Remotely Operated Vehicles

Washington, D.C.
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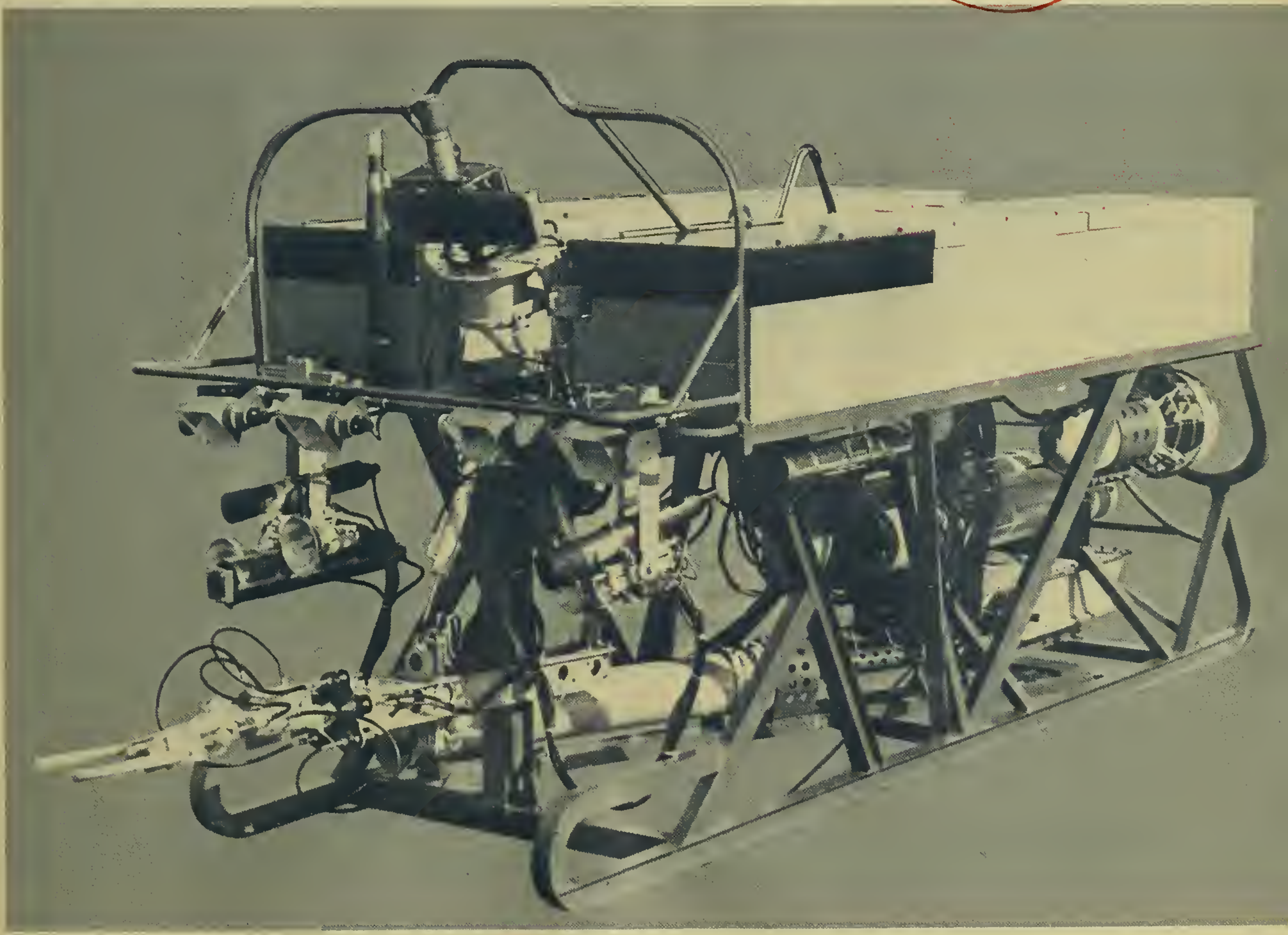

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Ocean Engineering

Remotely Operated Vehicles

NOAA/Office of Ocean Engineering
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U.S. DEPARTMENT OF COMMERCE
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PREFACE

The extraction of offshore oil and natural gas from deep, cold and hostile ocean regions has encouraged development of a wide variety of underwater support services. Saturation diving systems, manned submersibles and observation/work bells, one-atmosphere diving suits and remotely operated vehicles are all engaged in the exploitation and production of these offshore resources. Of all these capabilities, the greatest recent surge in activity and employment has been in the area of remotely operated vehicles (ROVs). Although ROVs were introduced to the offshore community 26 years ago, it was not until the past three years that the concept took hold in industry. By 1974 twenty ROVs had been constructed, at the end of 1979 at least 139 of the tethered, free-swimming type will have been constructed. Their application has been varied and each design is unique. To date they have produced many successes and indicate a great future potential.

The need for increased ROV capabilities to work at a wider variety of tasks and at greater depths is pressing. Already exploration for offshore oil is taking place in water depths of 1,500m (4,920 ft), and production platforms are pumping oil from depths of 310m (1,015 ft). Oil and gas pipelines are under construction which will be in waters 914m (3,000 ft) deep and more than 12,893km (7,000 miles) of undersea pipeline are in U.S. waters alone. In 1977, according to the Exxon Company, offshore oil accounted for 16 percent (10 million barrels daily) of the worldwide crude production. Offshore proved crude oil reserves are estimated at 26 percent (170 billion barrels) of the world total. As the scope of oil and gas extraction widens and the depth increases, the ambient pressure diver is quickly reaching his physiological limits to provide support. Alternative systems, both unmanned and manned must be developed to intervene for the human manipulator in a wide variety of ocean environments.

The purpose of this study was: 1) to identify the types and capabilities of currently operating ROVs; 2) to determine the type of work they are now conducting; 3) to assess the performance and problem areas now encountered; 4) to locate and describe current research related to ROV technology and 5) recommend research and development programs required to increase present and future ROV performance in all areas (industrial activities and scientific/research) of present and potential application. While the study treats all types of ROVs, it has concentrated on the tethered, free-swimming variety, although recommendations for towed vehicles are also included.

The data for this study were collected through literature reviews, telephone interviews and personal visits to operators and manufacturers of ROVs in the United States, Canada, England, Scotland, Ireland and France. Written correspondence was used to contact operators in Japan, Norway, Sweden, West Germany, Italy and the Soviet Union. The operators contacted are listed in Appendix A and the sources of published information consulted are contained in Appendix B. The program began in August 1978 and concluded in July 1979.

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1.0 SUMMARY AND RECOMMENDATIONS

Four types of ROVs have been identified: tethered, free-swimming vehicles, bottom-crawling vehicles, towed vehicles and untethered vehicles. The growth of these vehicles - particularly tethered, free-swimming vehicles of the CURV variety - has been impressive. The first of this class vehicle was launched in 1953, and by 1974 only 19 additional vehicles were constructed. At the end of 1979 it is projected that a total of approximately 139 tethered, free-swimming vehicles will have been constructed. Over 90 percent of these vehicles are commercially oriented, and their employment is in support of offshore oil and gas development.

At this writing there are approximately 156 vehicles of all categories which have been constructed and 180 are either operating or under construction (Table 1.1), by category their numbers are as follows:

	Number of Vehicles
Tethered, Free-Swimming	112
Bottom-Crawling	17
Towed	17
Untethered	10

Not included in this summary are over 120 vehicles called PAP-104. These are mine neutralization ROVs built by Societie Eca, Meudon, France and employed by various Navys.

1.1 VEHICLE CHARACTERISTICS

Performance capabilities and designs of ROVs vary widely and, except for vehicles originating from the same manufacturer, there is little similarity from vehicle-to-vehicle. The areas in which ROVs do find similarity are: reliance on surface-generated power via an umbilical cable; closed circuit television for viewing, and a surface ship is required for support and maintenance. One additional similarity tethered, free-swimming vehicles have in common is that virtually all are rectangular-shaped of open metallic framework construction which encloses and support the vehicle components. Table 1.2 is a summation of vehicle characteristics; it is cautioned that these characteristics vary within wide ranges on specific vehicles.

1.2 VEHICLE APPLICATIONS

The dominant user of ROVs is the offshore oil and gas industry, the next is the military sector, and, lastly, the scientific/research community. A tabulation of the types of work engaged in by the various users is presented in Table 1.3. Over 90 percent of all tethered, free-swimming vehicles perform observation and video/photographic documentation. Manipulative tasks account for less than 5 percent of their work.

While a precise accounting of all U.S. operated tethered, free-swimming ROV diving activities is virtually impossible to attain, an indication of their activity level is possible. A survey of all U.S. operators was conducted to identify the degree of vehicle utilization during Fiscal Year 1978 (1 October 1977 - 30 September 1978). At the time of the survey there were 11 U.S. operators

TABLE 1.1
REMOTELY OPERATED VEHICLES DEPTH CAPABILITIES, MANUFACTURER AND OPERATOR BY CATEGORY

TETHERED, FREE-SWIMMING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
ANGUS 002	984/300	Heriot-Watt University	Same
ANGUS 003	1,000/305	Heriot-Watt University	Same
BOCTOPUS	2,170/661	British Oxygen Co., Ltd.	Same
CETUS	1,500/457	ULS Marine Ltd.	Same
CONSUB 1	2,000/610	Institute of Geological Sciences	British Aircraft Corp.
CONSUB 201	2,000/610	British Aircraft Corp.	Sub Sea Surveys Ltd.
CONSUB 202	2,000/610	British Aircraft Corp.	Same
CORD I	1,500/457	Harbor Branch Foundation	Same
CURV II	2,500/762	Naval Ocean Systems Center	Same
CURV II	2,500/762	Naval Ocean Systems Center	Naval Torpedo Station
CURV III	10,000/3,048	Naval Ocean Systems Center	Same
DART	1,200/366	International Submarine Engineering Ltd.	Same
DEEP DRONE	2,000/610	Supervisor of Salvage (USN)	Ametek Straza
ERIC II	19,685/6,000	C.E.R.T.S.M.	French Navy
ERIC 10	1,640/500	C.E.R.T.S.M.	French Navy
EV-1	1,500/457	Kraft Tank Co.	Same
FILIPPO	984/300	Gay Underwater Products	Same
FILIPPO	984/300	Gay Underwater Products	Nereides, Orsay, France
FILIPPO	984/300	Gay Underwater Products	Uncommitted
IZE	1,640/500	Sub Sea Surveys Ltd.	Same
MANTA 1.5	4,921/1,500	Institute of Oceanology USSR	Same
MURS-100	328/100	Mitsui Ocean Development and Engineering Co.	Same
MURS-300	984/100	Mitsui Ocean Development and Engineering Co.	Same
OBSERVER DL1	600/183	C. G. Doris	Same
OBSERVER III	984/300	C. G. Doris	Same
ORCA I	2,297/700	Saab-Scania	Oceaneering International
PAP-104	328/100	Society ECA	Various Nato Navies
PHOCAS II	1,000/305	Geologinen Tutkimuslaitos	Same
PINGUIN A1	330/100	VFW Fokker	Same
PINGUIN B6	6,500/1,981	VFW Fokker	Same
RCV-150	6,000/1,829	Hydro Products	Martech International
*RCV-225	6,600/2,012	Hydro Products	Seaway Diving
RCV-225	6,600/2,012	Hydro Products	Martech International
RCV-225	6,600/2,012	Hydro Products	SESAM
RCV-225	6,600/2,012	Hydro Products	Esso Australia Ltd.
RCV-225	6,600/2,012	Hydro Products	Taylor Diving and Salvage
RCV-225	6,600/2,012	Hydro Products	Wharton Williams
RCV-225	6,600/2,012	Hydro Products	Oceaneering International
RCV-225	6,600/2,012	Hydro Products	Japanese Navy
RCV-225	6,600/2,012	Hydro Products	Same
RCV-225	6,600/2,012	Hydro Products	Santa Fe Construction Co.
RCV-225	6,600/2,012	Hydro Products	Uncommitted
RECON II	1,500/457	Perry Oceanographics	Hunting Surveys Ltd.
RECON III	600/181	Perry Oceanographics	Oceanics Ltd.
RECON V	1,200/366	Perry Oceanographics	Same
RUWS	20,000/6,096	Naval Ocean Systems Center	Same
SCAN	328/100	Underwater Maintenance Co., Ltd.	Same
SCARAB I & II	6,000/1,829	Ametek Straza	AT&T Long Lines
SCORPIO	3,000/914	Ametek Straza	Stolt-Nielsen Rederi A/S
SCORPIO	3,000/914	Ametek Straza	Israel - Government
SCORPIO	3,000/914	Ametek Straza	Same
SEA INSPECTOR	3,280/1,000	Rebikoff Underwater Products	Same
SEA SPY	1,000/105	Admiralty Underwater Weapons Establishment	Underwater and Marine Equipment, Ltd.
SEA SURVEYOR	660/200	Rebikoff Underwater Products	Same
SMARTIE	984/300	Marine Unit Technology, Ltd.	Marine Unit Holdings, Ltd.
SMIT SUB-1000	3,280/1,000	Smit Tak International	Same
SMT 1 & 2	1,200/366	International Submarine Engineering Ltd.	Sonarmarine Ltd.
SNOOPY	1,500/457	Naval Ocean Systems Center	Same
SNOOPY	1,500/457	Naval Ocean Systems Center	Naval Facilities Command
SNURRE	3,280/1,000	Continental Shelf Institute	Same
SPIDER	820/250	Myrens Verkstad A/S	Same
TELESUB	2,000/610	Remote Ocean Systems	Same
TOM 300	984/300	COMEX	Same
TREC 1, 2, 3	1,200/366	International Submarine Engineering Ltd.	Martech International
TREC 4	1,200/366	International Submarine Engineering Ltd.	Horton Maritime Explorations
TREC 5, 6	1,200/366	International Submarine Engineering Ltd.	Ocean Systems Inc.

*No RCV-225 has a cable longer than 1,212 ft (400m), but the vehicle is designed for 6,600 ft operating depth.

TETHERED, FREE-SWIMMING VEHICLES (Continued)

Vehicle	Depth (ft/m)	Manufacturer	Operator
TREC 7, 8	1,200/366	International Submarine Engineering Ltd.	Sub Sea International
TREC 9	1,200/366	International Submarine Engineering Ltd.	Uncommitted
TROV B-1	1,200/366	International Submarine Engineering Ltd.	National Water Resources Institute
TROV O-1	1,200/366	International Submarine Engineering Ltd.	(Not resolved)
TROV E-3	1,200/366	International Submarine Engineering Ltd.	J. Ray McDermott
TROV S-4, 6, 7	3,000/914	International Submarine Engineering Ltd.	Ocean Systems Inc.
TROV S-8	3,000/914	International Submarine Engineering Ltd.	Intersub
UFO 300	984/300	Submersible Television Surveys	Winn Technology
UTAS 478	1,312/400	General Video System	Same

BOTTOM-CRAWLING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
GRANSEOLA	150/46	INCOP, Ancona, Italy	Same
JU 160	197/60	Hitachi Construction	Same
KVAENER MYREN TRENCHING SYSTEM	1,640/500	Kvaerner Brug A/S	Same
PBM	420/128	Sub Sea Oil Services	Same
RUM	6,158/1,877	Marine Physical Laboratory	Same
SEABUG 1	1,000/306	UDI Ltd.	Same
SEACAT	656/200	Vickers Oceanics Ltd.	Same
SL 3	164/50	Land and Marine Engineering	Same
SUBTRACTOR	150/46	Maui Divers of Hawaii Ltd.	Same
TALPA	150/46	INCOP, Ancona, Italy	Same
TALPETTA	150/46	INCOP, Ancona, Italy	Same
TM-102	660/201	Techomare S.p.A.	Same
TM III, IV	246/75	Land and Marine Engineering	Same
TRAMP	(Not available)	Winn Technology Ltd.	Same
UNDERWATER BULLDOZER	23/7	Komatsu Ltd.	Same
UNDERWATER TRENCHER	70/21	Sumitomo Heavy Industries	Same

TOWED VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
ANGUS	7,874/2,300	Woods Hold Oceanographics Institute	Same
BATFISH	650/198	Bedford Institute of Oceanography	Same
CRAB	13,123/4,000	Institute of Oceanology	Same
DEEP TOW	20,000/6,096	Marine Physics Laboratory	Same
DIGITOW	19,685/6,000	Jet Propulsion Laboratory	Same
DSS-125	20,000/6,096	Hydro Products	One Japanese and One German Industrial firm
GUSTAV	19,685/6,000	Dornier System GmbH	Same
MANKA 01	21,325/6,500	GPK Karlsruhe	Same
NRL System	20,000/6,096	Naval Research Laboratory	Same
RAIE I	19,685/6,000	CNEXO	Same
RAIE II	19,685/6,000	CNEXO	Same
RUFAS I	600/183	NMFS	Same
RUFAS II	2,400/731	NMFS	Same
S^3	6,000/1,829	University of Georgia	Same
SEP	19,685/6,000	Dornier System GmbH	Same
TELEPROBE	20,000/6,096	Naval Oceanographic Office	Same

UNTETHERED REMOTELY OPERATED VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
EPAULARD	19,685/6,000	CNEXO	Same
OSR V & H	820/250	Mitsui Ocean Development and Engineering Co.	Same
ROVER	984/300	Heriot-Watt University	Same
SPURV I	12,000/1,650	Applied Physics Laboratory	Same
SPURV II	5,000/1,524	Applied Physics Laboratory	Same
UARS	1,500/457	Applied Physics Laboratory	Same
UFSS	1,500/457	Naval Research Laboratory	Same
Unnamed	2,000/610	Naval Ocean Systems Center	Same
Unnamed	3,000/914	University of New Hampshire	Same

TABLE 1.2 GENERAL VEHICLE CHARACTERISTICS

	Operating Depth (m/ft)	Weight in Air (kg/lbs)	Speed (knots)	Operating Duration	Electrical Power	Maneuvering Capability	Propulsers	System Components
Tethered Free-Swimming	1,053/ 3,454	592/ 1,025	1.6	Unlimited	Cable	3-Dimensions	Thrusters	Vehicle, umbilical cable, control/ display console, power generator
Bottom-Crawling	118/ 387[1]	49,000/ 108,025[2]	N/A	Unlimited	Cable	3-dimensions	Tracks, wheels, rams	Same
Towed	4,712/ 15,549	1,488/ 9,921		Unlimited	Cable	3-dimensions	Surface ship	Same
Untethered	1,643 5,391	948/ 2,090		4-6 hours	Batteries	3-dimensions	Thrusters	Vehicle, control/ display console, batteries

[1] Does not include general purpose vehicles which have an average depth capability of 1,184m (3,885 ft)

[2] Does not include general purpose and cable burial vehicles which average 1,900kg (1.87 tons)

TABLE 1.3 ROV WORK CATEGORIES

TETHERED, FREE-SWIMMING VEHICLES

Industrial	Military	Scientific/Research
Inspection	Inspection	Inspection
Monitoring	Search/Identification	Survey
Survey	Installation/Retrieval	Installation/Retrieval
Diver Assistance		
Search/Identification		
Installation/Retrieval		
Cleaning		

BOTTOM CRAWLING VEHICLES

Industrial	Military	Scientific/Research
Bulldozing	Drilling	None
Trenching	Trenching	
Inspection		
Manipulation		

TOWED VEHICLES

Industrial	Military	Scientific/Research
Survey	Search/Indentification/ Location	Geological/Geophysical Investigations
	Survey	Broad Area Reconnaissance
	Fine-grained Mapping	Water Analysis
	Water Sampling	Biological/Geological Sampling
	Radiation Measurements	Bio-assay
		Manganese Nodule Survey/Study

UNTETHERED VEHICLES

Industrial	Military	Scientific/Research
None	Conductivity/Temperature/ Pressure Profiling	Bathymetry
	Wake Turbulence Measurements	Photography
	Under-ice Acoustic Profiling	

who represented a total of 27 tethered, free-swimming ROVs (the military sector was not included). Only three of the operators responded, but they represented 15 vehicles. The total diving days of these 15 vehicles was 2,007. All of this activity was financed by private industry. In 1978 manned submersibles operated for only 510 dive days.

1.3 PROBLEMS ENCOUNTERED

There are many recurring problems that are inherent in the design of the vehicle itself and its application in the field. The most prevalent problem operators have encountered is entanglement of the umbilical cable or the vehicle itself. Entanglement in its most mild form has resulted in merely a short delay until the problem can be worked out. In its more serious form it can lead to abandonment of the vehicle for several months until it can be retrieved or its complete loss. Another area where almost half the operators expressed dissatisfaction concerned erratic performance of electrical connectors. Other areas include sediment disturbance which obscures visibility; cable rupture due to drag, stress or abrasion; and electrical interference between the control, power, and data video transmission in the umbilical cable. Less severe problems lay in the area of support ship station-keeping ability, compass performance, power supply surges, currents and sea state limitations. One area of particular importance is the lack of - and need for - qualified experienced personnel. The type of personnel sought varies; but those with an electronics background and experience in undersea operations and shipboard handling techniques are most desired. A listing, by decreasing order of occurrance of problems encountered by free-swimming, tethered ROVs is shown in Table 1.4.

1.4 CURRENT RESEARCH AND DEVELOPMENT PROGRAMS

Current research and development in tethered, free-swimming ROV technology is being funded and conducted by a variety of sources; these include the federal governments of several nations and private industrial sources. In several instances the project is funded jointly by the government and industry, with the work being carried out by the industrial partner. (This is particularly true in the United Kingdom.)

Most of the ROV research and development programs deal with specific components or aspects of technology. However, the Government of England has embarked on a program which deals with the field in its entirety. The major thrust of the program is to sophisticate the ROV system, increase its efficiency and lessen the hazard to humans by replacing man underwater with a remotely operated system. A tabulation of the current research and development programs by country, task and objectives is contained in Table 1.5.

