sub-surface launch and recovery of manned submersibles.

- STSS. The STSS (Surface Towed Search System) is a towed ROV designed for search depths to 20,000 feet. Employing television and side looking sonar, its output is read and interpreted at a surface located console. It was fabricated by the Westinghouse Corporation and is operated by Submarine Development Group One, San Diego.

- CURV. The CURV (Cable-controlled Underwater Recovery Vehicle) has undergone an almost uninterrupted series of upgrades from CURV I to CURV III. Each design has been the traditional rectangular open frame equipped with syntactic foam buoyancy and ample space for a number of sensors and instruments. The sensors included are active/passive sonars, television cameras and supporting lights, still camera(s) with strobe light(s) and manipulators. CURV III is capable of working to 7,000 feet and has been modified for emergencies for operation to 10,000 feet. It has a submerged speed of 4 knots. Two horizontal propulsion motors are used to steer the vehicle and one vertical motor serves for close vertical control.

- RUWS. The RUWS (Remote Unmanned Work System) was developed by NOSC as a testbed for a variety of useful work missions such as recovery, repair, implantment, survey, documentation, and oceanogaraphic data gathering. Work is performed by a two-arm manipulator system -- one a relatively simple four-function, rate controlled grabber, and the other a seven-function position-controlled, highly articulated manipulator for which special tools were developed.

- MNS. The MNS (Mine Neutralization System) was developed and tested by NOSC. It is a tethered swimming ROV designed to be deployed from a fleet minesweeper. Its function is to classify and neutralize mines that have been located by other means. The system contains its own high resolution scanning sonar and television viewing system for relocation and classification of mine and mine-like targets. NOSC is NAVSEA's Technical Agent for the commercial production run which started in 1985. NOSC is also developing the first unit of a new low magnetic signature version of the MNS.

The commercial application of remotely operated vehicles (ROVs) has expanded rapidly since 1975. The world fleet has grown to over 700 in the last decade. Their utility and reliability has made them almost an obligatory support service system on each major offshore platform. The offshore oil industry, in most instances, has nurtured the commercial development of ROVs with the intent of eliminating or markedly reducing the requirement for the human diver. Ironically it is the dexterity and capabilities of man that have been used as a performance target for ROV designers and developers. Many tasks and functions formerly assigned to the human diver are now accomplished by the ROV. These include inspection of subsea systems, search and recovery. ROV technology has not been extensively used or even tested in arctic regions. In 1983 the ROV MiniROVER was used to explore and photograph the remains of the 140 year old British bark, the Breadalbane, under the arctic ice. The oil industry has used a small ROV to inspect the ice keels of multi-year pressure ridges.

A combination of a towed vehicle with a tethered free-swimming vehicle carried on-board the towed vehicle is being developed by the Woods Hole Oceanographic Institution. In the summer of 1985 a dramatic feat showed the versatility of the towed ARGO system as a means to achieve fine-grain surveys of the deep sea floor, but also to locate sunken ships, as it did when it found the TITANIC at 13,000 feet.

The towed ARGO will carry a small, remotely operated vehicle (JASON) in a "garage" located at the stern of the towed body. Operating as deep as 20,000 feet, JASON will transmit data on its tether to ARGO which in turn will relay information via the umbilical cable to the surface ship. Since the system can remain submerged for weeks at a time, it is expected to significantly increase the amount of information collected during research cruises. The prototype JASON is a Benthos RPV-430 with a Deep Ocean Engineering manipulator arm.

In July 1986 Woods Hole personnel returned to the TITANIC and were able to probe some of the interior of the ship using the video robot JASON JR, operated from ALVIN.

The cable controlled free-swimming vehicle has evolved to be the dominant ROV vehicle class and is the most recognized ROV type. The ROV SCARAB, for example, located and retrieved the flight recorders from the crashed Air-India jumbo jet 6,700 feet beneath the Atlantic. In addition, it recovered a substantial portion of the aircraft bit by bit. Such achievements have significance to the scientific community when one realizes that this operation required accurate geodetic position fixes for each piece of debris. Navigational fixes are now accomplished as routinely as surface navigation.

In March 1986 the space shuttle CHALLENGER was destroyed by a rocket booster explosion. The debris field was extensive and recovery operations continued into May. Recovery operations inlcuded the use of ROVs SPRINT 101, RECON IV, DEEP DRONE, GEMINI, CORD, SCORPIO and ORION.

2.2 Towed ROV Systems

Many of the sensors and research capabilities incorporated into the design of towed vehicles have potential application aboard tethered free-swimming and autonomous underwater vehicles. In addition, some hybrid systems are being developed that involve both a towed vehicle with a tethered free-swimming vehicle carried on-board the towed fish. Hence, the following vehicle descriptions are included in this assessment.

A representative towed ROV is the SEA MARC CL which is one of the newest towed sea floor mapping systems on the market. Incorporated in the towed fish is a 150 kHz side looking sonar system with a very wide operational envelope. The system can image swaths from 50 m to 1 km wide and create real-time, digitally processed, slant range and speed corrected acoustic images of the bottom. The system maintains a good grey scale across the image over the entire range of swaths, tow speeds, and towfish attitudes. The quality of an acoustic image of the seafloor is critically dependent upon platform stability. SEA MARC CL uses a passively stabilized sensor platform with optimized towing speeds from one to six knots.

Its light weight and small size makes it readily portable and easy to deploy from ships of opportunity. A light weight winch and a one centimeter contrahelically armored coastal cable is required for survey towing. The system has a depth capability greater than 1500 m. Its overall weight is 100 kg, and it is 2 m long, 0.4 m wide and 0.4 m high.

Unprocessed acoustic data and corrected data can be recorded in real time on standard audio tape for backup and post processing. All telemetry communications between the tow fish and the surface console can also be recorded on audio tape. All data from sensors such as compass, magnetometer, temperature sensor, and pressure/depth gauge are digitized for communications to the surface or on-board data storage. As a towed system the SEA MARC CL uses a highly flexible multiplex telemetry link to the surface. This link has sufficient unused capacity to accommodate additional sensors or systems aboard the towed fish. SEA MARC can also support a very high accuracy super short baseline tow fish positioning system to increase survey scope by avoiding the use of bottom mounted acoustic references.

Operating these towed systems is inherently difficult because the long length of cable involved constrains maneuverability. Towed vehicles are also constrained by high winds and sea conditions. These constraints might be partially overcome by using autonomous vehicles.

2.3 Autonomous Underwater Vehicles

Autonomous ROVs have been used by the Navy since the early 1960s but their numbers were small. More recently, due in large part to the advent of the microprocessor, R&D investment in this type vehicle has seen a greater emphasis by the military. Since the autonomous vehicle is, by nature, designed to operate at distances beyond visible range of its support craft or station, it can conduct a mission covertly and free of a surface tether. The capability is particularly pertinent to this study.

Some 23 development programs in this area can be identified from the open press. Of these, 14 are supported by the military. At present most autonomous vehicles are primarily developmental. The R&D vehicles are being developed primarily for identifying problems and technology that must be advanced to make this type of vehicle practical and an effective alternative to cable-connected vehicles. Although the world inventory of AUVs is less than 30 the number of vehicles in this class is expected to increase in the next decade. The operational characteristics inherent to autonomous vehicles suggest that this class will have a number of under-ice applications.

Two general AUV classes are currently under development. One is of an open frame design, much like tethered free-swimming ROVs, and the other is torpedo-shaped which offers lower drag for long-range traverses.

The developmental program of Gaseby Dynamics of the U.K. illustrates a few of the potential applications for this technology. That firm is currently developing an intelligent decoy and has prototype systems under test. Mounted in magazines on a surface vessel, as many as six of these vehicles can be deployed into the water if the presence of acoustic torpedoes is suspected. Against a passive seeker it would automatically begin a seduction or distraction program, while against an active seeker it would store the sonic transmission then retransmit it with added dopler and time difference to attract the torpedo. (Military Technology, Vol. IX, No. 11, 1985). Such decoys could also be launched from submarines or aircraft.

The European-based Scicon Company's SPUR (Scicon's Patrolling Underwater Robot) is an advanced concept in the design phase (Busby, 1986). The full-scale vehicle would be between 10 and 11 meters long with a 1.8 meter cross-section. Normal propulsion would be by an oxygen/hydrogen fuel cell and higher attack speeds of up to 50 knots may be obtained from either a closed-cycle engine or batteries. At cruising speed the vehicle would have an action radius of 1850 kilometers, an endurance of two months and, for certain applications, be capable of diving to 6000 meters. SPUR would be under shore control and artificial intelligence would be used to assist functions which SPUR would need to perform autonomously, especially in the fields of tactical decision-making (e.g., route planning, target classification, attack maneuvers, and communications routines). Scicon foresees such roles as mine counter-measures (using manipulators), vessel destruction via torpedoes, wrap-around wire system deployment directed against a ship's propellors, and, as a last resort, an intelligent mobile mine. The company further envisions "wolf packs" of SPURs deployed in a patrol line to create barriers up to 370 kilometers long.

The French built (IFREMER) AUV EPAULARD is a survey vehicle designed for photographic sorties in deep water (6000 m). It can take 5,000 photographs in one dive and has been found to be highly effective in the following field investigations:

- surveys of manganese nodules in the Pacific,
- sediment slumping observations in a canyon off the coast of Nice, France.
- search for salvage and cables, and
- trials on the Gorda Ridge, off the coast of Oregon.

150 dives have been completed. The EPAULARD maintains constant altitude off the seafloor through the use of a weighted drag rope, combined with a forward-looking obstacle avoidance sonar which is used automatically to interrupt propulsion in the event of any collision situation.

An acoustic image-transmission link to the surface is being developed to operate at 25 kHz and thus transmit a picture at intervals of 5-40 seconds. The acoustic imaging capability is intended to improve mission control and search strategy, not to replace the on-board still cameras. The vehicle can cover 15 km during a dive of 6 hours. Service time on deck is 1 hour to recharge batteries and re-load cameras.

Also under development by IFREMER is a smaller vehicle system ELIT designed for shallower water inspection tasks associated with the offshore oil and gas industry. It will be much more intelligent than the EPAULARD with the capability of maintaining station near the ocean bottom and transmitting video data, through an acoustic telemetry link, to an operator. System tests are planned for 1986.

The AUV PLA II is an experimental vehicle designed to carry out research into the feasibility of collecting manganese nodules from a depth of 6000 m. The development effort is supported by the French atomic energy research authorities. The broad principle of the system is that the vehicle descends under its own weight, with buoyancy and trim control, so that a soft landing is made on the bottom. The vehicle then covers a distance of about 600 m on the sea bed, uses a dredging device to lift nodules into the hopper which can hold 3 cubic meters of nodules. Ballast is then dropped so that the vehicle ascends using fixed buoyancy, and is recovered on the surface. After processing of the nodules on board the support factory ship, the waste rock is loaded into submersible vehicles to act as ballast in subsequent trips. Additional ballast, for fine trim, would be in the form of iron shot.

Technomare of Italy is developing an AUV work system with remote operator control via an acoustic communications link and with multiple arms. Some arms are used for vehicle position keeping and torque reaction, while the other arms serve as manipulator operating tools. Video information will also be provided via an acoustic telemetry link to provide the operator with on-scene information.

At the Heriot-Watt University of Edinburgh, Scotland, development is underway on a small AUV (ROVER) that will transmit video data via an acoustic telemetry link to a tethered free-swimming ROV operating near the AUV work area for relay to the surface control station. This approach to gaining a short acoustic transmsision path hopefully will reduce some of the problems that plague long distance acoustic transmission of video data.

The U.S. Department of the Interior, Minerals Management Service, is sponsoring robotics (AUV) engineeering R&D in an attempt to provide more effective means to conduction inspection of seafloor pipelines and the inspection of underwater structures. This AUV technology development program, called the Experimental Autonomous Vehicle (EAVE) Program, has progressed to a point where both the NOSC and the University of New Hampshire (UNH) experimental vehicles have been tested in water to perform certain fundamental maneuvers. The vehicles are known as EAVE-WEST (NOSC) and EAVE-EAST (UNH). Neither of these vehicles is planned to be a prototype for a specific function, but, as indicated, both are test beds for new technology and techniques. This technology development program is a collaborative effort between the Naval Ocean Systems Center (NOSC) and the University of New Hampshire (UNH). Germane to this study, EAVE-EAST includes a computer routine entitled "The Arctic Inspection Mission System Sonar Acquisition Routine".

At NOSC, an open-frame torpedo-like submersible (EAVE-WEST) has been constructed to study magnetic navigation and optical fiber communications. This vehicle is powered by lead-acid batteries, which, together with electronics, are located in the four canisters within the vertical frame. Twin propellers located aft, and a vertical propeller amidships, between syntactic foam buoyancy blocks, provide propulsion for the vehicle.

The AUSS (Advanced Unmanned Search System) is a current NOSC AUV development. The objective of the development is to create an autonomous system for search using acoustic command, control, and telemetry links in addition to a significant amount of artificial intelligence technology. AUSS will serve as a testbed for overall evaluation of the system and its subsystems. A secondary objective is to have a derivative of the AUSS replace the Surface Towed Search System (STSS). The UFSS (Unmanned Free-Swimming Submersible) was designed and built at the Naval Research Laboratory in order to demonstrate and evaluate advanced technologies as applied to underwater vehicles.

International Submarine Engineering, Ltd., Canada, built the torpedo-shaped ARCS to perform surveys under the arctic ice canopy. It is now operated by its owner the Bedford Oceanographic Institute, Halifax, Nova Scotia. ARCS has seen limited use in the Arctic and is being prepared for additional trials in 1986.

The Applied Physics Laboratory, University of Washington, pioneered in the development of AUV technology. The Unmanned Arctic Research System (UARS) was designed with under-ice operations in mind and was tested successfully in the Arctic in 1972. As part of a DARPA-ONR sponsored arctic technology program at the University of Washington, the AUV was developed and successfully deployed. The UARS is a compact, torpedo shaped vehicle that weighs 410 kg in air and has a length of approximately 3 meters and a diameter of 75 cm. It can operate to depths of 457 meters and can cruise for 10 hours at 3.7 knots. Its payload of acoustic instrumentation provides for measuring physical phenomena and communications both to and from the AUV. The vehicle is launched in a horizontal attitude after being lowered through a 4x12 ft ice hole. The position of the UARS is known at all times from information derived from an acoustic tracking system. The UARS is recovered by ensnaring it in a net. The capture net contains an acoustic beacon which the UARS homing system seeks. In the event that command communication with the UARS is lost for a preset period of time, the homing system will automatically activate and UARS will began a search for the beacon. The field tests were conducted from Fletcher's Ice Island (T-3) when it was at approximately 85°N Lat. and 85°W Long, about 150 miles north of Ellesmere Island during May 1972. Pressure ridge keels to a depth of 23 m were observed. Included in the instrumentation suite of UARS was an ice profiler system which measures the relief of the under-ice surface on each of three separate, narrow, upward looking beams, to provide an overall elevation accuracy of 9 cm.

As a part of the development of UARS, a 10,000 baud underwater acoustic link was designed and developed. This phase-shift-keyed (PSK) data link was used both to control the UARS and to receive real time data from the vehicle.

Observations of the under-ice profile were made using the (UARS) system which was developed as part of an ARPA-sponsored arctic technology program. Briefly, the system consists of an acoustic telemetry-controlled, torpedo-like vehicle that can operate under the arctic ice while carrying acoustic and other research instrumentation (Figure

2.1). An acoustic tracking system determines the position of a tracking projector mounted on the UARS at 2-second intervals. Within a typical 4-km diameter operating area, the standard error of the position measurement is about 15 cm relative to an established reference baseline. The vehicle dynamic controls play an important role in the measurement process. The vehicle controls its depth within 7 cm, and pitch and roll are controlled within 0.5° with 30-sec periods for all three functions. During turns, slightly larger errors are incurred, but these damp out very rapidly when straight running is resumed.

The multi-beam, upward-looking acoustic lens that is used to measure the under-ice profile is mounted directly over the tracking transducer (Figure 2.1).

The UARS has been inactive for several years. Dr. John Harlett, University of Washington, Applied Physics Laboratory (personal communication) indicates that the UARS could be placed back in operation by four men with six months of effort.

Current AUV development effort at the University of Washington Applied Physics Laboratory is the modification of an Mk 38 vehicle to do acoustic assessment of krill under the antarctic ice shelf and pack. The AUV will be pre-programmed and will return to the launch platform using acoustic homing; a technique utilized by the UARS. In this application, there are no plans to track the vehicle. This is a relatively low-cost vehicle and is a modified version of the Mk 38 Mod 5 Fleet Sonar Training Target which is 204 cm long, 14 cm in diameter, weighs 7.3 kg in air, has a speed of 3.5 knots for

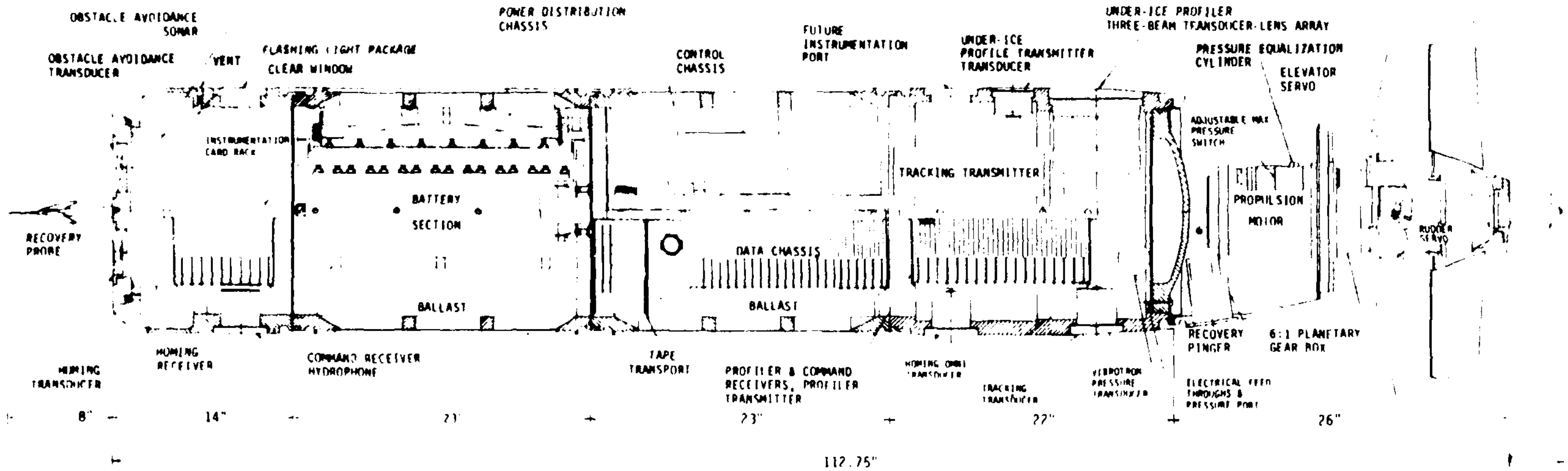


Figure 2.1. Cross-Sectional View of UARS
(from Francois, 1977)

4 hours, and a depth rating of 152 meters. The current contract calls for a unit cost of $1500.

A capability vital to the ultimate success of untethered vehicles is the ability to acoustically transmit reliable images in real time. Hence, it is deemed necessary to develop technologies that support reliable image transmission. Imaging in near real-time from an untethered vehicle is possible because of certain data reduction techniques that can be used. Even at the very low resolution of 100x100 pixels, digitized to four bits, there is still a significant amount of redundant information present. Using a special redundancy removal algorithm (Micro Adaptive Picture Sequencing) much of the excess data can be removed while important scene features are maintained.

An image of 100x100 pixels (40,000 bits) would require about 4 seconds to transmit an acoustic telemetry link (9600 bps). By using data reduction techniques, it is possible to transmit the same scene in 0.5 seconds. In order to test the usefulness of the data reduction algorithm, an EAVE compatible imaging test bench was built. On this system images were sensed, digitized, compressed and transmitted and reconstructed for a remote operator with acceptable image fidelity and image transmission time. If many frames per second are necessary to control the vehicle through a difficult maneuver, the compression ratio can be increased and the transmission time decreased.

There are some drawbacks attendant with autonomy. All power for the entire mission must be carried on-board.

This limits the amount of work that can be accomplished -- power must be shared on each mission between propulsion and the tools/sensors used to carry out a meaningful mission. Many untethered missions will involve only inspection and information gathering with no requirements for high energy for sensors or tools. Real-time viewing at a manned control center is limited due to the transmission capabilities of an acoustic communication link. However, without direct human intervention, the system must incorporate substantial intelligence onboard which involves extensive computational capability. Accordingly, the following areas are being emphasized in AUV technology R&D:

- improvement of sensors and expanding sensor options.
- improvement of guidance systems and artificial intelligence.
- use of enhanced acoustic communication using advanced bandwidth compression.

2.4 Bottom Crawling Vehicles

ROVs in this category are limited in number and each has been developed for a specific mission. Most of these systems are designed to conduct pipeline or cable laying missions. However, the University of California, Scripps Institution of Oceanography, Marine Physical Laboratory bottom crawling vehicle, RUM III, the latest in the RUM development series, is designed to perform research in the deep ocean and on the seafloor.

3. ROV SYSTEM COMPONENTS

3.1 Materials and Lubricants

Materials and lubricants used in ROV systems must be selected and designed to operate effectively under arctic conditions. Several factors must be considered:

(1) the mechanical properties of the materials used at cold temperatures,

(2) seals and water tight integrity,

(3) lubricant viscosity,

(4) ice formation on the tether, and

(5) the impact of large and sudden temperature changes.

Many arctic researchers have learned the "hard way" that special preparations and precautions are necessary when operating systems under arctic conditions. Low temperatures change the strength, elasticity, and hardness of metals and generally reduce their impact resistance. Leather, fabrics, and rubber lose their pliability and tensile strength. Rubber, during extreme cold, becomes stiff and flexing may cause it to break. Rubber, rubber compound seals, and O-rings can warp. Plastic, ceramics, and other synthetic materials are less ductile. Items composed of moving parts and of different materials can experience changes in tolerances thus operate with reduced efficiency. Glass may crack if it is exposed to sudden change in temperature.

Lubricants destined for use in ROV systems that are not specifically developed for cold weather use may congeal and retard the motion of moving parts if exposed to freezing arctic air temperatures. Low temperature lubricants (oils and greases) developed expressly for the winterizing of equipment may be suitable, but should be evaluated before going into the Arctic. Lubricants must have a low rate of viscosity change, a freedom from corrosive actions, and low volubility. Cold weather lubricants must be capable of diffusion over all surfaces requiring lubrication, and permeation of the pores and surface cracks of metal. Cold weather lubricants will evaporate at a more rapid rate than do regular lubricants at low temperatures. Their tendency to dry out requires frequent checking of lubricated surfaces and repeated replenishment. Oils, at cold temperatures, become more viscous and difficult to pump to places where lubrication is needed. Higher viscosity oils, until they become hot, increase the drag on engines and moving parts. Grease, which is a semisolid, also becomes more viscous and loses some of its lubrication properties. Lubricants are difficult to apply at cold temperature, fittings may be frozen and brittle, so that lubrication should be done in heated spaces.

3.2 ROV Structure

The fundamental structure for larger versions of tethered swimming and towed ROVs is an open rectangular frame. The framework serves the function of enclosing, supporting, and protecting the vehicle components (thrusters, junction boxes, television, lights, etc.). The frame size in most designs represents the outside dimensions of the ROV.

Small ROVs and AUVs are usually fully covered with a shroud over selected portions to improve hydrodynamic performance. Hydrodynamic considerations are more important to a small tethered swimming ROV than desired flexibility of access to the subsystems in larger systems. Vehicle size varies widely and ranges from the size of a beach ball, e.g., Hydro Products RCV-225 (0.17 cu. m.) to the automobile size of ERIC II (27 cu. m.).

Manipulators and mechanical "grippers" (for stabilizing the ROV during work functions) may extend well beyond the protective framework. In some instances grippers and manipulators are folded so as to retract within the protection of the frame. Some tethered swimming ROVs are operated from a deployment cage. The deployment cage provides protection during launch and retrieval; the time when an ROV is particularly vulnerable to damage from contact with other structures. Deployment cages are also open rectangular metal frame structures and may house a substantial portion of the umbilical tether cable.

3.3 Remote and On-Board Power

ROV electrical requirements vary by design. Most common are 50/60 Hz and 220/440 VAC. ROV instrumentation and power requirements can be accommodated, in part or totally, by most surface support platforms. The basic portability of an ROV system may generate the impression that the systems can function from any suitable platform. However, experience has shown that ROV dependency on ships power may be neither adequate nor reliable. Dedicated AC power sources are considered desirable and are required in those instances where surface support platform power is either unavailable or unreliable. Electrical interference in the custom designed ROV power/communications cable is negligible in most systems.

Battery power is a convenient portable energy source and has many applications. ROV auxiliaries are often equipped with a self-contained battery power source to obviate the need for utilizing a portion of the power supply provided through the umbilical or limited hotel load of an autonomous vehicle.

The extreme atmospheric cold that can be encountered in arctic regions requires a special awareness of maintenance and use of battery power. Three environments have to be considered -- a warm heated shelter, ambient air temperature exposure and water temperature exposure. In the Arctic, buildings are often overheated (25-30°C), the air temperature may be -50°C or colder, and the water temperature will never be colder than -2°C. Batteries, in general, sustain a loss of output capacity as the temperature decreases. Lead-acid batteries should be transported to the Arctic without electrolyte in the cells. The concentrated electrolyte should be properly diluted before being added to the cells for use. If they freeze, the expanded solution will crack the battery cases. Batteries, should be operated and stored in insulated containers and should be warm before taken outdoors to be used in subzero temperatures. Care and protection should be given to batteries with a low charge because the acid content of the electrolyte is lower and the solutions freeeze at higher temperature. Batteries used at low temperatures should be maintained at full charge.

Guidance for the selection and use of batteries in polar regions:

1. Dry cell batteries used for cold weather operations should be of the high energy type. As the temperature of a battery falls its amperage output is reduced. For example, at -40°C, a good flashlight battery is inoperative.

2. At -20°C, the carbon-zinc battery is usually inoperative unless special low temperature electrolytes are used.

3. Wet cell storage batteries are dependable for cold weather operation when they are specifically serviced and protected. However, they are generally too heavy for providing power for ROV auxiliary instruments and sensors.

4. Lightweight, high energy, wet cells operate well at -30°C and can be clustered to supply necessary operating power to auxiliary equipment.

5. There are wet cells designed to operate at -70°C such as the Yardney Silver-Zinc battery.

6. Alkaline-manganese primary batteries are good at low temperatures.

7. Nickel-cadmium cells experience a relatively small change of output capacity over a wide range of operating temperatures.

8. In the past, mercury batteries have not performed well at low temperatures, however, recent developments have produced several popular cell sizes that do.

9. Inorganic lithium cell power sources offer high volumetric and weight efficiencies.

10. Silver oxide batteries are used in expendable sound velocimeters because of their long shelf-life and good low temperature performance.

11. Since a battery does not reach ambient temperature immediately, insulation is helpful in transition from very cold air temperatures (-10°C and lower) to water temperatures (-1.8°C).

Despite recent progress to achieve reliable, small, high energy density, long endurance power supplies suitable to support arctic deployments of data buoys, oceanographic instruments, small manned stations, and autonomous vehicles, it is a problem that has not been completely solved.

3.4 Small Self Contained Power Sources

Unmanned untethered underwater vehicles require self contained power sources to operate life support, propulsion, controls and sensor systems. The type of the power source depends on the application. Broadly, the available power systems can be divided into the following categories:

- Nuclear
- Gas Turbine
- Gas Engine
- Diesel Engine
- Liquid Propellent
- Solid Propellent
- Fuel Cell
- Battery

Torpedoes used closed cycle gas and diesel engines and more recently solid propellents to achieve their high speed, short endurance mission. These power systems are unsuited for the long endurance mission requirements or autonomous vehicles. Liquid propellants fall into the same high power low endurance category. For both solid and liquid propellent power sources the burn rate is very difficult to control.

According to the Manual for Manned Submersibles: Design, Operation, Safety and Instrumentation (CNO, 1984) there were one hundred seventy-four operational submersibles at the time of publication, seventy-nine untethered, and all but one are powered by the lead acid batteries. The twenty-five ton Italian prototype diver lock-out vehicle, the PH 1350, is the only submersible using a closed-cycle engine. Regardless of the power system, all current vehicles are electric motors and conventional propellors for propulsion. These units are chosen for efficiency and reliability. Additionally, their performance is easily predicted with established theory. Lead acid batteries are chosen most often because these vehicles are designed almost exclusively for missions where duration is less than 24 hours. None of the power systems listed in the Manual meet the design requirements for autonomous long endurance missions.

A recent review of battery technology has been published by Smith (1985). In this review he summarizes the types, applications, properties, construction, and performance characteristics of batteries. Table 3.1 is taken from this reference and shows battery characteristics for various types of chemical batteries. The table provides information on the "practical" energy and power densities. It shows how chemical composition affects cell voltage, and the increase in energy and power densities for batteries containing lighter elements such as lithium. However, even for lithium batteries, which have a power density of about an order of magnitude higher than lead-acid batteries, it would require a large mass to

Table 3.1 Battery Characteristics

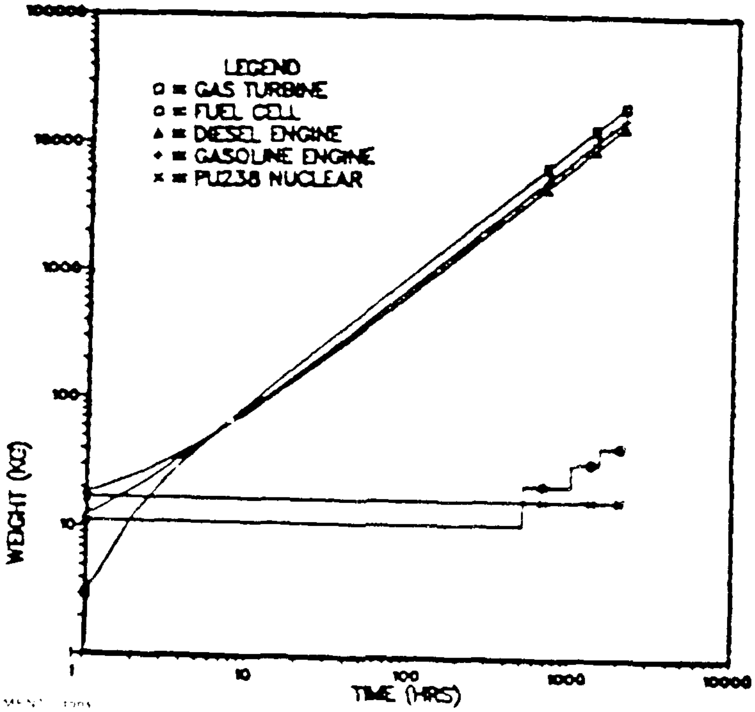
Battery	Voltage (per cell) (V)	Energy Density (WH/Kg)	Power Density (W/Kg)
Lead-Acid (SLI)	2.04	20-30	50-75
Lead-Acid (Traction)	2.04	10-20	50-75
Nickel-Zinc	1.74	50-70	100
Nickel-Iron	1.37	54	120
Nickel-Cadmium	1.3	15-30	100
Nickel-Hydrogen	1.32	45-50	200-250
Lithium-Titanium Disulfide	2.1	100	TBD
Sodium-Sulfur	2.0	60	30-100
Lithium-Thionyl Chrloride	3.6	200-700	400
Lithium-Silver Oxide	2.2	200	1000

achieve sustained high power outputs. Batteries are best suited for short to medium term low power applications. Other aspects that must be considered in battery applications are storage, shelf life, activation, and safety in undersea application.

Figure 3.1 shows a comparison of power system weight for five possible candidates (gas turbine, fuel cell, diesel engine, gasoline engine, nuclear) as a function of the operation time for a 10 kw system (Smith et.al, 1986). Note the exponential increase in weight as a function of endurance (time) for closed cycle systems. Table 3.2 (page 3-13) shows the power-to-weight ratio, nominal efficiency, normalized for a 10 kw system. The 10 kw requirement is an arbitrary value selected to make this comparison. The curves in Figure 3.1 are computed assuming a gas turbine fuel consumption of 120 percent, and diesel engine fuel consumption of 80 percent of the gasoline engine with a 14:1 fuel to air ratio.

Small self contained power systems for autonomous vehicles required to operate at depths to several thousand meters for several months are limited to a few choices. Only the nuclear and fuel cell technology offers the capacity required for long endurance operational requirement. Figure 3.2 shows the power delivered to the water required for low drag hulls of various displacements and speed requirements (Boretz, 1984). A one ton vehicle operating at 10 knots, requires 2.5 kw and is marked in the figure. Figure 3.3 shows the power system's weight as a function of mission duration for various sources required to provide 2.5 kw. Clearly, for long duration missions only fuel cells and nuclear power sources can meet the endurance requirements for extended missions.

Figure 3.1. System weight as a function of operation time with exponential growth of internal combustion engine weight (from Smith et al, 1986)



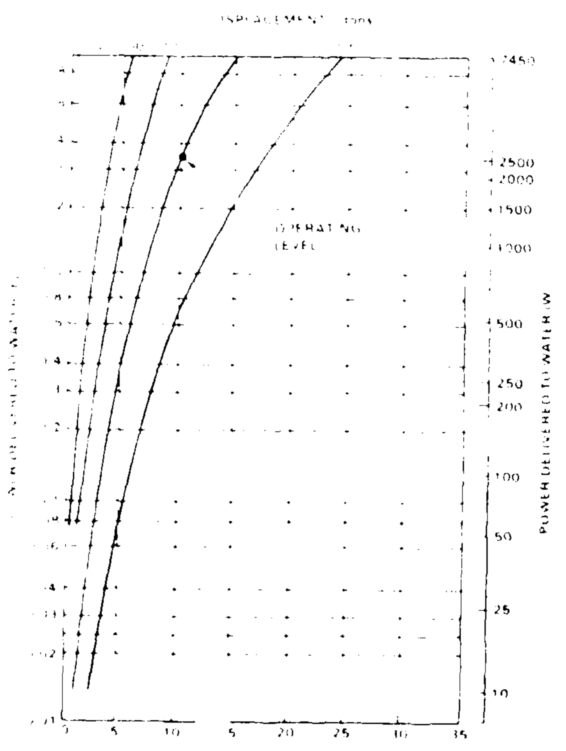


Figure 3.2. Submersible power delivered to water versus speed (from Boretz, 1984)

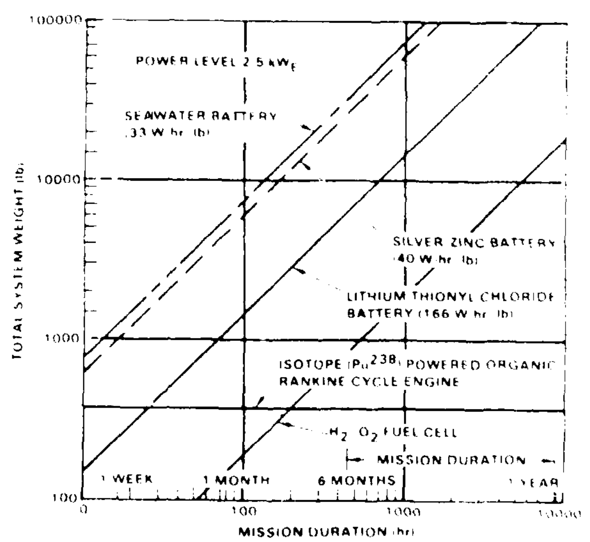


Figure 3.3. Comparison between ORCEPS and Electro-Chemical Storage Systems (from Boretz, 1984)

However, closed cycle diesel systems may provide an option for larger vehicles.

The nuclear power plant is an indirect energy conversion system, while the fuel cell is a direct energy conversion system which offers very high efficiency (Table 3.2).

Boretz (1984, 1985) describes a nuclear plant based on the organic Rankine cycle electric power system (ORCEPS). Figure 3.4 is a schematic representation of this system. The isotope heat source provides thermal energy to the boiler which supplies a superheated organic working fluid to the turbine of a closed Rankine cycle system. Table 3.3 shows the characteristics of some candidate isotopes, and Table 3.4 shows the design parameters for a .5 to 2.5 kw system. An alternative design (Figure 3.5) replacing the thermoelectric generator (TEG) with a samarium cobalt permanent magnet (PM) alternator would provide for not only propulsion but also sensor electrical power requirements. This design improves efficiency resulting in reduced isotope inventory and reduces materials cost as operating temperatures are reduced from 1800° F for the TEG to 800° F.

There are two commercial nuclear systems in the planning stage. The Canadian AMPS which is expected to be available in 1991 in the SAGA-N vessel. The second is the TRW ORCEPS system described previously for which there is no production schedule available. Both systems would be capable of producing 10 kw of power for at least 1000 hours of operation.

Fuel cells were originaly developed for the National Aeronautics and Space Administration as power supplies for space craft. Many types of fuel cells are available commerci-

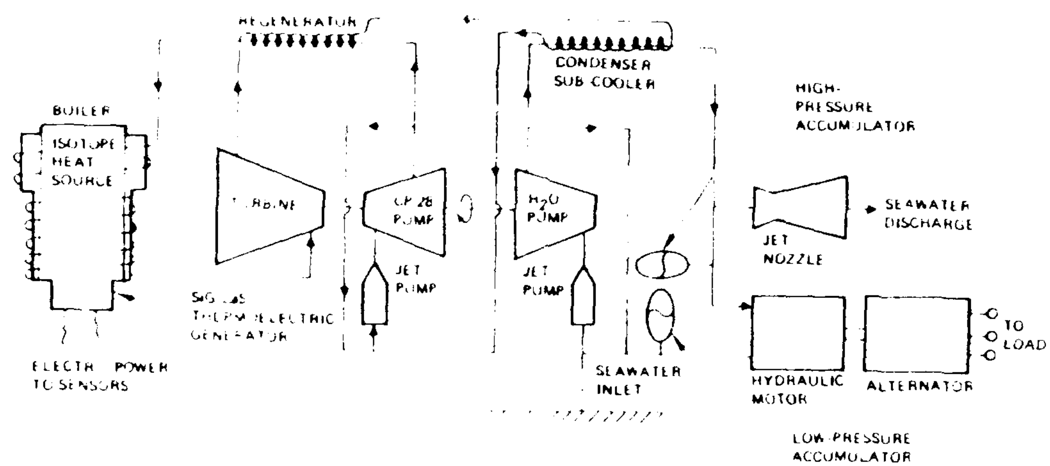


Figure 3.4. Silent compact radioisotope powered submersible - Type A. (from Boretz, 1985)

Table 3.2. The Impact of Power-to-Weight Ratio on Initial Power System Weight for a Ten Kilowatt Demand (from Smith, et al, 1986)

System	Power-to-Weight Ratio (kW/kg)	Nominal Efficiency (%)	Initial System Weight (kg)
Nuclear	0.60	40	16.67
Gas Turbine	3.30	20	3.03
Diesel Engine	0.55	35	18.18
Gasoline Engine	0.82	25	12.20
Fuel Cell	0.91	90	11.00

Table 3.3. Characteristics of candidate isotopes (from Boretz, 1985)

FUEL	Tm-170	P_o-210	GdP_o	Cm-242	Cm-244	Pu-238(REF)
HALF-LIFE	127 DAYS	138.4 DAYS	138.4 DAYS	163 DAYS	18.1 YR.	87.8 YR.
MODE OF DECAY	BETA	ALPHA	ALPHA	ALPHA	ALPHA	ALPHA
SPECIFIC POWER (PURE (WATTS/GM-ISOTOPE)	13.6	144.0	144.0	120.0	28.4	0.56
SPECIFIC ACTIVITY (CURIES/WATT)	445	31	31	28	29	30
SPONTANEOUS FISSION HALF-LIFE (YEAR)	--	--	--	7.2×10^6	1.4×10^7	4.9×10^{10}
FUEL FORM	METAL	METAL	RARE EARTH POLONIDE	Cm_2O_3	Cm_2O_3	PuO_2
SHIELDING REQUIRED	MODERATE	MINOR	MINOR	MINOR	MODERATE	MINOR
SPECIFIC POWER (WATTS/GM-FUEL FORM)	2.1	140	78	90	2.4	0.4
SPECIFIC WEIGHT (LB-FUEL FORM/KW_T)	1.050	0.0157	~0.030	0.0245	0.958	5.512
HEAT SOURCE FLIGHT APPLICATIONS OR OTHER	NONE	SNAP-29	SNAP-29	SNAP-11	NONE	SNAP-3A -9A -19 -27 KIPS/BIPS

Table 3.4. Remotely powered submersible system design parameters (from Boretz, 1985)

Working fluid	Toulene (Monsanto CP-25)
Turbine inlet temperature	650°F
Turbine inlet pressure	300 PSIA
Cycle flow rate	0.4323 lb/min
Turbine outlet pressure	5.0 PSIA
Condenser temperature	170°F
Condenser pressure	~5.0 PSIA
Turbine outlet temperature (ideal)	447°F
Turbine outlet temperature (actual)	490.2°F
Turbo-generator speed	48,000 RPM
Turbine efficiency	0.80
Cycle pump efficiency	0.60
Generator efficiency	0.85
Regenerator effectiveness	0.90
Boiler efficiency	0.90
Output power level range	500-2500 watts
Sonobuoy velocity	5 to 10 knots
	5.76 to 11.5 MPH
	8.44 to 16.87 ft/sec
Radioisotope	Pu 238 (87.8 yr half life)
Mission Duration	1000 hours or greater

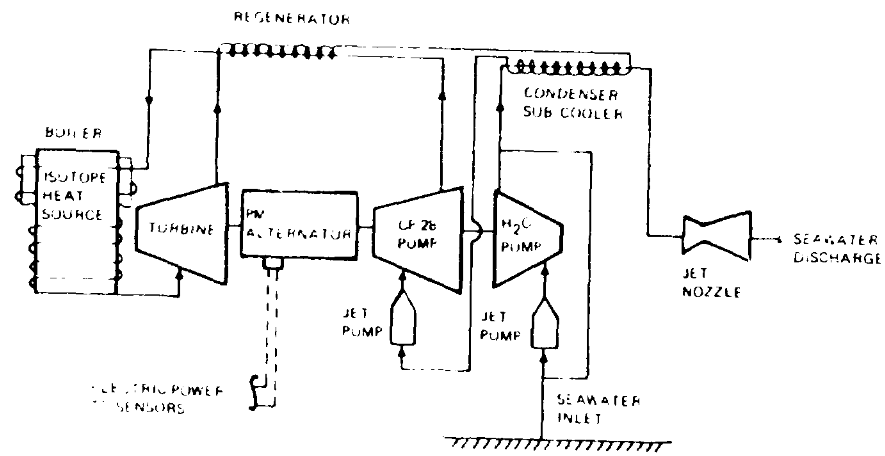


Figure 3.5. Silent compact radioisotope powered submersible - Type C. (from Boretz, 1985)

ally, the primary difference among them being the chemicals used as oxidizers and reactants. Two examples of such cells are the hydrogen-oxygen cell and the hydrazine-hydrogen peroxide cell.

The ALSTHOM ten-kilowatt self-contained cell is a hydrazine-hydrogen peroxide cell. It will produce full power for a minimum of 500 hours, but weighs only eleven kilograms. Designed specifically for use onboard submersibles, it was tested onboard the vessel STAR 1. The major disadvantage of this system is its excessive cost--hydrazine is approximately $45.00 per liter, while a 50 percent solution of hydrogen peroxide is $23.00 per liter. Thus, a hydrazine-hydrogen peroxide cell represents a substantial cost in both the construction and life cycle use of the vehicle. Both chemicals are considered to be hazardous. Hydrazine is toxic, flammable, and highly reactive, requiring special procedures for handling under any conditions. Hydrogen peroxide is a strong oxidizer. It can irritate skin and eyes. It also requires careful evaluation of its compatability for storage and handling when in the presence of other materials.

The second example of a fuel cell is the hydrogen-oxygen system engineered for the DSRV-PC15, but never installed. This hydrogen-oxygen system will provide ten kilowatts for seventy hours, but it weighs more than four tons. This unacceptable weight addition is due primarily to the cryogenic storage containers for both the hydrogen and the oxygen. In addition, waste water produced by the system is stored onboard the vessel. A similar system was installed onboard the vessel Deep Quest, which completed nineteen dives with an energy production of one-thousand kilowatt hours. Note that Deep Quest is no longer listed as operational in the Manual of Manned Submersibles.

Despite these problems, both the nuclear system and the fuel cells are possible power sources for a submersible with extended range requirements. An evaluation of these two alternatives will help to determine which of these may be the most appropriate.

Several factors need to be considered in comparing nuclear and fuel cell power systems for autonomous vehicles of the future. These are:

- Stage of development
- Complexity
- Size limitations
- Safety
- Reliability
- Life cycle costs
- Technology development risk

Fuel cells are a proven and established technology in comparison to nuclear systems. Furthermore, nuclear systems are regulated by international treaties, and their use as power sources may not be possible for unattended ocean deployment. The fuel cell is simple, relatively light, reliable and highly efficient in energy conversion. Their life cycle costs would be low compared to nuclear systems. However, the nuclear system provides potentially greater endurance.

Energy Conversion Systems, Inc. (ECS), Canada, specialists in small nuclear power source design, and the

International Submarine Engineering, Ltd. (ISE) have jointly undertaken a program directed toward the development of a proof-of-concept nuclear powered robotic vehicle.

The nuclear power source proposed for the subject vehicle will use a fully developed and working reactor, SLOWPOKE, which has been licensed in Canada for unattended continuous full power operation. It is the only reactor in the world so licensed.

SLOWPOKE consists of a non-pressurized convectively cooled light water moderated, beryllium reflected reactor. The core comprises the fuel cage and fuel elements with overall dimensions of 8.9 inches high and 16.7 inches in diameter. The reactor and energy conversion system to meet AUV power requirements can easily be contained within the envelope the size of a conventional torpedo. The original SLOWPOKE reactor and its descendants have operated for approximately 36 trouble-free, full-power years. A complete SLOWPOKE system sells for $650,000. An AUV equipped with such a power supply could make substantial underwater track sorties for environmental and acoustic data acquisition.

A novel technique for the extraction of oxygen from seawater is being investigated by Aquanautics, Inc. Mr. Steve Carnavale (personal communication) indicated that the firm has successfully extracted one-half liter of oxygen per minute directly from seawater. Such an inexhaustible oxygen supply, when combined with another fuel, can be used in a fuel cell or combustion engine, to provide long-life power for military marine applications. The company is currently working on Phase II of a DARPA contract. This is the second step in testing its technology which is ear-marked for propulsion of an autonomous vehicle. This new technology will, if successful, provide for longer-range endurance beyond that currently available from batteries or stored oxygen and at a substantially lower cost than nuclear power. The DARPA program manager and point-of-contact is CDR Ralph Chatham.

3.5 Umbilical Tether Cable

A key tethered free-swimming ROV subsystem is the umbilical cable that provides power to and communications with the ROV. Mission requirements strongly influence the design and operational effectiveness of the ROV umbilical. ROVs that tow the full cable at its operating depth requires propulsion/power capabilities quite different from an ROV system that uses a deployment cage. The ROV is then burdened only with a tether extending from the cage out to its maximum operational radius. There is little commonality in umbilicals, particularly for ROVs not of the same class or manufacturers production run.

Umbilical cable varies greatly from one vehicle to another, some cables are positvely buoyant, while others are negatively buoyant. Negatively buoyant cables may be made less negative by the addition of flotation devices, but these are cumbersome and add drag that must be overcome by the ROV.

Most umbilical cables contain a strength member, conductors for power, and communication conductors for control and data telemetry. They are all encased in a protective sheath of neoprene or polyurethane for insulation and abrasion protection. Diameter of such unitized cables range from 6.3 mm (0.24 in.) to 38 mm (1.5 in.). One to three coaxial conductors are often used in addition to solid core conductors. The longest umbilical in use is the U.S. Navy's RUWS system cable. It is 6,858 m (22,500 feet) and transmits all power, command and control functions, television and sonar over a single coaxial cable through use of time sharing and frequency multiplexing techniques.

Most conventional power cables are unsuitable for use in temperatures below -10°C because of extreme brittleness of synthetic rubber insulation. Either a low voltage, natural rubber insulated cable especially manufactured for low temperature or a validated substitute material suitable for arctic extreme low temperature use and ice abrasion resistance should be specified for any arctic ROV applications.

Fiber optic umbilical cables were first used for ROV applications about 1982. This technology was incorporated into the umbilical cable for the Slingsby Engineering ROV SOLO, in 1982. Fifty micron fibers with 125 micron cladding allow for considerable data transmission expansion. An LED system with frequency shift keying was adopted from other commercial practices where it has proven to be very reliable. Using fiber optic transmission, studio quality pictures can be obtained.

Umbilical cables also serve as a lift member during the launch and retrieval of an ROV. For large systems the strength member is usually Kevlar, a high strength-to-weight synthetic fiber. To reduce the size and weight of an umbilical, a separate lift line is substituted for the launch and retrieval phase of an at-sea operation. Most cables are negatively buoyant. Therefore, a length of broken umbilical may exceed available ROV reserve buoyance, and carry it to the bottom. To overcome a potential catastrophe a variety of flotation devices are available for attachment to the umbilical. Some of them also serve to reduce abrasion caused by a cable catenary reaching the seafloor and to a degree it reduces some of the bottom drag that must be overcome by ROV propulsion thrust.

3.6 Acoustic Communication Links

Although untethered vehicle development is tending toward full computer controlled autonomous operation, there will remain periodic need for operator supervision of some missions and communications between an operator and the vehicle. However, acoustic communications using the Frequency Shift Key (FSK) method or other encoding techniques can provide reliable means of two-way data communications between the support platform and the AUV. Such a data link uses advanced signal processing and error encoding techniques to provide users with reliable telemetry at a data rate of 50 baud.

An acoustic telemetry system has been developed by International Submarine Technology, Ltd., Redmond, WA, to support the AUV ARCS for the severe multipath conditions that it will encounter in the shallow-water underice arctic environment. This system was developed for long-range, medium-rate, full duplex digital data transmission in water depths varying from 10 m, to 200 m. The system includes the capability to overcome the Doppler shift generated by the AUVs velocity. The system consists of a transmitter and a receiver which may be used together for full duplex communications, or singly for one-way communications. A communications range of 4500 m is possible in the full duplex mode. Greater range is achievable in the one-way mode. Communication was maintained at a distance of four miles and at AUV speeds up to 7 knots despite external noise and severe multipath interference at a non-arctic test site. The manufacturer claims Doppler immunity to 8 knots. Data rate can be varied to suit multipath conditions. Available data rates include 24, 50, 100 and 200 bits per second. From field tests the system was found to provide a reliable 50 baud, full duplex, synchronous link through water. Although acoustic systems lack the communication capacity achievable with hard-wire or fiber optics it does offer a useful real-time communications link with autonomous vehicles. This feature permits data sampling to ensure that sensor(s) are functioning and gives the operator an opportunity to make decisions regarding vehicle maneuvers. Onboard data storage from add-on sensors will have to be used to achieve a greater data set.

A vertical cone acoustic transmission system has been developed for the AUV AUSS that can handle 4800 baud -- enough for good quality video signal transmission.

3.7 Television

The larger ROVs frequently have two or more television cameras which are often mounted on pan-and-tilt units;

this allows for increased viewing area, viewing different scenes simultaneously, accommodation for a somewhat reduced maneuverability in restricted environments, and redundancy. Two cameras are often employed as follows: one is fixed and used by the pilot for navigation and maneuvering and the second is mounted on a pan-and-tilt mechanism and dedicated to use by the customer (an engineer, scientist, etc.). Television camera position control, as indicated above, may be accomplished by maneuvering the ROV. The position of television cameras and artificial illumination is important to provide adequate viewing perspective and to reduce illumination backscatter. Some manipulator systems include an auxillary television located on the arm and close to the work site; this serves to expedite manipulation of tools and to partially overcome longer viewing under turbid water situations. Manipulator operations are viewed and controlled by a topside operator.

3.8 Lights

Light sources are independently housed and are available in power ranges from 45 to 1,000 watts. The relatively high power requirements of lights must be accommodated through the umbilical. Quartz iodide lights are most commonly used but mercury vapor, tungsten iodide and thallium iodide lights are also used. The lights are usually located to support both the operator's television and are located on the bow of the ROV. To reduce the effect of backscatter some are mounted on extendable or fixed booms or at off-center locations. If still camera arrays are used for seafloor surveys then the lighting may be directed down. Stroboscopic light sources, usually in the 250 microwattsecond range, are used with a still camera.

3.9 Film and Video Camera Recording

Documentation of underwater scenes and situations is often accomplished with a still camera (with strobe lighting). Video camera recording can be accomplished on-board the ROV (limited to one cassette) or at the surface. The quality of video cameras and recording is improving rapidly and will likely replace most film systems, since video systems provide valued real-time viewing and recording.

3.10 Manipulators/Tools

The effective performance of useful work by an ROV is strongly dependent upon the availability of one or more manipulators, tools that can be placed and operated by a manipulator, and adequate optical viewing. The degrees of freedom or motion of an arm and its dimensions determine the manipulator's operating envelope and its ability to position its hand (or an object/tool) in space. There are three types of manipulators that are currently used on ROVs:

1. Rate controlled limited motions (3-5 degrees of freedom). Control of the manipulators and tools is generally accomplished by toggle switches or joy stick. Typical work capability includes recovery of small objects, simple module replacement and as a restraint device.

2. Rate controlled all motions (7 degrees of freedom). Control of the manipulators and tools is generally accomplished by toggle switches or

joy stick. Typical work capability includes debris removal, simple power tool/cleaning tasks. Task performances are relatively long.

3. Master/slave manipulator with force feedback. This type is also known as a spatial correspondent manipulator system since the master/slave units operate in synchrony and the two manipulators are geometrically similar. Master-slave manipulator system technology has not been widely adopted. Typical work capability includes complex tasks -- drill, tap, assemble, disassemble, non-destructive testing.

The spectrum of tasks that can be accomplished by a remotely operated manipulator, for the most part, fall in these generic classes:

1. recovery of objects,
2. simple assembly and disassembly operations,
3. making and breaking connections (hoses, pipes, electrical lines), and
4. docking.

Of the above tasks, it is frequently possible to recover objects, and in some cases to achieve docking with manipulators, with less than six degrees of freedom, but the other tasks require the full number of motions unless supplemented by vehicle mobility.

Vision is the most important sensing support for the remotely located manipulator operator. For example, it is estimated that 70% of the useful sensing capability for a force feedback manipulator operator comes from optical viewing. As a comprehensive explanation on viewing is not possible here, it is important to stress that viewing is dependent on viewing angle, water clarity and acceptable levels of backscatter (particularly when artificial illumination is used). The performance of some tasks makes it desirable to have three active television cameras available:

- a fixed wide angle camera for an over-all view for the operator,
- a camera on a pan-and-tilt mount with a zoom lens for selective close viewing,
- a camera manipulator either hand held or fixed on the wrist or forearm.

The number of firms manufacturing manipulators for underwater applications is adequate for the buyer to select an off-the-shelf unit or to have one customized from available components.

Requirements for tools to be placed or operated by the manipulator "hand" have been identified for most generic functions. The "hand" or terminal device of most anthropomorphic manipulators is usually capable of gripping and rotating. Simple, light load tasks can be accomplished with this terminal device. In many instances a specialized tool is more appropriate and its power requirements are frequently met by a dedicated power source (electric or hydraulic). Accessory tools include water jets, various kinds of cutters, impact wrenches, stud fastener guns and attachment devices.

3.11 ROV Propulsion/Maneuverability/Self Noise

There is a nearly universal use of electric driven propellers for propulsion. Only a few systems have water jets. Drive motors may be electric or hydraulic. The larger vehicles normally use a shrouded Kort nozzle propeller. This provides both greater efficiency and protection against propeller contact damage and ingestion of debris. The number of propulsion units per vehicle is dependent on desired levels of maneuverability and total thrust with three thrusters considered minimum.

Six degrees of motion are almost a standard requirement for tethered swimming ROVs. Three are translational: thrust, heave and slide or sway; three are rotation: yaw, pitch, and roll. Reversible electric motors provide reversible thrust and the combined maneuvering forces allow for three-dimensional movement without the forward motion required by rudder controlled vehicles.

3.12 Operating Depth Rating and Horizontal Range

The majority of commercial ROVs have a design operating depth of less that 330 m. However, several Navy ROVs developed as R&D vehicles have been influenced by anticipated Navy missions and have operating depth ratings to 6,000 m (98% of the seafloor can be reached with this capability). Several commercial ROVs could be immediately qualified for deeper depths by the addition of a longer umbilical cable as all other components are compensated for full depth operations.

Horizontal range capability has not been a particularly important parameter for tethered free-swimming ROV applications in the offshore oil and gas industry. In most industry operational scenarios the ROV can be effectively employed within a short horizontal excursion radius of the site; either from the launching platform or from a deployment cage. Under-ice mission scenarios are expected to require a longer horizontal operating radius. Cable technology is not expected to change significantly in the next decade to allow for major growth in ROV horizontal operating range capabilities of tethered free-swimming ROVs. Systems that can operate effectively on a self-contained power source and light weight fiber optics cable for command/control/and data telemetry would be more suitable for scientific acoustic research functions. The present maximum horizontal range is less than 500 meters.

3.13 Speed and Thrust

Tethered ROVs, as a class have speeds ranging from 0.5 to 4 knots with the average approximately 2.5 knots. Tethered free-swimming ROV propulsion designs are dedicated primarily to maneuvering functions and to overcoming reasonable ocean currents, not speed. The capability to reach and stay at the work site in order to complete specific tasks expeditiously is fundamental to commercial and military applications.

Vehicle speed performance is a result of umbilical size, length of free umbilical, ocean current profile, vehicle hydrodynamics, thruster horsepower, rpm and propeller characteristics. These parameters are interrelated. In general, the system drag equation is umbilical dominated. This factor influenced the design and adoption of a deployment cage for many systems. The primary cable length and lift support are in the cable connection between the launch/ retrieval winch and the deployment cage. The ROV is thereby relieved of all but the short and lighter design umbilical tether between the ROV and to the deployment cage.

3.14 Acoustic Subsystems

Acoustic subsystems have come to provide capabilities to support not only the operations of ROVs, but also contribute significantly to their performance specifications. The descriptions here are brief and are included to indicate the range of subsystems that have been found useful to support ROV operations.

Navigation and Sub-Sea Positioning

ROV navigational requirements are varied and the number of commercial acoustic systems to meet them are many. Most have emerged to meet specific ROV requirements. Requirements for an ROV navigational system are directly tied to the ROV operational effectiveness. The spectrum of operational requirements has widened greatly in the past decade, creating the need for task oriented and dedicated ROV tracking and navigational systems.

The classical acoustic depth sounders are used to determine vehicle altitude above the sea floor and distance below the sea surface when mounted in an upward looking direction.

The following characteristics are common to most ROV field operations and are to be considered in the navigational equipment selection process.

1. The surface control station equipment must be designed to withstand the marine environment. This includes the consideration of platform motion and vibration, exposure to salt and sea air and substantial temperature and humidity variations (a particular concern in polar regions).

2. The surface platform type may vary dramatically. Equipment, to be effective, must be readily transportable to different sites and used on different platforms; surface vessels, fixed platforms, ice canopy and ice islands, etc.). The equipment needs to be portable, easy to install and designed to be used from both small boats and large platforms. Mobilization and demobilization time and cost requirements should be minimized.