1.5 RECOMMENDED RESEARCH AND DEVELOPMENT PROGRAMS

There are a variety of areas in which present and future ROV capabilities can be improved. For convenience, these are categorized into "immediate" (those programs which enhance present vehicles) and "long-term" (those which call for new developments or further refinements to new techniques). The programs recommended include developments recommended by operators and manufacturers, and those indicated by trends and potential requirements of the future. The majority of recommended research programs are in support of industrial and

TABLE 1.4 ROV PROBLEMS REPORTED

Problem	Number of Operations
Entanglement	18
Electrical Connectors	12
Vehicle Disturbs Sediments, Obscures Visibility	11
Cable Ruptured by Abrasion	10
Electrical Interference in Cable	8
Support Ship Cannot Station-Keep	6
Compass Affected by Structure	6
Ship Power Surges Affect Vehicle Operations	5
Current Required Aborting Mission	5
Sea State Required Aborting Mission	5
Vehicle Damage During Launch/Retrieval	2
Vehicle Station-Keeping Inadequate	2
Manipulation Inadequate	2
Vehicle Payload Inadequate	2
Human Engineering Inadequate	2
Vehicle Lost Due to Low Surface Freeboard	1
Electrical Shocks Due to Inadequate Grounding	1
Vehicle Maneuverability Inadequate	1
Water Visibility Required Aborting Mission	1
Television Resolution Inadequate	1

TABLE 1.5 CURRENT RESEARCH AND DEVELOPMENT PROGRAMS

Country	Participants	Title	Objectives
England	Government, Industry, Academic	Progressive Replacement of Man Underwater	To develop technology required for underwater engineering to move toward the progressive replacement of man underwater by remotely controlled systems.
	Chanister Investment Ltd.	Advanced Sea Bed Instrumentation	Development of a wide range of instruments and equipment applicable to underwater engineering tasks (e.g., underwater inspection and maintenance).
	Ferranti Ltd.	Inertial Navigation System	To implement an inertial guidance navigation system into ROV application.
France	Intersub	Pipeline Inspection System	Integration of instrumentation, remotely operated vehicle, support ship and navigation system into a single operating entity.
	CNEXO	Untethered Vehicle	Development of a 6,000m depth vehicle for exploratory missions of the ocean bottom.
Scotland	Heriot Watt University	Untethered Vehicle	Development of an untethered, free-swimming vehicle operated from a submerged launcher.
United States	Naval Ocean Systems Center	Untethered Vehicle	Development of a robot, test-bed vehicle to permit demonstration of improved ROV system technology.
	University of New Hampshire	Untethered Vehicle	Development of an untethered vehicle which will automatically follow a pipeline using an acoustic array as a sensing element.
	Naval Research Laboratory	Untethered Vehicle	Development of a pre-programmed, low drag vehicle designed initially for scientific data collection.
	Massachusetts Institute of Technology	Thru-water Television	Conduct research into underwater communication systems for untethered vehicle and submerged systems.
	NOAA, Office of Ocean Engineering (OOE)	Remotely Operated Diver Assist Vehicle	Concept design of an ROV to assist NOAA-oriented diving activities
	NOAA-OOE and NASA/JPL	Digital Side Scan Sonar in JPL DIGITOW	Incorporate improved sonar components and digital processing techniques into side scan sonar deployed from ROVs.
	NOAA-OOE and University of Georgia	Remote Sea Bed Sampling	Development of techniques to facilitate remote sampling and <u>in situ</u> analysis of the sea floor sediments.
	NASA/JPL/NOAA-OOE	Sub-bottom Profiling	Development of advanced techniques for profiling the sub-bottom from ROVs.
	Massachusetts Institute of Technology	Manipulation	Analyses and experimental programs to optimize manipulative techniques.
	The Continental Group	Lithium Power Cell	Development of a lithium-sea water battery for application to ROVs and other undersea systems.
	Exxon Production Research Company	Tethered Maintenance Vehicle	Development of a Tethered Maintenance Vehicle to perform observation and manipulative tasks on a deep water marine production riser system.
West Germany	Dragerwerk	Diver Assistance Vehicle	Development of a diver assistance vehicle for underwater inspection and maintenance duties.

military vehicles, however, these programs will be of direct benefit to the scientific/research user of ROVs when such technology is employed in this field. A tabulation and brief description of the recommended research and development programs is contained in Table 1.6

TABLE 1.6 RECOMMENDED RESEARCH AND DEVELOPMENT PROGRAMS

Immediate Programs	Development Goals
Cable Technology	-Light weight, stronger, abrasion-proof cable -Rapid, non-destructive testing technique
Television	-True color rendition -Dimensional measurements
Surface Location Techniques	-Light weight, low power surface location device
Thruster/Power Module	-Adaptable power module for high thrust conditions
Diver Assist Vehicle	-Concept design for specialized diver assist ROVs
Acoustic Imaging	-Evaluation and/or design of an acoustic imaging system for turbid waters
Heave Compensation	-Sub-surface heave compensation device
Reliability/Performance	-Transfer of technological data
Scientific Indoctrination	-Evaluation of ROVs for scientific use
Instrumentation	-Acoustic identification of fish -ROV-compatible biological sampler -Rapid photo-assay techniques
Seafloor Sampling	-Rapid, remote seabed sampling and analysis techniques
Long-Term Programs	
Untethered Vehicle Technology	-Untethered vehicle with real-time TV
Manipulation	-Manipulative substitute for human intervention at great depth
Navigation	-Non-acoustic, in-structure positioning system
Free-Swimming/Towed Vehicle	-Towed vehicle with independent maneuvering/manipulative capability

2.0 REMOTELY OPERATED VEHICLES

Four classes of ROVs have been identified in the course of this study:

Tethered, Free-Swimming Vehicles: Powered and controlled through a surface-connected cable. Self-propelled, capable of 3-dimensional maneuvering, remote viewing through a closed-circuit television (CCTV).

Bottom-Crawling Vehicles: Powered and controlled through a surface-connected cable. Self-propelled by drive wheels, capable only of maneuvering on the bottom, or a structure, remote viewing through CCTV.

Towed Vehicles: Powered and controlled through a surface-connected cable. Propelled by surface ship, capable of maneuvering only forward and up/down by cable winch. Remote viewing through CCTV.

Untethered Vehicles: Self-powered, controlled by acoustic commands or pre-set course. Self-propelled, capable of maneuvering in 3 dimensions. No remote viewing capability.

The primary vehicle of interest to this study is the tethered, free-swimming vehicle. Consequently, this class is treated more comprehensively than are the other three. While the term "tethered, free-swimming" is paradoxical, it is used to differentiate this type vehicle from the bottom-crawling vehicles which are tethered also, but capable of maneuvering only in contact with the ocean bottom, or a structure.

2.1 TETHERED, FREE-SWIMMING VEHICLES

The pioneer vehicle in this class was Dimitri Rebikoff's 1953 POODLE, a modified version of the diver transport vehicle PEGASUS. The primary components of present day systems consist of: 1) a control/display console; 2) a power source (ship's power or dedicated generator); 3) an umbilical cable (providing power, control and data telemetry from surface-to-vehicle); 4) a launch/retrieval system and 5) the underwater vehicle itself (Plate 2.1).

The growth of vehicles in this class has been impressive. In the 21 years following the debut of Rebikoff's POODLE (1953-1974), 20 vehicles were constructed. Seventeen (85 percent) of these were funded totally or partially by various governments (U.S., France, England, Finland, Norway, USSR). From 1975 through 1978, 82 additional ROVs were added to the world inventory. Where industrial users accounted for 15 percent of the 1974 market, they now (excluding specialized mine neutralization ROVs) account for 90 percent. The cause of this remarkable growth is the burgeoning offshore oil and natural gas industry. The year 1974 is significant because in that year the OPEC nations tripled the price of oil. Consequently, offshore oil which theretofore was not profitable to extract became profitable, and development proceeded accordingly.

The pre-1974 ROVs were primarily, if not solely, dedicated to military and scientific/research missions. Rebikoff's POODLE, for example, performed much of its work in archeological exploration. The Soviet Union's MANTA 1.5; Norway's SNURRE; Finland's PHOCAS and Scotland's ANGUS 01 were used in geological and biological exploration.

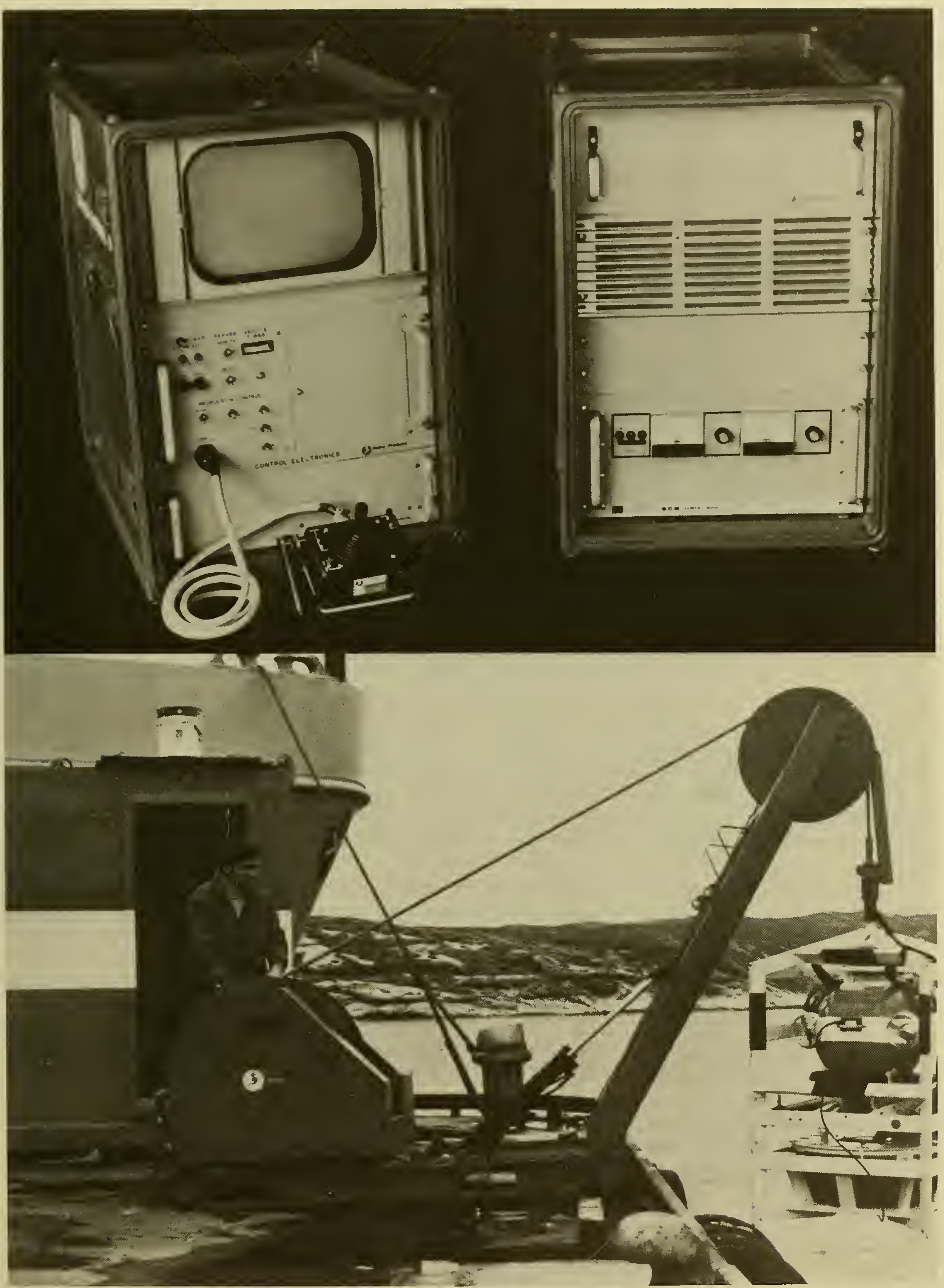


PLATE 2.1 THE RCV-225 SYSTEM
(Courtesy Hydro Products, a Tetra Tech Company)

The U.S. Navy's CURV (Cable-controlled Underwater Recovery Vehicle) grew out of interest in a mobile underwater TV system produced by the New Jersey-based Vare Co. and purchased by the Navy in 1957. A need for more expanded capabilities prompted the Naval Ocean Systems Center (then Naval Electronics Laboratory) to produce the first CURV in 1958. CURV's existence for the next six years was scarcely noticed by the marine community, although it recovered some 600 torpedos and other objects in support of Naval activities.

The first worldwide visibility obtained by an ROV was CURV's retrieval of an H-bomb in 869m (2,850 ft) of water off the coast of Spain in 1966. The retrieval - aside from its drama - is interesting because it foretold the strengths and weaknesses of ROVs. CURV, instead of the manned vehicle ALVIN, was selected to retrieve the H-bomb owing to the likelihood of entanglement with the shroudlines of the bomb's parachute. An ROV does not jeopardize human life -- a major asset over manned vehicles. In spite of cautious maneuvering CURV did become entangled. There was no choice but to retrieve the bomb if CURV itself was to be retrieved. Entanglement, as is pointed out in a subsequent section, is a major problem with today's ROV operators when working in and around subsea structures. In any event, CURV did the job and received international acclaim.

From 1958 through 1974 the U.S. Navy constructed and funded development of eight more ROVs. Three of these were additions and replacements for the original CURV, the others were primarily testbed vehicles for advancement in technology, two such vehicles were TORTUGA and ANTHRO built by Hydro Products, San Diego, California.

The design goal of TORTUGA was to produce a small (relative to CURV) maneuverable underwater video system designed for close examination of normally inaccessible underwater areas. Although its military application is not publicly reported, TORTUGA's shape, size and mode of operation indicates a potential for deployment from a submarine. Several experimental versions of TORTUGA were built, the first units relied on water jets for propulsion, later vehicles used propellers to increase maneuvering and responsiveness.

The ANTHRO (anthromorphic) vehicle was a follow-on to TORTUGA which was also constructed by Hydro Products with U.S. Navy funding. ANTHRO was developed to investigate a concept wherein normal human perception would be preserved in the vehicle. The technique employed (Strickland, 1969) was referred to as "head coupled" video presentation and involved slaving the vehicle and/or camera orientation to the operator's head attitude. The video presentation was mounted on, and moved with, the operator's head. Consequently, the scene being viewed moved in exact synchronization with the operator's head movement, and his memory recorded the relative location of all objects in the field of view. Binaural audio inputs (obtained from a pair of hydrophones on the vehicle) were also continuously provided to investigate the feasibility of detecting and localizing underwater objects either by their own self-generated sound or by reflected sound generated from the vehicle.

The ANTHRO operator's control station included an instrumented swivel chair and a helmet containing a television display (a 5 inch TV screen), roll, pitch and azimuth sensors and dual headphones. Manned controls for vehicle maneuvering, depth functions and television camera remote focus were provided at the operator's right hand. Vehicle depth was controlled by servo-controlled vertical thrusters which automatically maintained a desired depth.

SCAT (Submersible Cable-Activated Teleoperator) was a U.S. Navy-built follow-on to ANTHRO and served as a test-bed demonstration vehicle for the purpose of evaluating head-coupled television and three-dimensional television display. The two SNOOPY vehicles were developed as extremely portable, lightweight systems which could replace divers in a variety of observation and surveillance tasks.

The Institute of Oceanology, USSR, capitalizing on experiences with the 4,000m CRAB-4000 in 1971, developed the MANTA vehicle. The operational theory behind MANTA was that it is practically impossible for a man to successfully operate a moving system without a proper feedback which acts upon the whole complex of sensors within his central nervous system (Mikhaltsev, 1973). A group of tenso-sensors was mounted on MANTA and a special servo-controlled, hydraulically-driven operator's chair which closed the feedback circuit, was constructed. The chair repeated all the roll and pitch movements of the underwater vehicle and allowed the operator to feel MANTA's maneuvering. Further sophistication was added by incorporating the feedback provided by the manipulator's tenso-sensors into a simple computer which gave the preprogrammed computer the ability to command the manipulator system. As of 1973 the preprogramming was fulfilled, but only under laboratory conditions.

Other government funded vehicles of the early seventies included the English SUB-2 and CONSUB-01, the Scottish ANGUS 001, the Norwegian SNURRE and the French Navy's ERIC. The SUB-2 vehicle was a prototype built by the Admiralty Weapons Research Establishment in conjunction with the Admiralty Underwater Weapons Establishment (AUWE). The 2¼ ton, 600m ROV was used to conduct feasibility trials off Portland in late 1972. The prototype, as late as 1976, was inactive and remains so at Aldermaston. At least one ROV, called CUTLET, was constructed by AUWE for torpedo recovery. Reportedly three of the 300m vehicles were built, but their details are not available.

CONSUB 01 was built by British Aircraft Corporation (BAC) for the Institute of Geological Sciences (IGS) to conduct bottom investigations in offshore U.K. waters. The vehicle was also used to conduct commercial tasks in the North Sea before being turned over to IGS, Edinburgh. ANGUS 001 (A Navigable General purpose Underwater Surveyor), now retired, was a test bed vehicle built by Heriot-Watt University, Edinburgh to "get their feet wet" in the area of ROVs. The original ANGUS was used to generate a background of operational expertise and design feedback to the subsequent ANGUS 002 and 003 (now under development). The original SNURRE was developed in 1972 by the Norwegian Institute for Industrial Research and Det norske Veritas, and sponsored by the Royal Norwegian Council for Scientific Research, Continental Shelf Office. The vehicle has been operated, under the aegis of the Continental Shelf Office, to conduct basic research and industrial tasks in the North Sea.

The first commercial vehicle since Rebikoff's 1953 POODLE made its appearance in 1975, Hydro Product's RCV-225 (initially designated RCV-125). The two RCV-225s would be the first of a total of 26 such vehicles built by Hydro Products by 1978 to make it the world's leader in construction of industrially-oriented vehicles. (RCV, Remotely Controlled Vehicle, is a registered trademark of Hydro Products, a Tetra Tech Company.)

Capitalizing on their experiences with TORTUGA and ANTHRO, Hydro Product's RCV set the initial standards for industrially-oriented vehicles. The RCV is a portable, lightweight and extremely maneuverable observation/video documentation vehicle. The complete system (Plate 2.1) consists of a vehicle control/display console, cable winch, launch/retrieval or deployment apparatus, a power source, a launcher and the vehicle itself. (Performance specification for the RCV-225 and other operational ROVs are contained in Appendix A.)

The control station allows the operator to precisely position the RCV-225 relative to the object being inspected using a fully proportional joy-stick. Vehicle depth and heading are automatically maintained by servo controls and, in conjunction with lens pitch angle, are displayed in the television picture and continuously recorded on video tape records. Additional displays include number and direction of cable twists, tether cable payout length and elapsed time. The heart of the viewing subsystem is the Hydro Products low light level SIT television camera. It is equipped with a lens assembly that enables the operator to remotely pitch the angle of view ±90 degrees from the horizontal. Two 45-watt tungsten halogen lamps provide a viewing range of up to ten meters with no ambient light. The light reflector configuration can be adjusted for optimum viewing in either clear or turbid water.

The vehicle is highly maneuverable, even in currents approaching 1 knot. Four oil-filled electric motors give the vehicle three degrees of freedom in translation (thrust, sway, heave) and one rotational degree of freedom (yaw). A syntactic foam hull encloses the motors and camera/electronics pressure housing in a buoyant envelope.

The deployment unit includes a protective RCV launcher with tether cable winch, a deck winch with double armored cable mounted on a skid/A-frame assembly, and a Hydraulic Power Supply. The vehicle is transported to working depth in the launcher, flies out of the launcher to perform the inspection task, then returns for transport back to the deck. Tether cable can be winched in or out of the launcher by remote control. The RCV system is designed to avoid entanglement situations through its small size, smooth hull, and high maneuverability. Kevlar reinforcement provides a high strength, positively buoyant tether cable, free of separately attached floats. The submersible winch in the launcher allows the operator to retain excess tether cable in a protective enclosure to reduce entanglement risk or potential tether cable damage. Emergency retrieval provisions facilitate vehicle recovery in the event of unavoidable entanglement. Upon command, the vehicle can be separated from its cable to freely ascend to the surface. A pinger and strobe flasher aid in location and surface recovery.

Vehicle-to-vehicle diversity in characteristics and performance precludes describing a vehicle representative of the entire field. However, using commercial acceptance as a guide, the TROV and TREC vehicles constructed by International Submarine Engineering Ltd. (ISE), Port Moody, British Colombia represent another approach to remotely operated vehicle technology.

The first TROV (Tethered Remotely Operated Vehicle) was constructed in 1976 for the Canadian National Water Resources Institute (then Canadian Center for Inland Waters) and was battery operated. The later models, beginning in 1976 with TROV 01, are powered from the surface. By March 1979 eight TROVs will have been constructed. The first prototype TREC (Tethered Remote Camera) was built in 1976; two years later seven production-line vehicles were produced. Six were sold by the end of 1978.

The TREC vehicle (Plate 2.2) provides many of the capabilities offered by the RCV-225. The vehicle is more typical of the field at large, in that it is rectangular-shaped and composed of an open-aluminum framework which encloses and supports all components. Atop the framework is a block of syntactic foam which provides positive buoyancy. The vehicle occupies 0.9m^3 (34.6 ft^3) relative to the RCV-225's 0.2m^3 (6 ft^3) and is 77kg (170 lbs) heavier. The complete system consists of a control/display console, umbilical cable and the vehicle itself. TREC's maximum depth is limited to 366m (1,200 ft). Unlike Hydro Product's vehicle, the TREC system does not employ a launcher.

TREC's control/display console includes propulsion, light intensity, camera focus, tilt, manipulator control, TV and video recorder controls, TV display, depth and altitude. A manipulator may be fitted which provides three motions: up/down, in/out, open/shut (claw). An off-the-shelf Panasonic low light level TV camera provides remote viewing, and four, 1 hp thrusters produce yaw, thrust and heave vehicle motions. Navigation can be provided by a magnetic compass or gyrocompass or through one of the commercially-available acoustic tracking systems.

There is no objective in this report to assess or compare one ROV to another. It is still too early to determine which of the numerous vehicles is "best". The ISE vehicles offer certain advantages over the Hydro Products vehicles and vice versa. Indeed, a general purpose ROV that can perform every task with 100 percent efficiency is as unlikely as is a general purpose manned submersible. As operational experience accumulates, and is fed back to the manufacturers, each subsequent vehicle becomes more reliable and efficient in its operation. Initially there was some question as to the need for a launcher or clump within/and from which, the vehicle was deployed. Now it has become clearer - although not fully accepted - that a launcher is desirable during platform inspections because it performs the task of keeping the greater part of the tether cable taut and outside of the platform to avoid entanglement, while the vehicle itself operates on a relatively short umbilical and generally in the horizontal plane while within the structure. The non-launcher vehicles have gained greater - although not universal - acceptance in tasks where the vehicle operates underway in such work as pipeline inspection where the support vessel maintains station above the vehicle as it progresses (a function termed "live boating").

The statistics used in the following discussion do not include an ROV designated PAP 104. The Societie Eca, Meudon, France has produced and sold over 128 PAP 104s to various NATO Navies. Since this number is almost more than has been produced by the entire field, including PAP-104 in the discussion would not produce a representative assessment. The vehicles are designed specifically

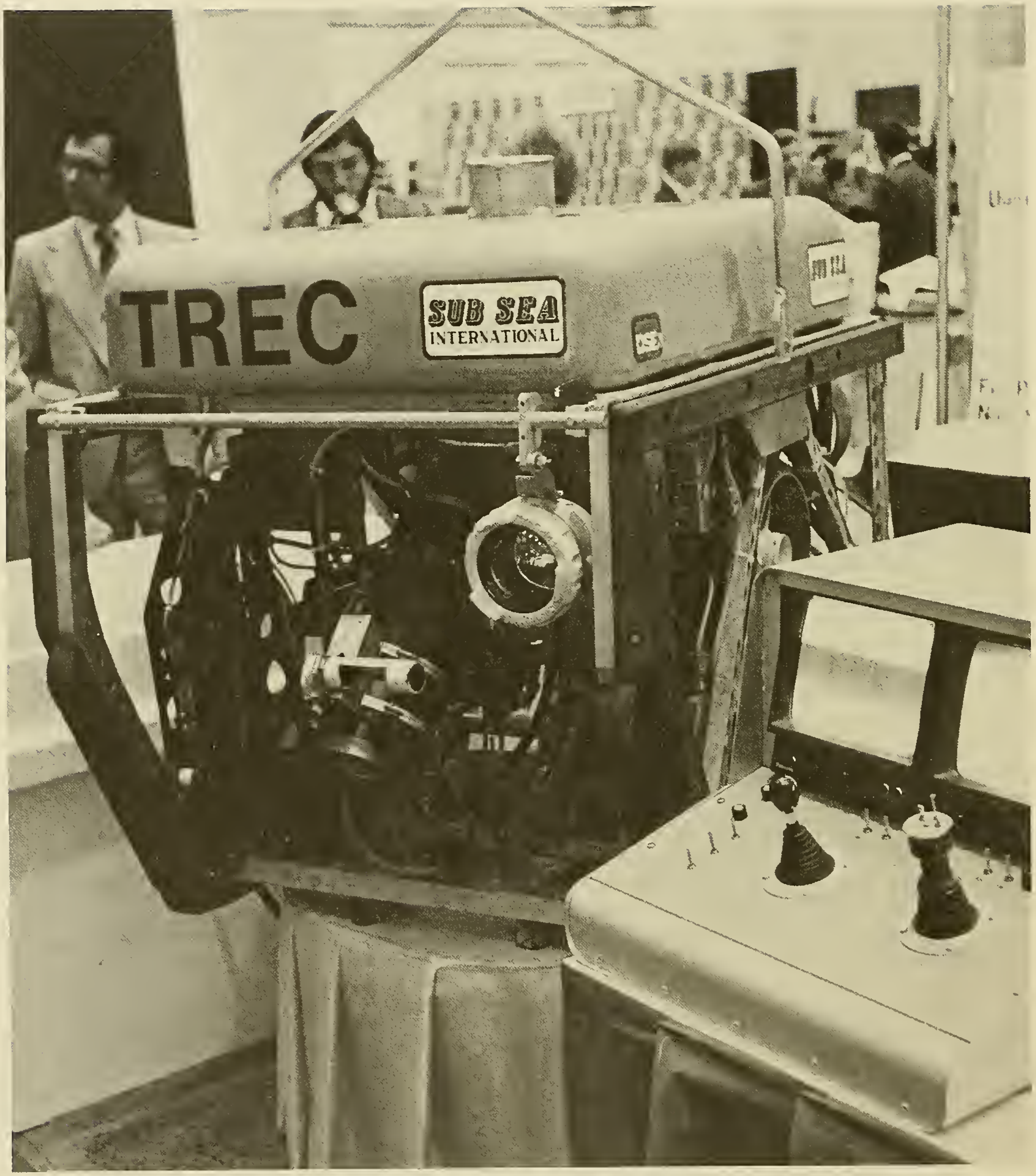


PLATE 2.2 THE TREC SYSTEM
(Courtesy International Submarine Engineering Ltd.)

for ordinance (mines) inspection and neutralization. PAP-104 is battery-powered and carries an explosive weight of 100kg (220 lbs) which is released by the operator. Guidance of the vehicle to the ordinance is performed by the support ship's mine-hunting sonar. Detonation of the charge is possible 15 minutes after its release and for 30 minutes thereafter. After 30 minutes the igniters are mechanically isolated from the explosive and firing becomes impossible. PAP-104 is propelled by two electric motors with variable pitch propellers. Control in the vertical is by a guiderope which holds the vehicle at near-constant altitude off the bottom. Operations in currents of 4 knots and depths of 100m are attainable, operational duration is 20 minutes.