3. Availability and performance must be reliable and consistent. The operator has to depend on availability, repeatability and reliability in performing to required standards. The equipment must also be designed to operate across the spectrum of operational depths and geometries.

4. The system must be simple to use and maintain. Personnel turnover, commercial or military, and lack of experienced operators dictate the need for simplified operator interface and maintenance.

5. Proper position display should give the operator a line of sight between the vehicle and another subsea point, reducing the time it takes to travel from point A to point B.

6. By using additional beacons to mark subsea locations, the time it takes to relocate a site can be reduced considerably, especially when visibility is poor.

7. For initial site location where there is no acoustic marker, an alphanumeric and graphic readout in rectangular (X and Y) coordinates provides the information necessary to run an efficient grid search.

8. If the vehicle umbilical is severed, the system's real-time range and bearing information significantly reduces recovery time and improves the probability of success.

Sub-sea positioning, navigation, tracking and relocation of ROVs has evolved through long baseline, short baseline, to ultra-short baseline. Each of these techniques is applicable to arctic requirements and researchers will likely find use for each of them at one time or another.

The earliest systems were known as long baseline and involved the deployment of several transponders on the seafloor, accurate relative calibration, then fixing by slant range measurement by interrogation from a *single transducer* mounted on a surface vessel hull. These systems required a significant amount of subsea hardware, frequently lengthy calibration, and a highly trained operator to achieve valid data.

In the 1970s the short baseline technology was adopted. This consisted of a subsea transponder beacon and an array of at least 3 hydrophones mounted in an orthogonal array on a vessel. ROV position was calculated on pulse arrival angle and time.

In the mid-70s the ultra-short baseline system was introduced and it has become the most widely used technology for ROV navigation. A single sub-sea transponder is required. A transducer is used in conjunction with a multi-element hydrophone mounted on the support vessel hull. Again, arrival time and phase angle are measured for each element. Phase differences in the horizontal and vertical planes result in measured azimuth and slant angle. Given a known vertical separation from the beacon and the hydrophone, range is automatically computed by triangulation. Angular measurement accuracies in both instances are typically plus or minus 1 degree. Two inclinometers are included in these systems to account for phase difference errors induced by ship movement.

Transponders for acoustic markers and underwater vehicle positioning are available with remote release, dual command relay output, remote transducer and responder operation.

Sub-sea positioning, navigation, tracking and relocation systems are available from several commercial sources and custom systems can be acquired from most of these firms. For example, 80 to 90% of today's ROV navigational requirements can be satisfied with a system such as HYDROSTAR, manufactured by Honeywell, Inc., Marine Systems Division (Seattle, WA). The Honeywell RS/900 can handle more sophisticated and demanding operations -- complex geophysical surveys, deep-water facility installations, and deep-water ROV operations. The RS/900 operates simultaneously in both long-baseline and short-baseline modes which provides maximum flexibility and optimal accuracy over full-ocean ranges. Several other manufacturers offer navigation and sub-sea positioning systems to meet a variety of ROV needs.

3.15 Obstacle Avoidance/Search and Survey Sonars

Obstacle avoidance/search/survey sonars are available for ROV applications. As these sonars involve different principles of operation each is described.

Fixed Narrow Beam Sonar

Fixed narrow beam depth sonars have been used on manned submersibles and submarines for many years. This simple pulse sonar has been mounted on ROVs to detect near field obstacles and/or to identify positioning clues. The range requirements are modest, the physical size of the transducer is small, and the operating frequency is normally about 50 kHz. However, the fixed field of view, characteristic of this approach, limits its usefulness.

Parametric Sonar

The parameteric sonar uses two transducers operating at a slightly different frequence to generate a difference frequency by wave interference. Though this process is very inefficient (requiring typically 5 to 10 kW at two higher transmit frequencies) its main benefit is that the difference beam (at lower frequency) is essentially identical to that of the two high frequency beams. The beam can, therefore, be very small for a given transducer size. Longer range is possible with this technique due to the lower adsorption losses at low frequencies.

Narrow Beam Mechanical Scanning Sonar

To gain more forward acoustic viewing area a narrow beam mechanical scanning sonar can be used. A wide vertical beam (25° to 50°) can be used to effectively decouple vehicle motion in this plane; the horizontal beamwidth is normally kept narrow (1.4° to 2°) to provide azimuthal resolution. At operating frequencies of 100 kHz to 500 kHz the transducer size is smaller and target resolution good (88 to 213 mm). This type of system can be used for obstacle avoidance, search, and classification depending on the specific design parameters. Slow coverage rate is its most serious drawback. Each bearing must be sampled for the acoustic transit time out to maximum range and back. The higher the bearing resolution and/or acquisition range, the slower the data rate. For example, two commercially available systems advertise 58 seconds for a plus or minus 90° scan at a 400 meter range setting and 10 seconds for a plus or minus 90° scan at 100 meters, respectively. The output data is displayed on a Plan Position Indicator (P.P.I.). It must be recognized that the uncompensated vehicle motion during slow scan can significantly distort the output. As detection/classification is most often a process of relative comparisons rather than absolutes, distortion can become a significant liability. Additionally, in a generic sense mechanical scanning systems are often unreliable.

Continous Transmission Frequency Modulation Sonar

Continuous transmission frequency modulation (CTFM) sonars are a variation of mechanically scanning sonars. CTFM converts range (time) to the frequency domain by transmitting a continuous sawtooth frequency slide pulse. This type of sonar has been effectively used on manned submersibles and

ROVs as an obstacle avoidance sonar because of its small size and relatively good target detection capabilities.

Phase Comparison Sonar

Phase comparison type sonars process the phase information inherent in a return to determine bearing. Time of arrival, phase or correlation interval measurements are made on two or more wide beam elements to determine bearing of the return. Data rate is improved over simple mechanical scan systems in that large bearing slices are processed in a single, two-way acoustic travel time interval. However, bearing resolution is proportional to the signal-to-noise-ratio and the processor may become confused by numerous simultaneous targets of comparable amplitude but different phase typical of interface returns.

Side Scan Sonar

Side-scan sonar looks to the side and is very effective for seafloor search and identification. It is usually towed by a surface vessel. The system operates on the concept of displaying interruption in reverberation caused by the acoustic target shadow. The length of the shadow can be used to estimate the vertical relief of the target. The length of the target can be determined by the along track shadow assuming vehicle speed is known and side-lobe detection is precluded. The horizontal image build-up requires vehicle motion, and one "fly by" may be inadequate to determine geometries. Distortion will be experienced if vehicle attidude and/or speed changes occur. ROV/AUV speeds are in a range highly compatible with side look sonar performance characteristics.

Multi-Beam Sonar

Multi-beam sonars operate on the principle that a multi-element fixed array can be electronically steered in bearing. Duplicate electronic steering networks generate a number of adjacent preformed beams to cover a given arc. Electronic scanning of these fixed beams, within the transmit pulse width, achieve complete bearing coverage in the time interval for sound to travel to maximum range and return. In low resolution sonars with the beam widths that might be used by ROVs/AUVs for obstacle avoidance, electronic focusing is not required and the spatial separation of the beams can be accomplished by a circular array of transducer elements. Although multi-beam sonars have not been applied to ROV platforms the virtues of these systems are important to gaining swath sweep survey capability. Even though there is a lot of parallel channel redundancy, its main disadvantage is the requirement for a fair amount of electronics. Recent and projected advances in solid state electronic technology is expected to reduce this disadvantage. The multi-beam approach has been employed extensively by the U. S. Navy and NOAA for bathymetric survey vessels. Multi-beam has the potential of being used both in the vertical and horizontal to produce bottom survey data and obstacle avoidance for the vehicle. Also in the vertical, an upward directed multi-beam could provide underice topography data.

Scanning Profiler Sonar

It is not unusual to have severely occluded optical viewing conditions around a bottom-crawling ROV. A high resolution, high speed, scanning echo-sounder has been developed by Ulvertech, Ltd., Cumbria, England, that provides real-time graphic or video displays and digital magnetic tape recordings. This system (the Dual Scanning Profiler) shows the position of a pipeline or cable burial and any trench erosion or scouring that has taken place. The acquired information is a composite display of two scanning heads. Using a computer the data obtained can be prepared for plotting cross-sections and depth presentations. Outlines of pipelines, cables, dredged areas and the condition of structures are features of this system. Depending on water conditions, maximum range of the system is 50 m per channel.

3.16 Buoyancy

Most ROVs are designed to have slight positive buoyancy at all times. This arrangement provides vertical stability and assists a vehicle's return to the surface in the event of a power loss. Syntactic foam is used in most instances to provide static buoyancy at all operating depths. Syntactic foam can easily be formed (cast or machined) into conformal shapes to provide some hydrodynamic cleanliness. For additional payload capacity additional syntactic foam may be easily added to the vehicle.

3.17 Remote Control Station

A substantial amount of support equipment is needed during ROV operations involving the larger vehicle systems. A typical control/display station contains video displays,

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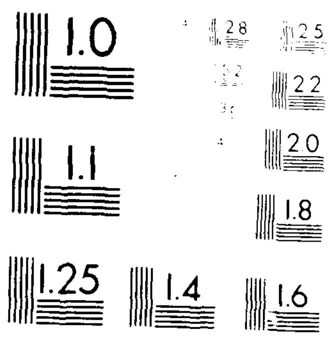
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video recorders, navigational displays and plotters, navigation and positioning equipment, communication links to the launch/retrieval team, power supply and control. The control/display station provides information for both the operator and the user.

The control/display subsystem incorporates a spectrum of sensors, controllers, displays, and data recording. The degree of complexity of the control/display system is strongly influenced by the number and difficulty of functions that must be within the capability of the ROV and the human operator.

Computer driven navigation displays, in both black-and-white and color, provide information on the relative positions of the surface platform, the ROV, and various targets or beacons. These displays offer the operator an over-view of the whole scene. Consequently, maneuvering to the work site and to other locations within the radius of the ROV is greatly simplified.

3.18 Deck Space

Surface support platforms normally do not include a dedicated or full-time ROV in its inventory. To accommodate the ROV system components that are to be located on a surface support platform, portable vans are outfitted for a deck installation. The vans also serve as transportation containers for the entire system. Several vans may be used to keep the size and weight of each unit reasonable for a variety of logistics transport methods -- land, air and sea. The vans allow for the manufacturer and operator to prepare the system for field use before it goes to sea. At sea the vans serve as the control/display center for the ROV operator; other vans house power sources, spares, personnel housing, and repair shop. There is a wide variety of van sizes and area space/volume associated with the present family of vehicles. Deck tie-down accommodations are available, or can be readily installed, for the vans on most surface support platforms. The vans are usually specially reinforced and outfitted for deck loading.

3.19 Launch/Retrieval

The wide range of ROV vehicle weights (80 to 5,000 kg) results in a broad spectrum of launch/retrieval requirements. There are ROVs that can be launched and retrieved by one person. The majority, however, are of a size and volume that require mechanical assistance. Most are lowered over the side of a support platform by a stiff-legged boom crane. Most surface ships are equipped with a boom whose length is equal to or greater than its freeboard. This feature allows for a launch/retrieval that can be kept from slamming into the ship's side during a severe roll. It is quite effective when the ROV is close-hauled to the tip of the boom. An alternative method is launch/retrieval by a stern-mounted A-frame. A-frames are common to most oceanographic research ships and serve to lower relatively large loads over the side. However, tethered ROVs are vulnerable to entanglement of the umbilical cable in the ship's screw(s).

To improve safety most ship operators prefer to have the ROV launched and retrieved alongside so that the operation can be observed by the ship's Master. Because operating ROVs from surface platforms is a relatively new experience for most Masters it is important that the required coordination be practiced extensively.

Many vehicles are both launched and retrieved using a strength member other than the umbilical cable -- even though the umbilical cable might be designed to have launch/retrieval capability. Repeated use of an expensive umbilical is usually avoided to gain extended umbilical service life by relieving it, whenever possible, from the rigors of repeated launch and recovery duty. The air-water interface can often produce extraordinary stresses that can be tolerated better by final lift strength members. When launching, a quick release hook is used that is tripped (released) by a lanyard on deck. For retrieval some operators prefer to maneuver the vehicle on the surface to a point where the lift line hook can be attached from a long pole aboard the ship. The vehicle is then quickly retrieved to this point where it is locked to the crane boom and then swung aboard. In some instances an auxiilary lift line can be married to the umbilical cable. When it reaches the deck winch the strength member can be used to bring the vehicle aboard. This procedure requires a second winch or windless for the lift line.

Most ROV systems use a drum to store the umbilical cable. In some instances, the cable is laid out on deck or within a suitable container. In other designs much of the large umbilical cable is housed within a deployment cage. The deployment cage serves then as a clump to carry the ROV to depth. The ROV swims clear of the deployment cage towing a much lighter weight cable to its maximum radius. Using this method the deployment cage and attached ROV enter and leave the water as an integral unit, thus obviating some of the difficulties associated with handling the more delicate ROV alone.

Although a ship's launch/retrieval equipment can be used it is usually more efficacious to have a launch/retrival system designed specifically for each vehicle. Large ROVs benefit from a special lift compensation system integrated into the design of a handling system. Such systems are of benefit not only during the launch/retrieval events, but also while the ROV is deployed. A compensation system provides a marked reduction in vertical motion that significantly relieves the operator of having to make frequent vertical position adjustments. Nearly zero vertical motion control can be achieved by hydro-pneumatic motion compensation systems. A secondary boom angle signal can be incorporated that serves for boom centering and active cushioning near the stops.

A motion compensation launch/retrieval system was developed for handling the U. S. Navy RUWS. It is capable of handing 7,010 m (23,000 ft) of umbilical cable. The launch, tending and recovery of the RUWS lift package requires the use of three separate modes of operation of the Motion Compensation Deck Handling System (MCDHS).

1. Stiff boom mode - This mode permits operation of the boom as a conventional crane and is used for all deck handling work. This mode is also used for handling the vehicle/PCT package at the surface of the water during launch/retrieval operations when high boom tip speeds are required.

2. Passive mode - This mode is used after launch when the payload is submerged over 61m (200 ft). It is used for motion compensation in Sea State 2 or less and also serves as the power failure mode. In this mode, the boom is solely supported by the hydro-pneumatic accumulators that act as pneumatic springs.

3. Active mode - This is the mode generally used when the payload is submerged over 61 m (200 ft) in Sea State 3, or higher. In this mode the boom tip speed is minimized which reduces the dynamic load on the primary umbilical cable. The MCDHS permits work operations in rather severe weather conditions and Sea State 3 and Sea State 4.

It is the add-on sub-systems that provide much of the work capability, operational effectiveness and versatility needed to meet specific requirements. Using state-of-the-art sub-systems it is possible to configure an ROV to meet many scientific research requirements. The following sub-systems are now available from U. S. commercial sources:

Obstacle avoidance sonar
Gyrocompass
Depth sensor
Altitude sensor
Current meter
Acoustic velocimeter
Cable tracking systems
Transponder/interrogator
Transponder/responder
Side scan sonar
Conductivity potential probe
Transponder place/replacement tool
Hydraulic tool package
Still cameras
Video cameras
Flood and strobe lights
Fiber optics
3-function grabber

7-function manipulators
High pressure water jet (cavitation jet)
Low pressure jet for silt removal
Alignment measurement tool
Specialized lifting tools
Hydraulic power pack
Conductivity-temperature-depth sensor
Sound velocity
pH
Redox
Oxygen sensor
Corrosion potential monitor
Specific ion sensors
Radiographic instruments

Oceanographic instruments, available as off-the-shelf units, can be installed aboard most ROVs as extra payload. Buoyancy can be added to compensate for items that exceed the normal ROV payload. It is fortuitous that many newer versions of oceanographic instruments have built-in recording capability for unattended use. Consequently these systems can be mounted on an ROV quickly and without concern for telemetry links or power connections. However, oceanographic sensor telemetry requirements can be readily accommodated by most ROV vehicle umbilical cables without modification.

3.20 Personnel & Training

Personnel destined for operating an ROV in polar regions need to be adequately prepared for the rigors of the environment. Personal gear and a knowledge of the hazards to surviving in the Arctic are covered here in direct relationship with the special requirements of effectively operating an ROV system. If the ROV crew expects to enter the water as divers they should acquire a copy of "A Guide to Polar

Diving" 1974, by W. T. Jenkins, Naval Coastal Systems Center, Panama City, Florida.

ROV control stations vary from a unit the size of a suitcase to a fully enclosed, temperature regulated van designed for that purpose. However, all systems require some human involvement for launch/recovery that will take them out into the rigors of the weather and climate. Clothing designed for protection against cold inherently means some bulk. Bulky mittens markedly reduce manual dexterity when small items require manipulation, e.g., knobs, switches, toggles and latches, etc. ROV systems destined for employment in arctic regions should be appropriately equipped to allow a "well dressed" operator to handle metal objects and to actuate the full range of items necessary to operate an ROV system.

Crew size and qualifications to operate ROVs varies greatly according to the ROV system size, complexity and operational requirements. Sustained on-site operations, such as those associated with emergency search, recovery, and rescue that involve 24 hour operations and rotating crews require large well trained crews.

The level of stress varies greatly with mission and function. "Flying and looking" is not considered stressful and operator endurance is not severely taxed. In contrast, a live boating survey that requires precision navigation over long distances where almost constant support platform and ROV maneuvering are involved causes fatigue to set in more rapidly. A study by Busby found that the operators felt they could effectively operate their ROVs between one to four hours depending on the difficulty of the operation. Under stressful conditions the average effectiveness time was about one and one-half hours.

Operator training, until recently, was accomplished by operating available systems and developing skills through trial and error under the supervision of an experienced operator. Recently, International Underwater Contractors, Inc. has established a formal course and a shore facility specifically for training prospective ROV operators. This type of training is expected to reduce the on-the-job training methods that sometimes required six to twelve months. In addition, the training facility is expected to alleviate the personnel shortage that developed during the rapid build-up of the world inventory of ROVs.

3.21 Operator Training

"Flying" an ROV in benign conditions (calm, clear water where there are no hazards) is relatively easy and satisfactory performance can be achieved by a neophyte in less than an hour. When requirements for precision piloting and accurate navigation are added then the time to develop proficiency is markedly increased. Many scientists prefer hands-on operation of their data acquisition systems and this is feasible with the smaller ROVs. However, larger more complex ROVs will require an experienced operator.

Formal, customized operator training is the most expedient means to quickly gain maximum field proficiency from ROV operator teams and for the safety of both personnel and equipment. The field application of larger ROVs involves a multiplicity of actions that must be accomplished simultaneously and requires experienced individuals for each. Accordingly, a team of individuals is usually required to support the operator, e.g. launch/retrieval deck operators, navigation control, data monitoring, and vehicle operation. The team approach is likely to be required for meaningful scientific investigations -- particularly under the artic ice canopy.

Technician Training

Prudent planning for ROV/AUV operations in the Arctic will include personnel trained to maintain and repair all ROV systems. Most available ROVs have been well tested and reliable performance can be expected from each subsystem. However, field investigations are likely to be jeopardized should any one of the sub-systems not be functional, e.g., the navigation system. Technician assistance should also be available for the sensors and other instruments that are to be carried by the vehicle.

Training Program

ROV and AUV operators and technicians should have training in the following areas:

1. Vehicle design and performance characteristics.
2. Vehicle subsystems (structure, ballast, propulsion, electrical/electronics and hydraulic systems.

3. Tools, sensors, and scientific instrumentation (installation, operation and maintenance). Examples: manipulators and their work tool package, video, pan and tilt, still camera, conductivity-temperature-density sensor, magnetometer, water current, sonars, etc.

4. Controls and consoles. Pilot's console for "flying" the vehicle and manipulator operation, navigation console, equipment status console, video and other real-time displays, communication links.

5. Power distribution. Vehicle propulsion and support systems electrical/hydraulic source(s) and distribution. Power source(s), launch/retrieval systems, tether management system, connectors, slip rings, and power distribution consoles.

6. Umbilical-tether cable(s). Internal design, repair, and maintenance of tethered vehicle systems. Operational procedures, umbilical maintenance, waterproof field splicing of hardwire and fiber optics, connectors, slip ring assemblies, and performance characteristics.

7. Acoustic navigation. Operational applications for shortbase, longbase and other acoustic navigation devices available for navigation and surveying.

8. Handling systems. Instruction on controls and hydraulic functions of handling systems for launch and retrieval.

9. Team operations. Definition of functions required to effectively operate a specific system. Indentification of organization and methods involved in team operations.

10. Project definition and requirements. Specific indoctrination regarding project objective, data acquisition requirements, logistics support needs, special team knowledge and organization arrangements.

11. Operational considerations. Detailed instruction in normal ROV procedures and methods. For example: mobilization, demobilization, pre-post dive system procedures, launch/recovery procedures, platform support, ship support, navigation/posistioning/communications network, data logging, spare parts, transporation and field station logistics, preparations for cold weather operations.

12. Safety and emergency procedures. Protocols to be used to maintain maximum safety for personnel and equipment. Emergency protocols to be used that include unique procedures for handling emergency situations unique to the arctic regions.

13. Pilot training. Hands-on training for basic ROV piloting which is augmented with training for specific scientific arctic operations.

14. Scientific projects. Customizing an ROV platform to support specific scientific projects that includes sensor and instrumentation add-ons, specific navigational requirements, "flignt" plans, data volume and recording, data processing and display, sensor and instrumentation maintenance, logistics support platforms.

15. Legal requirements. Identification of permit requirements and OSHA/U. S. Government inspection requirements, including authorization to operate in foreign waters.

Formal ROV Operator/Technican training is now available year-round from commercial sources. The International Underwater Contractor's full-time standard ROV Pilot Technician course involves 8 weeks to fulfill requirements for entry level ROV positions. All fundamental and contributing skill relating to the planning and execution of commercial ROV operations are covered in this course. Graduates are qualified to work the entire spectrum of commercial ROV operations such as supporting exploration, construction, inspection, maintenance, and salvage.

3.22 Guidelines for Selecting ROV Systems for Arctic Applications

Appendix 3 contains a detailed description of most available ROVs. For many arctic applications the smaller units provide the necessary capabilities and keep the logistic requirements within acceptable limits.

The following factors must be considered:

- Cost Effectiveness
- Safety
- Personnel Requirements
- Task Requirements
- Mobility
- Launching Systems
- Guidance Systems
- Logistics Support
- Work Capability--operational reliability and work ability are the key

The smaller ROVs can be mobilized and transported to the ice by available aircraft (e.g., Twin Otter). They can be moved by sled across the ice and do not require large enclosed structures or ice entry holes. The payload capacity is satisfactory for many oceanographic and acoustic systems. Multiple sensor/instrumentation array installations are feasible. Self-contained oceanographic sensors can be added and removed from the ROV to accommodate changes in data acquisition needs and to serve more than one investigator during a field operation period.

Some of the potential candidate ROV systems are compared in Table 3.5

TABLE 3.5
ROV Comparisons

Small ROV Comparisons
A small ROV weighs less than 75 kg with a base price less than $100,000.

Vehicle	Total Wt (kg)	Depth Rating (M)	Cost (1985 $)
RASCL	67	360	55,000
MINIROVER	23	122	24,850
SEAROVER	40	244	40,000
PHANTOM 500	28	152	28,400
PHANTOM 500 HD	39	305	36,800
RTV-100	25	100	27,000
SEA WHIP	32	150	25,000
VICTOR	--	183	28,600
SPRINT 101	52	610	65,000
DART	67	360	95,000
JTV	10	200	20,000

Medium-Size ROV Comparisons
A medium-size vehicle weighs more than 75 kg and costs between $100,000 and $500,000

Vehicle	Total Wt (kg)	Depth Rating (M)	Cost (1985 $)
DART	112	369	140,000
HYSUB	802	900	200,000
TRAIL BLAZER	135	360	500,000
HORNET 500	120	500	200,000
SCORPI	22-34	610	335,000
RCV-150	545	610	200,000
RCV-225	82	410	160,000
RECON IV	410	450	400,000
UFO	145	430	266,000
SUTEC USA	85	350	165,000

LARGE ROV COMPARISONS
A large vehicle is one that weighs more than 120 kg and costs more than $500,000

Vehicle	Total Wt (kg)	Depth Rating (M)	Cost (1985 $)
DOLPHIN-3K	2,600	3,300	5,000,000
GEMINI	2,045	1,250	875,000
TRITON 202	1,905	1,000	600,000
ASD/620	454	915	591,000
SUPER SCORPIO	1,635	915	805,000
SCORPIO	998	915	590,000
PLUTO	160	915	230,000
HORNET 500	120	500	200,000
DRAGONFLY	1,590	1,828	1,102,000
DUPLUS II	300	1,000	520,000
RIGWORKER	1,065	915	570,000

4. THE ARCTIC ENVIRONMENT AND ROV OPERATIONS

4.1 Introduction

The arctic remains a difficult geographic area for survival for both personnel and equipment. Only a limited number of arctic region ROV evaluation tests have been completed by industry and none recently by the Navy. Each of the industrial tests was declared successful and more are planned for both tethered, free-swimming and autonomous vehicles. However, the agents and sponsors of these tests are reluctant to release their proprietary information. Polar conditions will affect the operation of ROV systems -- not prevent them. ROV field operations, similar to most arctic operations, require advance planning and thoughtful preparation of equipment and logistics support for a complete system. Additional time is often required to conduct field operations in polar regions so allowance must be made for time-consuming tasks that are not present during operations in more temperate areas.

This section briefly describes and assesses the environmental parameters that can be expected to influence both human and ROV equipment performance, as well as logistics support functions whether over the ice (air or air-cushion), on the ice, or under the ice.

Tasks that are probably generic to arctic region ROV field operations are:

- Providing a supply route,

- Staging of support equipment and personnel,

- Locating and establishing a suitable launch/retrieval site,

- Erecting shelters,

- Protecting support equipment from the environment,

- Preparing the entry hole,

- Maintaining the launch/retrieval site, entry hole(s), and supply routes,

- Recovering the system from the site when operations are terminated.

If the ROV is submarine launched under the ice, or surface launched from a ship outside the ice, then all these tasks are carried out by the support platform.

4.2 ROVs in the Arctic

The arctic environment presents some unusual operating challenges for ROVs. These include:

- The presence of ice cover, restricting deployment and recovery opportunities whether the ROV is operated from a surface ship or an ice station.

- The limitations imposed by aerial deployment to an ice station, for example, visibility, weather, size, shape, weight, handling facilities, power requirements and navigation.

- Logistics associated with arctic deployments can be very costly and difficult.

- Field support for systems may be difficult.

- If the system is surface controlled then human resource factors (isolation, cold, dark, etc.) must be considered.

- Special preparations are necessary to operate electrical/mechanical systems in a cold environment. (Cable becomes brittle, o-rings fail, plastic breaks, rime ice forms, etc.).

- Cable penetrations through the ice risk cable abrasion on ice or between the ice and ship hulls.

These operating constraints can be overcome. ROV field operations, as most arctic operations, require advance planning and thoughtful preparation of personnel, equipment and logistics. However, in some respects the Arctic provides some unique advantages to ROV operations.

- The ice can provide an excellent platform for ROV operations. Some effort is required to cut and maintain a large hole in the ice, but the ice cover is extremely stable compared to a ship in open water.

- Since the pack ice is rough, moving men and equipment across the ice may be difficult. The ROV can move relatively freely under the ice.

- Using aircraft, a portable ROV system could be moved quickly from one site to another.

- There are many tasks to be performed under the ice which require mobility and under-ice diving by personnel can represent significant risk.

This latter point is very important. Serious questions have to be objectively addressed when asking personnel to take unnecessary risks in a harsh remote environment when the required tasks can be accomplished by automated systems. In addition, the logistics required to support a two-man diving team are probably greater than those for a moderately capable ROV with operator. Each man on the ice requires cold weather gear, shelter, food, fuel, and support equipment. A diver would have greater requirements than most research scientists working at an ice camp.

ROVs can be deployed from the ice surface, ships (ice breakers) and submarines. However, surface ships (even ice breakers) are severely limited in the Arctic. Ice-breakers generally limit their operating season to the late spring (May) through the early fall (October). Some experience has been gained with the use of a small ROV off one of the U.S. Coast Guard Polar Class icebreakers (Volker, 1985). The system performed the task of surveying the structure of ice keels. Care to protect the tether had to be exercised, but the icebreaker crew was able to keep the tether from being abraded between the ship and surrounding pack. It is noted here that the Soviets have a research icebreaker (OTTO SEMIDT) with a center well that could be used for deploying an ROV or other equipment.

Deployment of ROVs from ice camps will require either aircraft or icebreaker staging to set up an operations base. Most ice camps have been set up by aircraft which obviously poses some size and weight restrictions. Size and weight restrictions are not significant factors in ship deployment. Aircraft can operate safely from pack ice in the Arctic from February through early May. Small, ski-equipped, fixed wing aircraft and helicopters can land almost anywhere in the central Arctic. However, their range and payload are very limited (a few hundred miles and a few hundred pounds). Large aircraft (C130 with a payload capacity of 35,000 pounds) can land on refrozen leads more than four feet thick. However, the runway must be tested for thickness and prepared for safe operations. Buck et al (1979) review many aspects of arctic flying and field operations. Tables 4.1 and 4.2 show some of the performance specifications for fixed wing aircraft and helicopters. It is evident that a large ROV could be transported on to the arctic pack and operated. Several logistical factors must be considered -- size, weight, shape, handling and support gear, power requirements, sensors, navigation, etc.

Submarines have provided the most mobile all-weather platform for data collection in the Arctic. Their only restriction is the water depth required for safe operation under ice, and obvious security limitations. However, they represent the most versatile platforms for ROVs or AUVs in the underice environment.

4.3 Through-Ice Launch/Retrieval Openings

When the general location for the entry hole has been chosen, a small test hole should be drilled through the ice with a hand or powered auger. The ice thickness and the water depth can be determined using the test hole. After the site is selected for the entry hole, all the snow covering the ice in the immediate vicinity should be cleared away. The cleared area should extend at least 3 to 4 feet beyond the intended hole perimeter.

GENERAL FIXED WING AIRCRAFT CHARACTERISTICS

(from Buck, et al, 1979)

AIRCRAFT DESIGNATION	TRADE NAME	CRUISE SPEED (KNTS)	PAYLOAD (lbs.)	SKI EQUIPPED	ENGINE TYPE	MAX. RANGE (NM)	RUNWAY SURFACE REQUIRED	MIN. OPERATING TEMPERATURE	ARCTIC USE
Cessna 180	Skywagon	125-142	500	Yes	1-Piston	600	Any	30°F	Extensive
Cessna 185	Skywagon	132-145	1,140	Yes	1-Piston	600	Any	30°F	Extensive
DHC-2 Beaver	Beaver	105-115	800	Yes	1-Piston	700	Any	30°F	Extensive
DHC-3 Otter	Single Otter	110-116	800	Yes	1-Piston	1,900	Any	30°F	Extensive
DHC-6 Twin Otter	Twin Otter	120-160	3,500	Yes	2-Turboprop	800	Any	-45°F	Extensive
DHC-5 Turbo Beaver	Turbo Beaver	140-160	1,500	Yes	1-Turboprop	300	Any	-45°F	Extensive
DHC-7 Otter 7	Dash 7	220-233	6,500	No	4-Turboprop	1,500	Any	45°F	New
DC-3	R4D & C-47	130-10	5,000	Yes	2-Piston	1,200	Hard Prepared	-40°F	Extensive
Tri Turbo 3	DC-3 with PT6A-1 Engines	200 (EST)	10,000 (EST)	Yes	3-Turboprop	3,000	Any	40°F	New
C-117 D	Super DC-3	130-150	5,200	No	2-Piston	1,200	Hard Prepared	25°F	Extensive
C-121	Constellation	220-240	20,000	No	4-Piston	3,500	Hard Prepared	25°F	Extensive
C-141	Starlifter	435	64,000	No	4-Jet	6,500	Hard Prepared	45°F	Limited
Helio H-295	Helio Courier	143-156	1,200	No	1-Turbocharged	550	Any	30°F	Extensive
Helio AU-24A	Helio Stallion	140-180	1,200	No	1-Turboprop	600	Any	40°F	Extensive
DHC-5	Buffalo	225-233	18,000	No	4-Turboprop	2,000	Hard Prepared	50°F	Limited
C-130	Hercules	300	35,000	No	4-Turboprop	3,600	Hard Prepared	45°F	Extensive

Table 4.1

GENERAL HELICOPTER CHARACTERISTICS

(from Buck, et al, 1979)

AIRCRAFT	CRUISE SPEED (mph)	PAYLOAD	SKI EQUIPPED	ENGINE TYPE	MAX. RANGE	RUNWAY SURFACE REQUIRED	INFORMATION SOURCE	ARCTIC USE
AEROSPATIALE								
Alouette II	95	1,300	Yes	Turbine	290	N/A	Evergreen	Extensive
Lama	100	2,400	Yes	Turbine	320	N/A	Helicopter of Alaska	Limited
Alouette III	100	2,300	Yes	Turbine	308	N/A	Helicopter of Alaska	Limited
Gazelle	163	1,840	Yes	Turbine	405	N/A	Helicopter of Alaska	Extensive
Puma	160	7,950		Twin Turb	341	N/A	Helicopter of Alaska	Limited
BELL								
206B	100	1,620	Yes	Turbine	341	N/A	Helicopter of Alaska	Extensive
204B	110	3,000	Yes	Turbine	150	N/A	Helicopter of Alaska	Limited
205A	120	4,180	Yes	Turbine	311	N/A	Helicopter of Alaska	Extensive
212	125	5,330	Yes	Twin-Turb	261	N/A	Helicopter of Alaska	Extensive
BOEING								
105C	140	2,260	Yes	Twin Turb	350	N/A	Helicopter of Alaska	Limited
HILLER								
FH 1100	100	800	Yes	Turbine	135	N/A	Helicopter of Alaska	Extensive
12E	80	1,340	Yes	Recipro	146	N/A	Helicopter of Alaska	Extensive
HUGHES								
500C	160	1,640	Yes	Turbine	350	N/A	Helicopter of Alaska	Extensive
SIKORSKY								
S58T	115	5,000	No	Twin Turb	170	N/A	Helicopter of Alaska	Extensive
S61N	140	7,990	Yes	Twin-Turb	545	N/A	Helicopter of Alaska	Extensive
S64E	100	20,00	Yes	Twin-Turb	350	N/A	Helicopter of Alaska	Limited

Table 4.2

The size of any entry hole will depend on several factors including the size and shape of the ROV or AUV, and launch and recovery techniques. Usually an entry hole will require some routine chipping to remove new ice forming on the surface and around the perimeter. A protective heated cover (tent or hut) will normally be placed over the hole but even this will not stop the formation of surface ice. Long term projects should set up a system to keep the holes as ice free as possible. Systems that have been used include heating cables, lamps, ducts, and bubble generators.

The method of cutting the hole through the ice will vary from one operation to another, the choice depending on several factors including ice thickness and the availability of equipment and energy.

Chipping an entrance hole by hand should be reserved for thin ice or if no other alternative is available. This is not only time-consuming, but very fatiguing. Whether chipping an entire hole or the final perimeter, care should be taken to ensure that the breakthrough to the water is delayed until the last moment; once the breakthrough occurs, the hole quickly fills with water. Chippers are handy for periodic clearing of new ice formation from an entrance hole.

A standard ice saw, such as used for years to cut ice cakes commercially on freshwater rivers and lakes, can be used if the surface temperature is not too low or the ice not too thick. Entry holes are made by cutting the ice into blocks after which they are broken free with a heavy-duty chipper and removed with ice tongs. Care must be taken that the cut of the ice is kept vertical and that the ice does not freeze up again behind the blade. The teeth of the saw must be set so as to produce a wide cut to reduce the chance of such refreezing. Chain saws have also been used to cut large ice holes in thick multi-year ice.

One of the most common methods currently used for preparing an entrance hole through the ice is the powered ice auger which can drill a hole through several feet of ice in minutes. Bit sizes vary from small, 1 to 2 inches, to over 9 inches and with the use of extensions, they have drilled through thick ice, even pressure ridges. The auger is normally used in combination with hand chippers and chain saws to make large holes.

The thermal ice cutter uses warm water circulating in a cutting tube in a controlled manner to cut a groove of the desired shape. A delivery manifold of the desired "cookie cutter" shape delivers the water uniformly along the manifold through a series of loosely spaced, small diameter, downward directed orifices. Such a manifold is mounted directly above the cutting manifold to pick up the mixed melt and deliver the water for reheating at the heat source. When penetration is completed, seawater floods the groove and the core is left floating free. Holes of 28 inches can be cut at 5 feet per hour with a system delivering 80,000 Btu per hour to the ice. Holes have been cut through 15-foot thick ice at these rates. Multiple cuts can produce holes of large dimension; enough to accommodate most ROVs.

4.4 ROV Logistics Support in the Arctic

System logistics is probably the most important factor in any arctic operation. Because arctic field investigations depend heavily on the logistics, careful planning and organization are mandatory in transporting an ROV system to a work site and supporting it while in polar regions. The success or failure of a mission can depend on the thoroughness that is devoted to logistics support planning.

It is extremely important that equipment be prepared and tested for the arctic climate and weather prior to deployment. Many items that have performed well in laboratory engineering and user tests, including tests made in cold chambers, have failed when used in polar regions.

General features of polar operations that affect logistics support are:

1. Environmental factors, including blowing snow, low temperatures, and irregular terrain.
2. The general lack of facilities that can be used for support purposes.
3. The general lack of communications -- even near populated areas.
4. The distances over which support must be rendered.
5. Polar regions are sparsely populated and amenities for every transportation mode is affected by the lack of established roads, runways and other transportation support facilities.

The choice of a surface vehicle will depend on the size, bulk, and weight of equipment to be moved and the type of terrain to be negotiated. Vehicles that are commonly used range from the small snowmobile to heavy duty specialized tractors that may be equipped with wheels or tracks. Specifications of each should be considered when choosing the most appropriate terrain vehicle.

1. Wheeled vehicles such as a crew cab truck, provide an adequate and relatively inexpensive means of transportation when roads or cleared paths across the ice are available. It is best to use four-wheel drive vehicles.

2. Snowmobiles are excellent for local operations as a personnel and small load carrier. When coupled with a small sled these vehicles can effectively support most local operations as they are capable of operating where larger vehicles are not.

3. Tracked vehicles range in size from oversized snowmobiles with a cab to 16-ton vehicles that can pull a giant sled across the ice. Larger ROV systems would require vehicles of this class. In addition, these vehicles are useful for supporting other facets of an ROV mission, e.g., clearing snow from a new site, towing large sleds of equipment, and assisting in moving and handling heavy equipment and supplies.

4.5 Launching/Recovery of ROVs and AUVs from Arctic Pack Ice

Arctic deployments of ROVs and AUVs do not appear to hold any major obstacles for small and medium sized systems. Large systems would be hampered by the lack of handling equipment. However, the ice does provide a strong stable platform and we see no insurmountable logistics or handling obstacles even for larger systems. The C130

Hercules and even larger aircraft can land on refrozen leads. The U.S. estabished an ice camp with as many as 40 individuals, 30 buildings and over 500 tons of equipment during AIDJEX.

Small ROVs can be deployed by hand from the ice edge or through a suitable hole. Medium and heavy vehicles can be ramp-launched and recovered. Native Alaskans recover whales using a block and tackle to hoist the dead animal onto the ice with the block anchored to an ice beam cut into the ice. For heavy vehicles a launch and recovery frame with electric motors may be more effective. The point is that ice is very strong when cold, and can support large vertical loads.

5. SUMMARY AND RECOMMENDATIONS

This study included a review of the physical and performance characteristics of the present world inventory of remotely operated vehicles. During the last ten years significant progress has been made in the design, development and operational experience of commercial ROV systems. The primary requirement for this technology has been the offshore oil and gas industry. The present ROV industrial base has been an outgrowth of developments by the Navy. Within the United States and Canada, as well as Japan and Europe, there are well-established manufacturing firms offering ROV systems design and development services. ROV technology state-of-the-art systems have demonstrated commercial cost-effectiveness and have successfully performed a broad range of functions; many of the functions can be translated to military application scenarios.

ROV technology experience in the Arctic has been limited to field tests of autonomous underwater vehicles, some trial visual investigations of icebergs using tethered free-swimming vehicles, and, at least one recent commercial evaluation of a low-cost tethered free-swimming vehicle deployed from a Coast Guard ice-breaker.

From the ROV information data base developed for this study an evaluation was made regarding the ROV technology support potential to the AEAS Arctic Program. There is ample evidence that significant benefits can be derived from military application of this technology to the key areas of arctic site characterization, exercise support, and environmental data collection.

Performance characteristics determined to be available from this technology are:

- Three-dimensional mobility under the control of an operator
- Under-ice operational limits are not set by weather
- One-time measurement support of temporal and transient measurement support at selection location
- Long-term measurement support at one location
- Cost-effective for a variety of tasks
- Safety when accessing hazardous areas
- Platform for accommodating a variety of sensors, instruments, and tools
- Systems can be tailored for specific missions
- Covert
- Install data collection arrays
- Easy to transport and operate
- Candidate environmental data collection substitute for fleet submarines.

ROV technology research and development requirements do exist. An evaluation of anticipated military requirements for site characterization, environmental data collection, and exercise support reveal that technical solutions are needed to overcome deficiences in:

- High energy, long endurance, on-board energy sources for autonomous underwater vehicles.

- Quality and quantity of two-way through-water communications, both open and covert.

- On-board computer command and control utilizing artificial intelligence.

- Umbilical cables.

It is recommended that:

1. One small and one medium-size tethered free-swimming vehicle be instrumented and field evaluated under the arctic ice canopy and in the marginal ice zone for site characterization, exercise support, and environmental data collection.

2. One or more autonomous underwater vehicles be instrumented and field evaluated under the arctic ice canopy and in the marginal ice zone for site characterization, exercise support, environmental data collection and tactical development.

3. An arctic ROV workshop should be convened in FY87 to establish requirements for ROV technology to support the AEAS program.

4. An ROV workshop should be convened in FY87 to establish requirements for ROV technology to support all naval warfare areas.

5. A short course be developed and convened in FY87 on the potential of ROV technology to support U.S. Navy arctic and other military programs.

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APPENDIX 1

List of ROV's Including Operating Depth and Dry Weight
January 1986

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
1	(AUV) ARCS	(CANADA) I.S.E.	400	1312	1510	3322
2	(AUV) AUSS	(U.S.) NOSC	6096	20000	907	1995
3	(AUV) AUV	(U.S.) DARPA	NA	191	420	NA
4	(AUV) B-1	(U.S.) NUSC	90	CK	420	924
5	(AUV) CSTV	(U.S.) NCSC	NA	NA		
6	(AUV) DOLPHIN	(CANADA) I.S.E.	NA	NA	NA	NA
7	(AUV) EAVE-EAST	(U.S.) UNIV. NEW HAMPSHIRE	91	300	305	670
8	(AUV) EAVE-WEST	(U.S.) NOSC	670	2200	204	449
9	(AUV) ELIT	(FRANCE) COMEX/EFREMER	305	1000	NA	NA
10	(AUV) EPAULARD	(FRANCE) E.C.A. & C.S.I	6000	20000	3000	6600
11	(AUV) LSV	(U.S.) NCSC	NA	NA	NA	NA
12	(AUV) OSR	(JAPAN) MITSUI	250	820	NA	NA
13	(AUV) PLA 2 6000	(FRANCE) C.E.A./IFREMER	6000	20000	16000	35200
14	(AUV) ROBOT II	(U.S.) M.I.T.	091	298	NA	NA
15	(AUV) ROVER 01	(U. K.) HERIOT-WATT	1000	3300	120	264
16	(AUV) RUMIC	(U.S.) NCSC	NA	NA	NA	NA
17	(AUV) SKAT	(USSR) INST. OCEANOLOGY	NA	NA	NA	NA
18	(AUV) SPUR	(U.K.) SCION, LTD.	6000	20000	NA	NA
19	(AUV) SPURV I	(U.S.) UNIV. WASH.	3658	12000	454	999
20	(AUV) SPURV II	(U.S.) UNIV. WASH.	1524	5000	454	999
21	(AUV) TELEMINE	(ITALY) TEKSEA	150	492	600	1320
22	(AUV) TM 308	(ITALY) TECHNOMARE	400	1312	NA	NA
23	(AUV) UARS	(U.S.) UNIV. WASH.	457	1500	410	900
24	(AUV) UFSS	(U.S.) NRL	457	1500	2458	5408
25	(B-C) CLEM	B85	060	197	150000	330000
26	(B-C) D155W	(JAPAN) KOMATSU	A7	23	NA	NA
27	(B-C) EAGER BEAVER	(NETH) HEEREMA ENG. SERV	NA	NA	NA	NA
28	(B-C) GRANSEOLA	(ITALY) INCOP	46	150	9000	19800

Note: AUV - Autonomous Underwater Vehicle
B-C - Bottom Crawler
T - Towed Vehicle

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
29	(B-C) JH 160	(JAPAN) HITACHI	60	197	32000	70000
30	(B-C) KVAERNER MYREN	(NORWAY) MYRENS VERKSTED	500	1640	90000	198000
31	(B-C) LTM IV	(FRANCE) FLEXSERVICE OPER.	NA	NA	NA	NA
32	(B-C) M.T.S.	(U. K.) UDI LTD.	300	985	22700	49940
33	(B-C) PIUT	(U.S.) BROWN & ROOT, INC	366	1200	150000	330000
34	(B-C) PBM	(ITALY) SUB SEA OIL SERVICES	650	2132	5000	11000
35	(B-C) PBP1	(U.K.) LAND & MARINE ENG. LTD	150	492	80000	176000
36	(B-C) PBP3	(U.K.) LAND & MARINE ENG. LTD	200	656	60000	132000
37	(B-C) PORTUNUS	(NETH) PUBL. WORKS AUTH.	050	164	4500	9900
38	(B-C) ReCUS	(JAPAN) KOMATSU	070	230	26300	57800
39	(B-C) RTM III	(U. K.) LAND & MARINE ENG.	060	197	176000	387000
40	(B-C) RUBBLE LEVELING ROBOT	(JAPAN) KOMATSU	030	98	65300	143660
41	(B-C) RUM III	(U.S.) UNIV. CAL.	6000	20000	1815	3993
42	(B-C) SAS	(U.S.) PERRY OFFSHORE INC	650	2133	NA	NA
43	(B-C) SCV	(U. K.) SLINGSBY	100	330	NA	NA
44	(B-C) SEA BUG	(U.K.) UDI LTD.	305	1000	1588	3494
45	(B-C) SEA CRAB	(SWEDEN)) AB HAGGLUND & CONER	500	1640	NA	NA
46	(B-C) SEA DOG	(U.K.) SLINGSBY ENG. LTD.	274	900	22700	49940
47	(B-C) SEA PLOUGH	(FRANCE) SOCIETE ECA	900	2953	22000	48400
48	(B-C) SEA PLOW IV A	(U.S.) BELL TELEPHONE LABS	914	3000	20412	44906
49	(B-C) SEABED CRAWLER	(U.K.) SLINGSBY ENG. LTD	100	328	302	664
50	(B-C) SEACAT	(U.K.) BRIT. U/W ENG. LTD.	200	656	NA	NA
51	(B-C) SL 4	(U.K.) LAND & MARINE ENG. LTD	050	164	30,000	66000
52	(B-C) STV	(U.S.) NCEL	045	148	NA	NA
53	(B-C) SUBSEA CABLE PLOUGH	(U.K.) BRITISH TELECOM INT'L	250		9,000	19800
54	(B-C) SUBSEA PIPELINE PLOUGH	(U. K.) SOIL MACHINE DYNAMICS	250	820	37000	81000
55	(B-C) SUBTRACTOR	(U.S.) MAUI DIVERS	1371	4500	1800	53960
56	(B-C) TALPA	(ITALY) INCOP	46	150	17000	37400

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
57	(B-C) TALPETTA	(ITALY) INCOP	46	150	2500	5500
58	(B-C) TIM	(FRANCE) S.N.E.A.	610	2000	12000	26400
59	(B-C) TM 102	(ITALY) TECHNOMARE	200	660	190000	418000
60	(B-C) TM 402	(ITALY) TECHNOMARE	160	525	22000	48000
61	(B-C) TRAMP (NEW)	(U. K.) WINN TECHNOLOGY	NA		NA	NA
62	(B-C) TRUCS	(CANADA) I.S.E.	NA		NA	NA
63	(B-C) UBUG	(W. GER.) P. DE LA MOTTE	060	197	NA	NA
64	(B-C) UNDERWATER BULLDOZER	B85			NA	NA
65	(B-C) UNDERWATER CRAWLER	(FRANCE) ANCHOR SYSTEMS (FR)	061	200	NA	NA
66	(B-C) UNDERWATER TRENCHER	(JAPAN) SUMITOMO	70	230	NNAANA	NA
67	(B-C) UNIPLOW		NA			
68	(B-C) UNNAMED NODULE COLLECT(	(U.S.) LOCKHEED	6000	20000	NA	NA
69	(B-C) UWAG I	(W. GER.) P. DE LA MOTTE,	100	328	87500	192500
70	(T) ANGUS	(U.S.) WHOI	6000	20000	2177	4790
71	(T) ARGO-JASON	(U.S.) WHOI	6000	20000	2200	4840
72	(T) BATFISH	(CANADA) GUILDLINE INSTS	396	1300	NA	NA
73	(T) BENIGRAPH	(NORWAY) BENNEX(NEW)	305	1000	NA	NA
74	(T) BRUTIV MK III	(CANADA) BIOL. STA. N.B.	274	900	227	500
75	(T) CLEM	(U. K.) BALFOUR KIRKPATRICK	060	197	NA	NA
76	(T) CSA/STCS	(U.S.) CONT. SHELF ASSOC.	305	1100	136	299
77	(T) CSA/UTTS	(U.S.) CONT. SHELF ASSOC.	350	1148	NA	NA
78	(T) DEEP CHALLENGER	(JAPAN) JAMSTEC	6000	20000	1000	2200
79	(T) DEEP TOW	(U.S.) UNIV. CAL.	7620	25000	1000	2200
80	(T) DEEP TOW SURVEY SYSTEM	(U.S.) LOCKHEED	6000	20000	1134	2495
81	(T) DOSS	(U.S.) NRL SYSTEM	6000	20000	1134	2495
82	(T) DSS-125	(U.S.) HYDRO PRODUCTS	6000	20000	630	1386
83	(T) GUSTAV	(W. GER.) DORNIER	6000	20000	NA	NA
84	(T) KLEIN SLS	(U.S.) KLEIN ASSOC.S			NA	NA

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
85	(T) MANTA	(CANADA) SEA-1 RES CAN LTD	650	2132	NA	NA
86	(T) NODULE COLL. VEH.	(JAPAN) NAT'L RES INST POLL	34	115	200	440
87	(T) OCEAN ROVER	(U. K.) SEAMETRIX	335	1100	315	693
88	(T) PBP1	(U. K.) LAND & MARINE ENG.	150	492	80000	176000
89	(T) PBP3	(U. K.) LAND & MARINE ENG.	200	660	52000	114400
90	(T) RAIE II	(FRANCE) CNEXO	6000	20000	600	1320
91	(T) RUFAS II	(U.S.) DOI/NMFS	732	2400	454	999
92	(T) S.S.S. U of Ga.	(U.S.) UNIV. GEORGIA	1828	6000	NA	NA
93	(T) SAR	(FRANCE) E.C.A. & C.S.I.	6,000	20000	NA	NA
94	(T) SEA KITE	(FRANCE) BLUE DEEP SARL	300	984	500	1100
95	(T) SEA PLOUGH	(FRANCE) SOCIETE ECA	900	2953	NA	NA
96	(T) SEA PLOW IV A	(U.S.) BELL TELEPHONE LABS	914	3000	NA	NA
97	(T) SEP	(W. GER.) DORNIER	6000	20000	NA	NA
98	(T) SL 4	(U. K.) LAND & MARINE ENG.	050	154	NA	NA
99	(T) SOUND	(USSR) INST OCEANOLOGY	4023	13200	400	880
100	(T) STSS	(U.S.) WESTINGHOUSE	6000	20000	1134	2495
101	(T) SUBSEA CABLE PLOUGH	(U. K.) BRIT. TELCOM INT'L	250	820	9000	19800
102	(T) SUBSEA PIPELINE PLOUGH	(U. K.) SOIL MACHINE DYNAMICS	250	820	37000	81400
103	(T) TELEPROBE	(U.S.) NAVAL OCEANO. OFF.	6000	20000	1588	3493
104	(T) TM III	(U. K.) LAND & MARINE ENG.	75	246	95000	209000
105	(T) TM IV	(U. K.) LAND & MAR. ENG.	050	165	85000	187000
106	(T) TUMS	(U.S.) SPERRY	6000	20000	2860	6292
107	(T) UNIPLOW 24/1.2	(U. K.) BOELE'S SHIP. & ENG.	NA	NA	70000	154000
108	(T) ISV	(JAPAN) JAMSTEC	100	330	5	11
109	(T) VIBRO-SLED	(W. GER.) VIBRO-EINSPULTECHIK	NA	NA	NA	NA
110	.				NA	NA
111	ADROV	(U.S.) NAVAL EOD TECH CNTR	NA	NA	NA	NA
112	AMPHORA	(U. K.) U/W MARINE EQUIPT.	610	2000	NA	NA

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
113	ANGUS 002	(U. K.) HERIOT-WATT	300	1000	700	1540
114	ANGUS 003	(U. K.) HERIOT-WATT	300	1000	1300	2860
115	ARGUS new	(CANADA) I.S.E.	610	2000	NA	NA
116	ASD/620	(U.S.) AMETEK-STRAZA	914	3000	454	999
117	ASD/620	(U.S.) AMETEK-STRAZA	914	3000	515	1133
118	AUSSIE	(U. K.) HERIOT-WATT	050	165	135	297
119	BANDIT	(U.S.) DEEP OCEAN ENGINEERING	365	1200	771	1696
120	CETUS	(U. K.) ULS MARINE	457	1500	907	1995
121	CHALLENGER	(U.S.) PERRY OFFSHORE INC	152	500	1450	3190
122	CHECKMATE	(NORWAY)	335	1100	NA	NA
123	CIRRUS	(U. K.) SLINGSBY	1000	3280	3000	6600
124	CONSUB 1	(U. K.) BRIT. AIRCRAFT	610	2000	1361	2994
125	CONSUB 201 & 202	(U. K.) BRIT. AIRCRAFT	365	1200	4400	9680
126	CORD II	(U.S.) HARBOR BRANCH FNDTN	914	3000	454	B0999
127	CUDA (AT&T)	(U.S.) AT&T			NA	NA
128	CURV IIB	(U.S.) NOSC	C762	2500	1565	3443
129	CURV IIC	(U.S.) NOSC	1829	6000	3130	6886
130	CURV III	(U.S.) NOSC	3048	10000	2517	5537
131	CUTLET	(U.K.) ROYAL NAVY	300	1000	NA	NA
132	CYCLOPS (ISE)	(CANADA) I.S.E.			NA	NA
133	DART/RASCL	(CANADA) I.S.E.	365	1200	32.00	70
134	DAVID	(W. GER.) ZF-HERION-SYSTEMTECHNIK	1000	3300	NA	NA
135	DEEP DRONE	(U.S.) AMETEK-STRAZA	1,645	5400	726	1597
136	DLT-300C	(JAPAN) Q. I. INC	200	660	NA	NA
137	DOLPHIN -3K	(JAPAN) MITSUI	3000	9843	2500	5500
138	DRAGONFLY	(U. K.) OSEL GROUP	1828	6000	1588	3494
139	DUPLUS II	(U. K.) OSEL GROUP	700	2300	1650	3630
140	ERIC 10	(FRANCE) CERTSM	500	1640	2800	6160

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
141	ERIC II	(FRANCE) CERTSM	6000	20000	2800	6160
142	EV-1	(U.S.) KRAFT OCEAN SYSTEMS	460	1500	NA	NA
143	FILIPPO	(ITALY) GAYMARINE SRL	350	1150	86	189
144	FMV	(CANADA) I.S.E.	914	3000	907	1995
145	FOA SUB	(SWEDEN) NAT'L DEF. SWEDEN	250	820	600	1320
146	FORCE 1	(SWEDEN) SUTEC	700	2300	1000	2200
147	FUGE	(W. GER.) PREUSAG AG	800	2600	5500	12100
148	GEMINI	(U.S.) AMETEK-STRAZA	1524	5000	2041	4490
149	GEMINI	(U.S.) AMETEK-STRAZA	3000	9843	2041	4490
150	GOLIATH	(W. GER.) ZF-HERION-SYSTEMTECHNIK	500	1640	3810	8382
151	HARVEY	(U.S.) TAYLOR DIVING	305	1000	158	348
152	HORNET-500	(JAPAN) JAMSTEC	8500	1640	90	198
153	HYDRA 5-14	(CANADA) I.S.E.	1000	3280	1200	2640
154	HYDRA 1-4	(CANADA) I.S.E.	3261	10700	1200	2640
155	HYSUB 20	(CANADA) I.S.E.	1000	3280	802	1764
156	INSPECTOR	(U. K.) SLINGSBY	366	1200	54.4	120
157	IZE 1 &101	(U. K.) SLINGSBY	300	895	200	440
158	JTV	(JAPAN) JAMSTEC	200	656	NA	NA
159	LADY BIRD	(JAPAN) JAMSTEC	500	1640	43	95
160	LENS	(U.S.) LOCKHEED	NA	NA	NA	NA
161	MAGNUM	(U. K.) UVITEK	550	1800	NA	NA
162	MANTA 1.5	(USSR) ACAD. SCI (USSR)	1300	4291	1200	2640
163	MARCAS	(JAPAN) KDD LABS	200	650	600	1320
164	MICROV	(U. K.) OSEL GROUP	200	656	100	330
165	MIN	(ITALY) ELECT. SAN GIORGIO	150	500	1300	2860
166	MINIROVER MK 1	(U.S.) DSSI	100	330	20.00	44
167	MINNOW	(U. K.) MARCONI U/W SYSTS)	NA	NA	NA	NA
168	MMIM	(U. K.) SLINGSBY	400	1312	NA	NA

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
169	MNS	(U.S.) HYDROPRODUCTS	NA		1134	2495
170	MODEXA	(ITALY) M.I.C &FNPDI	400	1320	280	616
171	MOSQUITO	(JAPAN) JAMSTEC	100	330	NA	NA
172	MURS-100	(JAPAN) MITSUI	100	330	NA	NA
173	MURS-300	(JAPAN) MITSUI	300	985	2600	5720
174	MURS-300 MKII	(JAPAN) MITSUI	300	985	NA	NA
175	OBSERVER DL1	(U. K.) SLINGSBY	200	650	5000	11000
176	OBSERVOR	(U. K.) SLINGSBY	600	2000	700	1540
177	ORCA	(U.S.) AQUA AIR IND.	305	1000	100	220
178	ORCA I	(SWEDEN) SAAB-SCANIA	1828	6000	100	220
179	ORION (MAXI DART)	(CANADA) I.S.E.	1000	3281	NA	NA
180	ORVIL	(U. K.) SLINGSBY	200	660	NA	NA
181	PAP-104	(FRANCE) E.C.A. & C.S.I.	300	985	700	1540
182	PHANTOM 500	(U.S.) DEEP OCEAN ENGINEERING	152	500	58	62
183	PHANTOM 500 HD	(U.S.) DEEP OCEAN ENGINEERING			NA	NA
184	PHOCAS II	(FINLAND) GEOL. TUTKI...	300	985	227	500
185	PIC	(U. K.) SLINGSBY	1000	3300	3500	7700
186	PINGUIN B6	(W. GER.) VFW FOKKER	100	330	1350	2970
187	PIONEER	(U.S.) SUB SEA INT'L	1525	5000	1360	2992
188	PIPER 101	(U.S.) AMETEK-STRAZA	610	2000	726	1597
189	PIV	(U.S.) NCSC	259	860	8300	18260
190	PLUTO	(ITALY) GAYMARINE	400	1312	140	308
191	POPE	(FRANCE) E.C.A. & C.S.I	150	500	400	880
192	PROES 200	(U.S.) AMETEK-STRAZA	610	2000	1158	2548
193	RASCL MK II	(CANADA) I.S.E.	360	1181	54	119
194	RCV-150	(U.S.) HYDRO PRODUCTS	610	2000	482	1060
195	RCV-225	(U.S.) HYDRO PRODUCTS	400	1320	82	180
196	RECON II	(U.S.) PERRY OFFSHORE INC	400	1312	281	618