Unlike other ROVs, PAP-104 does not pull its tether through the water, instead, a small diameter cable (spooled around a reel) is paid out from the vehicle as it progresses through the water. In this manner cable drag is avoided. Surface components consist of a main control console and a TV monitor.

At present there are 28 industrial, government and academic manufacturers of ROVs. Approximately 140 vehicles will have been constructed by 1980 and at least 100 are now operating (Figure 2.1). The following sub-sections deal only with operational vehicles and those under construction - or funded for construction. Table 2.1 presents the salient characteristics of these vehicles and Table 2.2 presents the vehicles in order of increasing depth capability and the organizations which own and operate specific vehicles.

2.1.1 Structure

The majority of vehicle manufacturers (19) produce a vehicle which is rectangular in shape and composed of an open metallic (usually aluminum) framework. The framework serves the function of enclosing, supporting and protecting the vehicle components (thruster, junction boxes, CCTV, lights, etc.). Frequently the framework members are square and rectangular rather than tubular to facilitate attachment of components. Variations from the open aluminum framework are vehicles which have faired the framework entirely with either fiberglass or metal. The vehicle shape in these instances are torpedo-like, disc-like or spherical.

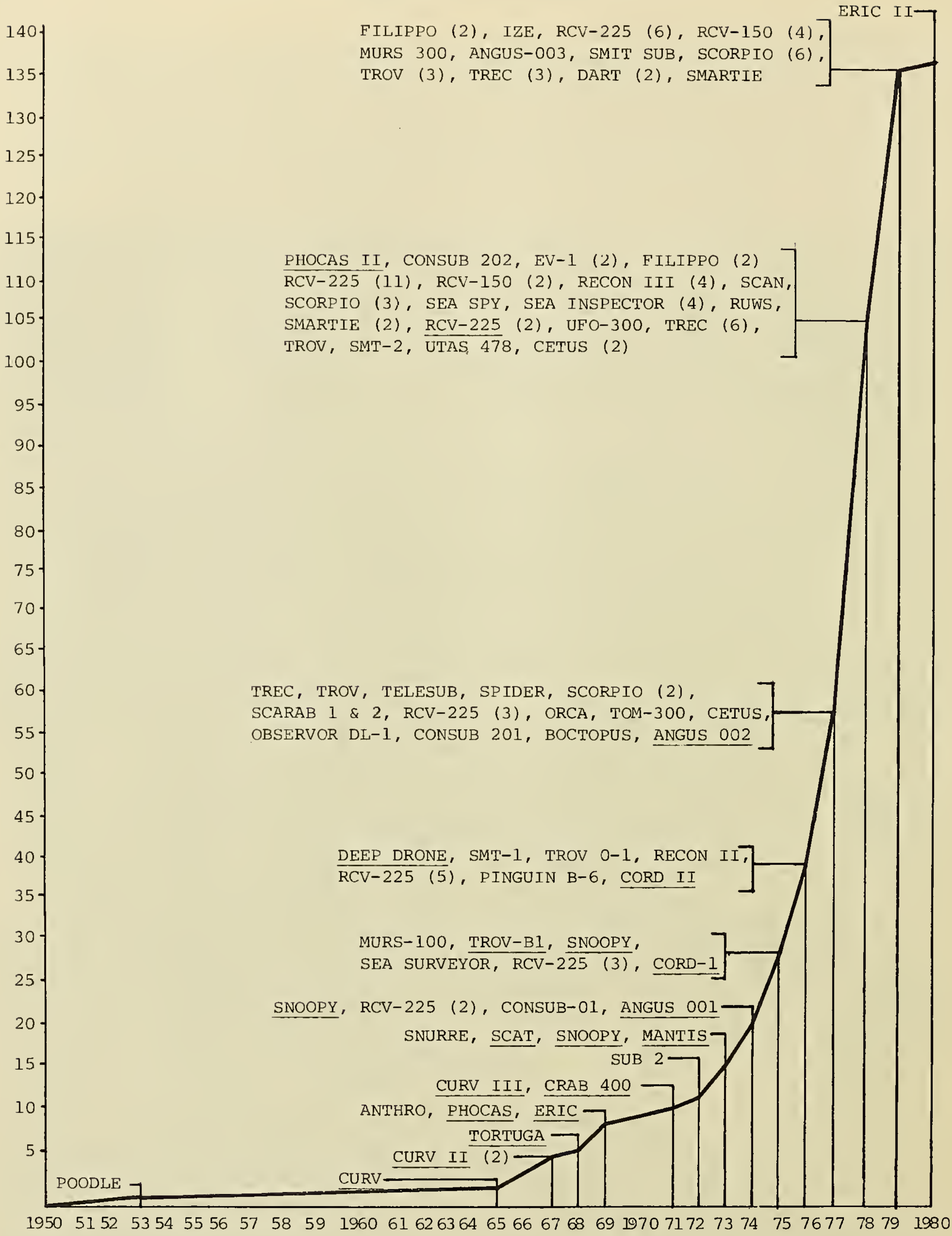
Vehicle size varies widely and ranges from the basketball-sized RCV-225 (0.17m^3) to the automobile-sized ERIC II (27m^3). Approximately 46 percent are less than 1m^3. Figure 2.2 graphically portrays vehicle size distribution.

Vehicle dry weight is as variable as is vehicle size, and ranges from 80kg to 5,000kg (176 to 11,023 lbs) (Figure 2.3). Most (66 percent) are less than 500kg (1,102 lbs).

2.1.2 Buoyancy

All ROVs have slight positive buoyancy when submerged. In all but a few instances the buoyancy is supplied by syntactic foam blocks fixed to the top of the framework. Alternatives to syntactic foam take the shape of small, hollow plastic spheres (fishing floats) which are much less expensive, but limited in depth capability. To overcome the positive buoyancy the vertical thrusters are employed to thrust the vehicle downward. The propeller wash, being directed upward, does not disturb the bottom sediments and obscure visibility. Variable buoyancy tanks (blown free of water by compressed air)

FIGURE 2.1 TETHERED, FREE-SWIMMING ROV GROWTH



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

TABLE 2.1 SALIENT CHARACTERISTICS OF PRESENT AND FUTURE ROVs

Vehicle	Dimensions (cm) L	W	H	Dry Weight (kg)	Speed[1] (KTS)	Power Req.	Dynamic Maneuverability[2] T	H	Y	P	S	R	Launcher/ Clump	Structure[3]	Crew	Horizontal Thruster hp
ANGUS 002	225	127	135	700	1.0	50Hz 415/240V	+[4]	+	+	+	0[5]	+	0	OAF	2	7
ANGUS 003	240	145	145	1,000	2.0	50/60Hz 210/440V	+	+	+	+	+	+	0	OAF	NA	12
BOCTOPUS	320	213	167	970	2.0	33KVA	+	+	+	0	+	+	0	OAF	5	20
CETUS	244	152	122	1,089	3.5	50-60Hz 415/480V	+	+	+	0	+	0	0	OAF	4	8.6
CONSUB 1	271	182	145	1,360	2.0	50Hz 240/415V	+	+	+	0	0	0	0	OAF	4	10
CONSUB 201 & 02	368	213	175	2,900	2.0	50/60Hz 380/415/440V	+	+	+	0	0	0	0	OAF	3	25
CORD II	73	104	140	327	1.5	60Hz 480V	+	+	+	0	0	0	+	OAF	3	3
CURV II	457	183	183	1,565	4.0(S)	120/50Hz 440V	+	+	+	0	0	0	0	OAF	7	20
CURV III	457	183	183	1,814	4.0(S)	50Hz 120/440V	+	+	+	0	0	0	0	OAF	7	20
DART	94	46	31	32	NA	NA	+	+	+	0	+	0	0	OAF	NA	NA
DEEP DRONE	213	137	122	726	1.5	115/440V	+	+	+	0	0	0	0	OAF	5	6
ERIC 10	400	200	200	3,100	2.0	60Hz 440V	+	+	+	0	0	0	0	OAF	5	1
ERIC 11	500	300	180	5,000	NA	400Hz 115V	+	+	+	+	+	+	+	EFF	5	NA
EV-1	132	81	61	107	1.5	60Hz 220/440V	+	+	+	0	0	0	0	OAF	3	NA
FILIPPO	65	65	65	86	0.5	Battery	+	+	+	0	+	0	0	EFF	1	1
IZE																
MANTA 1.5	198	158	107	998	3.0(S)	50Hz 380V	+	+	+	0	0	0	0	OAF	3	3
MURS-100	255	189	150	900	2.5	60Hz 440V	+	+	+	0	0	+	0	EFF	4	4
MURS-300	266	190	163	2,400	1.0(S)	60Hz 220V	+	+	+	0	0	0	0	OAF	2-3	15
OBSERVER DL1	175	NA	150	NA	NA	NA	+	0	+	0	0	0	0	OAF	NA	NA
ORCA I	350	200	200	2,721	NA	50/60Hz 380/440V	+	+	+	+	+	+	0	OAF	4	16
PAP-104	270	120	130	700	4.0	Battery	+	0	+	0	0	0	0	EFF	2	NA
PHOCAS II	200	80	80	227	1.5	50Hz 220V	+	0	+	0	0	0	0	OAF	NA	1
PINGUIN B6	315	175	175	1,626	2.0	NA	+	0	+	0	0	0	0	EFF	NA	NA
RCV-225	51	66	51	82	1.0	50/60 Hz 320/440V	+	+	+	0	+	+	+	EFF	3	0.2
RCV-150	135	122	112	204	2.0	50/60Hz 220/440V	+	+	+	0	+	0	+	OAF	3	15
RECON II	107	96	81	281	1.5	60Hz 220/440V	+	+	+	0	0	0	+	OAF	5	2
RECON III	142	71	61	150	3.0(S)	60Hz 220/440V	+	+	+	0	0	0	0	OAF	3	2.6
RECON V	175	99	81	259	2.5(S)	60Hz 220/480V	+	+	+	0	+	+	0	OAF	3	5
RUWS	335	145	152	3,200	1.5	60Kw	+	+	+	0	0	0	+	OAF	NA	15
SCAN	61	61	36	NA	1.0	50Hz 420V	+	0	+	0	0	0	0	EFF	1	NA

TABLE 2.1 (CONTINUED)

Vehicle	Dimensions (cm)			Dry Weight (kg)	Speed[1] (KTS)	Power Req.	Dynamic Maneuverability[2]						Launcher/ Clump	Structure[3]	Crew	Horizontal Thruster hp
	L	W	H				T	H	Y	P	S	R				
SCARAB I & II	335	183	152	2,268	0.5	448V	+	+	+	0	+	+	0	OAF	3	20
SCORPIO	223	122	163	680	1.0	60Hz 440V	+	+	+	0	+	0	0	OAF	4	10
SEA SPY	127	66	58	102	0.5	240V	+	+	+	0	+	0	0	OAF	3	0.4
SEA INSPECTOR	334	120	61	145	5.0(S)	60Hz 230V	+	+	+	+	0	0	0	EMF	2	2
SMT 1	213	127	127	998	1.5	60Hz 440V	+	+	+	0	+	0	0	OAF	7	14
SMT 2	274	127	127	1,497	1.5	60Hz 440V	+	+	+	0	+	0	0	OAF	7	14
SMIT SUB	220	220	160	700	2.0	NA	+	+	+	0	+	0	0	OAF	NA	NA
SNOOPY	101	66	46	68	1.0	60Hz 115V	+	+	+	0	0	0	0	OAF	2	2
SNURRE	200	180	150	1,200	1.5(S)	420V	+	+	+	0	+	0	0	OAF	4-5	2
TELESUB	140	79	69	104	1.5	60Hz 200/440V	+	+	+	0	+	0	0	OAF	NA	2
TOM 300	360	170	182	2,900	1.5	220/380V	+	+	+	0	+	0	0	OAF	5	12
TREC	119	91	135	181	1.5	60Hz 120V	+	+	+	0	+	0	0	OAF	4	3
TROV B1	159	91	122	544	2.0	60Hz 460V	+	+	+	0	+	0	0	OAF	4	10
UFO 300	91	NA	NA	91	NA	NA	+	+	+	+	+	+	+	EFF	2	NA
TROV-01	213	127	127	726	NA	60Hz 440V	+	+	+	0	+	0	0	OAF	2	NA
SMARTIE	110	110	46	82	NA	50Hz 440V	+	+	+	0	+	0	+	EFF	3	NA
TROV 4	274	127	127	1,179	1.0	60Hz 440V	+	+	+	0	+	0	0	OAF	4	14
UTAS 478	140	55	30	80	2.3		+	+	+	0	0	0	0	EMF	NA	1

[1] Speed at maximum operating depth under zero current conditions. (S) indicates surface speed.
[2] T: thrust; H: heave; Y: yaw; P: pitch; S: sway; R: roll.
[3] OAF: open aluminum framework; EFF: enclosed fiberglass fairing; EMF: enclosed metallic framework.
[4] +: capability.
[5] 0: not a capability.
NA: information not available.

TABLE 2.2 TETHERED, FREE-SWIMMING VEHICLES, DEPTH AND DISTRIBUTION

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer
SCAN	1	328/100 (approx)	Operational	Underwater Maintenance Co., Ltd.	Same
PAP-104	128	328/100	Operational	Various NATO Navies	Societie Eca
MURS-100	1	328/100	Operational	Mitsui Ocean Development and Engineering Co.	Same
PINGUIN A1	1	330/101	Operational	VFW Fokker	Same
OBSERVOR DL1	1	600/183	Operational	C.G. Doris	Same
RECON III	5	600/183*	Operational	Oceanics Ltd. (2)	Perry Oceanographics (3)
SEA INSPECTOR	2	656/200	Operational	Rebikoff Underwater Products	Same
SEA SURVEYOR	1	660/200	Operational	Rebikoff Underwater Products	Same
SPIDER	1	820/250	Operational	Myren Verksted A/S	Same
FILIPPO	1	984/300	Operational	Gay Underwater Products	Same
FILIPPO	1	984/300	Operational	Nereides, Orsay, France	Gay Underwater Products
FILIPPO	2	984/300	Construction	Uncommitted	Gay Underwater Products
OBSERVOR III	1	984/300	Construction	C.G. Doris	Same
MURS-300	1	984/300	Construction	Mitsui Ocean Development and Engineering Co.	Same
UFO-300	1	984/300	Operational	Winn Technology	Submersible Television Surveys
SMARTIE	3	984/300	Operational	Marine Unit Holdings, Ltd.	Marine Unit Technology, Ltd.
TOM 300	1	984/300	Operational	COMEX	Same
ANGUS 002	1	1,000/305	Operational	Heriot Watt University	Same
ANGUS 003	1	1,000/305	Construction	Heriot Watt University	Same
CUTLET	3	1,000/305	Operational	Admiralty Underwater Weapons Establishment	Same
SEA SPY	1	1,000/305	Operational	Underwater and Marine Equipment Ltd.	Admiralty Underwater Weapons Establishment
PHOCAS II	1	1,000/305	Operational	Geloginen Tutkimuslaitos	Same
RECON V	1	1,200/366	Construction	Perry Oceanographics	Same
SMT 1 & 2	2	1,200/366	Operational	Sonarmarine Ltd.	International Submarine Engineering Ltd.
TREC 1, 2, 3	3	1,200/366	Operational	Martech International	International Submarine Engineering Ltd.
TREC 4	1	1,200/366	Operational	Horton Maritime Explorations	International Submarine Engineering Ltd.

*RECON III's depth has been upgraded to 1,200 ft (366m)

TABLE 2.2 (CONTINUED)

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer
TREC 5, 6	2	1,200/366	Operational	Ocean Systems Inc.	International Submarine Engineering Ltd.
TREC 7	1	1,200/366	Operational	Sub Sea International	International Submarine Engineering Ltd.
TREC 8	1	1,200/366	Operational	Sue Sea International	International Submarine Engineering Ltd.
TREC 9	1	1,200/366	Construction	Uncommitted	International Submarine Engineering Ltd.
TROV B-1	1	1,200/366	Operational	National Water Resources Institute	International Submarine Engineering Ltd.
TROV 0-1	1	1,200/366	Inactive	(Not resolved)	International Submarine Engineering Ltd.
TROV S-3	1	1,200/366	Operational	J. Ray McDermott	International Submarine Engineering Ltd.
UTAS 478	1	1,312/400	Operational	General Video System	Same
CETUS	3	1,500/457	Operational	ULS Marine Ltd.	Same
CORD II	1	1,500/457	Operational	Harbor Branch Foundation	Same
EV-1	2	1,500/457	Test and Evaluation	Kraft Tank Co.	Same
RECON II	1	1,500/457	Operational	Hunting Surveys Ltd.	Perry Oceanographics
SNOOPY	1	1,500/457	Operational	Naval Ocean Systems Center	Same
SNOOPY	1	1,500/457	Operational	Naval Facilities Command	Naval Ocean Systems Center
ERIC 10	1	1,640/500	Operational	French Navy	C.E.R.T.S.M.
IZE	1	1,640/500	Operational	Sub Sea Surveys Ltd.	Same
SNURRE	1	1,969/600	Operational	Continental Shelf Institute	Same
CONSUB 1	1	2,000/610	Operational	Institute of Geological Sciences	British Aircraft Corp.
CONSUB 201	1	2,000/610	Operational	Sub Sea Surveys Ltd.	British Aircraft Corp.
CONSUB 202	1	2,000/610	Construction	British Aircraft Corp.	Same
MANTIS	2	2,000/610	Operational	Star Offshore Ltd.	OSEL Group
DEEP DRONE	1	2,000/610	Operational	Ametek Straza	Supervisor of Salvage (USN)
TELESUB	1	2,000/610	Operational	Remote Ocean Systems	Same
BOCTOPUS	1	2,170/661	Operational	British Oxygen Co.	Same

TABLE 2.2 (CONTINUED)

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer
CURV II	1	2,500/762	Operational	Naval Ocean Systems Center	Same
CURV II	1	2,500/762	Operational	Naval Torpedo Station	Naval Ocean Systems Center
SCORPIO	1	3,000/914	Operational	Stolt-Nielsen Rederi A/S	Ametek Straza
SCORPIO	1	3,000/914	Operational	Israel - Government	Ametek Straza
SCORPIO	2	3,000/914	Operational	*Ametek Straza	Same
TROV S-4, 6	2	3,000/914	Operational	Ocean Systems Inc.	International Submarine Engineering Ltd.
TROV S-7	1	3,000/914	Construction	Ocean Systems Inc.	International Submarine Engineering Ltd.
TROV S-8	1	3,000/914	Construction	Intersub	International Submarine Engineering Ltd.
TOM-300	1	3,280/1,000	Operational	COMEX Services	COMEX Industries
SEA INSPECTOR	2	3,280/1,000	Construction	Rebikoff Underwater Products	Same
SMIT SUB	1	3,280/1,000	Construction	Smit Tak International	Same
SNURRE	1	3,280/1,000	Operational	Continental Shelf Institute	Same
MANTA 1.5	1	4,291/1,500	Operational	Institute of Oceanology USSR	Same
ORCA	1	6,000/1,829	Operational	Oceaneering International	Saab-Scania
RCV-150	1	6,000/1,829	Operational	Uncommitted	Hydro Products
RCV-150	3	6,000/1,829	Construction	Uncommitted	Hydro Products
SCARAB I & II	2	6,000/1,829	Operational	AT&T Long Lines	Ametek Straza
**RCV-225	2	6,600/2,012	Operational	Seaway Diving	Hydro Products
RCV-225	3	6,600/2,012	Operational	Martech International	Hydro Products
RCV-225	2	6,600/2,012	Operational	SESAM	Hydro Products
RCV-225	1	6,600/2,012	Operational	Esso Australia Ltd.	Hydro Products
RCV-225	6	6,600/2,012	Operational	Taylor Diving and Salvage	Hydro Products
RCV-225	1	6,600/2,012	Operational	Wharton Williams	Hydro Products
RCV-225	1	6,600/2,012	Operational	Oceaneering International	Hydro Products
RCV-225	2	6,600/2,012	Operational	Japanese Navy	Hydro Products
RCV-225	2	6,600/2,012	Operational	Santa Fe Construction Co.	Hydro Products
RCV-225	1	6,600/2,012	Operational	Global Divers & Construction Inc.	Hydro Products
RCV-225	5	6,600/2,012	Construction	Uncommitted	Hydro Products
CURV III	1	10,000/3,048	Operational	Naval Ocean Systems Center	Same
ERIC II	1	19,685/6,000	Construction	French Navy	C.E.R.T.S.M.
RUWS	1	20,000/6,096	Test and Evaluation	Naval Ocean Systems Center	Same

*Lockheed Petroleum Services Ltd., New Westminster, B.C. took delivery of a SCORPIO on 31 July 1979

**No RCV-225 has a cable longer than 1,312 ft (400m), but the vehicle is designed for 6,600 ft operating depth.

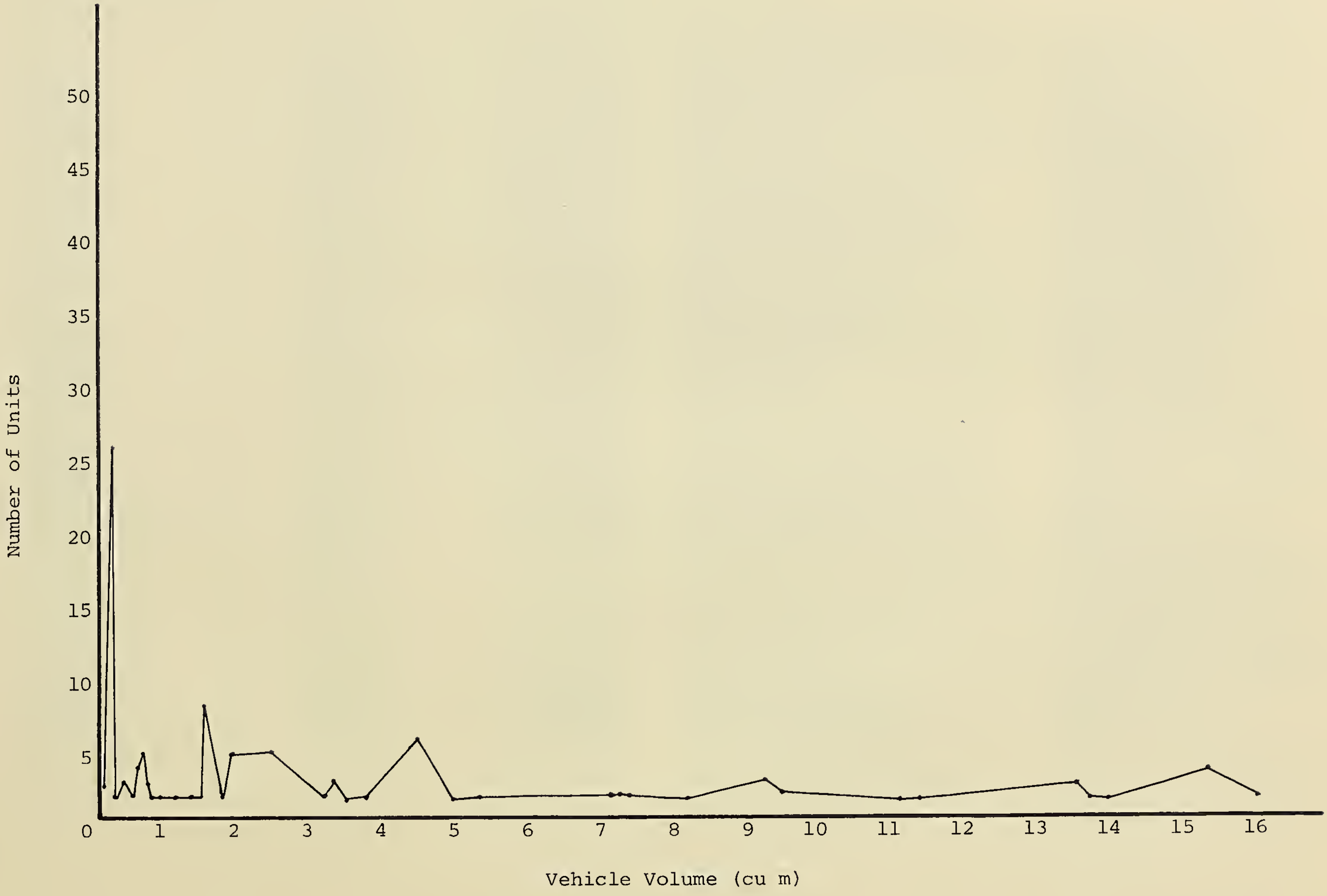


FIGURE 2.2 VEHICLE VOLUME (NOT INCLUDING ONE VEHICLE OF 27cu m)

FIGURE 2.3 VEHICLE DRY WEIGHT

are used on the TROV and CETUS vehicles to gain neutral buoyancy at operating depth and also to provide additional payload to accommodate instrumentation or work tools beyond those routinely carried. Other ROVs provide extra payload simply by adding more syntactic foam to the basic vehicle. The PAP-104 vehicles deploy a guiderope which drags along the bottom and holds the vehicle at near-constant height above the bottom.

2.1.3 Power

All manufacturers but two rely on surface-supplied AC power; the two exceptions relv on lead-acid, self-contained batteries (Table 2.1). The source of the surface-supplied power is either ship's power or a dedicated diesel generator. Operators are almost equally divided in their preference of one power source over the other. Those who prefer a dedicated generator do so because at sometime in their operations it has been necessary for the support ship's Master to use his propulsion when the ROV is in a critical position within or around a structure. The sudden drop in power to the ROV caused it to temporarily lose power and, because of its inherent positive buoyancy, drift up into the structure and entangle. This problem is avoided by use of a dedicated generator.

Electrical requirements vary, but 50/60Hz and 220/240 VAC are most common. Cable design varies from vehicle-to-vehicle, There is nothing in common between cables, some are buoyant others are non-buoyant and require attachment of floats to keep them from entangling with the vehicle or dragging on the bottom. Most vehicles can be lifted out of the water by their umbilicals, but many operators attach a short length (30 to 50m) of line to the vehicle which is used to lift it clear of the water. Electrical interference in the cables is infrequent, and occurs mostly in non-industrially-built vehicles.

2.1.4 Propulsion/Maneuverability

All ROVs except one employ propellers for propulsion; the exception (SMARTIE) uses water jets. Several of the large vehicles shroud the propellers with Kort nozzels for greater thrust under high slip conditions. Data from 92 vehicles show that 81 percent (75 vehicles) use electric thrusters, the remainder use hydraulic.

Six degrees of motion are produced by ROVs; three are translational: thrust, heave, and sidle or sway; three are rotational: yaw, pitch, and roll. The following indicates the precentage of vehicles which obtain these motions dynamically.

Thrust	100%
Heave	96%
Sidle or Sway	31%
Yaw	100%
Pitch	7%
Roll	33%

Only four vehicles are designed to obtain all six motions.

2.1.5 Operating Depth

Maximum vehicle operating depths range from 100 to 6,096m (328 to 20,000 ft). The distribution of vehicles <u>vs.</u> operating depth is shown in Figure 2.4 and

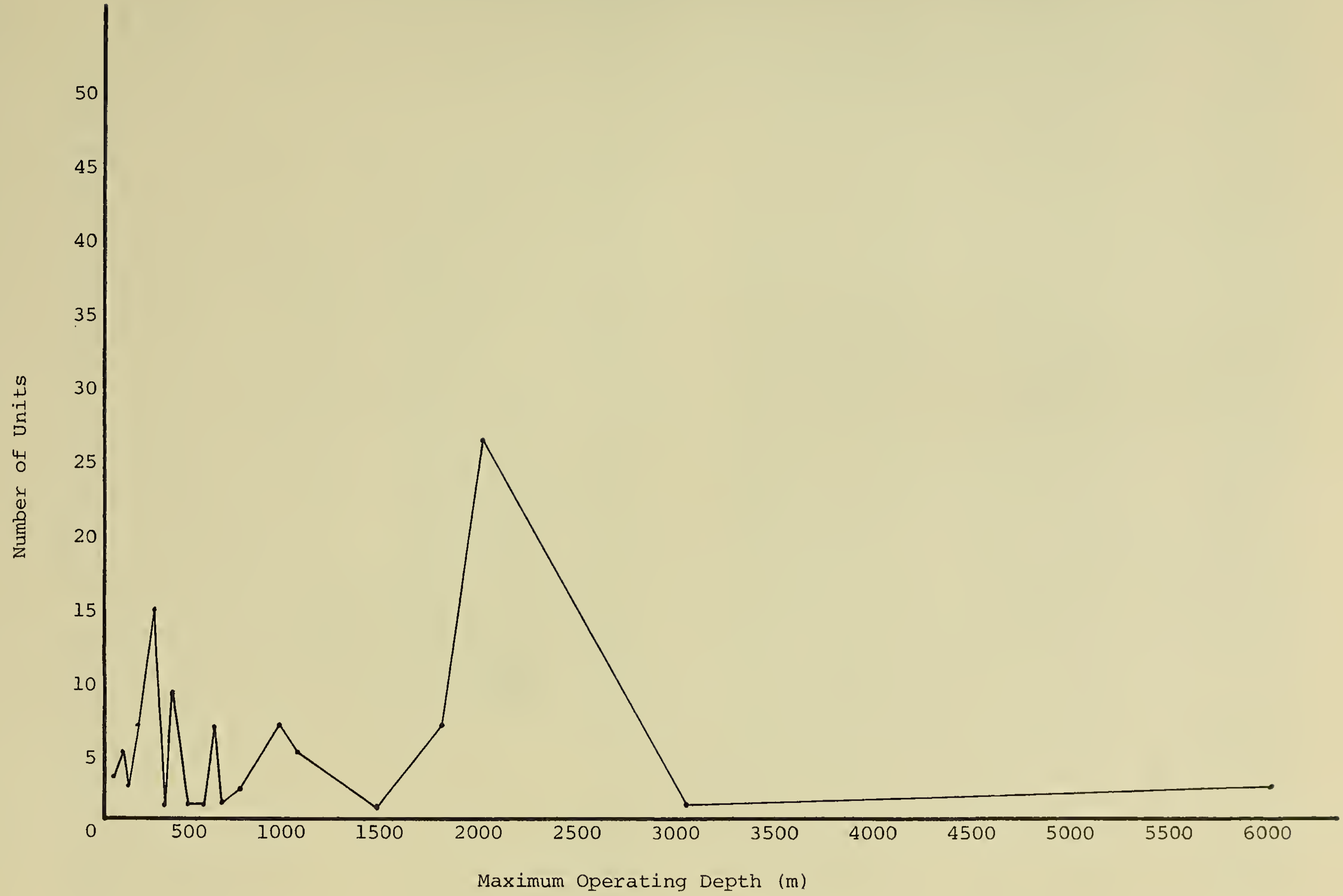


FIGURE 2.4 VEHICLES MAXIMUM OPERATING DEPTH

indicates that 68 percent operate in less than 1,000m (3,280 ft) depth. The peak at 2,023m (6,600 ft) reflects the 26 RCV-225s constructed. Significantly, while the RCV-225 vehicles themselves can reach 2,000m depth, as of September 1978 no operating vehicle had a cable longer than 400m (1,312 ft).

2.1.6 Speed

Vehicle speed at maximum operating depth ranges from 0.5 to 4 knots, the average is 1.6 knots. These same values represent the bottom currents in which the vehicles can operate at their maximum operational depth. Speed in itself is not an important factor, since all work is conducted at very low speed, instead, it is the ability to stay on the job and maneuver in the presence of fast currents that is significant.

2.1.7 Instrumentation

A matrix of vehicles and their data-gathering instrumentation is presented in Table 2.3. In view of the dynamics of this field it is likely that the data in Table 2.3 will be out of date almost by the time it is published, and the reader is therefore cautioned to use this data as a guide, rather than a conclusive tabulation. Several operators have instrument development programs now underway which will add to this list by the spring of 1979. To the extent possible, these future developments are discussed in a later chapter of this report.

2.1.7.a Television

The heart of an ROV system is its closed circuit television. All vehicles have CCTV, the following manufacturer's TV systems are employed:

Hydro Products (TC-125 and TC-125-SIT)
Panasonic (low light level)
Marine Unit Technology Ltd. (SIT and vidicon)
Rebikoff Underwater Products (DR630)
Sub Sea Systems (CM8)
CSF Thompson (low light level silicium)
Rees (181 low light level)
RCA (TC 100)
EMI (England)
Winn Technology Ltd. (low light level)

Hydro Products and Panasonic are the two most frequently used television systems.

Only MURS-100 and 300, and SEA INSPECTOR use color TV, all other vehicles employ black and white. Line resolution is nominally 525 to 550, but reportedly can reach 700 at the center of the screen. Viewing distance varies according to water clarity, 7 to 10m (23 to 33 ft) is generally accepted. Low light level television cameras are used almost as frequently as the standard vidicon tubes.

The majority of ROVs have one television camera which is either fixed in its viewing position (and relies upon the vehicle's manueverability for re-positioning)

TABLE 2.3

ROV INSTRUMENTATION

	TV	ST CAM	STE CAM	CINE CAM	MAN-IP	ECHO SOUN	DIR HYD	SCAN SON	S S S	SUB-BOT PROF	C-P MON	UT	RAD	CL	CUR-RENT	TEMP	MAG COMP	GYPO	DEPTH	MAG
ANGUS 002	+(2)	+		+		+	+										+		+	
ANGUS 003	+(2)	+		+			+									+	+		+	
BOCTOPUS	+(2)					+											+		+	
CETUS	+(2)	+		+	+	+				+							+	+(D)	+	+
CONSUB 1	+(2)		+														+		+	
CONSUB 201	+(3)	+	+		+	+			+	+	+						+		+	+
CORD II	+				+	+		+							+	+	+		+	
CURV II	+(2)	+			+	+		+									+		+	
CURV III	+	+			+	+		+									+		+	
DARTS	+																			
DEEP DRONE	+(2)	+				+		+									+		+	
ERIC 10	+	+			+	+		+									+		+	+
ERIC 11	+			+	+(2)	+		+										+	+	
EV-1	+																+		+	
FILIPPO	+																+		+	
MANTA 1.5	+								+											
MURS-100	+				+										+		+		+	
MURS-300	+(2)	+			+(2)	+		+										+	+	
OBSERVOR DL-1	+																		+	
ORCA	+(2)	+	+		+(3)	+	+(2)											+(D)	+	
PAP-104	+																	+		
PHOCUS II	+	+			+	+											+		+	
PINGUIN B6	+					+		+											+	
RCV-150	+																	+(D)	+	
RCV-225	+																	+(D)	+	
RECON II	+				+										+		+		+	
RECON III	+																+		+	
RECON V	+				+												+		+	
RUWS	+(2)	+			+(2)	+	+(2)	+									+		+	
SCAN	+	+																		
SCARAB I & II	+(2)	+			+(2)	+		+										+(D)	+	+
SCORPIO	+				+	+		+										+(D)	+	
SEA INSPECTOR	+																	+(D)	+	
SEA SPY	+																+		+	
SMARTIE	+(3)																+	+(D)	+	
SMT 2	+(3)	+	+		+(2)	+	+				+	+	+	+				+	+	
SMIT SUB	+																			
SNOOPY	+			+													+		+	
SNURRE	+(2)	+	+	+(2)	+	+	+(2)											+	+	
TELESUB	+																+		+	
TOM 300	+(2)	+			+	+											+	+	+	
TREC	+					+											+		+	
TROV	+				+	+	+										+		+	
UFO 300	+	+									+						+		+	
UTAS 478	+					+										+	+		+	

Legend

TV: closed circuit television
ST CAM: still camera
STE CAM: stereo-cameras
CINE CAM: cine camera
MANIP: manipulator
ECHO SOUN: echo sounder
DIR HYD: directional hydrophone

SCAN SON: scanning sonar
SSS: side scan sonar
SUB-BOT PROF: sub-bottom profiler
C-P MON: corrosion potential probes
UT: ultrasonic measurement probes
RAD: radiographic analysis device

CL: cleaning device
CURRENT: current meter
MAG COMP: magnetic compass
GYRO: gyrocompass, +(D) = directional gyro
DEPTH: depth measurement/indicator
MAG: magnetic sensing device (pipeline or cable tracking)

or mounted on a pan/tilt device. Some, such as the RCV-225, are capable of tilting in the vertical and rely on the vehicle for changes in azimuth. Instead of physically moving the camera, MURS-100 employs a system of moveable mirrors which provides the pan/tilt motion desired.

Most of the large ROVs employ two cameras. One is fixed and used by the pilot for navigation and maneuvering. The second is mounted on a pan/tilt mechanism and dedicated to - and controlled by - the customer. For more detailed viewing Sonarmarine Ltd. has mounted a TV camera on the manipulator which permits the camera to be brought close to the object of interest. The same company has also mounted a camera on the stern of their ROVs in order to observe the umbilical. Hydro Products has solved this problem on their RCV-150 by designing their forward-mounted camera to rotate up and through the vertical to provide rear viewing. The only head-coupled CCTV system known to be in use is that of the U.S. Navy's RUWS. Although two commercial manufacturers offer 3-dimensional TV viewing (Sub Sea Systems, San Diego, Ca., and Honeywell Marine Systems, Seattle, Wa.) only the Norwegian vehicle SNURRE is known to use a TV stereo viewing system. Control of the vehicle's heading by pointing the camera is employed by Sub Sea Surveys on their CONSUB 201. On this vehicle the pilot's camera is coupled with the joystick and the vehicle moves in the direction in which the camera is pointing.

2.1.7.b Lighting

The number of lights on ROVs ranges from as few as one to as many as nine. Quartz iodide lights are on the greater majority of vehicles, then mercury vapor and tungsten iodide and, lastly, thallium iodide. Lighting power ranges from 45 watts to 1000 watts. Most vehicles, however, use 250 watts. The lights are generally clustered on the bow, but a few vehicles provide an extendable boom whereby the light can be extended forward to reduce backscatter.

2.1.7.c Cameras

A variety of photographic cameras are found on ROVs, 35mm still cameras (with strobe lights) are most common, although a few vehicles also carry 8mm cine cameras. The cameras are used to provide high resolution, color documentation which is superior to the resolution and color rendition provided by contemporary video records. Stereophotography is not common, but its application as a tool in underwater inspection/measurements appears to be increasing.

2.1.7.d Manipulators

Approximately 104 vehicles are represented in the listing of Table 2.3; 35 of these vehicles (33 percent) are equipped with one or two manipulators, one (ORCA) carries three. The capabilities of these manipulators range widely, some are simple grasping devices which rely upon the vehicle's maneuvering capability to locate them on the correct work site, others are quite sophisticated. The TROV vehicles, for example, are fitted with two manipulators, one with four degrees-of-freedom and one of seven. (The former has a static lift capacity of 45kg (100 lbs).)

The most sophisticated manipulative system is that of Saab Scania's ORCA, it consists of one master-slave primary work effector and two rate-controlled work-assistance grabbers. The master-slave manipulator has seven degrees-of-freedom and can perform tasks such as handling tools, providing force and torque, taking samples, placing instruments and clearing debris. The grabber manipulators have six degrees-of-freedom. Either of the grabbers can be used as an anchor while the other performs work tasks or assists the master-slave manipulator during work. In lateral water currents both grabbers may be needed as anchors or thruster supports in order to keep the submersible in a fixed position during work.

The master-slave manipulator is a bilateral, terminus-control unit with general purpose capability and high accuracy. The system consists of one master arm and an electronic package mounted at the operator console and one slave arm on the submersible and an electronic package in the capsule. The operator grasps the handle of the master, which, except for appearance and detail, is geometrically similar to the slave arm. The master joint axes correspond to those of the slave, and the master members' lengths are scaled proportional to the slave members. The operator moves the master, concentrating on the position and orientation of the slave grip on the monitor. The slave joint axes follow those of the master (position-control). The terminus-control system allows a greater range of movement in certain of the joints than the operator's own arm does. The operator must therefore ignore lack of spatial correspondence between his own arm and the master in all but the hand position in space. The work effector includes force-feedback to all master functions except grip to achieve positional bilateral (force and position feedback) control modes.

The slave arm is bolted to the right of the vehicle's x-axis. The arm is mounted on the skeleton frame and connected to the vehicle's hydraulic pack and to the data transmission system.

The grabber manipulators are located one on each side of the front end of the submersible low to right and high to the left and bolted to the skeleton frame. The necessary valves for controlling the grabber manipulators are installed in an electro-hydraulic control box one for each grabber. These boxes are connected to the grabbers with hoses and at the other end to the data transmission system and to the hydraulic pack. One, two or all manipulatives can be carried on a single mission.

2.1.7.e Echo Sounders

The echo-sounder provides primary input into vehicle altitude or distance-to-the-bottom. The type and capabilities of echo-sounders vary, some are conventional devices which measure the height of the vehicle from nominally 0.3m (1 ft) to 61m (200 ft) and display this information digitally. A few are scanning or forward-looking sonars which can be tilted vertically downward to serve as an echo-sounder. Sub Sea Surveys Ltd. uses a very high accuracy (750kHz) echo-sounder which not only measures vehicle altitude, but also produces a heave-compensated bottom profile which is used as a trench and/or pipe profiling record. The two major data inputs are the high frequency transducer and a high precision micro processor-based pressure sensor. Data from both sensors are fed to a DEC PDP II computer where they are programmed to remove vehicle motion, plot the pipe trench profile and are stored. By "flying" the vehicle across the pipeline at various intervals, Sub Sea Surveys reports that echo soundings of 1cm (0.4 in.) accuracy are attainable with this system.

2.1.7.f Directional Hydrophone

A directional hydrophone consists of a housing containing a row of transducers or hydrophones which can receive an acoustic pulse and provide a bearing to the pulse source. This capability permits the ROV to home-in on an active - and frequency compatible - acoustic source (i.e., pinger). Frequency range of the hydrophone is generally from 25 to 50 kHz (Helle Model 6550), but wider ranges (0-200 kHz) are also employed.

2.1.7.g Scanning Sonar

Scanning sonars serve multifunctions on ROVs: obstacle avoidance, object location, pinger location, transponder navigation and relative bearing to surface vessel. All scanning sonars listed in Table 2.3 (except for PINGUIN B6) are of the CTFM (Continuous Transmission Frequency Modulated) type produced by Ametek. The ranges are from 2m to 914m (6 to 3,000 ft), the frequencies vary depending upon the operational mode. The transducer scans 360 degrees (90 degrees sector scan) and can be tilted ±15 degrees. Commercial vehicles are tending towards a less sophisticated scanning sonar, such as offered by the Wesmar Corp., to provide obstacle avoidance and object location capabilities where visibility is limited to less than a few meters.

2.1.7.h Side Scan Sonar

There are a variety of commercial side scan sonar manufacturers (e.g., EG&G, International, Klein Associates, Wesmar, Edo Western, UDI Ltd.), the characteristics of each device varies so that one description does not necessarily represent all models available. The general purpose of a side scan sonar is to distinquish topographic features of the sea floor and objects on or above it. Side scan sonar employs an acoustic beam whose main axis is slightly below horizontal. The beam is narrow (0.75 to 1.5 degrees) in the horizontal plane, yet adequately broad in the vertical (35 to 60 degrees) to obtain echos from a point on the bottom directly below the transducer to points some 500m (1,600 ft) abeam of the transducer. The combination of the beam shape and short length of the acoustic pulse (about 0.1 millisecond) provides the capability to resolve small topographic irregularities and small objects (man-made and natural) on or above the sea bottom. The transducer is carried by the ROV at an appropriate altitude above the bottom, the reflected echoes are graphically recorded to produce a 3-dimensional facsimile or plan view of the bottom.

Only two vehicles list side scan sonar as a part of their standard equipment suite, however, virtually all of the larger vehicles have the payload and wiring capability to carry side scan sonar. Ocean Systems TROV S-4 deployed a side scan sonar during a recent bottom route survey in the Mediterranean, although it is not listed in Table 2.3.

2.1.7.i Sub-bottom Profiler

Sub-bottom profiling devices emit an acoustic pulse of suitable characteristics to provide a record of the ocean bottom topography and its sub-structure along the track of the ROV. The sub-bottom profilers are used to detect and measure depth of pipeline burial and to discern the nature of the sub-bottom preliminary to excavation or plowing.

A variety of commercial sub-bottom profilers are available where both the pulse length and frequency are selectable for operations in different types of sea bottoms.

2.1.7.j Corrosion Potential (c-p) Monitoring

Corrosion potential measurements are taken to monitor the effectiveness of a cathodic protection system (i.e., determine the need to replace the sacrificial anode). The instrument employed is some form of half-cell (silver/silver chloride, copper/copper sulphate) which measures the potential between the structure and ambient sea water. Several commercial organizations manufacture c-p monitors for application from ROVs (Corrosion and Welding Engineering Ltd., Sidcup, Kent; Sabines Industries, Inc., Long Beach, Ca.; Morgan Berkeley and Co. Ltd, Winchester, Hants). The procedure involves making contact between structure and c-p probe and reading or recording the data (digital or analogue).

Sonarmarine Ltd. employs a technique which involves holding the reference cell (silver/silver chloride) in the claw of one manipulator which is connected through the umbilical to a high impedance digital voltmeter. The circuit is completed by attaching the other side of the voltmeter to the structure. The potential values are displayed on the video monitor.

2.1.7.k Ultrasonic Thickness Measurements

Thickness of structures is being measured from ROVs using ultrasonic techniques. In this technique an electric pulse is converted into a mechanical vibration by a small transducer which is held against the cleaned structure. The vibrations are transmitted into the object being measured where they are scattered, attenuated, reflected or resonated. A portion of this energy returns to the transducer where it is reconverted to electrical energy and subsequently processed to be displayed either digitally or on a CRT. By knowing the sound velocity characteristics of the material in question and the round trip time of pulse from the transducer head through the test material, it is possible to determine material thickness.

Several commercial firms manufacture ultrasonic thickness probes which are adaptable to ROV application Sonarmarine Ltd., the only ROV operator known to offer this service, has developed a probe specifically for use from their vehicles.

2.1.7.1 Radiographic Testing

Radiographic techniques are used for flaw detection in metals. The components of this technique consist of a radiation (gamma) source and a photographic film in which the voids or flaws in the test material appear as shadows. The technique can also be used for thickness measurements.

Sonarmarine Ltd is the only ROV operator known to offer this service. Their technique is, at present, applicable only to risers and involves placing a radiographic source and photographic plate around the riser for some specified time before recovering them. Details of the technique are not available.

2.1.7.m Cleaning

Prior to any of the testing techniques described above in sections 2.1.7.j through 2.1.7.1 and for detailed visual inspection, whatever fouling organisms are present on the structure must be removed. For localized cleaning of areas of a few square centimeters virtually any ROV with a manipulative capability can be equipped with a rotary brush or grinder which will satisfy this requirement. For larger area cleaning and in the acute angles of "K" joints, high pressure water jets up to 1,054kg/cm^2 (15,000 psi) are employed by divers. In 1978 Sonarmarine Ltd. developed and operationally used a water jet from its vehicle SMT 2. The water jet pump is carried on the vehicle (therefore it does not have to overcome the hydrostatic head) and can operate to any depth. The pump feeds a reaction jet and delivers pressure up to 351kg/cm^2 (5,000 psi) at a flow rate of 38 liters (10 gals)/minute. The jetting can clean away encrusting organisms (barnacles, serpulid worm tubes, bryazoan, etc.) down to bare metal at a rate equal to the diver-held devices of the same pumping capacity.

2.1.7.n Current Measurements

Three vehicles have the capability of measuring water currents. The measurements are made by a savonius rotor with magnets spaced equally on the perimeter of its base. A magnetic switch counts the pulses per time interval and the speed is registered on a taut bandmeter such that, for example, 83.5 rpm equals one knot. Current direction is sensed by a vane connected magnetically to a compass. There are a variety of commercially available current meters which provide a wide range of data, generally speeds of 0.1 to 6.0 knots ±2% and direction of 0 to 360 degrees ±7 degrees are acceptable. Current measurement devices also serve as a rough measure of vehicle speed and course.

2.1.7.o Temperature Measurements

Only those vehicles employed in scientific research are equipped with water temperature measurement instruments (ANGUS 003 and CORD II). The sensing device is one of a variety of thermistors commercially available which generally span a range of -2 to 35°C and provide an accuracy of ±0.03C. Display can be either digital or analog.