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
197	RECON III	(U.S.) PERRY OFFSHORE INC	306	1000	227	500
198	RECON IV	(U.S.) PERRY	365	1200	405	891
199	RECON V	(U.S.) PERRY OFFSHORE INC	365	1200	NA	NA
200	RIGWORKER	(U. K.) OSEL GROUP	914	3000	771	1696
201	ROMIS I (100)	(W. GER.) RICO MIKROELEKTRONIK	100	328	50	110
202	ROMIS I (400)	(W. GER.) RICO MIKROELEKTRONIK	400	1312	50	110
203	ROSS	(CANADA) I.S.E.	500	1640	218	480
204	ROV	(JAPAN) MITSUI	400	1312	120	264
205	ROV 400	(FRANCE) COMEX	400	1312	540	1188
206	RPV	(U.S.) BENTHOS	600	1967	163	358
207	RPV 2000	(U.S.) BENTHOS	610	2000	163	358
208	RTV-100	(JAPAN) MITSUI			25	55
209	RUWS	(U.S.) NOSC	6000	20000	NA	NA
210	SCAMP	(U. K.) WINN TECH.			NA	NA
211	SCAN	(U. K.) U/W MAINT. CO.	100	328	NA	NA
212	SCARAB I & II	(U.S.) AMETEK-STRAZA	1829	6000	2268	4990
213	SCAT	(U.S.) NOSC	426	1398	NA	NA
214	SCORPI	(U.S.) AMETEK-STRAZA	914	3000	318.00	700
215	SCORPIO	(U.S.) AMETEK-STRAZA	914	3000	680	1496
216	SEA DOG	(U. K.) SLINGSBY	700	2300	NA	NA
217	SEA DOG/ORCA	(SWEDEN) SAAB/SUTEC	700	2300	NA	NA
218	SEA EAGLE	(U. K.) SUTEC	350	1150	90	198
219	SEA GRANT I	(U.S.) M.I.T.	365	1200	385.00	2847
220	SEA HAWK	(U. K.) SUTEC	350	1150	125	275
221	SEA HORSE	(U. K.) HERIOT-WATT	400	1300	1200	2640
222	SEA INSPECTOR	(U.S.) REBIKOFF U/W PROD.	1000	3280	127	280
223	SEA OWL	(U. K.) SUTEC	350	1150	80	176
224	SEA PUP II	(U. K.) U/W MARINE EQUIPT.	456	1500	77	169

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
225	SEA PUP III	(U. K.) U/W MARINE EQUIPT.	610	2000	77	169
226	SEA ROVER	(U.S.) DSSI	244	800	45	99
227	SEA SCAVANGER	(CANADA) I.S.E.	NA	NA	NA	NA
228	SEA SPY	(U. K.) U/W MARINE EQUIPT.	305	1000	NA	NA
229	SEA SURVEYOR	(U.S.) REBIKOFF U/W PROD.	200	660	NA	NA
230	SEA WHIP	(CANADA) SEA SCAN TECH INC	152	500	23 est.	50 est.
231	SMARTIE	(U. K.) MARINE UNIT TECH	300	984	37	82
232	SMIT SUB-1000	(NETH) SKADOC SUB. SYSTS	1000	3280	700	1540
233	SMT 1	(CANADA) I.S.E.	365	1200	451	1000
234	SMT 2	(CANADA) I.S.E.	365	1200	682	1500
235	SNOOPY	(U.S.) NOSC	460	1500	136	299
236	SNURRE	(NORWAY) CONT. SHELF INST.	1000	3280	1800	3960
237	SNURRE TYPE 2	(NORWAY) MYRENS	600	2000	1400	3080
238	SNV	(U.S.) DSSI	300	985	41	90
239	SOLO	(U. K.) SLINGSBY	1,500	4950	2000	4400
240	SOP	(NETH) SKADOC	1000	3280	1800	3960
241	SORD	(U.S.) NUWES, KEYPORT, WA	1950	6398	5171	11376
242	SPIDER	(NORWAY) MYRENS	500	1640	3300	7260
243	SPRINT 101	(U.S.) PERRY OFFSHORE INC	610	2000	48.00	106
244	STINGER	(CANADA) SEA SCAN	NA	NA	NA	NA
245	SUB 300	(NETH) HEEREMA	300	985	500	1100
246	SUPERDART	(CANADA) I.S.E.	365	1200	340	748
247	SURVEY SUB	(CANADA) I.S.E.	1000	3281	802	1764
248	TAXI	(U.K.) EURO SUBMERSIBLES	350	1148		NA
249	TELESUB 1000	(U.S.) REMOTE OC. SYSTS	610	2000	NA	NA
250	TIV	(U.S.) TAYLOR DIVING	038	125	43	95
251	TM 308	(ITALY) TECHNOMARE	400	1312		
252	TMV	(U.S.) ESSO	914	3000		

ALPHABETICAL LISTING 1/24/86

	WORLD ROV LIST	BUILDER	D. R. (m)	D. R. (ft)	D. W. (kg)	D. W. (lbs)
253	TOM 300	(FRANCE) COMEX	1000	3280		
254	TONGS I & II	(U.S.) NAVAL SYSTWARFARE CNTR	600	1969	NA	NA
255	TRAIL BLAZER	(CANADA) I.S.E.	500	1640	775.00	1705
256	TREC 1-9	(CANADA) I.S.E.	365	1200	159.00	350
257	TRIDENT	(U.S.) TAYLOR DIVING	600	2000	590	1298
258	TRIGLA	(NETH) SKADOC	035	115	NA	NA
259	TRITON 202	(U.S.) PERRY	1524	5000	1955	4300
260	TROJAN	(U. K.) SLINGSBY	1000	3300	1800	3960
261	TROY	(CANADA) I.S.E.	365	1200	513	1129
262	UDATS	(U.S.) NAVEXPLORDDISFAC	125	350		
263	UFO 300	(U. K.) OSEL GROUP.	430	1410	143	315
264	UTAS 280	(SWITZ.) TEKSEA, S.A.	200	656	110	242
265	UTAS 478	(SWITZ.) TEKSEA, S.A.	400	1312	350	770
266	VICTOR	(U. K.) KBA SUBSEA LTD	183	600		
267	VIKING	(CANADA) I.S.E.	365	1200	499	1098
268	VIPER MK I	(U.S.) BENTEX, INC.	152	500	30	67

APPENDIX 2

DIRECTORY OF ACTIVE ROV USERS

Directory

1 Ametek Straza
790 Greenfield Dr.
P. O. Box 666
El Cajon, CA 92022
(619) 442 3451

2 Anchor Systems S A
Tour Super Montparnasse
9, Rue Georges Pitard
75015 Paris, France
(1) 533 71 11

3 Aqua-Air Industries, Inc
P O Drawer 719
Bark Drive
Harvey, LA 70058
(504) 362 8124

4 AT&T Longlines
No 5 Wdorld Trade Center
New York, NY 10048
(212) 393 5366

5 Batelle Columbus Laboratories
505 King Avenue
Columbus, OH 43201
(614) 424 6424

6 Benthos, Inc
Edgerton Drive
N Falmouth, MA 02556
(617) 536 5917

Directory

7 BOC New Venture Secretariat
Institute of Offshore Engineering
Heriot-Watt University
Riccarton, Edinburgh EH14 4AS, U.K.
031 449 3393/3374

8 Busby Associates, Inc.
Mr. R. F. Busby, Pres.
576 South 23rd Street
Arlington, VA 22202
(703)

9 C.S.I. (Export Company)
39, rue de la Bienfaisance
75008 Paris, France
(1) 562 32 68

10 Comex Services
36 Boulevard de Ocean
13275 - Marseille Cedex 9
France
(91) 69-90-03

11 Continental Shelf Associates, Inc.
P.O. Box 3609
Jupiter, FL 33458
(305) 746 7946

12 Deep Ocean Engineering
1431 Doolittle Drive
San Leandro, CA 94619
(415) 562 9300

Directory

13 Deep Sea Systems International
P.O. Box 622
Falmouth, MA 02541
(617) 540 6732

14 Dornier Systems Gmbh
7990 Friedrichshafen
Postfach 648
Federal Republic of Germany
Tel: 07545/81

15 E.C.A.
17, avenue du Chateau
92190 Meudon-Bellevue
France
(1) 626 71 11

16 Euro Submersibles
Unit K1, Seseronto Estate
St. Mary's Road
Langley, Slough
England SL3 7EW
Tel: (0753) 44879

17 French Navy
Commandant la Division des
Vehicules d 'Intervention sous la
Mer
Toulon/Naval 83800 FRANCE
(91) 24.91.00

18 Freund, John
Naval Sea Systems Command
Code 05R2
Washington, D. C 20362
(202) 692 0344

Directory

19 Gaymarine Electronic Products
I-20090 Trezzano sul Naviglio
Via Papa Giovanni XXIII
Italy
(02) 2423294

20 Harbor Branch Foundation, Inc.
Box 196
Ft. Pierce, FL 33450
(305) 465 2400

21 Heerema Engineering Service B.V.
P.O. Box 9321
2300 PH Leiden
The Netherlands
(071) 31 04 31

22 Heriot-Watt University UK
Dept. of Electrical and Electronic
Engineering
31-35 Grassmarket
Edinburgh, EH1 2HT
(031) 225 8432

23 Honeywell Inc.
5303 Shilshole Ave. N.W.
Seattle, WA 98107
(206) 789 2000

24 Hydro Products
P.O. Box 2528
San Diego, CA 92121
(619) 453 2345

Directory

25 IFREMER (formerly CNEXO)
66 Avenue d,Ieana
75016 Paris
France
723 55 28

26 Institute of Oceanology
Academy of Sciences USSR
23 Krasikova St. 117218
Moscow, USSR
124 59 96

27 International Submarine Engineering
2601 Murray Street
Port Moody, B.C.
Canada V3H 1X1
(604) 931 2408

28 InterOcean Systems, Inc
3540 Aero Court
San Diego, CA 92123-1799
(619) 565 8400

29 Japan Marine Science and Technology Center
Deepsea Technology Department
2-15 Natsushima-cho
Yokosuka City, Kanagawa 237

30 Kaeverner Engineering A/S
P.O. Box 222 N01324 Lysaker
Norway
472 595050

Directory

31 KBA Subsea Ltd
Unit 7, Lister Road
Basingstroke RG22 4NP
United Kingdom
(0256)_ 52740/9 & 54682

32 Klein Associates, Inc.
Klein Drive
Salem, NH 03079
(603) 893 6131

33 Kraft Ocean Systems
11667 West 90th Terrace
Overland Park, KS 66214
(913) 894 9022

34 Land and Marine Engineering Ltd
Port Causeway, Bromborough
Wirral, Merseyside L62 RTG
051 645 8000

35 Lockheed Advanced Marine Systems
3929 Calle Fortunada
San Diego, CA 92123
(619) 569 8540

36 Marine Physical Laboratory
University of California
San Diego, CA 92152
(619) 452 2854

Directory

37 Massachusetts Institute of Technology
Dept. of Ocean Engineering
Cambridge, MA 02139
(617) 254 4316

38 Maui Divers of Hawaii
1520 Liona Street
Honolulu, HI 96814
(808) 259 5978

39 Mitsui Engineering and Shipbuilding Co. Ltd.
5-6-1, Tsukiji, Chuo-ku
Tokyo 104, Japan

40 Mitsui Ocean Development and Engineering Co. Ltd. (MODEC)
3-1 Hitosubashi 2-chome
Chiyoda-ku
Tokyo 101, Japan
TOKYO 265 3141

41 Myrens Verksted A/S
Postbox 4200 Torshov
Olso 4 Norway
(47) 2 355 600

42 National Defense Research Establishment (FOA)
S-102 54 Stockholm, Sweden

Directory

43 Naval Coastal Systems Center
Panama City, FL

44 Naval Facilities Engineering
Command
Civil Engineering Laboratory
Ocean Engineering Dept.
Port Hueneme, CA 93043
(805) 982 5420

45 Naval Ocean Systems Center
Code 5212
San Diego, CA 92152
(619) 225 6686

46 Naval Oceanographic Office
NSTL Station
Bay St. Louis, MS 39522
(601) 688 4524

47 Naval Ordnance Disposal
Technology Center
Indian Head, MD 20640
(301) 743 4530

48 Naval Research Laboratory
Code 5823
Washington, D.C. 20375
(202) 767 2695

Directory

49 Naval Systems Warfare Center
Ft. Lauderdale, FL 33315

50 Naval Torpedo Station
Keyport, WA 98345
(206) 326 2511

51 Offshore Systems Engineering
Limited (OSEL Group)
Boundary Road
Harfreys Industrial Estate
Great Yarmouth, Norfolk NR31 0LU
England

52 Perry Offshore Inc
P.O. Box 10297
Riviera Beach, FL 33404
(305) 842 5261

53 Q.I. Inc
20-5, 2-Chome
Minmi-Yukigaya
Ohta-ku, Tokyo, Japan

54 Remote Ocean Systems, Inc
5111 Santa Fe St. Suite L
San Diego, CA 92109
(619) 483 3902

Directory

55 Robertson Radio-Elektro A/S
P.O. Box 55, N-4371
Egersund, Norway
(04) 49 17 77

56 Rockwell International
Electronic Systems Group
3370 Miraloma Avenue
Anaheim, CA 92686
(714) 632 8111

57 Sea-I Research Canada Ltd.
Marine Technology Center, Suite 106
P.O. Box 2282
Sidney, B. C. Canada V8L 3S8
(604) 556 2821

58 Skadoc Submersible Systems
7 Industrieweg
Yerseke
The Netherlands
(0113) 2106

59 Slingsby Engineering Ltd
Kirbymoorside
York YO6 6EZ
England
(0751) 31751

60 Smit International
5, Westplein
3016 BM
Rotterdam, Holland
010 36 27 00

Directory

61 Societe ECA
17 Avenue du Chateau
92190 Meudon
Bellevue, France
626 7111

62 Sonatech, Inc
700 Botello Road
Goleta, CA 93017
(805) 967 0437

63 Sperry Marine Systems
Lakefield Road and Marcus Avenue
Great Neck, NY 11020
(516) 574 1118

64 Submarine Development Group One
139 Sylvester Road
San Diego, CA 92106
(619) 225 6583

65 Sumitomo Heavy Industries, Ltd
New-Otemachi Bldg 2-1
Otemachi 2-chome
Chiyoda-ku, Tokyo 100
(03) 211 1361

66 Sutec USA
2812 Woodland Drive, N.W
Washington, D.C. 20008
(202) 628 1000

Directory

67 Taylor Diving and Salvage Inc.
Box 795
701 Engineers Road
Belle Chase, LA 70037
(504) 394 6000

68 Technomare S.p.A
San Marco 2091
Venice, Italy
041 708622

69 UDI, Ltd
Denmore Road
Bridge of Don Industrial Estate
Aberdeen, AB2 8JW
Scotland
703551

70 Underwater Marine & Equipment
16 Farnborough Road
Farnborough, Hampshire GU14 6BA
Tel. Farnborough (Hants)-45954

71 University of New Hampshire
Marine Sysems Engineering Lab
Durham, NH 03824
(603) 749 6056

72 University of Washington
Applied Physics Laboratory
Seattle, WA

Directory

73 Uvitek Ltd.
Unite 10, Barratt Industrial Park
Wellheads Terrace, Dyce
Aberdeen AB2 0GF
Scotland
(0224) 722109

74 Westinghouse Electric Corporation
P.O. Box 1488
Annapolis, MD 21404

75 Wynn Technology Ltd
Kilbrittain
County Cork, Ireland
(023) 49601

76 Woods Hole Oceanographic Inst
Woods Hole, MA 02543
(617) 548 1400

APPENDIX 3

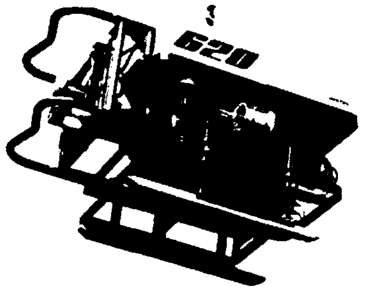
ROV MANUFACTURERS AND OPERATORS

Reprinted from 1985 ROV Review
Pages 11-27, 31-42
(with permission of Subnotes, Windate Enterprises, Inc.)

ROV MANUFACTURERS

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

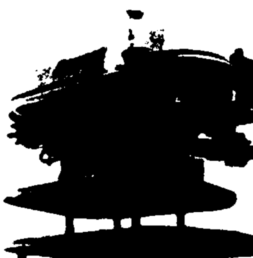
1. **AMETEK, Straza Division**
   790 Greenfield Drive
   P.O. Box 666, El Cajon, CA 92022
   Tel: (619) 442-3451 / Tlx: 288951



2. ASD/620
3. Inspection, NDT & light work (drill rig support can be performed with available cable cutter & manipulator
4. 910 m (3,000 ft)
5. Seven hydraulic thrusters, 20 hp standard (higher power packs optional)
6. Full cage or top interface management system (TMS). TMS provides for dead vehicle recovery.
7. Interfaces for stills camera, TV (any type), CTFM or pulse sonar, CP probe, aft camera.
8. Optional 5-function rate controlled and 3-function grabber.
9. 36 kg (80 lbs)
10. 180 cm (72") long, 102 cm (40") wide, 78 cm (32") high
11. 454 kg (1,000 lbs)/828 kg (1,821 lbs)
12. 2/3 (2 systems in service March 1985)
13. ...
14. Stabilized in pitch & roll, auto heading/depth/altitude

---

1. **AMETEK, Straza Division**
   790 Greenfield Drive
   P.O. Box 666, El Cajon, CA 92022
   Tel: (619) 442-3451 / Tlx: 288951



2. GEMINI 100
3. Heavy work, multi-purpose
4. 1250 m (4,000 ft)—standard. Depth rating up to 3000 m (10,000 ft) —optional
5. Seven 15 hp hydraulic thrusters; 100 hp standard.
6. Tether management system standard.
7. CTFM sonar w/scan conversion, auto depth/heading/altitude, standard interfaces provided.
8. Optional—any type.
9. 225 (500 lbs) standard. 360 kg (800 lbs) with additional buoyancy. Vertical lift approx. 675 kg (1,500 lbs) plus payload.
10. 271.8 cm (107") long, 182.8 cm (72" wide, 127 cm (51") high (height increases 48 cm (12") or more with addition of work module.)
11. 2045 kg (4,500 lbs)/10 tons
12. 1/0 (sea trials to begin March 1985; operational by mid-summer)
13. $875,000 (approx)
14. Work module can be factory configured to order or by user with drawings supplied by AMETEK.

---

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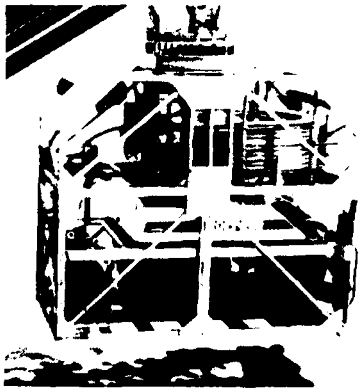
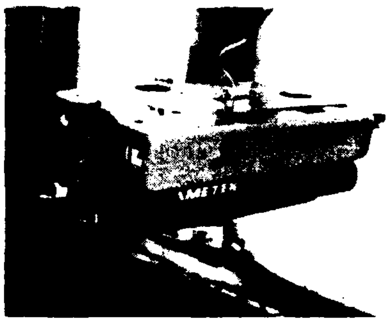
   790 Greenfield Drive
   P.O. Box 666, El Cajon, CA 92022
   Tel: (619) 442-3451 / Tlx: 288951



2. PROES 200
3. Inspection, cleaning, NDT
4. 610 m (2,000 ft.)
5. 4 hydraulic thrusters, 40 hp
6. Standard
7. Color TV, SIT b&w TV, sonar (on cage), stills camera, thickness probe, CP probe
8. One 5-function master/slave
   One 7-function rate controlled
   Two 4-function rate controlled
   Two 2-function rate controlled
9. 67.5 kg (150 lbs.)
10. 2.5 m (98") long, 1.44 m (56.5") wide, 1.43 m (56") high
11. 1814 kg (4,000 lbs)/18,144 kg (40,000 lbs) — vehicle, garage, winch & launcher
12. 1/0
13. ....
14. High pressure erosion/cavitation system—to bright metal
    2 and 4-function manipulators have suction cups to secure ROV to structure when cleaning.
    High pressure pump on garage connected to vehicle through hose in center of neutral tether.

---

1. **AMETEK, Straza Division**
   790 Greenfield Drive
   P.O. Box 666, El Cajon, CA 92022
   Tel: (619) 442-3451 / Tlx: 288951



2. SCORPI
3. Inspection
4. 910 m (3,000 ft)
5. Six hydraulic thrusters; 10 hp
6. Standard
7. B&W LLLTV on pan tilt. Many options
8. 4-function rate controlled optional
9. 22-34 kg (50-75 lbs)
10. 160 cm (63") long, 102 cm (40") wide, 80 cm (32") high
11. 430 kg (950 lbs)/863 kg (1,900 lbs)

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

12. 14/0 (12 in service; 1 destroyed in truck accident)
13. $335,000/....
14. Designed for easy piloting and access to steel jacket nodes. Succeeded by ASD/620 ROV system.

---

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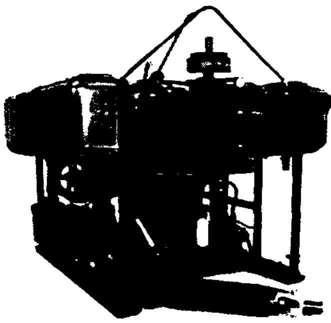
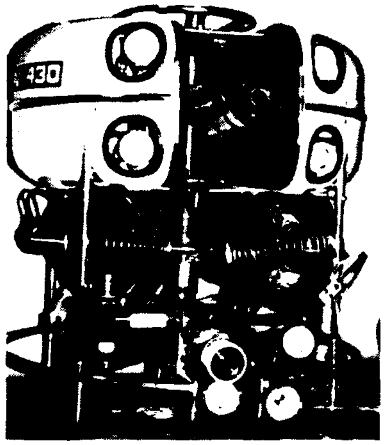
   790 Greenfield Drive
   P.O. Box 666, El Cajon, CA 92022
   Tel: (619) 442-3451 / Tlx: 288951



2. SCORPIO
3. Drill support, pipeline inspection/survey, general work
4. 900 m (3,000 ft); 1500 m (5,000 ft) optional
5. 4 hydraulic thrusters; 25 hp (up to 60 hp optional
6. Optional
7. CTFM sonar, LLLTV (b&w). Optional: color TV, TVP, CP probe, 35 mm stills or stereo camera, acoustic thickness NDT, pipetracker, sub-bottom profiler optional
8. One 5-function rate controlled standard
   Optional: 7-function master/slave, or 4-function grabber
9. 160 kg (350 lbs) depending on options selected
10. 223.5 cm (88") long, 177.8 cm (64") high
11. 998 kg (2,200 lbs)/6 tons
12. 53/3 (50 systems are in service; 2 lost; 1 damaged and not returned to service)
13. ...
14. Manufactured to highest commercial standard with MIL spec components.

---

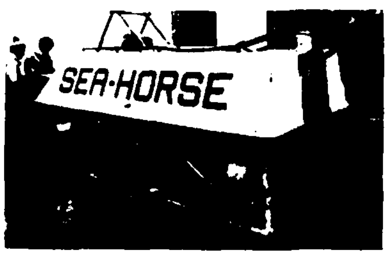
1. **Benthos, Inc.**
   Edgerton Drive
   North Falmouth, MA 02556
   Tel: (617) 563-5917 / Tlx: 940884



2. RPV-2000
3. Inspection, light work
4. 610 m (2,000 ft)
5. Five DC electric thrusters
6. Standard
7. B&W TV, stills camera. Color TV, stereo cameras, sonar optional
8. 3-function "Articulator" optional
9. 6 kg (13 lbs)
10. 108.5 cm (43.4") high, 95 cm (38") diameter
11. 183 kg (407 lbs)/5,400 kg (12,000 lbs)
12. 6/....
13. ...
14. ...

---

1. **BOC New Venture Secretariat**
   Crawley, UK
   ROV modified, owned and operated by:
   Institute of Offshore Engineering
   Heriot-Watt University
   Riccarton, Edinburgh EH14 4AS
   United Kingdom
   Tel: 031 449 3393/3374
   Tlx: 727918 IOEHWU G



2. SEAHORSE (ex BOCTOPUS)
3. Applications testbed and environment surveys
4. 400 m (1,300 ft)
5. 5 electric thrusters; 35 hp
6. None
7. SIT TV, color TV, depth sensor, stills camera, compass
8. 1 OSEL 7-function seawater hydraulics manipulator
9. 200 kg (440 lbs)
10. 3.2 m (10.5') long, 2.1 m (7') wide, 1.7 m (5.5') high
11. 1180 kg (2,600 lbs)/15,240 kg (15 tons)
12. 1/0
13. ...
14. SEAHORSE is available for hire worldwide. Systems are completely self-contained with control cabin, workshop/stores area, launching crane and diesel generator.

---

1. **COMEX SERVICES**
   36, Boulevard des Oceans
   13275 Marseille Cedex 9
   France
   Tel: (91) 41-01-70 / Tlx: 410985

2. ROV 400
3. Inspection and specialized work (valve activation, "H" frame operation, etc.)
4. 600 m (1970 ft)
5. 4 hydraulic thrusters; 20 hp
6. Slip ring tether management system standard

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

7. Color TV, b&w TV, north-seeking gyro, pitch & roll sensor, interface for sonar.
8. 1 manipulator optional
9. 50 kg (110 lbs)
10. 1.5 m (5') long, 1.2 m (4') wide, 1.4 m (4.6') high
11. 500 kg (1,100 lbs)
12. 1/1 (1 ROV 400 is now in service)
13. ..../....
14. Excellent hydraulic power available for tools

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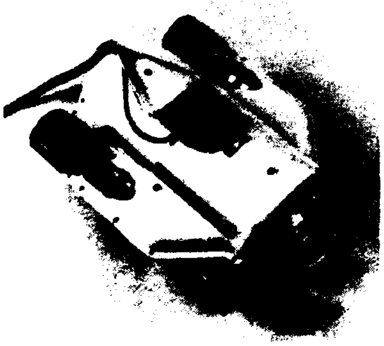
1. **Deep Sea Systems International Inc.**
P.O. Box 622, Falmouth, MA 02541
Tel: (617) 540-6732



2. MiniRover MK I
3. Inspection
4. 120 m (400 ft)
5. .45 hp
6. Optional
7. Depth gauge, magnetic compass
8. Optional
9. 6 lbs. (max)
10. 28", 12.5", 18.5"
11. 55 lbs; 100 lbs (in case)
12. 19/25
13. $28,850/$32,000
14. Options include high thrust motors, remote controlled iris, 350 line color TV. In late 1985, standard MiniRover will be upgraded to brushless thrusters and 300 m (985 ft) depth.

---

1. **Deep Sea Systems International, Inc.**
P.O. Box 622, Falmouth, MA 02541
Tel: (617) 540-6732

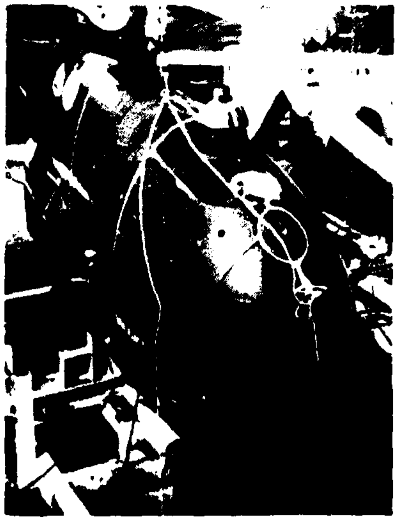
[No photo available]

2. Standard Navy Vehicle (SNV)
3. Mine neutralization (harbor and sea lane clearance)
4. 300 m (985 ft)
5. 3.5 hp; 2.6KW
6. Optional
7. Color TV, depth, heading & altitude sensors, scanning sonar
8. DSSI "Articulator" optional
9. 15 kg (33 lbs)
10. 42" long, 24" wide, 18" high
11. 90 lbs; 125 lbs
12. 1/0
13. $50,000 (estimated)/$100,000 (estimated)
14. Low cost military ROV system capable of operations from helicopter. DSSI predicts 300 to be sold within 5 years.

---

1. **E.C.A.**
17, avenue du Chateau
92190 Meudon-Bellevue
France
Tel: (1) 626 71 11 / Tlx: 200336

C.S.I. (Export Company)
39, rue de la Bienfaisance
75008 Paris, France
Tel: (1) 562 32 68 / Tlx: 200336

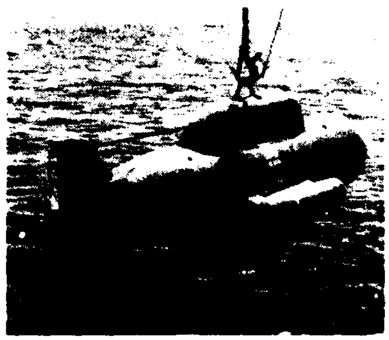


2. EPAULARD (untethered ROV)
3. Photographic and bathymetric survey
4. 6,000 m, (20,000 ft)
5. Electric thrusters, power from on-board battery
6. None required
7. Stills camera
8. None
9. ....
10. 4 m (13') long, 1.1 m (3.6') wide, 2 m (6.5') high
11. 2.9 tons
12. 1/0
13. ....
14. Operational since 1983. Has made 150 dives deeper than 2,000 m (6,600 ft). EPAULARD is presently the only operational UROV. Controlled by acoustic link. Has been refitted with a vertical thruster.