2.1.7.p Magnetic Compass

After visual navigation, the magnetic compass is the primary means of ROV navigation. The variety of compass types is as wide-ranging as is the variety of ROVs, consequently, no one magnetic compass will serve to describe the field at large. Generally, a magnetic fluxgate sensor is used which will provide an accuracy of ±1 degree. On many vehicles the compass information is telemetered electronically to the surface and displayed digitally on the control panel. On others the compass is located in a position on the vehicle such that it is read by the CCTV and displayed on its monitor.

2.1.7.q Gyrocompass

Most of the gyrocompasses used on ROVs are directional gyros which are referenced to the magnetic compass and used when the vehicle is in the presence of ferrous (magnetic) structures. Many different models are commercially available, but drift rates in excess of several degrees/hour are not uncommon in the less expensive models. Accuracies of ±1 degree and less than 1^{o}/hour drift rate are available and used on several ROVs.

Gyrocompasses are listed as onboard equipment on five ROVs, but details as to their characteristics and capabilities are not available.

2.1.7.r Depth Sensors

All vehicles but three are equipped with some form of gage or instrument to measure their depth. The most widely used depth measuring device is the pressure transducer, which consists of a pressure sensing element, such as a bellows, a device to convert its tip motion to an electrical parameter and a device to indicate or record pressure changes.

There are a wide variety of pressure transducers and other gages available and in use on ROVs. This variety is reflected in the following depth accuracies provided on the vehicles listed.

Vehicle	Depth Accuracy	Maximum Operational Depth	Maximum Depth Accuracy
CETUS	±0.25%	457m	± 1m
DEEP DRONE	±10%	610m	±61m
RECON III	±0.5%	183m	±0.9m
SCORPIO	±0.75%	914m	± 7m
SNURRE	±0.2%	600m	± 1m
TROV	±0.1%	914m	±0.9m
RUWS	±2.0%	6,096m	±122m

Resolution is in the order of 0.1m to 0.3m

2.1.7.s Magnetic Sensing Device

Magnetic sensing devices can be used to determine the thickness of overburden over a pipeline or cable, and to track the pipeline or cable under zero visibility conditions. Details of the various devices in use are not available since they are designed by the vehicle operator and their construction is considered proprietary. Essentially they consist of two fluxgate magnetometers which are coupled to act as a magnetic gradiometer which provides peak amplitude signals when the vehicle is directly over the buried pipeline.

A magnetic gradiometer/echo-sounder system has been designed and tested by Intersub Developpement, Paris, which can detect pipelines buried by 3m (10 ft) of overburden with an accuracy better than 10cm (4 in.). The tracking accuracy is such that the vehicle - in this instance, a manned submersible - is provided information allowing it to stay within ±50cm (20 in.) of the pipe axis.

2.1.8 Umbilical Cable

The umbilical cable provides the means of carrying propulsive and instrumentation power to the vehicle and telemetering video and instrument data to the surface. Owing to the wide diversity in vehicle instrument capabilities, operating depth, propulsive power, dry weight, etc., there is little commonality between umbilicals from vehicle-to-vehicle.

The breaking strength of umbilicals varies according to vehicle weight. Most cables are capable of lifting the vehicle out of the water, but not all follow this procedure. It is more common to either attach a separate length of lift line to the vehicle which is married (taped or tied) to the umbilical and to use this to retrieve the vehicle or to attach a lift line to the vehicle as it is maneuvered to an appropriate location alongside the support ship. Hydro Products RCVs are designed for launch and retrieval without the aid of a separate lift line. The strength member in most cables is Kevlar.

Most umbilicals are not positively buoyant. Consequently, there is a tendency for the cable to drag on the bottom and abrade or to tangle with objects on the bottom or the vehicle itself when it backs down. To provide positive buoyancy, floats are attached to the cable at intervals for some distance away from the vehicle (100m or thereabouts). The floats serve to keep the cable up and away from the vehicle and the bottom. In one instance, CONSUB 201, the cable winch is designed to automatically maintain a particular point on the cable at a set altitude above the bottom to prevent dragging. The Hydro Product's vehicles and Marine Unit Technology's SMARTIE operate from a clump or launcher. The cable from ship to clump is negatively buoyant and capable of retrieving both launcher and vehicle. The cable from the launcher to the vehicle is smaller in diameter and positively buoyant.

Most cables are a single unit combining all conductors within one protective insulation and wrapping. Neoprene or polyurethene constitute the protective outer jacket. One system has four separate cables (power, control, video, sonar) which are tied together and terminate in a clump from which the vehicle operates on a single cable. Diameter of unitized cables range from 6.3mm (0.24 in.) to 38mm (1.5 in.)

One to three coaxial conductors are used depending upon the vehicle manufacturer. The longest umbilical in use (the U.S. Navy's RUWS) is 6,858m (22,500 ft) and it transmits all power, command and control functions, TV and sonar over a single coaxial cable through use of time-sharing and frequency multiplexing techniques.

2.1.9 Control/Display Console

The data and controls required to operate ROVs range from the very simple to the very sophisticated. Some appreciation for the magnitude of range can be gained from Table 2.4. It is evident that the only commonality in data display is a TV monitor, and a vehicle depth indicator. Proportional joystick controls constitute the only vehicle-to-vehicle commonality in control functions.

The size and weight of the control/display consoles follows their capabilities accordingly. FILLIPPO weighs 15kg (33 lbs) and occupies $0.06m^3$ ($2\ ft^3$). RCV-225 weighs 158kg (350 lbs) and occupies $0.34m^3$ ($12\ ft^3$). SCORPIO weighs 159kg and occupies $2.5m^3$ ($89.4\ ft^3$). Data for CETUS are not available, but a 3.6 by 2.4m (12 x 8 ft) cabin is required to house it and the two operators. CETUS is not the most complex ROV control/display console, the U.S. Navy's RUWS is larger, heavier and contains additional displays and controls.

TABLE 2.4 SELECTED VEHICLE DISPLAY/CONTROL DATA AND FUNCTIONS

	FILIPPO	RCV-225	SCORPIO	CETUS
Displays	TV Monitor Voltage Meter (2 ea) Current Meter (2 ea) Water leak alarm Vehicle Depth Display	TV Monitor Vehicle Depth Vehicle Heading Lens Pitch Angle Cable Twists Tether Cable Payout Elapsed Time Cable Continuity Voltage/isolation reaction to sea water	TV Monitor Sonar Display Hydraulics temperature/ pressure Camera tilt/pan angle Vehicle depth Vehicle heading Ascend/descend rate Cable twists Water leak warning	TV Monitors (3) Navigation (pilots) Survey (observer) Graphics (computer) Attitude (tilt) Air Pressure Gyro heading Magnetic Compass Elapsed time total Event elapsed time Depth Ship heading Knot meter Distance run log Voltmeter Wind speed/direction Thermometer/barometer Vehicle Altitude
Controls	Emergency ballast/ cable release Proportional Joystick controls (2) (fwd/ reverse, up/down)	One fully proportional vehicle joystick control (fwd/reverse, left/right, heading) Automatic heading/depth control TV: lens pitch angle and focus Deployment controls: launcher lock, tether cable winch, tether cable cutter (Portable control)	Fully proportional joystick (2) (fwd/ reverse, up/down) Automatic heading/depth Manipulator and tool functions TV pan/tilt TV camera focus On/off light switch Lights (on/off) (Portable control - optional)	Fully proportional joystick control (2) (fwd/reverse, up/down, heading) Vent/Blow Camera Pan/tilt Manipulator (2) Lights (on/off) 35mm still camera 8mm cine camera
Options			Vehicle Altitude Vehicle Locator/Navigation Position Display Sub-Bottom Profiler Chart Recorder Pipe Tracking System Display	Trench profiler Bottom profiler Leak detector Magnetic Gradiometer

All ROVs have at least one control for maneuvering the vehicle, some require two. Piloting is made easier on many vehicles by including automatic depth and heading control, where this is the case the controls usually have manual override. Several manufacturers offer portable vehicle control units which allow the pilot to directly observe the vehicle as it maneuvers on the surface in close proximity with the support vessel.

Control of the manipulators is generally accomplished by manipulation of toggle switches or buttons. The most sophisticated manipulation control is found in Saab-Scania's ORCA where a link between the control console and slave arm on the submersible gives the operator the feel and impression of actually doing the work in situ. Movement of the master arm is copied by the slave arm. Force and position feedback from the slave manipulator to the master is geared at a force ratio of 13:1. The sense of presence is enhanced by a pan and tilt 200m television camera which is in the same relative position to the work manipulator as the human eye.

2.1.10 Emergency Location Devices

There have been several instances in which an ROV has been released (intentionally) from its umbilical and either floated to the surface or remained fouled in a structure. By design, ROVs have no more than 5 to 10cm (2 to 4 in.) of surface freeboard, and visually locating them when they surface can be difficult, and sometimes impossible.

To assist in surface location a self-powered, flashing (strobe) light is affixed to most vehicles which can be intentionally activated by the pilot to assist in nighttime location for maneuvering or is automatically activated if the umbilical is severed.

Sub-surface location is assisted by an emergency, self-powered pinger which permits homing to the vehicle. Two operators (ULS Marine Ltd., and Sonarmarine Ltd.) have designed releaseable buoys which, when released, float to the surface and mark the vehicle's location. ULS Marine's buoy consists of a standard 9kg (15 lb) plastic float attached to the vehicle by 610m (2,000 ft) of line with a lift capacity of 907kg (2,000 lbs).

In spite of such precautions several ROVs have been lost simply by floating to the surface and drifting out of visual and/or sonic contact.

2.1.11 Support Vessels

Remotely operated vehicles have worked and are working from a wide variety of surface support platforms: conventional displacement hull vessels, barges, fixed platforms, semi-submerged vessels, manned submersibles and ice caps. In one instance a vehicle worked off the back of a truck as it examined a flooded mine shaft. The wide range of vehicle dimensions and complexity permits deployment from virtually any floating, fixed, stable or unstable platform. The thrust of this discussion, however, is the requirements for vehicles working in the open ocean.

Prior to the present full-scale application of ROVs in the offshore industrial community many manufacturers advertised that their vehicle could be deployed from virtually any "Ship of Opportunity". The past two years of open ocean operations, particularly in the North Sea, have shown this term to be largely optimistic. Experience has demonstrated that an ROV is one component of a system which consists of the support platform, the launch/retrieval device and the vehicle itself. As operations with manned vehicles demonstrated, the system is only as strong as any of these components; the ROV system is bound by similar constraints. The capabilities of the support ship are as important as are the capabilities of the ROV. Equally important are the abilities of the support ship's crew. In spite of the tremendous technological advances achieved in the marine community, sound seamanship is as important now as it was in years past. Indeed, the requirements for maintaining a prescribed "footprint" over a submerged ROV without fouling the umbilical places demands on the support ship's Master equal to any in the offshore community.

Operations are conducted in two modes: anchored (or moored) and underway. In the first situation the work is generally conducted at a specific location and the support vessel requirements are minimal, calling only for adequate deck space, power (unless a dedicated generator is brought aboard) and a handling system. In the second situation the work task may require transits many kilometers long where the support ship is required to stay within a prescribed radius (foot print) above the vehicle which may be, for example, inspecting a pipeline or cable. This type of operation is referred to as "liveboating" and calls for a variety of support vessel capabilities. The following discussion is addressed primarily to the liveboating situation.

There is no industrially-operated ROV that works from a dedicated support ship. One of the chief assets of an ROV is transportability, hence, it should be able to operate from a vessel likely to be available at the work site. In areas such as the Gulf of Mexico a typical 40 to 60m (130 to 197 ft) LOA 700 to 1000 metric tons displacement offshore supply vessel may be adequate. In the North Sea the vessel might be 55 to 60m (180 to 200 ft) LOA. Cruising speed is not important from an operational point of view; however, the economics of transitting to and from the work site calls for speed in the neighborhood of 12 knots. The critical support platform characteristics are auxiliary power, deck space, and maneuverability at low speed.

2.1.11.a Power

Section 2.1.3 discussed the power requirements for ROV systems. Assuming that the support vessel can provide requirements for a specific vehicle (not only for the vehicle, but the launch/retrieval systems also if it is not supplied by the ship), then the next consideration is that the power supply not be affected by surges in the ship's power, such as those which may occur when additional power is required to maintain a particular bow heading at very low forward speed. Occasions have arisen where a sudden surge of ship's propulsion power was required which produced a voltage drop in the vehicle's power and permitted it to drift off station.

2.1.11.b Deck Space

All industrial ROV systems are transported in one or several containers or vans. Aboard ship the vans may serve as the vehicle control center (containing control/display console, spares and power distribution unit) and as a dark room/maintenance/repair facility. The standard air freight igloo container (Type A-2) used by SCORPIO is 3.2m L x 2.2m W x 2.1m H (10.4 ft x 7.3 ft x 6.8 ft) and weighs 320kg (700 lbs) (empty) with a maximum loading capacity of 5,900kg (13,000 lbs); it serves as the control center aboardship. The igloo container is just one of many different shapes and sizes used by ROV operators, consequently there is no standard size to work from when considering deck space requirements and tie-down locations.

The amount of open deck space required depends on the vehicle system. The components of TOM-300's system are shown in Plate 2.3; these consist of a control van, maintenance/repair van, cable winch/storage bin, and the vehicle itself. Not included in this plate is the crane for launching/retrieving the vehicle. The total shipping volume of the TOM-300 system is $43m^3$ (1,483 ft^3); deck space required to accommodate this equipment is about $37m^2$ (400 ft^2). This area does not account for the additional space required to site the launch/retrieval crane and the cleared area required to maneuver the vehicle aboardship and over the side. The range in ROV deck space requirements can be appreciated by comparing TOM-300 with FILIPPO which has a total shipping volume of approximately $0.4m^3$ (14.5 ft^3) and requires deck space of approximately $0.7m^2$ (7.8 ft^2). The vehicle specifications of Appendix C provide deck space requirements, where available, for several vehicles; the average is about $49m^2$ (527 ft^2) and, in the case of the CETUS system can reach a maximum of $156m^2$ (1,679 ft^2). In most instances the deck space requirements stated in Appendix C do not account for the space required between the various components, the cleared area required to swing the vehicle, and the lift crane.

Although all vehicle manufacturers will provide a control van as an option, many vehicles utilize enclosed ship space when it has suitable characteristics in the way of space and cable routing accommodations.

2.1.11.c Maneuverability

Maneuverability requirements for the support vessel are to maintain a prescribed position above the vehicle while it is operating. When the support platform is moored, anchored or fixed to the bottom, the task is simplified. When the ship is underway the task is difficult and is influenced by current and wind velocity and the speed at which the ship can respond to course changes while following a slowly-moving (generally 1 knot and less) vehicle. The route deviation which the ship follows while maintaining station above or just off to the side of the vehicle is referred to as the "ship print". According to Skidmore and Bircham (1976), a ship print in the order of 300m (984 ft) radius is maximum when working with CONSUB 1. Conversely, Perry Oceanographics recommends a ship print of 15m (49ft) maximum radius when live boating with RECON V.

PLATE 2.3 COMPONENTS OF THE TOM 300 SYSTEM

Ideally, the support ship should be equipped with a bow thruster and twin screws. Practically, most operators use vessels with single screws and a bow thruster. A bow thruster, however, is critical. No operator reported using vessels equipped with a dynamic positioning system. First, dynamic positioning is too costly to remain competitive. Second, the ships screws might automatically turn at some point when the umbilical or vehicle can be damaged by the propellers.

The following ship characteristics are described as typically those required for support of Perry Oceanographics RECON V in both the moored/anchored and live boating mode of operation.

Length: 40 to 60m (131 to 197 ft)
Beam: 10 to 12m (33 to 39 ft)
Tonnage: 700 to 1000 metric tons
Max. Speed: 12 kts
Anchoring/Mooring Capability: Two points in depths to 200m (656 ft)
Communications: VHF radio/transmitter
Navigation: Radar, Gyrocompass, echo-sounder, Decca navigator autopilot, RDF
Propulsion: Twin screws in Kort nozzles, bow thruster
Auxiliary Power: 100 kVA at 220/440, 60 Hz, 3 phase (vehicle and handling system)
Deck Space: 19.5m^2 (210 ft^2) (control van, winch, crane, vehicle) and 6m (20 ft) of clear operating space along the gunwale
Ship Print: Maintain a maximum 15m (49 ft) radius position relative to the vehicle's subsurface position.

Fixed platform inspection is conducted from a ship or barge tied up to the platform. Only one North Sea operator, Sonarmarine Ltd., is approved to use the platform itself as a support base. The obstacle to operating from a production platform is that of conforming to the safety standards laid down by certifying societies. Sonarmarine has packaged its SMT 2 system such that it can work in Division 2 areas in accordance with Lloyds standards. The precise requirements are considered company-proprietary because the effort involved in determining precisely what they are was extensive to the point where Sonarmarine considers the knowledge to be a competitive edge.

The heart of the problem is designing the system to be explosion proof. This involves, at the minimum, pressurizing the interior of the control van to prohibit ingress of potentially explosive gasses. The more difficult ROV system components to deal with are the diesel generator and cable winch. Sonarmarine has, nonetheless, designed all equipment to work safely and within the limited space available on a production platform. No other private company acknowledged that it was developing similar capabilities.

2.1.12 Launch/Retrieval

The wide range in ROV dry weights (80kg to 5000kg) results in a wide range of equipment capabilities requirements for launch/retrieval. However, there are several aspects of the launch/retrieval procedure which are relatively common from vehicle-to-vehicle.

The majority of ROVs are launched/retrieved over-the-side from a stiff-legged boom. On a ship the boom is of a length such that it is approximately equal to or exceeds the ship's freeboard. This arrangement prohibits the vehicle from slamming into the ship if it is rolling. Only two vehicles are known to launch over-the-stern, CONSUB 201 and ORCA. In this mode the procedure is similar to that used by manned submersibles, in that, an A-frame is used to lower/raise the vehicle to and from the water. The technique of launching over-the-side is preferred since it keeps the umbilical as far away as is practicable from the ship's screws.

Generally the vehicle is operated abeam of its support ship such that the trend of the umbilical can be seen by the ship's Master and the potential for fouling in either the main propellers or the bow thruster is minimized.

Many vehicles are both launched and retrieved by a line other than the umbilical cable. 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 ship. The vehicle is then quickly retrieved to the point where it is two-blocked to the crane boom and then swung aboard. As described in Section 2.1.8, other operators prefer to marry (tape) a length of lift line to the umbilical which, when it has reached the winch, is used to bring the vehicle aboard. This procedure requires either a second winch or windless for the lift line. Only in special circumstances is a swimmer used to attach the lift line, no company routinely operates on the basis of deploying swimmers. Most vehicle systems use a drum to store the umbilical cable. In several instances, however, the cable is simply faked out on deck or within a suitable container.

Several manufacturers provide an ROV system which also includes a launch/retrieval device designed specifically for its vehicle. One such system is shown in Plate 2.1; it consists of a control unit, a deck umbilical, winch unit, armored cable assumbly, winch skid assembly, deployment capsule (launcher) and the submersible winch unit. The deck winch unit is capable of reeling in/out at any speed between 2 and 37m (0 to 120 ft) and holds 305m (1,000 ft) of armored cable. The entire system (including the RCV-225) weighs 2,131kg (4,700 lbs) and occupies 4.6m^3 (162 ft^3). According to the manufacturer, Hydro Products, purging of the deck winch unit is all that is necessary to meet U.S. Coast Guard explosion-proof requirements for operation in hazardous gas environments.

The most sophisticated launch/retrieval system is the U.S. Navy's Motion Compensation Deck Handling System (MCDHS) used to deploy RUWS and its 7,010m (23,000 ft) of primary cable.

The MCDHS is a hydro-pneumatic motion compensation system with an active servo control which strives to minimize acceleration of the boom tip. The primary control sensor is a gimballed accelerometer at the boom tip. The servo control system minimizes the signal from this sensor by requesting compensating action from the MCDHS control valves. This results in a nearly zero vertical movement of the boom tip relative to the ocean floor. A secondary boom angle signal is incorporated which is used for boom centering and active cushioning near the stops.

In its stiff mode, the MCDHS is a rotating crane incorporating a traction winch, a storage reel, and a traveling carriage. The carriage incorporates a gimballed head sheave to facilitate deck handling and over-the-side launch and recovery operations. During deployment and recovery operations, the MCDHS lifts the combined in-air weight of the Primary Cable Termination (PCT) and vehicle, which is 5,897kg (13,000 lbs). An alternate capability permits retrieval of the vehicle separately in the event it is not mated with the PCT.

The MCDHS winch system is a twin-drum traction winch combined with a low-tension, large-capacity Primary Cable storage reel. Deck handling of payloads is achieved by a slewing turntable and by a traveling carriage on the boom. An anti-sway saddle at the boom tip incorporates hydraulic actuators that maintain positive control of the payload orientation about the pitch and roll axes.

The prime power source is a diesel generator providing 440 volt, three-phase power. One person can operate the MCDHS through all phases of operation.

The launch, tending and recovery of the RUWS lift package requires the use of three separate modes of operation of the 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 and recovery operations when high boom tip speeds are required.
2. Passive Mode - This mode is used after launch when the payload is immersed from the surface to depths of 61 m (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 which act as pneumatic springs.
3. Active Mode - This is the mode generally used when the payload is submerged over 61m (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 Cable. The MCDHS permits work operations in weather conditions up to Sea State 3 to Sea State 4.

Sea state limits for launch/retrieval vary widely between operators and, obviously, depends on the size and type of surface support platform. Generally, most operators can launch/retrieve up to and including State 4 from a conventional surface ship. Three North Sea operators (ULS Marine Ltd., Sub Sea Surveys Ltd., Sonarmarine Ltd.) however, have developed techniques which permit launching in State 6 and retrieval in State 8. One of these operators (ULS Marine) has retrieved their CETUS vehicle is an estimated Sea State 9 (Force 9); this,by definition, is a strong gale with seas running from 13 to 14m (41 to 47 ft).

The type of hull can greatly improve launch/retrieval capabilities. Taylor Diving and Salvage Co. deploys and retrieves their RCV-225 up to and including State 4 from a conventional displacement hull vessel. From a semi-submerged platform the limit increases to State 8.

Vehicles which are deployed from a launcher can experience some difficulty when docking into the launcher in heavy weather. Since the launcher will follow the ship's roll on an almost 1:1 basis, the vehicle, which is decoupled from this motion, must "park" inside a garage undergoing rapid vertical excursions. In some instances it has been necessary to place the launcher on the bottom to conduct the docking procedure.

2.1.13 Sub-Surface Navigation

There are several navigational techniques available to the ROV operator: visual sighting, magnetic and gyrocompass, and acoustic locating techniques. The magnetic compass and gyrocompass are well known dead reckoning navigation techniques which do not require a detailed discussion herein.

Visual sighting entails simply knowing the vehicle's location by identifying (on the CCTV monitor) a known object or feature whose position coordinates have been previously located. The object or feature may be a coded structural node, a pipeline field joint or lines painted on the structure specifically for providing navigational assistance. The technique is as old as human eyesight and is as accurate as the drawings from which the operator is working. This procedure, obviously, requires that some degree of underwater visibility is present and that recognizable features of known position are available.

Acoustic navigational techniques used by ROVs are essentially the same systems developed for manned submersibles. For convenience, they are herein categorized as bottom-oriented and surface-oriented systems. There are many manufacturers of sub-surface navigation systems, the systems described herein, however, are only those which are actually being used within the ROV community.

2.1.13.a Bottom-Oriented Systems

This category consists of systems that employ bottom-mounted reference points (i.e., acoustic transponders) which synoptically provide three or more ranges to the vehicle which are used to triangulate its position relative to the references. Four bottom-mounted systems are reportedly in use: ATNAV (AMF Electrical Products Development Division, Herndon, Virginia); AUTRANAV MK 3 (Polytechnic Marine Ltd., Daventry, Northants); the Mesotech system (Mesotech Ltd., North Vancouver, British Colombia); and the ELA system (ELA, Montrouge, France).

The same fundamentals control the use of all the systems, and except for frequency variations, depth capability, cost, and position accuracies, the systems are quite similar in operation.

<u>ATNAV System</u> - This system is used by Sub Sea Surveys Ltd., and the Supervisor of Salvage, U.S.N. The ATNAV (Acoustic Transponder Navigation) system hardware is comprised of four underwater transponders: (three are bottom-mounted, one is on the vehicle) and surface support craft equipment consisting of a Command/Interrogator and Ranging Receiver, a mini-computer, a teletype, an x-y plotter and interface electronics. With these components, a real-time, continuous x-y plot and x-y-z printout of the surface craft and the vehicle relative to the three bottom-mounted transponders is provided. Coverage within an area of 130km^2 (50 miles^2) is possible. The vehicle's position (relative to the transponders) and the surface craft is attainable to ±0.9m (3 ft) depending upon the accuracy of water sound speed measurements and surface ship velocity data.

To begin the at-sea procedures, the bottom-mounted transponders are installed and rough (surface) estimates of their positions are put into the mini-computer. The surface craft then cruises over the transponder network and interrogates the transponders at 10 to 15 random locations. The onboard surface equipment now has the capability of determining the transponder position relative to each other to within approximately ±0.6m (2 ft).

The navigation operation begins with interrogation of the bottom transponders from the surface craft. Each transponder replies individually to the surface and their slant range from the ship is automatically determined. Immediately thereafter, the transponder on the vehicle is interrogated. The reply from the vehicle transponder performs two functions: 1) it permits determination of the slant range from vehicle to ship, and 2) the same reply interrogates the bottom transponder to provide the total ranges from the ship to the vehicle to each transponder and back to the ship. The range data is processed to determine the positions of both the ship and the vehicle relative to the bottom transponders. The resulting track information is displayed on the x-y plotter and printed out by the teletype.

There are five standard transponders available for use in the ATNAV system; three are releaseable and two are not. The recommended interrogate/respond frequencies of the submersible transponder is 11 kHz and 9 kHz, respectively. The bottom-mounted transponders will respond to 9 kHz on one of 13 selectable frequencies ranging from 9 through 15 kHz at increments of 500 Hz. The range of frequencies, when using three or more transponders concurrently, must stay within a 4 kHz band in order to be compatible with the standard shipboard Ranging Receiver. The standard transponder battery life is one or two years, or 100,000 interrogations. The depth of transponder operation is 914m (3,000 ft) or 6,096m (20,000 ft).

An updated ATNAV system, ATNAV II, is used with the U.S. Navy's DEEP DRONE. This system offers larger area coverage (16 transponders), data recording, dead reckoning capability, and more rapid program loading.

ELA System - The ELA system is used by COMEX Services. The ELA Corporation no longer produces sub-surface navigation systems. Another French corporation, Oceano Instruments, Clamart, manufactures a navigation system which is, essentially, the successor to ELA. The navigation system's (series 20) underwater components consist of three bottom-mounted and one vehicle-mounted transponder; the surface craft components consist of an acoustic Ranger (PA21) with two interrogation channels, a computer and interfacing electronics. (A display unit, x-y plotter and data recorder are optional.) The deployment, net calibration, navigation procedures and mathematics are, to all intents, similar to that described for the ATNAV system.

The ELA system can also be used by a surface craft to determine the vehicle's position, or it may be used by the vehicle alone. When used by the submersible only, a position accuracy (relative to three transponders) of ±1 meter (3.2 ft) is obtainable. When the surface ship uses the system to obtain the vehicle's position, a variety of factors, e.g., celerity and the ship's own movements introduce inaccuracies. The manufacturers state that, if the surface ship is moving (drifting) at less than 1 knot, the position error will be in the order of ±5 meters (16.4 ft).

The Ranging components (which can be used on the surface or on the vehicle) consist of a unit for computing and displaying up to four distances (PA21), and a transducer for interrogating/receiving the transponders. The unit transmits on 16 kHz and can receive from 8.5 to 15 kHz at 500 Hz steps. The transducer can withstand a pressure of 200 atmospheres or approximately 2,012m (6,600 ft) of sea water. The weight in water of the transducer is 10kg (22 lbs) and the weight in air of the compute/display unit is 13kg (30 lbs). The transponders (Model AT21) are omnidirectional and can be interrogated on 9, 11 or 16 kHz and will respond from 8 to 15 kHz selectable at 500 Hz steps. The standard battery pack provides a life of two months (on standby) or 100,000 responses. The maximum depth capability of the transponders is 600 meters (1,969 ft).

Several options are available in the basic ELA System:

1. Navigation Display (PA22): displays the position of a moving craft with respect to four transponders on a CRT;
2. Data Recorder (PA23): data recorder with a digital clock and display, an eight-digit printer and a digital cassette recorder;
3. Cassette Reader (PA24): used in conjunction with a computer (Hewlett-Packard HP 21, 12 or comparable) and an x-y plotter for processing of results.

Mesotech System - The Mesotech system is used by the Canadian National Water Resources Institute. It consists of from 4 to 16 bottom-mounted transponders, two transmit/receive transducers, one receiver and one interrogator. A minimum of four transponders are required; these are installed by the support ship and their positions located to within 1km (0.5nm). Sixteen frequencies from 7 kHz to 16 kHz are used by the transponders. The remaining two frequencies are used by the interrogator and transducers to: 1) initiate transponder reply, 2) initiate a transponder into a 64 pulse pinger mode, or 3) to selectively operate the acoustic release on the transponders. The interrogator and receiver will either display the four closest or four selected transponders. The interrogator can be computer-controlled to interrogate at any rate with intervals of between 5 and 60 seconds, or automatically in 5-second steps between 5 to 30 seconds or it can be triggered manually. To correct for sea water sound velocity variations, temperature and conductivity sensor information is fed into the computer, as is depth of the vehicle from an onboard quartz pressure transducer.

All data in the Mesotech system is stored on discs and displayed on a teleprinter. A left-right track indicator box provides the vehicle pilot with course corrections to initially enter the transponder array or proceed to a chosen location, or to steer a selected track. The system provides a relative final accuracy of ±30m (98 ft) when correlated with a surface electronic aid to navigation (e.g., DECCA, SATNAV); overall geographic accuracy of 50 to 200m (164 to 656 ft) is attainable. The system is designed to provide relative position accuracy to within ±3m (10 ft) and ±0.3m (1 ft) depth.

AUTRANAV MK3 System - The AUTRANAV system is used by ULS Marine Ltd. The system can be bottom-oriented or surface-oriented, the following description applies to its bottom-oriented application.

In the basic installation three transponders are deployed approximately 4m (13 ft) above the seabed and approximately 1km (0.6nm) apart in a triangle. Approximate coordinates are taken for each transponder location and an accurate local measurement of sea water sound speed is also made. A calibration survey is then run in a cloverleaf pattern during which a number of interrogations are made from locations within the grid. The results are stored in memory, from these the actual relative transponder co-ordinates are computed and plotted.

The AUTRANAV system used with CETUS requires a fish transponder to be streamed from the survey ship. Provision must be made on the ship for the launch and recovery of the transponders and fish. The bottom-mounted or Long-Base-Line system is the most accurate (±3m), but the work area is limited to within the vicinity of the transponder array. Should the work point move outside this area these transponders will require re-surveying.

2.1.13.b Surface-Oriented Systems

This category includes systems which provide position fixes of the submerged vehicle relative to the surface support ship, rather than to bottom-mounted references. Four systems are in use: RS-7, RS/902 and RS/904, Digital Acoustic Position Reference System (Honeywell, Marine Systems Division, Seattle, Washington); AMF Model 301 Range/Bearing Acoustic Relocator (AMF Electrical Products Development Division, Herndon, Virginia); Wesmar SS210S Sonar Tracking System (Wesmar Marine Systems Division, Seattle, Washington); AUTRANAV MK3 (Polytechnic Marine Ltd., Daventry, Northants).

RS-7 System - The RS-7 system is used by Hunting Surveys Ltd., Ocean Systems Inc., Martech International, Taylor Diving and Salvage Co., and the Harbor Branch Foundation. The system consists of shipboard and subsea components. Shipboard components include: an operator's display and control cabinet (permits selection of operational modes, performs signal processing, and displays position coordination), and a vertical reference unit (measures ship's pitch and roll). The subsea component is a hydrophone in which a miniaturized array necessary for system functions is incorporated.

ROV components consist of a miniature position reference beacon and a depth sensor. A standard position reference beacon is installed on the bottom or on a wellhead or whatever might be an appropriate reference point. The system can and does work without a bottom reference beacon, for this reason the RS-7 and its successors (RS/902 and 904) are placed in the surface-oriented category.

Initially the bottom or hardware-mounted beacon is acquired by the shipboard hydrophone and displayed on a CRT in the display/control cabinet. When the ROV has submerged its beacon also appears on the CRT (as a different symbol). The support ship views the position of the ROV with respect to the wellhead beacon and maneuvers the ship to keep the submersible within the desired tether distance.

Specifications for the RS-7 systems are as follows:

System Accuracy (RMS error as % of slant range)
Precision Position Mode: less than 1% of slant range.
Acquire Mode: Offsets up to 50% of vertical separations (VS), less than 2% of slant range. Offsets up to 100% of VS, less than 3% of slant range.
Precision Mode, Differential Operations: less than 0.5% of slant range.
Acquire Mode, Differential Operations (relative position of two subsea beacons): Offsets up to 50% of VS, less than 2% of slant range. Offsets up to 100% of VS, less than 3% of slant range.

RS/902 System - The RS/902 system is used by Taylor Diving and Salvage Company and Ocean Systems, Inc. Shipboard components of the system consist of a hydrophone, signal processor, vertical reference unit and a display console. Sub-surface components consist of an acoustic beacon mounted on the vehicle and a second bottom - or hardware - mounted beacon (optional) for vehicle tracking relative to a sub-surface reference point.

The beacon is composed of a rechargeable battery-pack, signal-generating electronics and a transducer. The transducer converts the beacon's electronic signals to acoustic pulses, which are then transmitted through the water to the hydrophone. Standard beacon types include floating and hardmounted models; both come with a variety of battery configurations. The hydrophone receives the acoustic signals from the subsea beacon, converts them to equivalent electrical signals, and conditions them for transmission to the signal processor. The hydrophone contains a multisensor array, preamplifiers, and other signal-conditioning electronics. These components are packaged in a watertight housing, allowing the hydrophone to be mounted on the hull of the surface vessel below the waterline. The signal processor calculates the vessel's position for presentation on the CRT display. The processor includes two receivers, a microcomputer, CRT controller, system power supplies, and A/D and D/A interface and timing circuitry. These components are contained in a NEMA-type, drip-proof enclosure. A 17-slot card cage holds the circuit cards. The vertical reference unit (VRU) consists of pitch-and-roll sensors which provide vessel attitude information. The microcomputer uses the vessel's pitch-and-roll angle at the moment the position measurement is taken to adjust the apparent position calculations. The display console contains a single digital CRT for both graphic and alphanumeric data display, together with keyboards for system setup and operation. The basic controls consist of eight variable-function keys along the bottom of the CRT. During system setup and operation, the microcomputer assigns functions to these keys, displaying the appropriate labels on the CRT directly above the keys. As the operator selects a task, the computer changes the key labels on the CRT to reflect the next set of choices that the operator is to make. It also prompts the operator with a brief message concerning the next step - for example, SELECT DATA DISPLAY.

The RS/902 is an ultrashort-baseline position-reference system. This means that it requires only one free-running subsea beacon and one shipboard hydrophone to determine the position of a vessel. The system uses a phase-comparison position-measurement technique. With this method, the beacon transmits a short acoustic pulse at regular intervals. This pulse is received by a shipboard hydrophone whose three receiving elements are arranged in a known orientation with respect to the vessel's X, Y, and Z axes. As the acoustic wavefront reaches the hydrophone, the three elements measure the relative phase of the signal. When the vessel is directly over the beacon, an acoustic signal received by two hydrophone elements in the same axis will be in phase. As the vessel moves farther from the beacon, the relative phase of the signal increases. The microcomputer uses the difference in phase, together with the vertical separation between the beacon and the hydrophone, to determine the vessel's apparent position with respect to a specific subsea reference point.

To establish the vessel's true position, the computer then adjusts the apparent position for various offsets. The factors for which adjustments must be made are: vessel pitch and roll (The VRU reference sensor determines the degree of tilt of the vessel relative to the true horizontal plane at the instant the acoustic signal is received.); hydrophone offset (The distance between the vessel's reference point and the hydrophone is entered at the time of system installation. This offset translates the hydrophone's position so that it appears to be at the vessel's reference point.); and beacon offset (If it is impossible to place a beacon at the desired subsea reference point - for example, on a well-head - beacon offsets (X, Y, Z) may be entered before operations begin. Again, these adjust the apparent position to make the beacon appear to be located at the subsea reference point.)

The RS/902 can track an ROV and display its position relative either to the surface vessel or to a subsea reference point. For ROV tracking relative to a surface vessel, only one beacon is required. This beacon is mounted on the vehicle. The vertical separation between the beacon and the hydrophone may be obtained in one of three ways - by cable from the submersible, acousticall by depth telemetry, or manually by operator entry. For vehicle tracking relative to a subsea reference point, two beacons are required - a submersible-mounted beacon, assigned to one receiver, and a bottom-mounted beacon, assigned to the other receiver.

The system operates with one-pulse-per-second position reference beacons in the 22 to 30 kHz band (9 channels of 1 kHz intervals). It is accurate within 1 percent of slant range for horizontal ranges up to 100 percent of water depth and within 2 percent of slant range for horizontal ranges up to 200 percent of water depth (excluding the effects of the acoustic environment).

RS/904 System - This system is used by UDI, Ltd., Aberdeen, Scotland. The system shipboard components are: a hydrophone/projector, power amplifier signal processor, display console and a vertical reference unit. Sub-surface components are a bottom-mounted beacon (pinger or transponder) and a vehicle-mounted beacon (pinger or transponder). Similar to the RS/902 system, the RS/904 can track an ROV without the need of a bottom-mounted beacon.

The beacon generates the acoustic signals that are used to measure position. Three types can be provided: pinger, transponder, and responder. Pinger-type beacons are free-running and transmit continously. Transponders, in contrast, transmit only in response to an acoustic signal (interrogation) sent from the shipboard projector - and then only a single pulse. Responders transmit only in response to an electric signal sent by cable. A typical transponder for the RS/904 system consists of a battery pack, receiving and transmitting electronics, and a transducer. The transducer receives interrogation signals from the surface and transmits response signals to the hydrophone. The hydrophone projector transmits interrogation pulses to the transponders, receives the response pulses sent back by these units, and conditions these pulses for transmission to the signal processor. The projector portion of the unit consists of an omnidirectional transducer mounted above the hydrophone. The hydrophone portion contains a multisensor array, preamplifiers, and other signal-conditioning electronics packaged in a watertight housing, allowing the hydrophone/projector to be mounted on the hull of the surface vessel below the water line. The signal processor is similar to the RS/902 system, but also includes a transponder controller. The vertical reference unit and the display console are essentially similar in function to the RS/902 system.

The RS/904 measures vehicle position using acoustic pingers, transponders or responders - separately or combined. The type of beacon used determines the operating mode. Because the RS/904 is an ultrashort-baseline system, it can determine a vessel's position with only one beacon and one hydrophone. Additional beacons may be used, however, to provide position data over broader areas, or to furnish tilt and depth information. The system can pre-store as many as 31 sets of beacon data. The pinger mode of operation is identical to that described for the RS/902 system. Pinger-mode operation is useful in two types of situations: 1) when beacons are located in a noisy environment the noise may prevent a transponder from responding to an interrogation signal; and 2) when very rapid position-updating is required, since signals can be sent continuously. Transponder-mode operation, in contrast, involves a delay between the time that the response signal is sent and the time that the new interrogation signal is received.

When operating with transponders, the RS/904 determines position by interrogating one or more transponders. When it receives the transponder's response signal, it determines the vessel's position from both phase information and slant-range measurements. To determine relative phase the three sensing elements in the hydrophone array receive the transponder's response pulse and process it in the same way as a pinger signal. To determine slant range, the signal processor uses the two-way propagation time between transmittal of the interrogation pulse and receipt of the response signal. The microcomputer uses both sets of data - phase comparison and slant range - to calculate the vessel's apparent position. It then establishes the vessel's true position by adjusting for the same three factors as in pinger operation: vessel pitch and roll, hydrophone offset, and beacon offset. The interrogation rate for transponder-mode operation is operator-selectable, and can vary from four times per second to once every two minutes. The interrogation rate depends on the maximum slant range anticipated - the greater the slant range, the less frequent the interrogation can be, due to the increased travel time for the signal. The RS/904 can display the positions of four transponders simultaneously, assigning two to each receiver. The principal advantage of transponder-mode operation over pinger mode is its greater accuracy over broad areas. For horizontal offsets beyond 100 percent of vertical separation, transponder-mode operation is more accurate than pinger mode.

The RS/904 can also operate with responder beacons. The only difference between responders and transponders is that, in the case of responders, the beacons are interrogated electrically, by cable. The RS/904 then determines position by techniques similar to those used in transponder operation, instead of measuring the signal's two-way propagation time: however, the hydrophone only measures the one-way propagation time of the response signal. This method, which yields greater accuracy than acoustics alone, is particularly useful for applications involving remotely operated vehicles. In transponder and responder operations, knowledge of depth is not required for position calculations, although use of a depth-telemetry transponder can provide greater accuracy.

Operating frequencies for the RS/904 system include: interrogate - 3 channels at 13, 15 and 17 kHz; response - nine channels in the 22 to 30 kHz band at 1 kHz intervals. The system is accurate within 1 percent of slant range for horizontal offsets up to 200 percent of water depth. With a depth-telemetry transponder it is accurate within 1 percent of slant range for horizontal offsets up to 400 percent of water depth.

AMF 301 System - This system is used by British Oxygen Corporation, Ltd. and Sub Sea Surveys Ltd. Shipboard equipment consists of a power amplifier, a receiver, a coder and a transducer which is suspended in the water. Sub-surface equipment consists of a compatible transponder which is affixed to the vehicle.

The operational procedure involves manual or automatic interrogation of the vehicle-mounted transponder from the support craft. Slant range to the vehicle is displayed digitally on the receiver and bearing is displayed in analog format through a full 360 degrees. Bearing angle (relative to the surface craft) accuracy is ±5 degrees, timing error (slant range is computed on the basis of elapsed signal time from ship-to-transponder-to-ship) accuracy is ±0.5 milliseconds.

The shipboard system operates on 90 to 115 VAC, 50 to 60 Hz, 250 watts. The receiver frequency is 10 kHz (standard), 3 to 15 kHz are optional.

Wesmar SS210S Tracking System - The Wesmar system is used by COMEX Services and Sonarmarine Ltd. The system's shipboard components consist of a console (with CRT display and control functions), a soundome (containing a transducer which can scan from 0 to 360 degrees and can tilt the acoustic beam from 4 degrees above the horizontal to 90 degrees below), and an electrical hoist system for deploying the soundome in or out of the water. Sub-surface equipment consists of a vehicle-mounted transponder (Wesmar model T210).

The Wesmar system can operate in an active or passive mode. In the active mode the transducer emits a short burst of acoustical energy (160 kHz) which strikes the vehicle and is reflected back to the transducer where it is amplified, processed and displayed on the CRT. In the passive mode a transponder is mounted on the vehicle. The transducer then transmits a 25 kHz pulse which is received by the transponder and commands it to send a return pulse at 160 kHz. The return signal is displayed to give range, bearing and depth of the vehicle. The transducer in the soundome is stabilized to compensate for surface vessel pitch and roll up to 25 degrees.

Two CRT display modes are possible: A-Scan and B-Scan. The A-Scan mode displays a horizontal line across the CRT screen. The vehicle is displayed as a spike on the line whose position provides range to the vehicle. In the B-Scan mode (which is the normal mode for navigation) a PPI presentation is provided which is similar to search radar.

The vehicle is displayed as a blip on the CRT from which range and relative bearing (to the ship) can be obtained. The following specifications apply to the SS210S system.

Maximum Range: 1,000m (3,280 ft) active/sonar mode, 2,000m (6,560 ft) passive/transpond mode.
Frequency: 160 kHz active mode, 25 kHz transponder interrogation (passive) mode
Operating Voltages: 12, 24, 32 VDC, 110 VAC, 60 Hz
Transmitter Power Output: 2,000 watts peak-to-peak
Transducer Beam Width: 7 degrees
Sector Scanning: Switched in steps from 30 degrees to 360 degrees
Target Lock-on: Automatic tracking of a vehicle without operator control is a feature of the system

AUTRANAV MK 3 - This system is used by ULS Marine Ltd. The following describes the procedures this company employes to track their CETUS vehicle.

One transponder is suspended from the bow, another from the stern; both are approximately 5m (16 ft) below the surface. A fish transponder is streamed from the surface ship and slant range to the vehicle is calculated by noting the round trip time for a pulse to travel from the fish to a vehicle-mounted transponder and back to the bow and stern transducers. The angular bearing can be derived from the time difference of the transponder replies. Adequate means must be available to secure the forward and aft transducers and launch, stream and recover the fish. The system's work area is limited to within 500m (1640 ft) of the support ship, the accuracy is approximately 3m (10 ft).

The preceding discussion describes the various navigation systems as they are manufactured. In some instances the operators have modified these systems to satisfy their particular navigational requirements, in other instances they have designed their own system with components purchased individually from various suppliers. Sub Sea Surveys Ltd., for example, interrogates a vehicle-mounted transponder by sending an electrical pulse down the umbilical cable. The transponder signal is sent thru-water and received by two transducers on the surface ship to provide slant range. Phase variation between the two transponders is measured to provide bearing to the vehicle relative to the ship's heading. Some work tasks, such as pipeline "as laid" surveying, make it desirable to obtain the geodetic position of the vehicle as it progresses. In this instance Sub Sea Surveys has devised a technique where ROV range, bearing and depth and the ship's heading and position (determined by a surface electronic positioning system, such as Hi-fix, Pulse 8, Satnav, etc.) is fed via a specially developed interface unit into a PDP II computer system. A navigation program converts the data into UTM coordinates which provides the vehicle's position and, hence, the pipeline position.

ULS Marine Ltd. has also developed a program for determining UTM coordinates of the ROV based around a PDP II computer. The company states that ±2m (7 ft) geodetic position accuracy can be obtained.

One area of vehicle navigation that has not been addressed is navigation within a steel structure. The only present means of determining a vehicle's position inside a structure is by a combination of vehicle depth readings, directional gyro, and visual sightings. Since the steel members of the structure reflect and scatter acoustic energy, none of the above systems can be accurately used inside a structure. Magnetic compasses are also of marginal value inside a steel structure since they are affected by the steel itself.

Several ROV operators have expressed an interest in employing inertial guidance navigation systems. Although no operator has acknowledged using such a system, it is appropriate to describe one such system which has been used by a manned submersible and could possibly be configured for ROV application. Ferranti Offshore Systems Ltd, Edinburgh, Scotland has developed a system specifically for submersible use called HASINS (High Accuracy Submersible Navigation System).

The essential elements of the system are Inertial Navigator, a General Electronic Navigation Interface Equipment (GENIE), Display and Control Unit. The Inertial Navigation is a standard aircraft system containing an inertial platform and Digital Inertial System Computer (DISC). The platform comprises three accelerometers stabilized in all directions by three high precision gyroscopes. The accelerations of the platform are measured very accurately by the accelerometer and the DISC calculates the velocity and the distance moved. This is in the form of standard aircraft measurement units, and electronic processing of this data is then undertaken in the GENIE. The circuitry of this unit reduces the increment into measurements of 1/1000th of an inch. Although it is only relative displacement that is derived, the computer adds these algebraically to produce the new positions in latitude and longitude on a grid. The display and control unit allows an operator to insert and read the data, and is also used to switch the inertial navigator into its various operational roles.

Before a survey commences HASINS must be aligned to true north and a position of an initial, known reference point must be inserted into the control unit. To maintain accuracy the system must undergo periodic updates. In a submersible this is done at intervals of 1 to 10 minutes for several seconds. Updating is automatic, a push button activates the computer. Experiments conducted by Intersub's PC-1204 (a manned submersible) consisted of taking seven measurements over a total distance of 259m (850 ft) which demonstrated a total error of 20cm (7.9 in.). (See Section 5.7 for a detailed account of this system.)

2.1.14 Personnel

The number of personnel (crew) required to operate, maintain and repair the various ROV systems is shown in Table 2.1, and they range from one to as many as seven. Obviously, the complexity of the vehicle, the work task, and the length of time required for continuous operation are the factors governing crew size.

There is no standard watch bill or personnel allocations between operators. Some stand a watch of two hours on and two hours off, others for 3 hours and some for eight hours. The deciding factor is the nature of the task. When the job calls for intense concentration, such as working inside a structure or working with the manipulators, the duration of an individual's watch is short. Where the job calls for "flying and looking" the amount of concentration called for is less and, consequently, the watch duration is longer. The length of time for which an ROV pilot can operate effectively at a task calling for intense concentration is surprisingly short. The results of interviews with seventeen ROV operating companys reveal that the effective time span is between one to four hours, the average being 1.6 hours. At tasks requiring minimal concentration the duration range is four to eight hours. The longest continuous submerged operation by ROV operators interviewed in this study was 17 hours; three to five hours seems to be the average dive duration.