---

1. **E.C.A.**
17, avenue du Chateau
92190 Meudon-Bellevue
France
Tel: (01) 626 71 11 / Tlx: 200336

C.S.I. (Export Company)
39, rue de la Bienfaisance
75008 Paris, France
Tel: (1) 562 32 68 Tlx: 200336

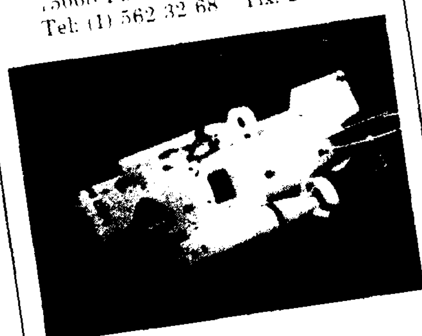


2. PAP 104
3. Mine countermeasures
4. 300 m (985 ft)
5. Two MG electric thrusters. Vertical thruster optional for mid-water operation.
6. None required

7. B&W TV. Options include color TV sonar, echo sounder, tracking unit.
8. Manipulator with cable cutters optional
9. ....
10. 2.7 m (8.9') long, 1.1 m (3.6') wide, 0.9 m (3') high
11. 800 kg (1,760 lbs)/....
12. 239/13
13. ....
14. Largest selling ROV in the world. In use by 10 navies.

---

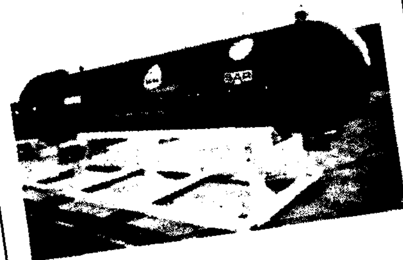
1. **E.C.A.**
17, avenue du Chateau
92190 Meudon-Bellevue
France
Tel: (1) 626 71 11 Tlx: 200336
C.S.I. (Export Company)
39, rue de la Bienfaisance
75008 Paris, France
Tel: (1) 562 32 68 Tlx: 200336



2. POPE
3. Inspection
4. 150 m (500 ft) — 300 m (985 ft) optional
5. 2 MG electric thrusters
6. None
7. B&W TV on pan/tilt. Sonar, color TV, manipulator optional
8. Optional
9. 70 kg (155 lbs)
10. 2.2 m (7.2') long, 1.2 m (4') wide, 0.9 (3') high
11. 400 kg (880 lbs)/....
12. 1/0
13. ....
14. ....

---

1. **E.C.A.**
17, avenue du Chateau
92190 Meudon-Bellevue
France
Tel: (1) 626 71 11 / Tlx: 200336
C.S.I. (Export Company)
39, rue de la Bienfaisance
75008 Paris, France
Tel: (1) 562 32 68 / Tlx: 200336



2. SAR
3. Deep Sea Survey
4. 6,000 m (20,000 ft)
5. Towed by surface ship
6. None required
7. Side scan sonar
8. None
9. ....
10. ....
11. ....
12. 1/0
13. ....
14. Sea trials conducted in 1984 off Portugese coast. SAR conducts side scan sonar survey 50-80 meters (165-260 ft) above the sea bed.

---

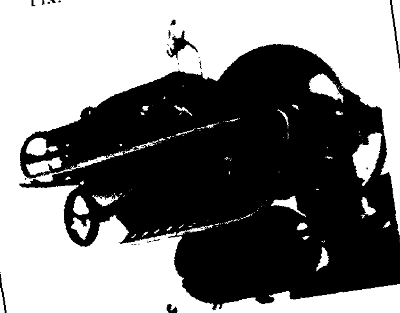
1. **GAYMARINE SRL**
Via Giovanni XXIII, 39
I-20090 Trezzano sul Naviglio
Milano, Italy
Tel: (02) 2423294
Tlx: 313539 GAYMARINE I

---

2. FILIPPO
3. Inspection, NDT
4. 350 m (1150 ft)
5. 4 electric motors, 3 hp
6. Optional
7. B&W TV camera, color TV, stills camera, compass, autodepth
8. None
9. 4 kg (9 lbs)
10. 650mm (26") spherical
11. 86 kg (190 lbs)/150 kg (330 lbs)
12. 26/2; 18 are in service; 2 known lost
13. $100,000/$150,000
14. ....

---

1. **GAYMARINE SRL**
Via Giovanni XXIII, 39
I-20090 Trezzano sul Naviglio
Milano, Italy
Tel: (02) 2423294
Tlx: 313539 GAYMARINE I



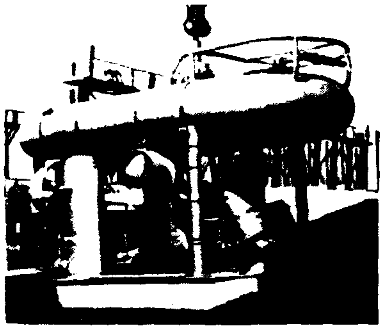
2. PLUTO
3. Inspection, NDT, mine neutralization (military version)
4. 350 m (1,150 ft)
5. 5 electric motors; 4.5 hp (5.5 hp optional)
6. Optional
7. B&W LLLTV, color TV, stills camera, avoidance sonar, compass, auto depth & auto heading
8. Four-function optional
9. 43 kg (95 lbs)
10. 700mm (28"), 600mm (24"), 600 mm (24")

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

11. 160 kg (353 lbs)/320 kg (704 lbs)
12. 5/12
13. $230,000 (commercial); $300,000 (military)/$280,000 (commercial), $350,000 (military)
14. Power by internal batteries or via tether cable. High resolution sonar (1986).

---

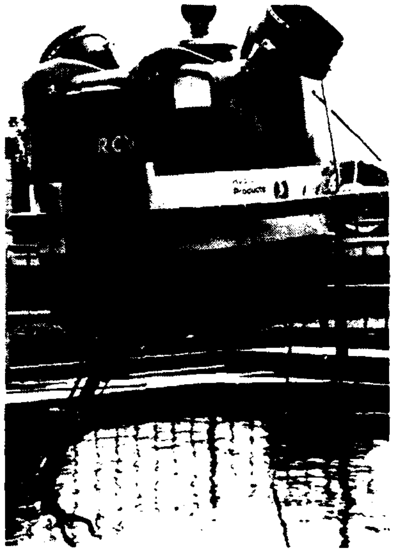
1. **Harbor Branch Foundation**
   RR 1, Box 196
   Old Dixie Hwy
   Ft. Pierce, FL 33450
   Tel: (305) 465-2400



2. CORD II (Cabled Observation & Rescue Device)
3. Observation/inspection
4. 914 m (3,000 ft)
5. 4 hydraulic thrusters; 6.7 hp
6. Not used
7. B&W LLLTV on pan/tilt, compass, side scan sonar, depth sensor, 70mm stills camera
8. One 6-function
9. 4 kg (9 lbs)
10. 152 cm (59") long, 109 cm (43") wide, 124 cm (48") high
11. 455 kg (1,000 lbs)
12. 1/0
13. —
14. 85 cm (0.33") umblical allows for operation in 3 kt. surface current. CORD II is being refurbished for summer 1985 operations in Lake Superior.

---

1. **Hydro Products, Inc.**
   P.O. Box 2528
   11777 Sorrento Valley Road
   San Diego, CA 92112 USA
   Tel: (619) 453-2345
   Twx: 910-322-1133



2. RCV-150
3. Inspection & limited access work
4. 610 m (2,000 ft)
5. 4 hydraulic thrusters
6. Standard
7. pan/tilt TV, altimeter, pitch roll angle, magnetic & inertial heading, turns counter, depth sensor
8. 3-axis single manipulator
9. 60 lbs.
10. 45" high x 52" wide x 59" long
11. 1,200 lbs; 29,140 lbs.
12. 11/0 (8 in service/3 lost)
13. $199,000 (vehicle only)/$750,000
14. Can be fitted with auto depth/heading, pinger strobe, cable cutter, sonar, diagnostics annotation, Photsea stills camera, dual manipulator, color TV and auxiliary channels for controls & sensors.

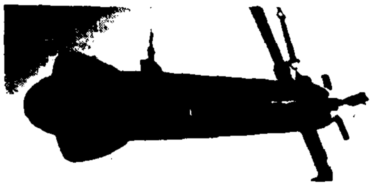
---

1. **Hydro Products, Inc.**
   P.O. Box 2528
   11777 Sorrento Valley Road
   San Diego, CA 92112 USA
   Tel: (619) 453-2345
   Twx: 910-322-1133

2. RCV-225
3. Inspection
4. 1,350 ft.
5. 4 electrical ([illegible] hp) thrusters
6. Standard
7. Depth, tether payout, LLLTV
8. Multi-function tool arm optional
9. N/A
10. 20" high, 26" wide, 20" diameter
11. 180 lbs.; 7,455 lbs.
12. 98 (includes spare vehicles only)/0 (75 are in service; 20 vehicles have been known lost or destroyed)
13. $159,500 (vehicle only)/$426,000
14. Also features auto depth/heading, pitching optics, screen annotation, tether management, strobe flasher. Options include pitching color TV, fm telemetry, image measuring system, emergency locator, tether cutter, keyboard annotation and multi-function tool arm.

---

1. **International Submarine Engineering Ltd. (ISE)**
   2601 Murray St.
   Port Moody, B.C., Canada V3H 1X1
   Tel: (604) 937-3421
   Tlx: 04-353554



2. ARCS (Autonomous Remotely Operated Submersible)

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

3. Under ice survey
4. ....
5. Battery
6. N/A
7. Altimeter, avoidance sonar, depth sensor, 2 axis Doppler, long baseline navigation.
8. None.
9. ....
10. 7 m (23') long, 0.7 m (2.3') diameter
11. ....
12. 1-0
13. ...
14. Future versions of ARCS will be fitted with manipulators.

---

1. **International Submarine Engineering Ltd. (ISE)**
2601 Murray St.
Port Moody, B.C., Canada V3H 1X1
Tel: (604) 937-3421
Tlx: 04-353554

2. DART/RASCL
3. Inspection, light work
4. 360 m (1,200 ft)
5. Electric propulsion
6. Optional
7. B&W TV, fluxgate compass
8. 3-function grabber optional
9. 9 kg (20 lbs) to 18 kg (40 lbs)
10. 132 cm (52') long, 51 cm (20") wide, 43-58 cm (17-23") high
11. 67.5 kg (150 lbs) to 112.5 kg (250 lbs)
12. 33/2
13. RASCL: $55,000 / $70,000
DART: $95,000 / $140,000
14. Basic difference between DART and RASCL is that DART has telemetry system. Canadian Defence Force's DARTs have been fitted with Mesotech color display sonars to enhance search capability. New DART design include the TARS and INSPECTOR.

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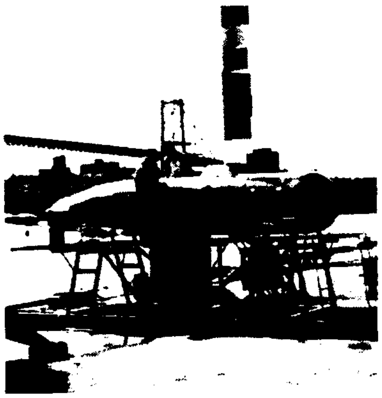
1. **International Submarine Engineering Ltd. (ISE)**
2601 Murray St.
Port Moody, B.C., Canada V3H 1X1
Tel: (604) 937-3421
Tlx: 04-353554



2. DOLPHIN (Deep Ocean Logging Platform Instrumented for Navigation). DOLPHIN is a radio-controlled ROV.
3. Survey, minecountermeasures, force multiplier
4. N/A
5. 120 hp Ford Lehman marine diesel
6. N/A
7. Depends on mission
8. None
9. ....
10. 6.6 m (22 ft) long, 99 cm (39") diameter
11. 2385 kg (5,300 lbs)/....
12. 1/4
13. ..../....
14. DOLPHIN can make up to 15.5 knots. Design has been completed for a 500 hp, 25+ knot version.

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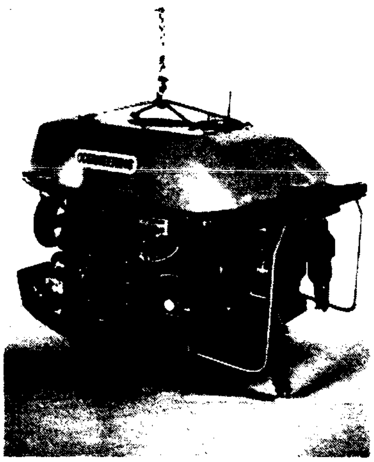

2. HYSUB
3. Drilling support, torpedo recovery, general purpose work
4. 900 m (3,000 ft). Note one version of HYSYB is rated at 2500 m (8,200 ft)
5. 20, 30, 40 or 60 hp customer specified
6. Standard
7. B&W SIT TV, color TV, gyro, depth and heading sensors
8. One 7-function master slave
One 5-function rate controlled
9. Variable
10. 210 cm (82.5") long, 121 cm (47.5") wide, 145 cm (57") high
11. 802 kg (1800 lbs) / ....
12. 53/6
13. $220,000 / $400,000
14. Many recent HYSUBs are fitted with the Mesotech color display sonar

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors
8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

1. **International Submarine Engineering Ltd. (ISE)**
2601 Murray St.
Port Moody, B.C., Canada V3H 1X1
Tel: (604) 937-3421
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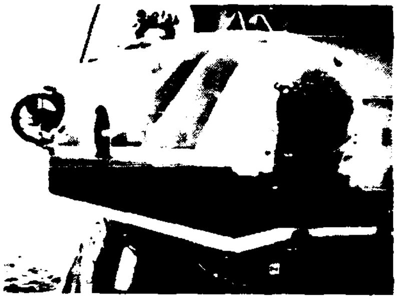

2. TRAIL BLAZER
3. Mine countermeasures
4. 360 m (1,200 ft)
5. 5 hydraulic thrusters; 30 hp
6. Optional
7. B&W LLLTV, sonar, gyro
8. One or 2 manipulators per customer specification
9. 135 kg (300 lbs)
10. 2.7 m (9') long, 78 cm (31") wide, 91 cm (36") high
11. 765 kg (1700 lbs)/....
12. 1/...
13. $500,000/....
14. Smaller versions of TRAIL BLAZER are CYCLOPSE (20 hp) and SEA SCAVENGER (10 hp).

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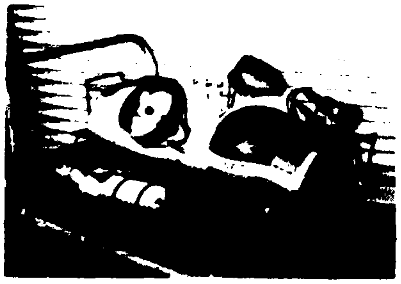
1. **Japan Marine Science & Technology Center (JAMSTEC)**
2-15 Natsushima-cho,
Yokosuka, Kanagawa Pref., 237,
Japan



2. HORNET-500
3. Scientific and fisheries survey. Inspection
4. 500 m (1,640 ft)
5. 4 DC motors; 1.8 hp
6. None
7. Color TV, b&w rear-looking TV, depth, fluxgate, rate gyro, stills camera
8. One 3-function
9. 20 kg (44 lbs)
10. 120 cm ((47") long, 96 cm (37") wide, 56 cm (22") high
11. 120 kg (264) lbs) / 300 kg (660 lbs)
12. 1/1; none currently in service – 1 lost
13. $200,000/....
14. HORNET-500 uses fiber optic electro-mechanical tether cable.

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1. **Japan Marine Science & Technology Center (JAMSTEC)**
2-15 Natsushima-cho,
Yokosuka, Kanagawa Pref., 237,
Japan

2. JTV
3. Scientific and fisheries survey. Inspection
4. 200 m (656 ft); 500 m (1,640 ft) optional
5. 4 DC electric motors; 0.5 hp
6. None
7. Color TV, b&w TV, depth meter, compass, stills camera
8. 1 optional
9. 10 kg (22 lbs)
10. 52 cm (20") long, 64 cm (25") wide 50 cm (19.5") high
11. 43 kg (95 lbs) / 120 kg (264 lbs)
12. 2/0; only 1 in service
13. $20,000/....
14. Uses cylinger type magnetic torque coupling thrusters

---

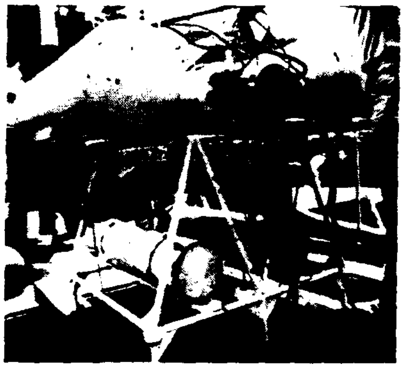
1. **KBA Subsea Ltd.**
Unit 7, Lister Rd.,
Basingstoke
Hampshire RG22 4NP
United Kingdom
Tel: (0256) 52740/9 & 54682
Tlx: 858877

2. VICTOR
3. Inspection
4. 300 m (985 ft)
5. Water jet (electric motors driving mini turbines
6. Standard
7. Flexgate compass and echosounder
8. None (can be fitted to future models)
9. Variable per requirement
10. 60", 24", 32"
11. 350 lbs.
450 lbs.
12. 1/1
13. $25,000/$30,000
14. Rugged, low cost, powerful ROV system. Provides new concept for propulsion. Basic design can be expanded into larger and more powerful ROV system.

ROV Manufacturers *(cont.)*

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

1. **Marine Systems Engineering Laboratory**
University of New Hampshire
Durham, NH 03824
Tel: (603) 749-6056



2. EAVE-East Autonomous Untethered Submersible.

3. Technology development testbed

4. 100 m (330 ft)

5. 6 thrusters @ ¼ hp, 24 V DC electric

6. ...

7. Pressure transducer, long short baseline acoustic nav system, flex-gate compass

8. ...

9. 27 kg (60 lbs); more with additional buoyancy

10. 130cm (51"), 135cm (53"), 155cm (61")

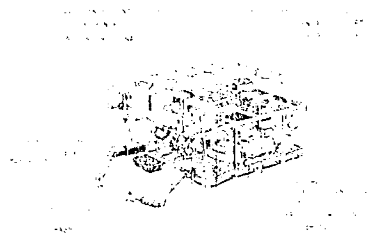
11. 272 kg (600 lbs)/....

12. 1/1

13. .../....

14. Precise station keeping to within 15 cm. Path tracking to within 30 m. Open frame allows for addition of sensors & tools. This vehicle has carried as much as 90 kg (200 lbs) payload.

1. **Mitsui Engineering & Shipbuilding Co., Ltd.**
5-6-1, Tsukiji, Chuo-ku,
Tokyo 104, Japan



2. Dolphin-3K

3. Pre-site survey of the manned submersible Shinkai 2000. Scientific reconnaissance survey.

4. 3,300 m (10,825 ft)

5. 6 hydraulic thrusters; 55 hp

6. None

7. Color TV, b&w LLLTV, rear looking b&w TV, avoidance sonar, current meter, stills camera, fluxgate and rate gyros, trim sensor, depth meter, altimeter

8. One 7-function master slave
One 5-function rate control

9. 150 kg (330 lbs)

10. 285 cm (9.3') long, 194 cm (6.3') wide, 190 cm (6.2') high

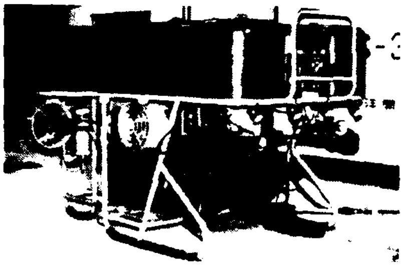
11. 3400 kg (7,480 lbs) / 33 tons

12. 0/1

13. $5 million

14. Dolphin-3K uses a 30mm fiber optic electro-mechanical cable. JAMSTEC will be owner & operator.

1. **Mitsui Ocean Development & Engineering Co. Ltd. (MODEC)**
3-1, Hitotsubashi 2-Chome,
Chiyoda-ku,
Tokyo 101, Japan
Tel: TOKYO 265-3141
Tlx: j 24978 (JAMODEC)



2. MURS-300

3. Inspection, search and recovery

4. 300 m (985 ft.)

5. 24KW

6. None

7. Acoustic pinger, altitude sonar, gyro, depth & trim sensor, water intrusion detector

8. One 7-function master slave

9. Variable

10. 2.73 m long, 2.06 m wide, 1.85 m high

11. 2,600 kg (5,720 lbs)/11,000 kg

12. 1 (prototype)/0

13. .../....

14. Also has 2 TV cameras (color/b&w), search sonar and nav system.

1. **Mitsui Ocean Development & Engineering Co. Ltd. (MODEC)**
3-1, Hitotsubashi 2-Chome,
Chiyoda-ku,
Tokyo 101, Japan
Tel: TOKYO 265-3141
Tlx: j 24978 (JAMODEC)

2. MURS-300 MKII

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

3. Inspection
4. 300 m (985 ft)
5. 4-300W electric motors
6. None
7. Directional gyro, depth sensor, acoustic transponder
8. None
9. 40 kg (88 lbs)
10. .95 m long, .75 m wide, .7 m high
11. 200 kg (440 lbs)
    10,000 kg (includes truck weight)
12. 1 (prototype)/0
13. .../...
14. ROV has DC brushless motors, pitching lens for TV and fiber optic tether cable.

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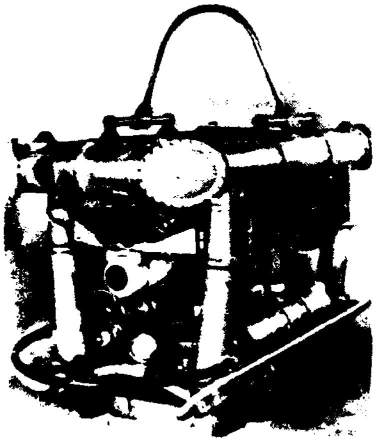
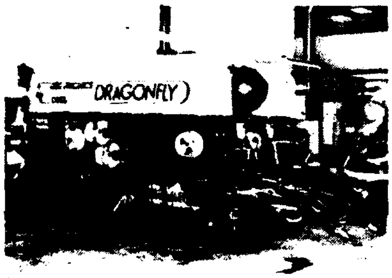
1. **National Defence Research Establishment (FOA)**
   S-102 54 Stockholm, Sweden



2. FOA SUB
3. R & D
4. 250 m (820 ft)
5. 4 hydraulic thrusters; 19 hp
6. ...
7. TV camera, depth sensor, altimeter, avoidance sonar, gyro compass, attitude sensors.
8. One simple hydraulic gripping arm to be installed
9. 40 kg (90 lbs)
10. 2 m (6.6') long, 1.2 m (4') wide, 1/2 m 1.2 m (4') high
11. 600 kg (1320 lbs) / 2000 kg (4,400 lbs)
12. 1/0
13. .../...
14. FOA SUB has been developed for R&D and testing of equipment, instrumentation and techniques for hydroacoustics, hydro-optics and navigation. Watertanks are used for compensation of payload.

---

1. **OSEL—Offshore Systems Engineering Ltd.**
   Boundary Rd., Harfreys Industrial Estate
   Great Yarmouth, Norfolk
   NR31 OLU United Kingdom
   Tel: (0493) 659916 / Tlx: 975084



2. DRAGONFLY
3. Multi-purpose
4. 1,828 m (6,000 ft)
5. 12 servo controlled thrusters; 60 hp
6. Standard for operations below 305 m (1,000 ft)
7. Fluxgate gyro, depth sensor, pitch & roll sensors, altimeter, sonar, color TV, b&w SIT TV (3)
8. Two OSEL 7-function seawater hydraulic manipulators (standard). One telescopic grabber (optional)
9. 450 kg (1,000 lbs) (with additional buoyancy material)
10. 2.54 m (8'4") long, 1.83 m (6') wide, 1.07 m (3'6") high
11. 1,590 kg (3,500 lbs) / 25 tons (approx)
12. 1/0
13. $1,102,000/...
14. Advanced telemetry system w/optical fiber data and video transmission lines with auto switching in the even of primary system failure. Modular construction.

---

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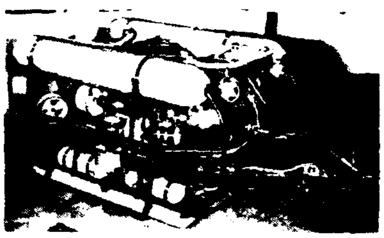

2. DUPLUS II
3. Multi-purpose
4. 1,000 m (3,280 ft) unmanned / 700 m (2,296 ft) manned.
5. 8 x 600 v. AC units
   4 x 120 v. DC units; 14.5 hp
6. Optional
7. Fluxgate gyro, depth sensor, pitch & roll sensors, altimeter, SIT b&w TV.
8. Two OSEL standard manipulators one grabber arm optional
9. 300 kg (660 lbs) unmanned
   180 kg (396 lbs) manned
10. 274 cm (108") long, 173 cm (68") wide, 136 cm (54") high
11. 1700 kg (3,740 lbs) / 12 tons
12. 6/1 (all 6 built are in service)
13. $522,000 / $597,000
14. ...

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   Boundary Rd., Harfreys Industrial Estate
   Great Yarmouth, Norfolk
   NR31 OLU United Kingdom
   Tel: (0493) 659916 / Tlx: 975084

2. HORNET/WASP ADS (atmospheric diving suit)

1. Manufacturer 2. ROV Name 3. Primary Task 4. Rated Depth 5. Propulsion & HP 6. Deployment Cage 7. Standard Sensors 8. Manipulators 9. Payload 10. Vehicle Dimensions 11. Weight 12. Total Built/Under Build 13. Base Price/Avg. Sale Price 14. Comments

3. Mid-water drill rig support

4. 700 m (2,300 ft)

5. Four 120 v. electrical thrusters; 6.5 hp

6. Optional

7. Depth sensor

8. 2 articulated arms (standard)

9. 150 kg (330 lbs)

10. 120 cm (47") wide, 208 cm (82") high

11. 780 kg (1,716 lbs) ... tons

12. 12 WASP ... 0, 1 HORNET ... 0 (none lost or destroyed)

13. $218,103 ...

14.

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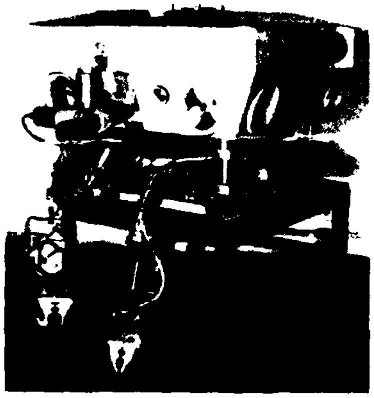
Boundary Rd., Harfreys Industrial Estate
Great Yarmouth, Norfolk
NR31 OLU United Kingdom
Tel: (0493) 659916 Tlx: 975084



2. RIGWORKER

3. Rig Support

4. 915 m (3,000 ft)

5. 6 hydraulic thrusters, 50 hp (standard)

6. Optional

7. Fluxgate gyro, depth sensor, altimeter, pitch & roll sensors, SIT b&w TV

8. Two OSEL seawater hydraulic manipulators standard ... 7-function master slave optional

9.

10. 1.8 m (72") long, 1.6 m (64") wide, 1.1 m (44") high

11. 1065 kg (2,347 lbs) ... 12 tons (approx)

12. 3/8

13. $568,400 ...

14. ...

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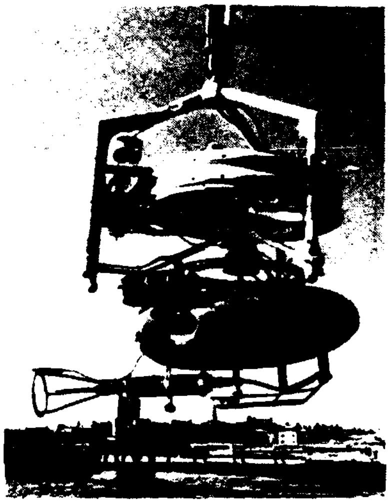
1. **OSEL—Offshore Systems Engineering Ltd.**
Boundary Rd., Hartreys Industrial Estate
Great Yarmouth, Norfolk
NR31 OLU United Kingdom
Tel: (0493) 659916 Tlx: 975084



2. UFO (Underwater Flying Observer)

3. Inspection

4. 430 m (1,410 ft)

5. Four 240v. fully reversible, variable speed electric thrusters, 1 hp

6. Standard

7. CP Probe, b&w SIT TV

8. 5-function "Articulator" optional

9. 10-22 kg (22-48 lbs)

10. 122 cm (48") long, 75 cm (29.5") wide, 57 cm (22.5") high

11. 145 kg (320 lbs) ... 10 tons

12. 18/3 (in service are 9 single and 2 dual UFO system. 5 have been lost or destroyed)

13. $266,800 (w/b&w TV) ...
$313,200 (w/color TV) ...

14. Many options available

---

1. **Perry Offshore, Inc.**
275 West 10th St.
P.O. Box 10297
Riviera Beach, FL 33404
Tel: (305) 842-5261 Telefax: (305) 842-5130 Tlx: 513439

2. RECON IV

3. Multipurpose inspection & light work

4. 450 m (1,500 ft)

5. 4 thrusters @ ... hp electric, developing 80 lbs each
5 hp standard electric
5 hp hydraulic optional

6. Tether management system (TMS) standard

7. Depth, heading & CP

8. Optional work package with 1 or 2 manipulators, 5-7 function each

9. 114 kb (250 lbs)

10. 198 cm (78"), 91 cm (36"), 84 cm (...")