In some operations the effectiveness of the ship's Master can limit the length of an operation. When the surface ship is live boating or continuously maneuvering to stay within one location the strain on the Master can be intense. One operator stated that eight hours was the effective limit on the Master in such circumstances. Relieving the Master with another officer is not necessarily a viable solution since the expertise required in the relief personnel to maneuver the ship may be - and often is - lacking.

The types of crew members and their responsibilities are quite varied. One RCV-225 operator has a crew of five: one supervisor and four Electronic Technicians (ETs)/pilots. One TROV operator fields a crew of four: one supervisor; two ETs, and one mechanical/hydraulic specialist - all of which are qualified pilots, and rotate on a four-man watch from pilot-to-navigator-to-winch handler. The U.S. Navy's DEEP DRONE fields a crew of five who rotate at three different stations: pilot, sonar operator, and plotter. Another operator provides a crew of seven: one supervisor, one vehicle engineer, one photographer and four operators/maintainers. The variety of people and their tasks are as varied as are the number of ROV operators.

The background of most vehicle crew members, particularly the pilots/maintainers, is in electronics. The better crew members according to the vehicle owners, also have had experience at-sea in handling heavy loads and are proficient marlinspike seamen. A common problem among operators is not a lack of people, but a lack of people with experience offshore.

Training of ROV personnel depends upon the operator. Some organizations simply assign a new member to an experienced crew and let on the job training do the rest. Several operators send their people to the manufacturer's plant where a two- to three-week course in operations, maintenance and repair is provided. Following the manufacturer's course, some operators have an additional in-house course before the new crew member is sent to sea. Training for operation and maintenance of some of the more sophisticated navigation systems may also require that a week or more be spent at the manufacturer's plant. Estimates vary concerning how long it takes to develop a thoroughly qualified pilot/technician; at a minimum, six months (one operating season) to an average of one year, is the most common estimate. Although the problems encountered by today's ROV operators are discussed in detail in a later section, it is appropriate at this point to note that the major problem confronting all operators is a lack of experienced personnel.

2.2 BOTTOM-CRAWLING VEHICLES

Vehicles in this category are primarily designed to perform a specific work task. A listing of bottom-crawling vehicles is presented in Table 2.5, individual specifications are contained in Appendix D. It is apparent from Table 2.5 that the number of bottom-crawling vehicles is much less than the free-swimming, tethered ROVs. Also, bottom-crawling vehicles are all operated by the same company responsible for their construction. Significantly, except for one instance, all bottom-crawling vehicles are industrially-oriented, and this orientation is overwhelmingly directed toward offshore oil and natural gas activities.

2.2.1 Functions

Bottom-crawling vehicles are designed to satisfy one of the following functions: Pipe trenching, cable burial, bulldozing/dredging, and general (inspection/manipulation) work tasks.

Pipe trenching is the predominant work function. Present capabilities permit trenching of 400 to 1,200mm (16 to 48 in.) diameter pipe to a maximum of 2.5m (8.2 ft) in water depths of 500m (1,640 ft). All vehicles but one discharges the trench cuttings to the side of the trench. The exception, TM 102, discharges the cuttings to the stern of the machine to act as backfill.

Two vehicles are designed for cable burial, SEACAT and TALPETTA. In both instances the trench dug is approximately 1m (3 ft) deep. SEACAT is not a true ROV since it relies upon a diver or a manned submersible to control its movements and work functions once it is on the bottom.

Bulldozing and dredging tasks are similar to those encountered on land. The commercial success of these vehicles is uncertain. Three bulldozers have been constructed, but it is not clear whether or not they have been used commercially.

Four general-purpose vehicles have been constructed; all but one are directed toward the commercial market. The exception is RUM II which was built with U.S Navy funds, but it has been inactive for the past six years. Typical work tasks these vehicles purport to accomplish in the view of SEABUG I's operators, are: Cable burial, pipeline inspection, debris mapping/clearance, bottom route surveys, valve opening/closing, hydro couple installations, and site investigations. These vehicles have only been available for commercial operations within the past two years, consequently, their actual at-sea utilization is still limited.

2.2.2 Operating Depths

	Range	Average
Trenching Vehicles	46-650m	190m (623 ft)
Cable Burial Vehicles	46-200m	123m (404 ft)
Bulldozers	7-60m	42m (138 ft)
General Purpose Vehicles	305-1,877m	1,184m (3,885 ft)

TABLE 2.5 BOTTOM-CRAWLING REMOTELY OPERATED VEHICLES

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer	Purpose
GRANSEOLA	1	150/46	Operational	INCOP, Ancona, Italy	Same	Pipe Trenching
JH160	2	197/60	Unknown	Hitachi Construction Machinery Co. Ltd., Tokyo	Same	Bulldozing
KVAERNER MYREN TRENCHING SYSTEM	1	1640/500	SEA TRIALS	Kvaerner Brug A/S Oslo, Norway	Same	Pipe Trenching
PBM	1	420/128	Operational	Sub Sea Oil Services S.p.A., Milan, Italy	Same	Pipe Trenching
RUM	1	6158/1877	Inactive	Marine Physical Laboratory San Diego, CA	Same	General
SEABUG 1	1	1000/305	Operational	UDI Ltd. Aberdeen, Scotland	Same	General
SEACAT	1	656/200	Operational	Vickers Oceanics Ltd. Leith, Scotland	Same	Cable Burial
SL 3	1	164/50	Operational	Land & Marine Engineering Ltd., Merseyside, England	Same	Pipe Trenching
SUBTRACTOR	1	150/46	Sea Trials	Maui Divers of Hawaii Ltd. Honolulu, Hawaii	Same	General
TALPA	1	150/46	Operational	INCOP, Ancona, Italy	Same	Pipe Trenching
TALPETTA	1	150/46	Operational	INCOP, Ancona, Italy	Same	Cable Burial
TM-102	1	660/201	Operational	Technomare S.p.A. Venice, Italy	Same	Pipe Trenching
TM III & IV	2	246/75	Operational	Land & Marine Engineering Ltd., Merseyside, England	Same	Pipe Trenching
TRAMP	1	Unknown	Unknown	Winn Technology Ltd. Kilbrittain, Ireland	Same	General
UNDERWATER BULLDOZER	1	23/7	Development	Komatsu Ltd. Tokyo	Same	Bulldozing
UNDERWATER TRENCHER	1	70/21	Inactive	Sumitomo Heavy Industries Tokyo	Same	Trenching

2.2.3 Construction

There is no general configuration which bottom-crawling vehicles tend to follow. The bulldozers are much like their land counterparts, but the remaining vehicles are uniquely configured and cannot be described generally. Undoubtedly, the most varied configurations are found within the pipe trenching and cable burial vehicles which virtually defy a geometrical analogy. One aspect in common with the trenching and bulldozing vehicles is their size: all are large and massive. The average dry weight of these vehicles is 49t (54 tons), and the range is from 9 to 193t (10 to 213 tons). Consequently, surface support platforms are much larger and the launch/retrieval capabilities required to handle these massive loads are more stringent.

Cable burial vehicles and general purpose vehicles are much smaller, of the active vehicles, the average weight is 1.9t (2.1 tons) and ranges from 1.25 to 2.5t (1.4 to 2.8 tons).

The size of the pipe trenching and bulldozing vehicles limits the sea state in which they can be deployed to about 4. In the event that inclement weather moves into the operating area once the vehicle has been deployed, several operators have made provisions to simply buoy-off the umbilical and re-engage it after the weather has passed.

2.2.4 Speed

Vehicle speed varies in accordance with the nature of the work task and the environment. In one instance, bulldozing, speed is not a particularly significant factor since it is the capability to move quantities of sediment, rather than the vehicle's speed over the bottom, which is important. In two tasks, pipe trenching and cable burial, a quantitative appreciation for the vehicle's average rate of advance is obtainable. For pipe trenching vehicles an average advance rate range from 48m (57 ft)/hr to 500m (1,640 ft)/hr is quoted to dig a trench 1.5m (4.9 ft) to 2.5m (8.2 ft) deep, respectively. The average rate of advance of six trenching vehicles is 157m (515 ft)/hr for an average trench depth of 2.0m (7 ft). These values are based on trenching a 122cm (48 in.) diameter pipe. They do not take into account bottom sediment types which will have a substantial effect on rate of advance. No trencher is known to operate in hard rock or in boulder-sized material.

Cable burying devices operate under the same environmental constraints as do pipe trenching vehicles. The average rate of advance to excavate a 1m (39 in.) deep trench is 111m (364 ft)/hr. The range is from 60m (197 ft) to 152m (499 ft)/hr.

General purpose vehicles can obtain a maximum speed of 3 knots (6km/hr), but this, too, is dependent on the type of bottom (smooth *vs.* rough) and the bottom slope gradient and the ability of the bottom to support the vehicle's weight (trafficability). The nature of the bottom can determine whether or not this type of vehicle can work at all. An example was provided in the summer of 1978 when one general purpose vehicle literally sunk beneath the bottom of the Gulf of Mexico and was forced to abandon its pipeline inspection task.

2.2.5 Power

All bottom-crawling vehicles but one receive their power through an umbilical cable from a surface platform. The general-purpose vehicles operate generally on the same power as do the tethered, free-swimming vehicles, e.g., 440 V, 3 phase, 50/60 Hz. The pipe trenching vehicles require higher voltages in the neighborhood of 3,300 V which are transformed to lower operating voltages at the vehicle.

The exception is found in the UNDERWATER BULLDOZER (D 155W) which is powered by an onboard diesel engine (KOMATSU S6D155-4) providing 270 hp at 2,000 rpm. Since this vehicle has a maximum operating depth of only 7m (23 ft), it is possible to incorporate the intake and exhaust ducts into a rigid mast which protrudes above the water surface.

2.2.6 Propulsion

Pipe trenching vehicle propulsion is by one of two means: 1) using the pipe itself for traction; or 2) using the sea bed for traction. Over half of the vehicles investigated fall into the first category. Initially the vehicle is joined to the pipe (with diver assistance or, in the case of the KVAENER MYREN system, by thrusters), and then engages either hydraulically-powered wheels or push-pull grasping arms to initiate movement. The two vehicles which rely on the bottom for traction, TM 102 and the UNDERWATER TRENCHER, receive propulsion from caterpillar tracks which straddle the pipe. In each case the vehicle provides it's own propulsion means.

The trenching vehicles of Land and Marine Engineering, Ltd. vary from all the others, in that they are towed along the pipe by the surface support ship. Coated rollers protect the concrete coating and guide the vehicle.

Bulldozing vehicles, similar to their land counter-parts, use caterpillar tracks for propulsion.

The general purpose vehicles use either individually-suspended wheels (4 to 6) or caterpillar tracks.

2.2.7 Tools/Instrumentation

The primary tool of the trenching vehicles is the cutting device. Two means of excavation are used: water jets which fluidize the sediment, and hydraulic cutters which mechanically breakdown the sediment. In both instances the cuttings are removed by suction pumps (airlift excavation is sometimes used in shallow water) and expelled to the side of the trench. In one instance, TM 102, the cuttings are expelled over the pipe as backfill. Closed circuit TV is occasionally used to monitor the excavation progress, and scanning sonar may also be used to profile the trench or to assist in initially docking the vehicle to the pipeline. In most instances the trencher's progress and performance is monitored by divers, remotely controlled vehicles or manned vehicles. Instrumentation can also include inclinometers (to monitor vehicle tilt and roll), and air pressure and hydraulic pressure gages.

Cable burial vehicles employ essentially the same techniques and instrumentation as do the trenching vehicles. Vickers SEACAT is an exception, in that control of the vehicle is not by remote means, but is performed in situ by divers or a manned submersible. In this respect SEACAT does truly fall into the category of a remotely controlled vehicle.

The general purpose vehicles are more akin to the free-swimming, tethered ROVs. SEABUG I, for example, has CCTV, two manipulators, an echo sounder, side scan sonar, directional gyro, depth gage and pitch/roll indicator. The vehicle can also accommodate tools for cable burial (jetting) or for various manipulative tasks, such as cutting, grinding, brushing, etc.

The TRAMP system is one of the more sophisticated bottom-crawling vehicles. Repetitive tool operations with continuous rate changes, for example, can be tape-controlled and the CCTV image is 3-dimensional and reflects vehicle tool arm movements, roll and pitch, front and rear axle angles and wheel speeds. The display/control console of the TRAMP system is guite similar to those of the more complex, tethered, free-swimming vehicles.

2.2.8 Navigation

Navigation of pipeline trenching vehicles is relatively simple since the position of the pipe is known prior to the operation and the position requirements call for no more than knowing where the device is as it proceeds along the pipe. This information can be obtained by a single surface-oriented acoustic tracking system or by CCTV which can be used to observe field joints on the pipeline. Geodetic positioning is supplied by the support barge which is moored over the device and periodically re-positioned as the trencher moves along the pipe. Similar techniques are employed by cable burial devices.

Since the bulldozing devices operate in shallow water, visual navigation techniques are often used. The JH160 vehicles, for example, support a mast that protrudes above the water surface which is configured and marked to show the direction and depth of the vehicle and the blade position. The operator, who is either on a barge or on the shore, maneuvers the bulldozer (with radio signal transmission or hardwire) by visually observing the mast orientation. For deep water work, where the mast approach is not feasible, a bottom-oriented transponder system (see Section 2.1.13.a) is used.

Since the general purpose vehicles are wider-ranging and their tracks are less predictable, they employ systems similar to the free-swimming vehicles. Visual sighting and magnetic compasses with directional gyros are common. Bottom-oriented and surface oriented positioning systems are also capabilities found on the general purpose vehicles. SEABUG I, for example, employs the RS/904 surface-oriented system, but is also capable of using the ATNAV bottom-oriented system.

2.2.9 Support Ship Components/Requirements

The wide variation in bottom-crawling vehicle size and mass guite naturally results in a wide variety of support ship components and requirements. Unlike the tethered, free-swimming vehicles, operators of bottom-crawling vehicles - particularly the trenching vehicle operators - do not speak of ships of opportunity. Launching, retrieving, supporting and maintaining a vehicle up to 192t weight calls for a surface platform of considerable magnitude, a highly-skilled crew and an extensive inventory of specialized equipment. For such reasons many of the pipe-trenching and cable-burial vehicles operate from dedicated support platforms. An appreciation for the components and support ship requirements of pipe trenching vehicles can be gained by reviewing the dedicated support ships of two systems, PBM and TM III.

PBM - Shipboard Components: Control cabin, hydraulic power pack, high pressure water pumps, air compressors, umbilical winch and cable, electric power generator, handling system, workshop van.

Support Ship Requirements: For shallow water (less than 50m depth) in good weather: a small supply vessel equipped with a 20t A-frame, an 8-point mooring system, open deck space to accommodate shipboard components, shallow diving equipment and accommodations for a crew of 12. For deep water: a larger craft with a 50t A-frame, one deep diving unit and accommodations for a crew of 25.

TM III - A specially designed and dedicated pulling/jetting barge, L.M. BALDER, is used to support this vehicle, its characteristics are as follows:

LOA: 110m (361 ft), Beam: 30m (98 ft), Draft: 7.7m (25.2 ft)
DWT: 15,000
Anchorage System: Four double-drum Skaggit winches with 750m (2,460 ft) of 50mm (2 in.) wire rope and eight 7.5t anchors
Storm Anchor: One electrically driven windless with chain and 5t anchor
Accommodations: 80 berthing and full messing
Craneage: One crawler crane with 25m (82 ft) boom, maximum lift of 136t (150 tons). One crawler crane (deck traveling) of 54t (60 tons) maximum lift
Navigational Equipment: Radar, Hi-Fix, Trisponder, Tellurometer

These two pipe trenching support craft reflect only the requirements of a specific system, other pipe trenching vehicle support requirements fall somewhere in between these. Where most pipe trenching vehicles rely on a moored support platform, the KVAENER MYREN system calls for a dynamic positioning system to hold the support ship on station, other specific support requirements are contained in Appendix D.

Support facilities for Vicker's cable burial vehicle, SEACAT, are unique, in that either a diving system or a manned submersible (depending on depth of operation) must be available to control and monitor the vehicle in situ. (SEACAT, therefore, is not truly a remotely controlled vehicle since it relies upon manned intervention for operation.) Details of the support ship requirements for SEACAT are not available. However, manned submersible support vessels of the Vickers fleet (VICKERS VOYAGER, VICKERS VANGUARD, VICKERS VIKING, etc.) are equipped to handle SEACAT and its attendant support equipment.

Surface support requirements for bulldozers are minimal since the vehicle works in one location and, generally, not far from the shoreline. In one instance - the shallow version of JH 160 - the operator can control the vehicle from the shoreline or a pier by merely observing the orientation of its mast. The following components and requirements apply to the deep water version of the JH 160 bulldozer. Appendix D presents the support ship requirements and surface components of the JH 160 system.

Shipboard Components: Diesel engine, electric generator, auxiliary generator, cable winch, air compressor, bulldozer hoisting winch, operating controls.

Support Ship Requirements: A non-self propelled barge of approximately 100t (110 tons) displacement with dimensions (LxWxH) of 16.5 m x 10.2m x 1.8m (54.1 ft x 33.5 ft x 5.9 ft).

2.3 TOWED VEHICLES

Vehicles in this category rely solely upon a mobile surface support ship for propulsion and maneuverability, and generally depend upon a surface-connected umbilical cable for power and data telemetry. Ownership of towed vehicles is divided almost equally between the industrial and government/academic community. Approximately 19 have been constructed, 15 of these are operational (Table 2.6). All industrially-owned vehicles belong to corporations involved in assaying or mining deep-sea mineral deposits (i.e., manganese nodules).

2.3.1 Functional Capabilities

The following discussion regards functional capabilities and work tasks towed vehicles have performed and are now performing, they are addressed under the categories of Industrial, Military and Scientific/Research. Capabilities and support requirements for these devices are contained in Appendix E.

2.3.1.a Industrial

DSS-125, GUSTAV, MANKA 01, SEP are included in this category. These vehicles are designed almost exclusively for assessment of manganese nodule deposits to depths of 6,096m (20,000 ft). Functional capabilities (Table 2.7) include television, photography and, in one instance, side scan sonar mapping. A fifth vehicle in this category has been built and tested under a consortium headed by the International Nickel Company. Details of the vehicle and its data-collecting capabilities are proprietary. MANKA 01 has the added capability of collecting sea floor samples and conducting in situ element analysis.

2.3.1.b Military

TELEPROBE and the NRL System are included in this category. Both vehicles are designed to conduct detailed sea floor surveys (photographically and acoustically) and to search, identify and locate objects of national interest. Both vehicles are capable of operating to 6,096m (20,000 ft) depth. Since some portion of the work these vehicles perform is classified, all of the work they have conducted is not available. However, some of the past work includes:

Search and identification of a scuttled ammunition ship
Search and identification of the submarine SCORPION
In situ monitoring of poison gas cannisters
Bottom site surveys
Cable route surveys
Sterophotographic bottom mapping

2.3.1.c Scientific/Research

BATFISH, CRAB, DEEP TOW, RAIE I & II, RUFAS I & II, S^3, DIGITOW and ANGUS are in this category. All of these vehicles are supported directly or indirectly by government funding.

TABLE 2.6 TOWED VEHICLES

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Builder
ANGUS	1	7,874/2,300	Operational	Woods Hole Oceanographic Institute Woods Hole, Ma.	Same
BATFISH	1	650/198	Operational	Bedford Institute of Oceanography Halifax, Nova Scotia	Same
CRAB	1	13,123/4,000	Operational	Institute of Oceanology Moscow	Same
DEEP TOW	1	20,000/6,096	Operational	Marine Physics Laboratory San Diego, Ca.	Same
DIGITOW	1	19,685/6,000	Construction	Jet Propulsion Laboratory Pasadena, Ca.	Same
DSS-125	4	20,000/6,096	Operational	One Japanese and one German Industrial firm.	Hydro Products San Diego, Ca.
GUSTAV	1	19,685/6,000	Operational	Dornier System GmbH. Fredrichshafen, West Germany	Same
MANKA 01	1	21,325/6,500	Lost at Sea	GFK Karlsruhe Karlsruhe, West Germany	Same
RAIE I	1	19,685/6,000	Operational	CNEXO Brest, France	Same
RAIE II	1	19,685/6,000	Operational	CNEXO Brest, France	Same
RUFAS I	1	600/183	Operational	NMFS/NOAA Bay St. Louis, Ms.	Same
RUFAS II	1	2,400/731	Refit	NMFS/NOAA Bay St. Louis, Ms.	Same
S^3	1	6,000/1,829	Inactive	University of Georgia Athens, Ga.	Same
SEP	1	19,685/6,000	Operational	Dornier System GmbH. Frederichshafen, West Germany	Same
TELEPROBE	1	20,000/6,096	Operational	Naval Oceanographic Office Bay St. Louis, Ms.	Same
NRL System	1	20,000/6,096	Operational	Naval Research Laboratory Washington, D.C.	Same

The equipment list in Table 2.7 demonstrates the wide range of capabilities (i.e., functional capabilities) of these vehicles. BATFISH and CRAB are relatively simple vehicles with television and side scan sonar capability. Their functional capabilities are primarily to reconnoiter the bottom. The remaining vehicles carry more sophisticated instrumentation and are, in some instances, more specialized. They are discussed below.

DEEP TOW - In addition to the equipment listed in Table 2.7, DEEP TOW can accommodate a directional hydrophone, a conductivity meter, and a nephelometer. DEEP TOW's primary work task has been to conduct fine-grained geological/geophysical investigations in deep ocean areas. Most of this work has been directed toward basic research such as erosion and sediment transport, investigation of small scale furrows near the base of major slope areas, sand waves, large scale depressions and other studies relating to the dynamics of the sea floor. Some aspects of DEEP TOW's work has been involved in investigation of wreckage and straight-forward documentation of the nature of the sea floor (surveys). Other work includes chemical sampling in the vicinity of brime pits and hydrothermal seeps, near-bottom plankton sampling, light scattering-absorption measurements.

DEEP TOW requirements are generated by the scientists who operate the system. DEEP TOW is considered a better tool for investigations of small-scale bottom features than conventional over-the-side or surface-oriented techniques. It is not DEEP TOW *per se* which is funded, but the opportunity to provide a more detailed investigation of the deep sea. Consequently, the driving force behind funding DEEP TOW is not necessarily development of technology, but it is the increase of scientific knowledge.

RAIE I and II - Both vehicles are operated by CNEXO and both are solely for research and survey of manganese nodules. RAIE I is used in scientific studies; RAIE II, towed by a steel cable instead of an electromechanical cable, is used for surveying nodule deposits. Since TV signals are not in real-time, the resolution of the signal is not of high quality. Photographs are preferred over video TV.

Funds for these vehicles are provided by government and industry through an organization called AFERNOD (Association for Study and Recovery of Manganese Nodules).

RUFAS I and II - RUFAS I (Remote Underwater Fishery Assessment System) was developed to accomplish the single objective of assessing calico scallops *in situ*. It has been used in the Gulf of Mexico and the Bering Sea for assessment of a variety of benthic organisms including scallops. Because of its unique mission orientation, it was designed for shallow water, near-bottom operation in relatively clear waters.

RUFAS II is considered an extension of RUFAS I with increased depth capability for benthic and mid-water organism assessment. Neither vehicle is capable of sampling, but relies upon photographic and TV documentation. RUFAS II is currently undergoing a number of modifications prior to operational field application.

S^3 (Seafloor Surveillance System) - The University of Georgia's S^3 was inspired and designed after RUFAS II. The distinction between the two vehicles is that the S^3 is designed for Outer Continental Shelf oil and gas lease surveys and deep water mineral exploration. Functional capabilities of S^3 include: detailed video-tape recordings of manganese nodules including readout of nodule density per unit area, seafloor micro-bathymetry, high-resolution sub-bottom profiling and underway seafloor sample retrieval.

DIGITOW - The Jet Propulsion Laboratory's Advanced Ocean Technology Development Platform (AOTDP) or DIGITOW is designed to provide JPL with a capability for testing and demonstrating new or advanced instruments, technology and concepts under operational (deep sea) conditions. The DIGITOW system is designed for adaptability, flexibility and future growth potential to accommodate new developments over an extended period of years. Patterned after the Marine Physics Laboratory's DEEP TOW, it consists of a cylindrical pressure hull containing the electronics and an external structure providing protection and mounting areas for instrumentation. One objective of JPL is to apply technology and expertise - developed under the aegis of the space program - to aid in the solution of non-space problems, and to transfer this technology and know-how, where appropriate, to an ultimate developer or user. At present JPL is field testing an experimental towed, sub-bottom profiling system referred to as the "Chirp" sonar. The system is intended to demonstrate improved performance in resolution and depth of penetration over conventional techniques and employs advanced transmission and signal processing using a frequency modulating or "chirp" technique. The system recently completed its fifth in a series of field applications. In March 1979 NOAA's Office of Ocean Engineering supported an at-sea evaluation of the advanced chirp sonar in conjunction with NOAA's National Ocean Survey, to track and delineate a portion of the San Andreas fault.