11. 410 kg (900 lbs) 7,167 kg (15,800 lbs)

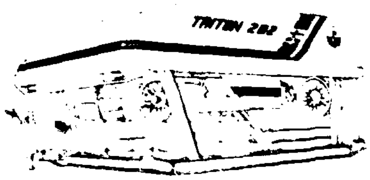
12. 12/1 (1 known lost)

13. $400,000/$450,000

14. Modular design allows easy deployment of a number of work and sensor packages

---

1. **Perry Offshore, Inc.**
275 West 10th St.
P.O. Box 10297
Riviera Beach, FL 33404
Tel: (305) 842-5261 Telefax: (305) 842-5130 Tlx: 513439



2. TRITON 202 (Mark 1 1000 x 6)

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

3. Heavy duty ROV Work Package
   - Platform maintenance
   - Subsea production & maintenance
   - Anode attachment
   - Drill rig support
4. 1,000 m (3,300 ft.). Up to 3,000 m (10,000 ft) optional
5. 6 Innerspace 1002 thrusters (3 @ 450 lbs thrust; 3 @ 180 lbs) 50 hp hydraulic / 100 hp hydraulic optional
6. Tether management system (TMS) standard
7. Heading, depth, altitude, pitch & roll, hydraulic pressure, hydraulic fluid temperature
8. One Hercules 5-function manipulator standard. Others optional
9. 227 kg (500 lbs). Increased payload optional
10. 244 cm (96") long, 142 cm (56") wide, 132 cm (52") high
12. 0/6
13. $600,000/$600,000 - $800,000
14. Buyer can choose from a large menu of options and work packages, thrust allocation, computer color graphics. TRITON is designed to carry work packages larger than itself; more power in a smaller package than other competitive systems.

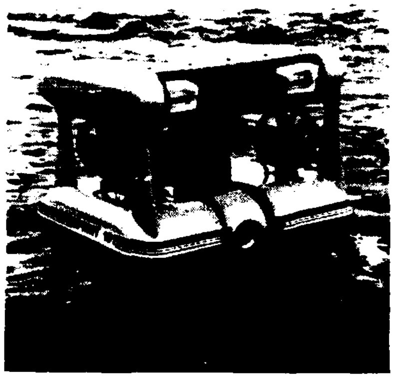
---

1. **Q. I. Inc.**
   20-5, 2-Chome
   Minmi-Yukigaya
   Ohta-ku, Toyko Japan

2. DLT 300C
3. Inspection
4. 200 m (660 ft)
5. DC motor
6. Optional
7. Depth & azimuth sensors, b&w or color TV
8. ....
9. 5 kg (11 lbs)
10. 620 mm (24.8"), 520 mm (20.8"), 655 mm (26.2")
11. 47 kg (103.4 lbs)/....
12. 30/5
13. $8,000 (b&w TV) or $9,600 (color TV)/....
14. ...

---

1. **Robertson Radio-Elektro A/S**
   P.O. Box 55, N-4371
   Egersund, Norway
   Tel: (04) 49 17 77
   Tlx: 33139



2. SPRINT 101
3. Inspection and light work
4. 610 m (2,000 ft)
5. 5 .5 hp electric thrusters; 2.5 hp
6. Optional
7. Auto heading & auto depth
8. 4-function hydraulic optional
9. 2.27 kg (standard) / 6.81 kg (optional)
10. .61 m (24"), .61 m (24"), .48 m (19")
11. 52.16 kg (115 lbs) / 340 kg (750 lbs)
12. 1 (prototype) / 20
13. $65,000 / $75,000
14. Special standard feature is duplex camera (color TV & stills camera through single lens). Triplex camera optional (add low-light-level b&w TV camera through single lens).
    SPRINT 101 is sold through Bennex A/S (Norway), Bennico Ltd. (UK) and Perry Offshore, Inc. (USA).

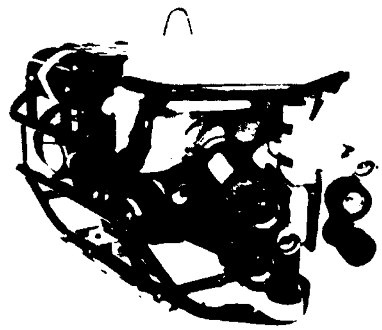
---

1. **Slingsby Engineering Ltd.**
   Kirbymoorside,
   York Y06 6EZ United Kingdom
   Tel: (0904) 769777
   Tlx: 57911 SEL G

   [Note – no photo available]
2. CIRRUS
3. Cable Burial & Repair
4. 1000 m (3,280 ft)
5. 7 hydraulic thrusters, 108 hp
6. None required
7. Cable detection system, 5 TV cameras, sonar, transponder, pinger detector, magnetic compass
8. Two SEL TA9 7-function master/slave
   Cable cutting & gripping tools
9. 75 kg (165 lbs)
10. 3.3 m (10' 10") long, 2 m (6' ") wide, 1.8 m (5' 11") high
11. 3000 kg (6,600 lbs)
12. 0/2
13. ...
14. Fiber optics are used for data transmission.

---

1. **Slingsby Engineering Ltd.**
   Kirbymoorside,
   York Y06 6EZ, United Kingdom
   Tel: (0904) 769777
   Tlx: 57911 SEL G



2. INSPECTOR
3. Inspection
4. 610 m (2,000 ft)
5. Four variable pitch electric thrusters, 240 VAC motor
6. Optional

1. Manufacturer 2. ROV Name 3. Primary Task 4. Rated Depth 5. Propulsion & HP 6. Deployment Cage 7. Standard Sensors 8. Manipulators 9. Payload 10. Vehicle Dimensions 11. Weight 12. Total Built/Under Build 13. Base Price/Avg. Sale Price 14. Comments

7. UMEL 70 mm stereo stills cameras, LLLTV, color TV (all on pan/tilt). Options include sonar, CP probe.

8. Optional

9. ....

10. 173 cm (68.5") long, 74 cm (29.5") wide, 66 cm (26.5") high

11. 165 kg (365 lbs) ....

12. 1/....

13. ....

14. INSPECTOR is built by UMEL, a division of Slingsby Engineering

---

1. **Slingsby Engineering Ltd.**
Kirbymoorside,
York Y06 6EZ, United Kingdom
Tel: (0904) 769777
Tlx: 57911 SEL G

2. [illegible]ZE

3. Inspection & diver support

4. [illegible]

5. [illegible] thrusters, [illegible]

6. Optional

7. B&W TV, color TV, CTFM sonar, depth sensor, transponder, compass

8. None

9. [illegible]

10. 1.8 m (5' 9") long, 0.9 m (2' 11") wide, 0.8 m (2' 7") high

11. 180 kg (396 lbs)

12. 2/0

13. [illegible]

14. [illegible]

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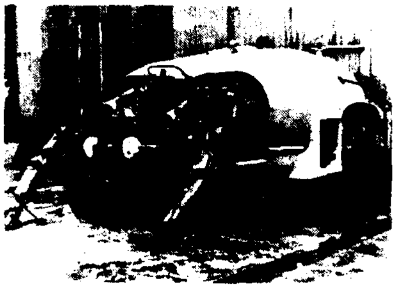
1. **Slingsby Engineering Ltd.**
Kirbymoorside,
York Y06 6EZ, United Kingdom
Tel: (0904) 769777
Tlx: 57911 SEL G



2. MMIM

3. Inspection

4. 400 m (1,320 ft)

5. 4 hydraulic thrusters, 50 hp

6. Standard

7. CTFM sonar, auto heading/depth, 2 b&w TV cameras.

8. Two 7-function master/slave

9. 150 kg (330 lbs)

10. V. large

11. 4000 kg (8,800 lbs) ....

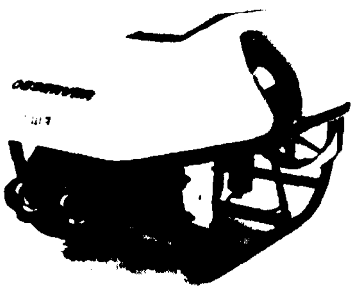
12. 1/0 (MMIM is no longer in service)

13. ....

14. MMIM was an experimental ROV designed to work inside steel platform structures.

---

1. **Slingsby Engineering Ltd.**
Kirbymoorside,
York Y06 6EZ, United Kingdom
Tel: (0904) 769777
Tlx: 57911 SEL G



2. OBSERVER

3. Inspection & diver support

4. 610 m (2,000 ft)

5. 4 variable pitch electric thrusters

6. Optional

7. Compass, auto heading/depth, LLLTV

8. Optional

9. ....

10. 1.2 m (3' 11") long, 0.78 m (2' 7") wide, 0.74 m (2' 5") high

11. 130 kg (286 lbs) ....

13. ....

14. Single joystick operation, photogrammetric capability

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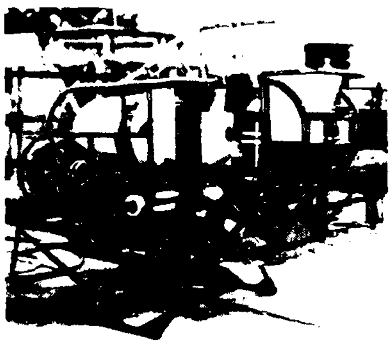
1. **Slingsby Engineering Ltd.**
Kirbymoorside,
York Y06 6EZ, United Kingdom
Tel: (0904) 769777
Tlx: 57911 SEL G



2. ORVIL (Object Recovery Vehicle)

3. Inspection, object recovery

4. 200 m (660 ft)

5. 3 electric thrusters, 0.5 hp

6. None

7. Compass, depth sensor, b&w TV

8. One SEL 2-function

9. ....

10. 1.3 m (4' 4") long, 0.85 (2' 10") wide, 0.55 m (1' 10") high

11. 90 kg (198 lbs)

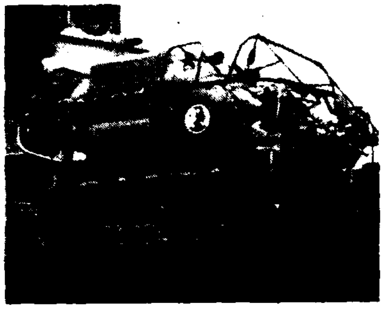
12. 1/0

13. ....

14. ORVIL carries a recovery life line

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

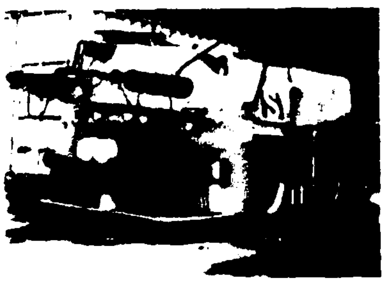
1. **Slingsby Engineering Ltd.**
   Kirbymoorside,
   York Y06 6EZ, United Kingdom
   Tel: (0904) 769777
   Tlx: 57911 SEL G



2. SEADOG
3. Cable burial & repair
4. 275 m (900 ft)
5. 7 hydraulic thrusters 240 hp
6. None required
7. Cable sensing & following, 2 b&w SIT TV cameras, 35 mm stills
8. 1 SEL general purpose
9. 400 kg (880 lbs)
10. 6 m (19'8") long, 4 m (13'2") wide, 3.4 m (11'3") high
11. 16,000 kg (35,200 lbs) /...
12. 1/0
13. ...
14. Seabed crawling and full midwater capability. Capable of flowline burial.

---

1. **Slingsby Engineering Ltd.**
   Kirbymoorside,
   York Y06 6EZ, United Kingdom
   Tel: (0904) 769777
   Tlx: 57911 SEL G



2. SOLO
3. Multi-purpose
4. 1500 m (4,950 ft)
5. 6 hydraulic thrusters, 40 hp
6. Passive clump weight (optional)
7. Gyro, sonar, LLLTV (many options available)
8. SEL TA9 7-function master/slave
9. 175 kg (385 lbs)
10. 3.18 m (10' 5") long, 1.67 m (5' 5") wide, 1.5 m (4' 11") high.
11. 2000 kg (4,400 lbs) /....
12. 1/1
13. ...
14. ...

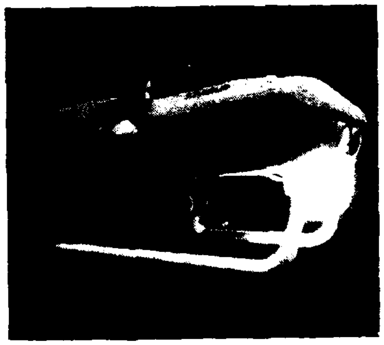
---

1. **Slingsby Engineering Ltd.**
   Kirbymoorside,
   York Y06 6EZ, United Kingdom
   Tel: (0904) 769777
   Tlx. 57911 SEL G

2. PIC
3. Platform Inspection & Cleaning
4. 1000 m (3,280 ft.)
5. 7 hydraulic thrusters, 80 hp
6. Standard
7. Echo sounder, sonar, gyro, LLLTV, stereo TV, CP probe, thickness gauge
8. Two SEL TA9 7-function master/slave
9. ...
10. 4 m (13'2") long, 2 m (6' 7") wide 1.5 m (4' 11") high
11. 3500 kg (7,700 lbs)
12. 1/0
13. ...
14. PIC employs a sole plate for clamping to structures

---

1. **Slingsby Engineering Ltd.**
   Kirbymoorside,
   York Y06 6EZ, United Kingdom
   Tel: (0904) 769777
   Tlx: 57911 SEL G



2. SEAPUP II
3. Inspection
4. 610 m (2,000 ft)
5. 4 variable pitch electric thrusters
6. Optional
7. LLLTV or color TV on pan/tilt, auto depth/heading
8. None
9. ....
10. 1.32 m (4' 4") long, 0.66 m (2' 2") wide, 0.61 m (2') high
11. 89 kg (198 lbs) /...
12. 5/0
13. ...
14. ...

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1. **Slingsby Engineering Ltd.**
   Kirbymoorside,
   York Y06 6EZ, United Kingdom
   Tel: (0904) 769777
   Tlx: 57911 SEL G

2. SEAPUP III
3. Inspection

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

4. 610 m (2,000 ft)
5. 4 variable pitch electric thrusters
6. None
7. Auto depth, heading, color TV on pan/tilt, 70 mm stereo stills cameras.
8. None
9. ....
10. 1.73 m (5' 7") long, 0.75 m (2' 6") wide, 0.75 m (2' 6") high
11. 165 kg (365 lbs)
12. 5/0: 1 lost or destroyed, 4 remain in service
13. ...
14. Special feature is all-round vision by means of special pan/tilt unit.

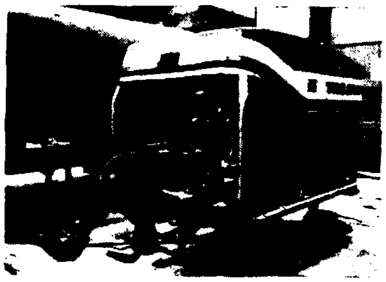
---

1. **Slingsby Engineering Ltd.**
Kirbymoorside,
York Y06 6EZ, United Kingdom
Tel: (0904) 769777
Tlx: 57911 SEL G

2. SCV (Seabed Crawler Vehicle)
3. Shallow water harbor, coastal and estuary survey, cable/pipeling inspection, sewar outfall inspection.
4. 100 m (330 ft)
5. Crawler tracks, 150 kg tractive force (nominal)
6. None required
7. Compass, depth gauge, b&w TV
8. Optional
9.
10. 1.725 m (5' 9") long, 1.4 m (4' 6") wide, 1 m (3' 4") high
11. 300 kg (660 lbs)
12. 1/0
13.
14.

---

1. **Slingsby Engineering Ltd.**
Kirbymoorside,
York Y06 6EZ, United Kingdom
Tel: (0904) 769777
Tlx: 57911 SEL G



2. TROJAN
3. Drilling support (inspection)
4. 1000 m (3,280 ft)
5. 7 hydraulic thrusters, 40 hp
6. Optional
7. Auto pitch, roll, depth/heading altitude, sonar, LLLTV, gyro, tracking pinger
8. One SEL TA9 7 function master slave
One SEL TA16 5 function rate controlled
9. 91 kg (200 lbs)
10. 2.2 m (7' 3") long, 1.6 m (5' 3") wide, 1.6 m (5' 3") high
11. 1800 kg (3960 lbs)
12. 1/6
13. ...
14. TROJAN has full diagnostic monitoring for ease of maintenance

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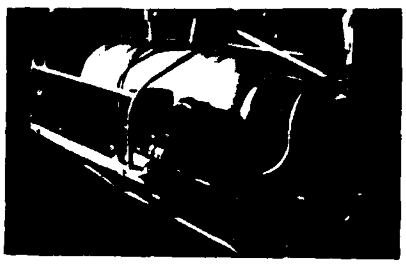
1. **SUTEC USA**
2812 Woodland Drive, N.W
Washington, D.C. 20008
Tel: (202) 628-1000 / Tlx: 904059



2. SEA EAGLE
3. Mine countermeasures
4. 350 m (1,150 ft)
5. 7 electric thrusters; 5 kva
6. Optional
7. Auto depth & heading, color TV, b&w TV, 3 spinning mass rate gyros, 2 pendulums
8. One 3-function
9. 10 kg (22 lbs)
10. .... (similar to SEA OWL)
11. 83 kg (185 lbs)
12. 2/14
13. ....
14. ....

---

1. **SUTEC USA**
2812 Woodland Drive, N.W
Washington, D.C. 20008
Tel: (202) 628-1000 Tlx. 904059

2. SEA HAWK
3. Drill rig support
4. 350 m (1,150 ft)
5. ...
6. ....
7. ....
8. ....
9. ....
10. ....
11. ..../....
12. 2/4
13. ....
14. Performance specs on SEA HAWK not available. Basically, a SEA OWL system with a stronger hull. Has rear looking TV camera

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

1. **SUTEC USA**
2812 Woodland Drive, N.W.
Washington, D.C. 20008
Tel: (202) 628-1000 / Tlx: 904059

2. SEA OWL
3. Inspection, light work
4. 350 m (1,150 ft)
5. 7 electric thrusters; 5 kva
6. Optional
7. Depth sensor, 3 spinning mass rate gyros, 2 pendulums, fluxgate compass
8. One 2-function optional
9. 8 kg (18 lbs)
10. 1450 mm (55") long, 780 mm (31") wide, 590 mm (23") high
11. 85 kg (185 lbs) / 1165 kg (2,575 lbs)
12. 31/16
13. $165,000 ($265,000 w/cage) / $200,000+
14. Reliable system 500 hours MTBF

---

1. **Taylor Diving & Salvage Inc.**
701 Engineers Rd.
Belle Chasse, LA 70037
Tel: (504) 394-6000 / Tlx: 0584152

2. TIV (Taylor Inspection Vehicle)
3. Inspection, light cleaning & NDT
4. 38 m (125 ft)
5. 4 1/10 hp DC thrusters
6. None required
7. Color TV camera
8. None
9. 9 kg (20 lbs)
10. 67.5 cm (27") long, 50 cm (20") wide, 52.5 cm (21") high
11. 43 kg (95 lbs) / 648 kg (1,440 lbs)
12. 1/1
13. ...
14. Designed for shallow inspection tasks, e.g. dams, outfalls, shallow lakes, tankers and so forth. Entire system fits into 9 containers each not weighing more than 180 lbs. to ensure portability.

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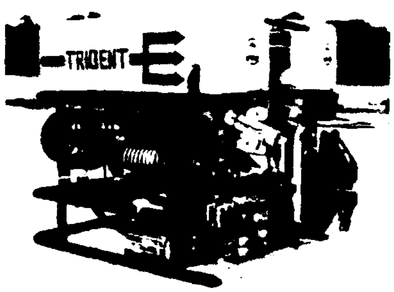
1. **Taylor Diving & Salvage Inc.**
701 Engineers Rd.
Belle Chasse, LA 70037
Tel: (504) 394-6000 / Tlx: 0584152



2. TRIDENT
3. Drill rig support, platform maintenance & cleaning
4. 610 m (2,000 ft)
5. 4 Innerspace hydraulic thrusters, 12 hp
6. Standard
7. Sonar, auto heading/depth
8. One 7-function master/slave
One 5-function rate controlled
9. 67.5 kg (150 lbs)
10. 152.5 cm (61") long, 120 cm (48") wide, 100 cm (40") high
11. 675 kg (1500 lbs) /29 tons (includes control vans, generator & all all equipment)
12. 1/0
13. ...
14. TRIDENT is a hybrid SOV system constructed of reliable RCV 150 components and other industry standards, such as manipulators cameras and other items.

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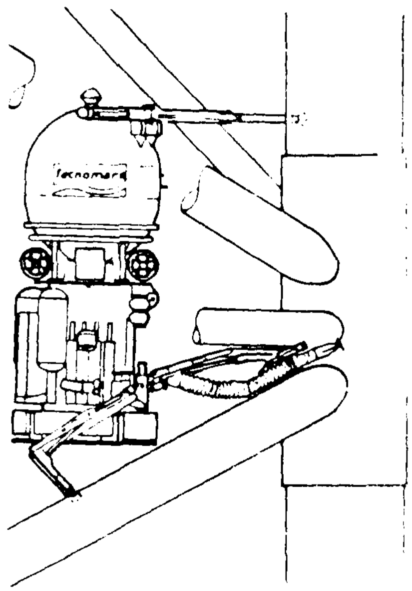
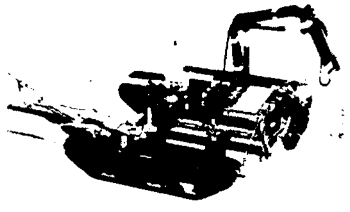
1. **Tecnomare S.p.A.**
S. Marco 2091
Venice, Italy



2. TM 308
3. Drill rig cleaning and support. Now in R&D phase.
4. 400 m (1,300 ft)
5. ...
6. None required
7. ...
8. 3 grabbers, 1 work manipulator
9. ...
10. ...
11. ...
13. ...
14. TM 308 is in early design phase

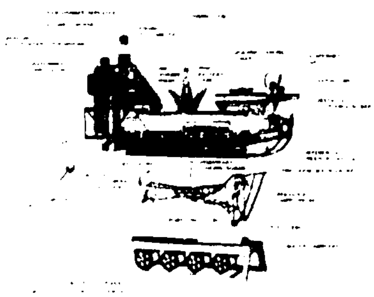
1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors / 8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

1. **UDI GROUP LTD.**
Denmore Road, Bridge of Don
Aberdeen AB2 8JW
Scotland



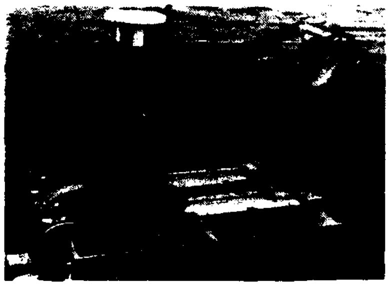
2. M.T.S. (Marine Trenching System)
3. Flowline trenching, cable lay burial and trench backfilling.
4. 300 m (985 ft)
5. Hydraulically driven dual tracks; 100 hp
6. None required
7. 6 TV cameras with full pan/tilt, 3 scanning sonars, gyro
8. Three 0.5 ton manipulators mounted on 100 KNM lift capacity hydraulic crane with 8.5 m reach
9. 150 KN pull capability
10. 6.38 m (20.9') long, 5 m (16.4') wide 3.9 m (12.8') high
11. 30 tons/...
12. 1/1
13. ...
14. MTS has been operated by UDI on behalf of various oil companies over the last 3 years, successfully trenching 250 km of flowline and cable.

1. **University of California, San Diego**
Marine Physical Laboratory
Scripps Institution of Oceanography
San Diego, CA 92152



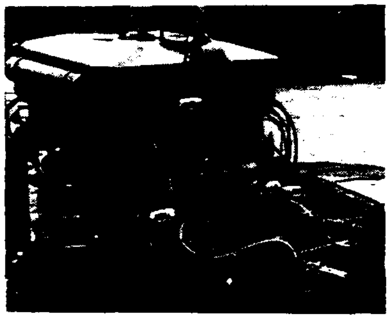
2. DEEP TOW
3. Deep sea floor search & survey
4. 7,000 m (23,000 ft)
5. towed by surface ship
6. N/A
7. Side scan sonar, 4 kHz & 125 kHz sounders, stills cameras, slow scan TV, proton magnetometer, transponder navigation, transmissometer.
8. None
9. 200 kg (440 lbs)
10. 2 m (6.6') long, 0.5 m (1.6') wide, 1 m (3.3') high
11. 1,000 kg (2,200 lbs) - 9,000 kg (19,800 lbs)
12. 5/0 - 2 DEEP TOW systems remain in service
13. $800,000/...
14. ...

1. **University of California, San Diego**
Marine Physical Laboratory
Scripps Institution of Oceanography
San Diego, CA 92152

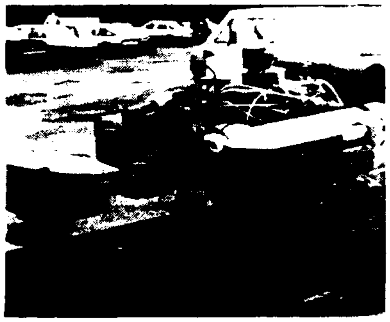


2. RUM III
3. General sea floor work (seabed crawler)
4. 6,000 m (20,000 ft)
5. Dual tracks, 2 variable pitch electric thrusters; 10 KW
6. None required
7. TV, compass, depth sensor, roll & pitch sensor, side scan sonar
8. Low pressure seawater hydraulic boom, manipulator hand & wrist
9. 200 kg (440 lbs)
10. 2.5 m (8.2') long, 2 m (6.6') wide, 3.1 m (10.3') high
11. 1,360 kg (3000 lbs)/...
12. 0/1
13. ...
14. Constant tension accumulator to decouple vehicle from cable surge while vehicle is on the bottom. Low pressure dual tracks for operation on deep sea sediments 70Pa (.1 psi)

1. **UVITEK (UK) Limited**
Unit 10, Barratt Industrial Park
Wellheads Terrace, Dyce
Aberdeen AB2 OGF
Scotland
Tel: (0224) 722109
Tlx: 73167



MAGNUM 010



MAGNUM 020

2. MAGNUM (Note: Designed & patented by UVITEK (UK) Ltd. Manufactured under license by OSEL.)
3. Platform cleaning & inspection. MAGNUM consists of a base or delivery vehicle (MAGNUM 010) and a magnetic module which attaches to and moves along ferrous structures (MAGNUM 020).
4. 540 m (1,800 ft)
5. 6 hydraulic thrusters, 50 hp (MAGNUM 010); 6 magnets for achieving motion and 3 magnets for anchoring (MAGNUM 020).

1. Manufacturer / 2. ROV Name / 3. Primary Task / 4. Rated Depth / 5. Propulsion & HP / 6. Deployment Cage / 7. Standard Sensors
8. Manipulators / 9. Payload / 10. Vehicle Dimensions / 11. Weight / 12. Total Built/Under Build / 13. Base Price/Avg. Sale Price / 14. Comments

6. Optional

7. MAGNUM 010: b&w TV, color TV, 35 mm stills camera
   MAGNUM 020: b&w TV

8. MAGNUM 010: Two 5-function rate controlled
   MAGNUM 020: One 3-function grabber

9. MAGNUM 010: 38 kg (85 lbs)

10. MAGNUM 010: 1350 mm (54") long 1350 mm (54") wide, 975 mm (39") high
    MAGNUM 020: 750 mm (30") long, 500 mm (20") wide, 450 mm (18") high

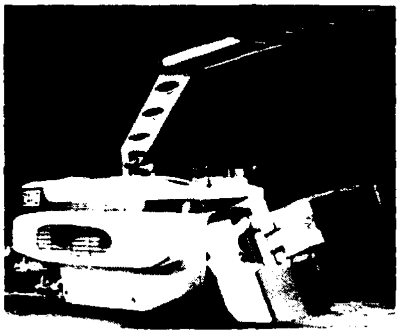
11. MAGNUM 010: 630 kg (1,400 lbs) /16 tons (total system)

12. 1/0

13. ....

14. MAGNUM *completed factory trials* early 1985. A single axis cleaning module is also being developed. UVTTEK offers many types of brushes, discs and water blasters for cleaning.

1. **ZF-HERION-Systemtechnik GmbH**
   Federal Republic of Germany
   Postfach 2168
   D-7012 Fellbach
   Tel: (0711) 507-351
   Tlx: 7254733 zfhs d



2. Submersible DAVID

3. Inspection; Maintenance & Repair; Salvage & Recovery

4. 1000 m (3,300 ft)

5. 8 hydraulic thrusters, 87 hp

6. None required

7. Two b&w TV cameras on pan/tilt pitch/roll sensors, auto heading/depth, tracking pinger. Many other sensors optional.

8. Clamping claw for attachment to tubular structures. Claw range: 400-1370 mm (16 - 54 in.) diameter.

9. Dependent upon outfitting.

10. 2700 mm (8' 10") long, 3800 mm (12' 5") wide, 1500 mm (4' 11") high (with platform assembly, 1800 mm or 6'1" high)

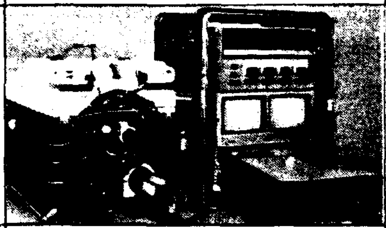
11. Base vehicle w/claw assembly - 3450 kg (7590 lbs) /winch - 150 kg (330 lbs)

12. 1/2 (+2 more authorized)

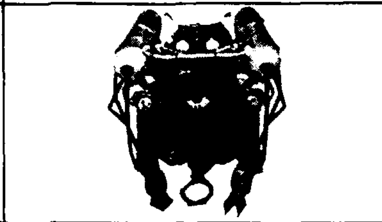
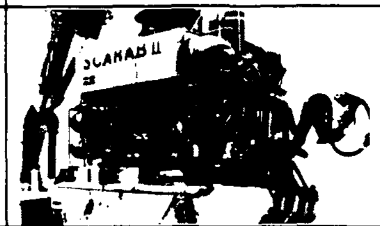
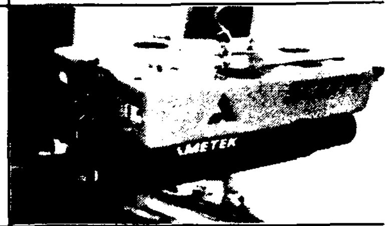
13. $920,000 (includes handling system) /$1,492,000 (includes all options).

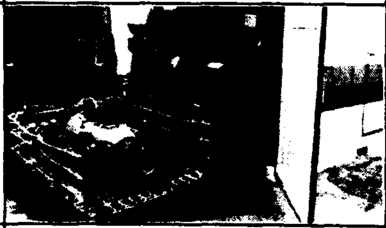
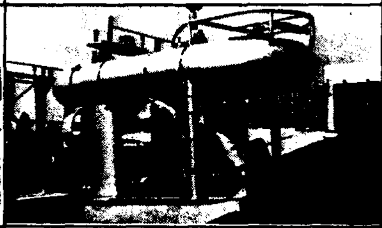
14. Can be fitted with special tools for cleaning and NDT. Can be operated by a diver or remotely.
    U.S.A. Rep
    Nautilus Enviromedical Systems, Inc.
    13800 Westfair East Drive
    Houston, TX 77041
    Tel: (713) 890-0909
    792209 NAUT ENV Hou

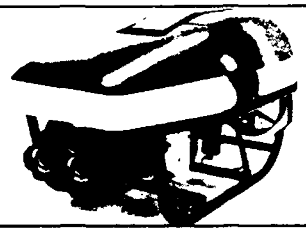
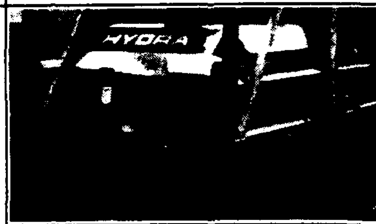
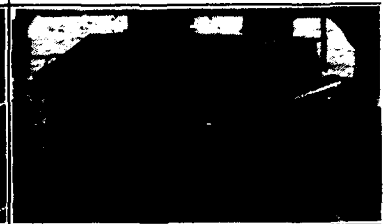
ROV OPERATORS

Operator	Bergen Underwater Services A/S	BUE SubSea Ltd.	Can-Dive Services Ltd.
			
Address	Nygardsvik, N-5034 Y. Laksevag, Norway	Stoneywood Park Dyce, Aberdeen AB2 ODF	1367 Crown St. North Vancouver, B.C., Canada V7J 1G4
Tel/Tlx	Tel. +475 34 30 50 Tlx. 40856 BUS N	Tel. (0224) 771242 Tlx. 739625	Tel. (604) 984-9131 or 987-4913 Tlx. 04-[illegible]
ROVs Owned/ Operated	DART 2 HYSUB 1 SCORPIO 2 SEA OWL 2 TREC 1 Total 8	CONSUB 2 1 IZE 2 PIC 1 RCV 225 3 SCORPIO 4 (1 SCORPIO leased from Sub Sea Offshore) UFO 300 4 Total 15	HAIDA 1 & 2 (HYSUB 20 series) 1 MiniRover
1984 Operations	UK, Norwegian, Dutch and Spanish waters, as well as Far East. *Highest use rate was* SCORPIO (#4) with 85	Operated during 1984 in the North Sea (*UK & Norwegian sectors*), southern North Sea, Campos Basin (Brazil), Morecambe Bay, *offshore* Sarawak, China and Singapore	HAIDAs: Offshore Newfoundland & Labrador, Ghana and Senegal (365 days total). MiniRover: Beaufort Sea (Arctic), Great Lakes, offshore Newfoundland, in Seattle and Vancouver areas
1984 Highlights	Recovery of 200 ton BOP from 240m (790 ft) using the powerful HYSUB	Received a letter of commendation from the British Royal Navy for operational trials aboard *HMS Challenger*, Britain's new diving operations vessel	HAIDA 2 has been uprated to 1,500 m (5,000 ft). Set a Canadian record ROV dive to 4,790 ft in November 1984. Performed multiple rig support dives to 4,400 ft during December 1984. All offshore Nova Scotia. For MiniRover, it was Can-Dive's first use of a low cost ROV in a variety of applications from Arctic inspections to dam inspections to 400 ft
1985 ROV Acquisition Plans	3 ROVs plus 2 or 3 more to be leased	UMEL (Slingsby) OBSERVER ROV	Upgrade components on HAIDA 2. Two MiniRovers
Comments		All of these ROVs are owned and operated by BUE SubSea with the exception of the UFOs and the new purchase OBSERVER. These belong to KD Marine, the BUE diving company	

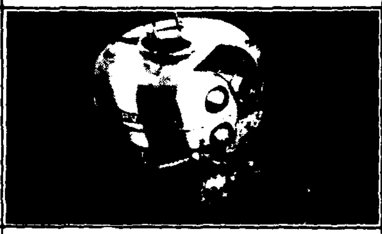
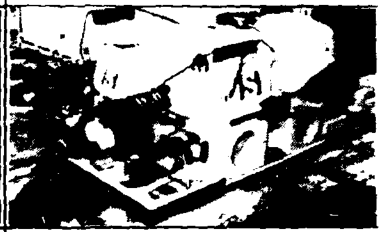
Operator	**CanOcean Resources Ltd.**	**John E. Chance & Associates, Inc.**	**Dominion Diving Ltd.**
	Photo Not Available	**Photo Not Available**	**Photo Not Available**
Address	610 Derwent Way New Westminster, B.C., Canada V3M 5P8	P.O. Box 52029 Lafayette, Louisiana 70505	145 Main St. Darmouth, Nova Scotia, Canada B2X 1R6
Tel/Tlx	Tel: (604) 524-4451 Tlx: 04-351372	Tel: (318) 237-1300 Tlx: 586678 TWX: 510-975-5073	
ROVs Owned/ Operated	1 SCORPIO (#006)	SURVEY SUB #1 & 2 (HYSUB Type 20) [operated as a dual system]	Scorpio (#49) VIKING III (HYSUB 20)
1984 Operations	Campos Basin, Brazil. Mobilized on vessel 264 days, performed 160 dives	Operated 75 days in the Gulf of Mexico. Pipeline inspections, pipeline as-builts, live bottom surveys and photo documentation operations	Canada east coast
1984 Highlights	Established flowline pull-in cable from platform underneath Flotel to lay vessel. Clear guidewire nest on around wet tree (where divers had failed)	1,500 ft. dive to document the precise location by recording X and Y coordinates of an anchor that had settled into the soft seabed	Recovery of 3/4" chain Drilling support activities
1985 ROV Acquisition Plans	Possibly 2 new ROV systems	Probably one ROV (type unspecified)	2 additional ROV systems
Comments			

Operator	Duikbedrijf Vriens b.v.	Eastport International	Energie Diving Service b.v.
			
Address	Van Konijnenburweg 151 4612 PL Bergen op Zoom, Holland	5001 Forbes Blvd. Lanham, Maryland 20706	P.O. Box 27 Drachten, Holland
Tel/Tlx		Tel. (301) 459-8555 TWX 7108260459	Tel 05120 10405 Tlx 46247
ROVs Owned/ Operated	1 ROV DUPLUS II	Operates U.S. Navy DEEP DRONE III AT&T SCARAB II	SCORPI #13
1984 Operations	North Sea, Gulf of Biscaye — 255 total days	DEEP DRONE was operated in the Caribbean, Gulf of Mexico and the North Atlantic. SCARAB was operated in the North Atlantic — 158 days.	Platform inspections and salvage operations
1984 Highlights	Cable jetting program in Gulf of Biscaye	SCARAB assisted in making repairs to 2 transatlantic telephone cables as well as the USA Bermuda cable system. The vehicle spent 1513 hours working on the seafloor. SCARAB was operational 92% of the available time and operated to 4,200 ft. burying cable.	Salvage operations on the *Ocean Ranger*
1985 ROV Acquisition Plans	ROV DUPLUS II	One SCORPI or ASD 620	
Comments		Eastport Int'l operates and maintains DEEP DRONE for the U.S. Navy. See Cover.	

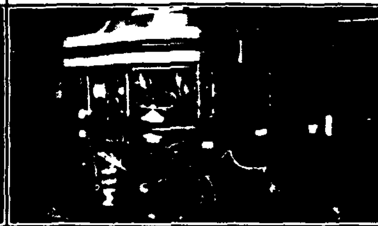
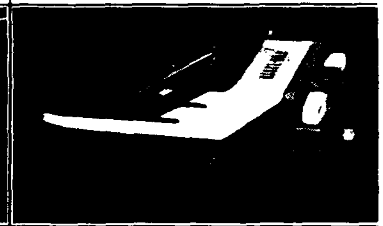
Operator	Hallstrom Holdings PTE Ltd.	Harbor Branch Foundation	IUC, International, Inc.
			
Address	07-02 Marina House, Shenton Way Singapore 0207	RR 1 Box 196 Old Dixie Hwy Ft. Pierce, FL 33450	222 Fordham St. City Island, New York, N.Y 10464
Tel/Tlx	Tel. 2224541 Tlx. 28047 HALLHO	Tel: (305) 465-2400	Tel: (212) 885-0600 Tlx: 147242 (IUC INC NYK)
ROVs Owned/ Operated	2 SEA OWL ROVs	CORD II (Cabled Observation & Rescue Device)	RECON IIIA . . . 1,000 ft RECON IV . . . 1,000 ft ROV MANTIS . . . 2,300 ft SUPER RECON IV . . . 2,300 ft
1984 Operations	Operated offshore Southeast Asia and China — 216 days		Worldwide operations. IUC's ROV, ADS and submersible fleet were involved in over 1,000 days of operation during 1984
1984 Highlights	SEA OWL and a manned submersible		ROV MANTIS installed and clamped a shaped explosive charge at a depth of 1,650 ft. for the removal of a wellhead and retrieval tool from the seafloor During a contract for Brown & Root offshore California, IUC's RECON IV set new RECON records for continuous working dives. Seventy six working dives were made during a total of 251 hours, 4 minutes bottom times. One dive lasted 28½ hours. On another job, also offshore California, an IUC RECON IV made 12 working dives during a total bottom time of 51 hours and 21 minutes.
1985 ROV Acquisition Plans	With SIT camera, color TV and stills camera, SEA OWL has proved to be a useful tool for visual identification of various sonar echos		
Comments		CORD II has been refurbished and installed on R/V *Seward Johnson* for operations during 1985	IUC established its Underwater Vehicle Training Center in Houston, Texas. It is complete with various ROV systems and a training tank IUC also owns and operates a MANTIS ADS and 3 manned subs: Pisces VI, Beaver MK IV and Mermaid II. Much of this undersea is operated from IUC's DSV *ALOHA*

Operator	KD Marine	Oceaneering International, Inc.	OMIS
			
Address	Pitmedden Rd. Industrial Estate, Dyce, Aberdeen AB2 0DP	16001 Park Ten Place P.O. Box 218130 Houston, TX 77218	19407 Park Row, Suite 400 Houston, TX 77084
Tel/Tlx	Tel (0224) 723415 Tlx 73375	Tel (713) 578-8868 Tlx 775181 OCEANRNG HOU	Tel (713) 578-6700 Tlx 6868572 OMIS UW
ROVs Owned/ Operated	1 OBSERVER 4 UFO-300	DART .... 4 HYDRA .... 18 HYSUB 4 .... 1 ORION .... 2 RCV 225 .... 2 RECON .... 8 SCORPIO .... 2 SEAPUP .... 4 Total 41	PROES 100 & PROES 200
1984 Operations			
1984 Highlights			
1985 ROV Acquisition Plans			
Comments		Oceaneering also owns and operates 28 ADS (15 JIM/13 WASP). 1984 operations were chiefly rig support. Highlights included the record-setting ADS dive in the Gulf of Mexico to 2,010 ft. Oceaneering owns and operates 5 OCEAN ARMS bells. Use rate in 1984 was 60-70%.	

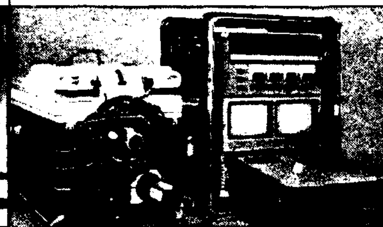
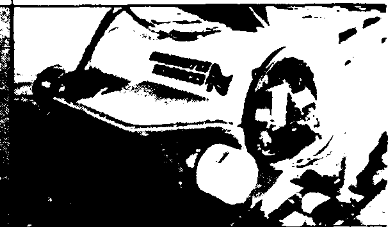
ROV Operators *(cont.)*

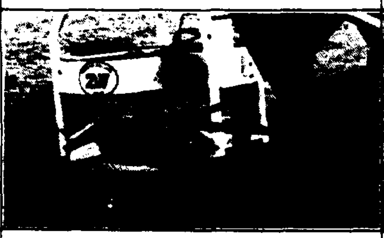
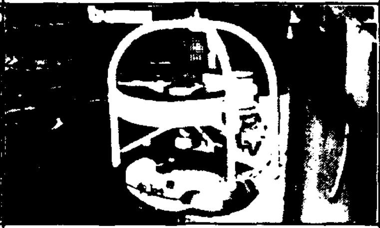
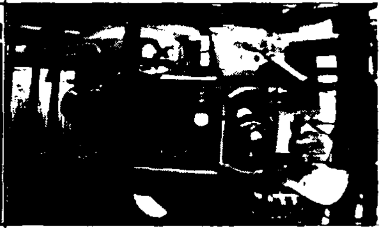
Operator	Salvage Pacific Ltd.	Sonat Subsea Services Inc.	Stolt-Nielsen Seaway Ltd.
			
Address	P.O. Box 3055 Lami, Fiji	P.O. Box 4428 Houston, TX 77210 4428	P.O. Box 9570 Egertorget Oslo 1, Norway
Tel/Tlx	Tel 361-200 Tlx: FJ2358	Tel: (713) 840-4900 Tlx: 775139	Tel: (02) 42 92 00 Tlx: 76600
ROVs Owned/ Operated	BENTHOS RPV 430	MiniRover . . . 4 RCV 150 . . . 4 RCV 225 . . . 6 RECON IV . . . 2 SCORPIO . . . 1 Total 17	RCV 225 . . . [illegible] SCORPIO . . . [illegible] SEA HAWK . . . [illegible] SEA OWL SOLO . . . [illegible] Total [illegible]
1984 Operations	Testing off Suva Harbor Fiji Islands Dive on the historical wreck of the *Pandora* in northern Queensland, Australia Dive on the wreck of the *Kyoten Maru* to a depth of 1,205 ft., which is on the Lihou Reef in the Coral Sea off the Australian coast	ROV operations from all regional operating bases: Houston, Morgan City, Los Angeles, Corpus Christi, Houma, Aberdeen, Singapore and Perth	SOLO operated 110 days in the North Sea on pipeline inspection & mine clearance in the Norwegian sector of the North Sea SCORPIO performed 20 contracts in the North Sea, Mediterranean, offshore Africa and Canada. RCV 225 North Sea, five contracts SEA HAWK operated on the *Tender Comet* supporting Mobil Exploration, Norway
1984 Highlights	RPV-430 obtained an unusual photo of the bottom at the entrance to the harbor of Suva, the capital of Fiji. Depth was 580 ft. See in this issue. Please offer explanation of what the formation means to Salvage Pacific with copy to *ROV REVIEW*	Acquisition of Santa Fe Underwater Services. Development of new generation ROV CHALLENGER. Addition of ROVs to S&H Diving, the operating subsidiary of Sonat Subsea Services	Four weeks of mine clearance operations in the Norwegian section of the North Sea with 2 SCORPIOs deployed from the *Seaway Labrador* and a SOLO ROV system operated from the *Master Surveyor*
1985 ROV Acquisition Plans		Significant expansion of worldwide operations and ROV fleet, including the new CHALLENGER series ordered from PERRY Offshore	
Comments			During 1984, over 3000 kilometers of pipelines were surveyed by Stolt Nielsen Seaway ROVs

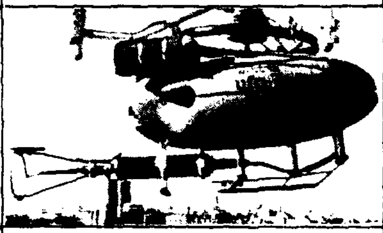
ROV Operators *(cont.)*

Operator	Sub Sea Dolphin A/S	SubSea Offshore Ltd.	Switzer Salvage
			
Address	P.O. Box 138 4056 Tananger, Norway	Greenwell Base, Greenwell Road Aberdeen, AB1 4AX Scotland, United Kingdom	No 1 Kvestausgate Copenhagen, 1251, Denmark
Tel/Tlx	Tel (04) 69 75 33 Tlx. 73630 subsd n	Tel (0224) 896505 Tlx 73494	
ROVs Owned/ Operated	1 PIONEER and 2 SCORPIOs	HYSUB 1 PIONEER 12 RCV 225 1 SCORPEE (renamed from SCORPI) 6 SCORPIO 22 TREC 1 VIKING (ISE forerunner of HYSUB) 4 Total 47	1 RASCL & 1 TARS (DART)
1984 Operations	Drilling support in the Norwegian & British sectors of the North Sea. Pipeline inspection and cleaning (concrete and steel). Pipeline survey in Norwegian sector	Montanazo D2 Field, offshore Spain in nearly 2,500 ft of water. Work involves hydraulic intervention to manifolds on the system, manual override valves on the tree and replace AX ring seals in the wellhead, tree and two flowlines	
1984 Highlights	Concrete and steel cleaning in Frigg field with PIONEER. Pipeline survey in Statpipe project with SCORPIO	Worldwide operations by SSO's ROV fleet. It was the most important year in the development of ROV technology in the company's building program and offshore operations	
1985 ROV Acquisition Plans		Build up to PIONEER #17. SSO defends building own ROV systems thusly a) Present market conditions make the price and delivery of ROVs from major manufacturers excessive b) Spares and maintenance backup from manufacturers abroad is less than ideal c) Through own operating experience with various ROVs, SSO is aware of engineering and operating deficiencies in present designs	
Comments	Sub Sea Dolphin is part of Sub Sea International	SSO operates the largest fleet of ROVs (47) worldwide	

ROV Operators *(cont.)*

Operator	Taylor Diving & Salvage Co., Inc.	Underwater Recovery Specialists, Inc.	Underwater Resources
			
Address	795 Engineers Road Belle Chasse, Louisiana 70037	840 Hermann St. Port Coquitlam, B.C. Canada V3C 4PE	P.O. Box 1817 Lafayette, CA 94549
Tel/Tlx	[illegible]	Tel (604) 681-8497 Tlx 04-352848 VCR	Tel [illegible]
ROVs Owned Operated	HYSUB 2 [illegible] system [illegible] RCV 225 [illegible] RECON IV [illegible] ROV MANTIS [illegible] SCORPIO [illegible] TIV [illegible] TRIDENT Total [illegible]	[illegible] INSPECTOR (DART)	MiniRover #[illegible] (renamed to SEA FERRET
1984 Operations	[illegible] HYSUB [illegible] Canada [illegible] RCV [illegible] Gulf of Mexico, SE Asia [illegible] RECON [illegible] Gulf of Mexico [illegible] ROV MANTIS Canada [illegible] SCORPIOS [illegible] TRIDENT [illegible] Gulf of Mexico Total [illegible]	Delivered November 1984	Inspections [illegible] MiniRover #[illegible] [illegible] track gate assembly [illegible] ceilings
1984 Highlights	[illegible] HYSUB [illegible] ROV MANTIS [illegible] offshore Canada SCORPIO [illegible] TRIDENT [illegible] Gulf of Mexico [illegible]		Successfully [illegible] under severe [illegible] U.S. Bureau of Reclamation [illegible]
1985 ROV Acquisition Plans	[illegible] HYSUB [illegible] [illegible] TRIDENT		More [illegible] ROVs [illegible]
Comments	TRIDENT ROV system is a reconfigured RCV [illegible] with a Kraft [illegible] function master slave arm [illegible] RSI [illegible] function rate controlled arm. Designed and assembled by Taylor Diving. TIV (Taylor Inspection Vehicle) is a light weight inspection vehicle rated to [illegible] ft. It has a tilting CM [illegible] color TV camera [illegible] probe and [illegible] Watt variable intensity light.		Underwater Resources is being established as expert in dam inspection and [illegible] use of ROVs with diving capabilities [illegible] repair, perform NDT and observe new construction.

Operator	Wharton Williams	Wolf Sub-Ocean Ltd.	Comex Houlder Diving Limited
			
Address	Farburn Industrial Estate Dyce, Aberdeen AB2 OHG Scotland	P.O. Box 1447, Stn. "C" St. John's, Newfoundland Canada A1c 5N8	Bucksburn House, Howes Road Bucksburn Aberdeen AB2 9RQ Scotland
Tel/Tlx	[illegible]	Tel. [illegible] 226-9246	Tel [illegible] Tlx [illegible]
ROVs Owned/Operated	DRAGONFLY [illegible] RCV [illegible] [illegible] RIGWORKER (2 [illegible] systems) [illegible] [illegible] Total [illegible]	[illegible] DUPLUS [illegible] SCORPI (leased) [illegible] UFO [illegible]	RCV-225 [illegible] (includes 1 system operated on lease & 2 spare vehicles) COMEX ROV [illegible] DART SCORPIO (operated on lease) UFO [illegible] Total [illegible]
1984 Operations	[illegible]	[illegible]	North Sea, offshore Brazil, [illegible] Spain & Southeast Asia. [illegible]
1984 Highlights	[illegible]	[illegible]	[illegible]
1985 ROV Acquisition Plans	[illegible]	[illegible]	[illegible]
Comments	[illegible]		[illegible]

Operator	Submersible Television Surveys Ltd.
	
Address	Unit 4, Barratt Trading Estate Murcar, Bridge of Don Aberdeen AB2 8JN Scotland
Tel/Tlx	
ROVs Owned/ Operated	RIGWORKER [illegible] SNORRE [illegible] owned by [illegible] and operated by STS under joint venture [illegible]
1984 Operations	[illegible]
1984 Highlights	[illegible]
1985 ROV Acquisition Plans	[illegible]
Comments	[illegible]

OTHER ROV SERVICES CONTRACTORS

Global Diving & Salvage

2763 13th Ave., S.W.
Seattle, Washington 98134

Tel: (206) 623-0621

Began operations in early 1985

UVITEK A/S

O. Svendsens Gt. 7B
N-9000
Tromso, Norway

[illegible]

UVITEK (U.K.) LTD.

Unit 10, Barratt's Industrial Park
Wellheads Drive, Dyce
Aberdeen, Scotland

[illegible]

[illegible]

APPENDIX !

Recent Pertinent Publications

1982-1986

RECENT PERTINENT PUBLICATIONS 1982-1986

The following publications contain information pertinent to this report. Readers that desire to delve more deeply into the subject will find the listed documents an adequate starting point as most of the authors have included references.

Askew, T. M. "Submersibles for Science--JOHNSON-SEA-LINK I & II," Conf. Record OCEANS '84, Mar. Tech Soc., Washington, D.C., 1984, pp 612-616.

Austin, T. C., Hosom, D. S., and Kuchta, D. H. "Long Baseline Acoustic Navigation--A Flexible Approach to Custom Applications," Conf. Record OCEANS '84, Mar. Tech Soc., Washington, D.C., 1984, pp 69-74.

Ballard, R. D. "ROV Development at Wood's Hole Deep Submergence Laboratory," Proceedings ROV '84 Mar. Tech. Soc., San Diego Section, 1984, pp 32-39.

[illegible], A. B. "ROV-150 Vehicle and Recent Operational Experience," Conf. Record OCEANS '83, Mar. Tech. Soc., Washington, D.C., 1983, pp [illegible]

[illegible], J. E. "Tactical Remotely Piloted Submersibles," Proc. ROV '85, Mar. Tech. Soc., San Diego Section, 1985, pp 233-236.

[illegible], R., Semac, D. and Leduc, B. "Acoustic Transmission of Pictures: New Developments and Applications to Untethered Vehicles," Proc. ROV '85, Mar. Tech. Soc., San Diego Section, 1985, pp 183-186.

[illegible] "New Concept on Very Fast and Stable Conductivity Probes of [illegible] Size for Modern High-Speed CTD-Systems," Conf. Record OCEANS '84, Mar. Tech Soc., Washington, D.C., 1984, pp 214-21[illegible]

[illegible] "Undersea Vehicles [illegible] New Directions [illegible] Requirements," Conf. Record OCEANS '[illegible] Mar. Tech. Soc., Washington, [illegible]

1, 1983, pp. 483-491

Busby, R. F. "Arctic Undersea Inspection of Pipelines and Structures", a Report for the Minerals Management Service, U. S. Department of the Interior, June 1983, pp.149 plus appendices.

Busby, R. F. "Undersea Vehicles Directory - 1985", Busby Associates, Inc. 1985, 430 pp.

Busby, Frank. "Undersea Vehicles--The Military Side", Sea Technology, 1986, Jan., p. 19

Carnevale, S. J. "ROV Operations for High Precision Bottom Topology," Proc. ROV '85, Mar. Tech. Soc., San Diego Section, 1985, pp. 146-155

Carrie, M. and Hampson, D. J. "Field Experience with Third Generation Eyeball ROVs," Proceedings Underwater Technology '83, Amsterdam, 1983, 22-24 June, Paper B16, 9 pp.

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Cruickshank, M. J. and Rowland, T. J. "ROVs in Deep Seabed Mining," Proc. ROV '83 Mar. Tech. Soc., San Diego Section, 1983, p. 230

Dessart, R. J. "The Use of Tethered Vehicles in Oil Field Applications," Conf. Record OCEANS '82, Mar. Tech. Soc., Washington, D. C., 1982, pp. 86-91

English, J. G. "Remotely Operated Deployment of Iceberg Towing and Fracturing Tools," Proc. ROV '85, Mar. Tech. Soc., San Diego Section, 1985, pp. 163

Farruggia, G. J. and Fraser, A. B. "Miniature Towed Oceanographic Conductivity Apparatus," Conf. Record OCEANS '84, Mar. Tech. Soc., Washington, D. C., 1984, pp. 1010-1014

Freund, J. "Underwater Work Systems Development," Conference Record 7th Meeting U.S.-Japan Marine Facilities Panel, U.S.-Japan Cooperative

Program in Natural Resources, 1985, pp. 212-216

Estabrook, N. B. "Advanced Search and Work Systems", Proc. Underwater Operations and Techniques Conference, Dec. 1982, pp. 325-346, Paris, Dec.

Geer, R. L. "Technology Trends for U. S. Deepwater and Arctic Offshore Oil and Gas Resource Development." Conference Record 13th Meeting U.S.-Japan Marine Facilities Panel, U.S./Japan Cooperative Program in Natural Resources, 1985, pp. 48-52

Gerwick, B.C., Editor, "Arctic Ocean Engineering for the 21st Century." Marine Technology Society, Washington, D. C. 1985, pp. 234 and Appendices

Gilbert, G. R., Blasco, S., Satirbys, A. F. and Lewis, C. F. M. "Beaufort Sea Ice Scour Analysis Using a Computerized Data Base." Proc. 1985 Offshore Technology Conference, 1985, pp. 111-118

Given, D. <u>SubNotes</u>, a monthly publication specializing on diving and submersibles. Windate Enterprises, Inc.

Given, D. Annual <u>ROV Review</u>, a Subnotes Publication, Spring Valley, CA First Edition issued in 1985

Given, R. R. and Benech, S. "The ROV as a Scientific Tool." Proc. ROV '83 Mar. Tech. Soc. San Diego Section, 1983, pp. 291-293

Godin, R. H. "The Methodology and Availability of Joint Ice Center Services to Commercial Users." Conf. Record OCEANS '84, Mar. Tech Soc., Washington, D. C., 1984, pp. 944-949

Harrington, J. P. and Williams, L.M. "Deepwater Diverless Technology Applied to Shallow Water Operations in Hostile Environments." Proc. 1985 Offshore Technology Conference, 1985, pp. 47-54

Hattori, M. Design of ROV "DOLPHIN 3-K". Conference Record 13th Meeting U.S.-Japan Marine Facilities Panel, U.S./Japan Cooperative Program in Natural Resources, 1985, pp. 195-198

Hendricks, P. J. "Velocity Measurements from a Self-propelled Vehicle." Conf. Record [illegible] OCEANS '81, Mar. Tech. Soc., Washington, D. C. [illegible] v ... pp 1180-1183

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Kibera, E. H. V. "Launch and Recovery of Untethered Vehicles." Proc. ROV '85, Mar. Tech. Soc., San Diego Section, 1985, pp 226-232

International Underwater Contractors, Underwater Vehicle Training Center, Remotely Operated Vehicle Pilot/Technician Training Course brochure, 1985

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Jeffcoat, C. M., Jackson, J. B. and Ewald, J. L. "Considerations in Design and Laying a New Undersea Fiber Optic Cable System." Conf. Record OCEANS '84, Mar. Tech Soc., Washington, D. C., 1984, pp 662-667

Kroebel, W. and Wernli, R. L. "ROV Technology Update from an International Perspective." Conf. Record OCEANS '84, Mar Tech Soc., Washington, D. C., 1984, pp 639-645

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Mackey, L. A. and McCarthy. "Technology and Its Affects on Cost-Effective ROV Systems." Proc. ROV '85, Mar. Tech. Soc., San Diego Section, 1985, pp. 237-240.

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Marine Technology Society, San Diego Section: Annual ROV Conference Proceedings for years 1982-1985

Muton, I. "Unmanned Remote-Controlled Submersible MURS-300 MK I" Conference Record 13th Meeting U.S.-Japan Marine Facilities Panel, U.S./Japan Cooperative Program in Natural Resources, 1985, pp. 204-206

Nelson, D. A. Ghost Ships of the War of 1812: Hamilton and Scourge. Photos by Emory Kristof. Paintings by Richard Schlecht. National Geographic Magazine, 1983, pp. 289-313

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