2.3.2 Operating Depth

Vehicle operating depth ranges from 400m to 6,096m (650 ft to 20,000 ft), the average being 4,712m (15,459 ft). Significantly, of the 19 vehicles listed in Table 2.6, 13 are capable of operating to depths of 6,000m (19,685 ft) and greater. This extended operating depth reflects the commercial interest in manganese nodule deposits. From a military viewpoint, 6,096m provides a search capability which includes approximately 98 percent of the ocean bottom.

2.3.3 Construction

Towed vehicle configuration is generally cylindrical. Unlike tethered, free-swimming ROVs, almost half are enclosed by fairings to reduce hydrodynamic drag, the remainder are unfaired and are open metallic framework construction.

The dry weight of the vehicles varies according to their operational depth and the instrumentation they carry. The lightest vehicles, BATFISH, weighs approximately 71kg (156 lbs); the heaviest, MANKA 01, weighed 4,500kg (9,921 lbs or approximately 5 tons). The average weight is 1,488kg (3,058 lbs).

At depths of 6,000m the weight of cable (approximately 1.5 x water depth in length) overrides the weight of the fish. DEEP TOW's 9,144m (30,000 ft) of cable, for example, weighs 10,750kg (23,700 lbs or approximately 12 tons) in air, some 12 times the dry weight of the fish.

2.3.4 Towing Speed

Towing speeds range from 1 to 8 knots (2 to 11km/hr) and average 3 knots (6km/hr). The higher tow speed vehicles are generally employed in mid-water operations while the slower vehicles are towed on - or very close (5 to 10m) - to the bottom. Fast speed is not advantageous since it is not conducive to photography of high resolution.

2.3.5 Power

Electrical power in all but three systems is supplied from the support ship via an umbilical cable. Since propulsive power is supplied by the surface ship also, the umbilical cable carries only power for instrumentation, and, in the case of the RUFAS vehicles and S^3, power to control the dive planes.

Power requirements vary from fractional amperage at 110 VAC to 20 amps at 440 VAC. Although no two vehicles call for identical power requirements, 60 Hz, 115 VAC, 20 amperes is fairly representative. Significantly, the voltage requirements listed in Table 2.7 are those required at the fish. Voltage losses through 6,000m of cable are significant and the shipboard voltage is frequently quite higher than what is required. RAIE I, for example, is supplied 400 VAC at the surface to provide 110 VAC at the fish.

Vehicles which do not obtain their electrical power from the surface carry batteries. Ordinarily the towing mission is limited to the battery endurance. However, the NRL System's nickel cadmium batteries are maintained in a fully charged condition throughout the towing operation by current from the support ship via the umbilical cable.

2.3.6 Vehicle Control

Maneuvering a towed vehicle is simple in concept, but can be difficult in practice. The most common approach involves lowering the vehicle to some appropriate depth (or altitude off the bottom) and maintaining this depth by winching in or winching out cable. Distance from the bottom is generally monitored by a downward-looking echo sounder. CCTV can be used to maintain an appropriate distance also. In addition to CCTV altitude control, DSS-125 employs a pair of collimated spot lights to assist in determining the size of objects in the scene and the distance of the vehicle above the ocean bottom. The difficulty is brought about by sea surface conditions which may impart heave to the ship. According to Dr. F. N. Spiess, Marine Physics Laboratory, San Diego, Ca., ship's heave motion is reflected about 1:1 on the submerged vehicle. At the very least it is 1:½. Consequently, focusing the TV camera or still cameras can be exceedingly difficult. For this reason, the DEEP TOW system employs accumulators aboardship which act to reduce the vehicle's vertical excursions.

An alternative solution to accumulators is found in the DSS-125 system. Here a 600kg (1300 lb) depressor is attached to the umbilical approximately 60m (200 ft) forward of the vehicle (lead ballast weighing up to 1,100kg (2,400 lbs) can be added to the depressor if necessary). With this arrangement surface-imparted heave is taken up by the depressor instead of the fish which trails astern. There is, quite naturally, a penalty in this approach. Instead of an up-down motion, the fish now undergoes an alternating fast-slow surge motion in concert with the depressor's up-down motion. The forward surge can be so great as to produce a blur on the TV monitor which seriously detracts from the quality of the video and still photographs.

The RUFAS vehicles take a quite different approach to vehicle altitude/depth control. Since they are towed at relatively high speeds (3 to 6 knots) and at relatively shallow depths, dive planes can be used to control vehicle pitch once an appropriate length of cable has been paid out. RUFAS II will also incorporate an automatic terrain-following control system. Altitude information from a downward-looking echo sounder is used to activate servos which control the two stern dive plane's pitch.

2.3.7 Instrumentation

Instrumentation carried by towed vehicles is much the same as that described in Section 2.1.7 regarding tethered, free-swimming ROVs and need not be discussed further. Those areas that differ significantly, however, are manipulation, CCTV and *in situ* analysis.

Towed vehicles do not carry manipulators simply because they cannot stop to use them. Lacking the capability of self-propulsion, the vehicles must be continuously underway if they are to operate as designed. There are, nonetheless, vehicles which have the capability to collect bottom samples. MANKA 01 carried a specially designed suction nozzle which picked up manganese nodules as the vehicle was towed along the bottom. A heavy wire mesh dredge-type sampler is housed on the underside of S^3, and the sampler (31cm L x 15cm W x 25cm H) is lowered and raised between the vehicle's skids by a shipboard-controlled servo system. The present S^3 sampler is only capable of single sample retrieval and storage, a multi-sampling system has been designed which permits multi-sample storage in a carousel storage compartment. The Soviet Institute of Oceanology's CRAB is the single exception regarding manipulation. Since CRAB is deployed from a drifting support ship rather than one which is underway, the vehicle can be placed on the bottom and, by maneuvering the support ship to station-keep above CRAB, adequate time is gained in which samples can be retrieved by the vehicle's manipulator.

Closed circuit television is not as heavily relied upon on towed vehicles as it is on the tethered, free-swimming vehicles. The reasons vary, but essentially reduce to the fact that there is no need for continuous video taping of the bottom. Since the vehicles move at very slow speeds (0.5 to 1 knot), periodic images of the bottom on TV (using strobes as light sources) are adequate. A further consideration involves image resolution of TV. Since resolution of the TV image does not compare in quality with photographic techniques, operators of deeply towed vehicles rely on photography for documentation rather than TV.

2.3.8 Navigation

Position accuracies acceptable to towed vehicle operators range considerably. Many, if not the majority, do not employ a means of tracking the vehicle itself.

Since much of their work does not call for precise positioning, they can accept the ship's position - obtained by one of several electronics positioning systems - as being reflective of the towed vehicle's position. Obviously there are discrepancies in this procedure, but when the task at hand involves surveying or mapping, for example, manganese nodules, vehicle position accuracy errors of hundreds of meters or more are acceptable since the deposit itself may cover hundreds of square kilometers. In shallow water investigations, such as conducted by RUFAS, the error between ship and vehicle positions is also acceptable owing to the relatively short length of towing cable.

The vehicle DEEP TOW, TELEPROBE and the NRL System operate within closer positioning tolerances. All of these systems are capable of positioning the towed vehicle (and the support ship, in some instances) relative to a bottom-mounted transponder system similar in concept to those described in Section 2.1.13.a. The DEEP TOW system reports position accuracies of 2 to 5m (7 to 16 ft) with a bottom-mounted system of the Marine Physics Laboratory, design. The NRL System, in addition to having a bottom-oriented navigational capability, also employs a surface-oriented, short baseline system for vehicle tracking.

2.3.9 Support Ship Requirements

For deep towed vehicles the support ship requirements are quite rigid and, similar to bottom-crawling vehicle support ship requirements, "ships of opportunity" are not acceptable. Since each vehicle has its own special requirements no general statement regarding support ships can be made which applies to all cases. The critical components in all deep towed systems are: good low speed handling characteristics, the winch, the handling system, storage and deck space, and berthing accommodations. The support ship requirements for the DEEP TOW System can serve to gain an appreciation for the deep towed vehicles at large. These are as follows:

> Must have installed winch or equivalent deck load carrying capability, ability to install crane, space for 2m x 3m (6 ft x 10 ft) storage and workshop van, at least 37 sq m (400 sq ft) of enclosed and dry lab area. Ship must have good low speed propulsion (diesel electric, cycloidal propulsion, variable pitch propellers, auxiliary low speed system, etc.) and bow thruster with enough horsepower to turn into a reasonable wind while maintaining a 4,536kg (10,000 lb) line pull at 1 to 2 knots. Almost any AGOR or AGSS should be satisfactory. Offshore drilling supply boats often satisfy all but the low speed capability, which could be provided by a pair of Murray-Tregurtha Harbormaster units, and the laboratory and living space requirements, which can be met with vans. Power: 20 amps of reasonably regulated 60 Hz 110 V single phase for the actual equipment. Crane has its own small diesel engine. Winch (if not normally installed) requires 120 kW 440 V, 60 Hz, 3 phase power.

All towed vehicles, but one, are launched/retrieved and towed off the stern of their support ship; the exception is the NRL system. This system was supported by USNS MIZAR, 81m (266 ft) long, 16m (52 ft) beam, 6m (19 ft) draft and displaced 3,447t (3,800 tons). Instead of stern launch/retrieval, the vehicle was deployed through a 4m x 7m (10 by 23 ft) centerwell. The well extends from main deck to keel and is open to the sea and covered over by hydraulically-actuated watertight doors at main-deck level. The forward and after bulkheads of the well are semicylindrical in order to break up wave action when underway. To further dissipate the energy of water in the well, baffle plates are mounted at the well ends, above and below the waterline. A completely enclosed bridge-truss structure straddles the well which has a 45t (50 ton) design load-carrying capacity. The carriage, an elevator-like structure riding four vertical guiderails through the well, provides the means for launching and retrieving the towed vehicle. During a towing operation the carriage is locked at keel level and provides the towpoint for the cable streaming the towed vehicle. Upon retrieval, the towed vehicle is nested to the underside of the carriage; both are then hoisted through the well. The carriage is then locked at its uppermost elevation, the well doors are closed, and the vehicle is lowered to rest atop the well doors. The carriage steadies the vehicle and permits launching and retrieving in sea states of 5 or more.

2.4 UNTETHERED VEHICLES

Technology in this field is best described as emerging. Although the Applied Physics Laboratory (APL) of the University of Washington has, for over a decade, successfully operated the untethered SPURV and UARS vehicles, there are several major technological areas where breakthroughs are required before untethered ROVs can equal the capabilities of their tethered counterparts. The following discussion describes current developments in this area and the present state-of-the-art. A listing of untethered vehicles and the activities involved with each vehicle is presented in Table 2.7. Appendix F contains descriptions of each vehicle to the extent that dimensional and operational data are available.

2.4.1 SPURV I & II and UARS

The APL vehicles are the only untethered vehicles known to be operational in the civil community. A particularly lengthy description of the SPURV vehicles is given in Appendix F since they are the only operational vehicles in this category.

The SPURV (Self-Propelled Underwater Research Vehicle) has been under development at APL since 1963, and has conducted hundreds of runs, mainly from U.S. Navy AGOR-type ships (Widditsch, 1973). The initial objective was to develop a controllable trajectory vehicle to acquire data on physical properties of the sea, particularly temperature and sound velocity, and for submarine wake investigations. A 3-element transistor array on the vehicle's bow was developed to obtain multiple microstructure data and a fluorometer for dye diffusion and water transport studies has also been developed. There are presently three operational SPURVs: two SPURV I's which are designed for 3,048m (10,000 ft), and one SPURV II for 1,524m (5,000 ft) depth. Oceanographic and vehicle performance data are multiplexed and digitized and taped on a special recorder. Digital-computer data reduction provides a run summary printout and system performance check a short time after a run. Data

TABLE 2.7 UNTETHERED REMOTELY OPERATED VEHICLES

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer
EPAULARD	1	19,685/6,000	Construction	CNEXO Toulon, France	Same
OSR V&H	2	820/250	Unknown	Mitsui Ocean Development and Engineering Co., Ltd., Tokyo	Same
ROVER	1	984/300	Development	Heriot-Watt University Edinburgh, Scotland	Same
SPURV I	2	12,000/3,658	Operational	Applied Physics Laboratory University of Washington Seattle, Washington	Same
SPURV II	1	5,000/1,524	Operational	Applied Physics Laboratory University of Washington Seattle, Washington	Same
UARS	1	1,500/351	Inactive	Applied Physics Laboratory University of Washington Seattle, Washington	Same
UFSS	1	1,500/357	Construction	Naval Research Laboratory Washington, D.C.	Same
Unnamed	1	2,000/610	Development	Naval Ocean Systems Center San Diego, California	Same
Unnamed	1	3,000/914	Development	University of New Hampshire Durham, New Hampshire	Same

are also telemetered acoustically to the support ship which carries a transducer array for receiving data and tracking/commanding SPURV. Frequency-shifted and digitally-coded signals provide the acoustic link. Depth control uses a digital reference which is manipulated to provide incremental, sawtooth or long, slow, ramp-like depth excursions. Course changes on an azimuth program are available on command.

The UARS (Unmanned Arctic Research Submersible) system was developed during a two-year program (1971-1972) with the objective of advancing technology to permit remotely controlled under-ice observations and demonstrating the system's capability (Francois and Nodland, 1972). The system consists of two major elements: the vehicle which serves as an instrument platform and an acoustic tracking, command and recovery system. The major instrumentation package aboard UARS is an under-ice acoustic profiling system by which the elevation of the under-ice surface is measured and digitally recorded five times a second on each of three separate, narrow, upward-looking beams which provide an overall elevation accuracy of 0.09m (0.3 ft). An obstacle avoidance sonar detects potential pressure ridge projections to the desired operating depth of UARS. Silver zinc batteries supply power for runs in excess of 10 hours at 3.7 knots. Launch and recovery of the vehicle was conducted through the Arctic ice cap and is described in Appendix F.

The UARS system was successfully demonstrated off Fletcher's Ice Island (T-3) in the Spring of 1972. It has been inactive since then.

2.4.2 EPAULARD

The EPAULARD vehicle is a development of the Centre National pour l'Exploitation de Oceans (CNEXO). Its purpose is to conduct exploratory missions of the deep ocean floor. The primary exploratory instruments carried by this vehicle are a photographic camera/strobe and an echo sounder. Its projected operating depth of 6,000m (19,685 ft) makes it the deepest operating untethered system under development. Operationally EPAULARD's mission is straightforward, in that, it is programmed to run a pre-determined course at a selected speed and duration once it arrives at the bottom. All data will be stored aboard the vehicle for processing on the surface. Sea trials of the prototype are scheduled to commence in July 1979.

2.4.3 ROVER

The ROVER vehicle will be the culmination of a five year program now underway at Heriot-Watt Unversity, Edinburgh, Scotland. Conceptually, ROVER will operate "piggy-back" from ANGUS-003 and at a specified depth will be deployed from it without a tether. TV signals (1 picture/second), command/control functions, and other data will be transmitted from ROVER to ANGUS-003 through-water.

The scheduled activities for the ANGUS-003/ROVER development program are as follows:

Period	Activity
June 78/79	Continuation of study through to trials of ANGUS-003 under computer control. Intensification of Dept. of Industry study, under headings of (i) acoustic command link; (ii) TV bandwidth reduction; (iii) vehicle studies. Preliminary studies of "piggy-back" vehicles and a model tetherless vehicle.
June 79/80	Continuation of ANGUS-003 program. Design of "piggy-back" and model tetherless vehicle. Design of total micro-computer control and display system, and navigation system. Study of alternative navigation and positioning systems. Manipulator and robotics studies.
June 80/81	Continuation through to initial hardware, and experimental systems carried aboard ANGUS-003. Deep-ocean vehicle studies with industry.
June 81/82	Commissioning trials of experimental vehicles, under wired control. Commissioning trials of full navigation and micro-computer command and information system. Design of deep ocean vehicle with industrial partner(s).
June 82/83	Commissioning trials of full "piggy-back" and tetherless vehicle systems. Completion of present study of manipulator and robotic systems. Intensification of deep ocean vehicle study.

2.4.4 Unmanned Free Swimming Submersible (UFSS)

The UFSS program is a development of the U.S. Naval Research Laboratory, Washington, D.C. Initially, the vehicle will be utilized for ocean science data gathering. As its intelligence quotient is enhanced (with techniques such as artificial intelligence and pattern recognition) in an evolutionary manner, the vehicle will assume additional functions and missions. Examples of such future work includes location of sunken submarines, mines, and other man-made objects on the ocean floor.

At present the UFSS program is in the construction stage. The vehicle is designed for 457m (1,500 ft) depth and an operating range of 125nm (230km) using lead acid batteries. Lithium thionyl chloride batteries are being developed to provide a 1,000nm (1,842km) operating range in the future. The current development program calls for complete at sea tests in September 1979. Similar to SPURV and EPAULARD, the UFSS vehicle will store its data aboard, basic course and speed data will be pre-programmed. The hull is designed for low drag and navigation updates will be accomplished by automatically and periodically surfacing to obtain OMEGA "fixes".

Ultimately, vehicle capabilities will include a 6,000m (20,000 ft) depth capability, more precise navigation capability (combining inertial navigation with OMEGA or doppler sonar), on-board data processing capability, pattern recognition and artificial intelligence and a mechanical manipulator.

2.4.5 Naval Ocean Systems Center

With funding derived from the U.S. Geological Survey, NOSC is presently developing a robot test-bed, untethered submersible to allow demonstration of new, improved ROV system technology. The submersible, which is 2.2m (9 ft) long, about 20 inches high and 20 inches wide, has a modular construction which allows expansions to accommodate additional payloads and new sensor systems as the technology for those systems becomes feasible to demonstrate. The vehicle is designed to follow a set of predetermined program tracks such as a parallel-path search or a figure-8 demonstration run. In this mode of operation, the vehicle is programmed via a computer console and an umbilical cable which is disconnected after the initial preprogramming phase. The vehicle is then allowed to follow this course until its mission is complete. A microprocessor is used to compare programmed altitude, heading, depth, and run sequence input data with measured data coming from an on-board altimeter, gyrocompass, depth sensor, and clock, respectively. The microprocessor generates digital error signals between the programmed values and the measured values, and issues error signals to the appropriate motor controllers. The motor controllers then power the DC motors which directly drive the propellers from a separate 24V battery supply. If emergency arises, there are automatic procedures which allow the vehicle to turn on an emergency beacon which shuts off all thrusters and is recovered at the surface.

After initial tests with this mode of operation, other methods of vehicle command control and communications will be demonstrated. Communication with the vehicle while it is underwater will eventually be incorporated by means of an acoustic or fiber optics link from the surface. The same programmable controls used for setting up initialization of the vehicle through the hard wire link on the surface will then be incorporated into this real time control system, together with some editing commands. The vehicle would then be able to (a) alter its preprogrammed mission sequence, and/or (b) respond to direct control commands from the surface.

The end result will be a system which is not limited by cable drag and cable-handling problems and one which should autonomously perform rudimentary tasks without direct operator control. At present vehicle power is obtained from sealed lead-acid batteries.

In-water tests of the vehicle were conducted in October 1978. Future plans for 1979 include: addition of a flux-gate updated gyro compass with a 12-bit A/D conversion accuracy; visual, colorgraphics display of programmed tracks; development of a magnetic pipeline following capability, and development of a fiber optics communication link to allow the use of both real-time command and control together with wide bandwidth data sensors such as TV and side scanning sonar.

2.4.6 University of New Hampshire

The objective of the University of New Hampshire's (UNH) program is to develop an underwater vehicle which will automatically follow a pipeline using an acoustic array as the sensing element. The vehicle has twin electric thrusters on three axes to allow navigation in any direction without preferred orientation.

The thrusters are controlled by an on-board micro-computer which is programmed to interpret information from 12 acoustic sensors mounted on a ring-like structure on the vehicle base. Basic characteristics of the UNH vehicle are: length: 1.5m (5 ft); width: 1.5m (5 ft); height: 0.9m (3 ft); dry weight: 372kg (820 lbs); speed (maximum sustained in still water): 3.5 knots (6.5km/hr); maneuverability: 5 degrees-of-freedom; mission duration: 8 hours; power: lead-acid batteries 7.5 kWh.

Field demonstrations of the test bed vehicle were conducted in the summer of 1978. Future work involves: investigation and determination of the optimum navigation system for a pipeline inspection vehicle; design and fabrication of a one-way (and, subsequently, two-way) acoustic telemetry link; and to develop a control concept which will allow operator control of an untethered ROV.

3.0 VEHICLE APPLICATIONS

The categories of tasks performed by all types of ROVs are presented in Table 3.1, and the foregoing sections briefly described the applications of bottom-crawling, towed and untethered vehicles. The following discussion relates to present applications of tethered, free-swimming vehicles.

The dominant user of tethered, free-swimming ROVs is the offshore oil and natural gas industry. Second is the military and third is the scientific/ research community. The functional performance of ROVs in the industrial sector are arbitrarily placed in one of the following categories:

Inspection
Monitoring
Survey
Diver Assistance
Search/Identification
Installation/Retrieval
Cleaning

These categories are not mutually exclusive, since overlapping to some degree occurs.

Inspection, as opposed to monitoring, consists of determining and documenting the location and/or condition of undersea structures.
Monitoring includes observation and/or measurement of tasks which are underway at the time of ROV deployment.
Survey involves measurement (i.e., mapping) and sampling of natural and man-made bottom features.
Diver Assistance includes tasks in support of diver activities.
Search/Identification entails locating and identifying objects intentionally and unintentionally placed on the ocean floor.
Installation/Retrieval includes assistance in installation of fixed structures and pipelines/cables and assistance in retrieval of hardware.

3.1 INDUSTRIAL TASKS

3.1.1 Inspection

The majority of work conducted at present falls into the inspection/monitoring categories. Operators estimate that ninety percent or more of the work they are called upon to perform are these tasks. The primary work instrument for inspection is the television camera, although more recent tasks include application of conventional non-destructive testing (NDT) equipment. The following list identifies the major inspection tasks:

Ascertain geometrical configuration and position of pipelines and/or cables following installation.
Determine and document the condition of pipeline concrete coating after installation
Accurate determination of pipeline tie-in positions
Leak detection
Wellhead structural integrity checks
Assure clearance of lowering/guiding lines
External examination of concrete platforms

TABLE 3.1 ROV WORK CATEGORIES

TETHERED, FREE-SWIMMING VEHICLES

Industrial	Military	Scientific/Research
Inspection	Inspection	Inspection
Monitoring	Search/Identification	Survey
Survey	Installation/Retrieval	Installation/Retrieval
Diver Assistance		
Search/Identification		
Installation/Retrieval		
Cleaning		

BOTTOM CRAWLING VEHICLES

Industrial	Military	Scientific/Research
Bulldozing	Drilling	None
Trenching	Trenching	
Inspection		
Manipulation		

TOWED VEHICLES

Industrial	Military	Scientific/Research
Survey	Search/Indentification/ Location	Geological/Geophysical Investigations
	Survey	Broad Area Reconnaissance
	Fine-grained Mapping	Water Analysis
	Water Sampling	Biological/Geological Sampling
	Radiation Measurements	Bio-assay
		Manganese Nodule Survey/Study

UNTETHERED VEHICLES

Industrial	Military	Scientific/Research
None	Conductivity/Temperature/ Pressure Profiling	Bathymetry
	Wake Turbulence Measurements	Photography
	Under-ice Acoustic Profiling	

- Dam integrity inspection
- Mine shaft inspection
- VLCC hull inspection
- Structure NDT inspection (including cleaning) for:
  - Sea floor scouring
  - Anode corrosion-potential measurements
  - Ultrasonic thickness measurements
  - Radiographic inspection of risers
  - Bent and/or broken members
  - Debris accumulation

Since most of the tasks involved in the foregoing list are self-explanatory, it is unnecessary to describe them all in further detail. A few tasks, however, warrant further explanation since they are major endeavors of the ROV industry. Accompanying several examples are references which indicate the source of the information. Where a date accompanies the reference, it can be found in Appendix B.

3.1.1.a Visual inspection of pipelines (Westwood, 1978, Sub Sea surveys, Ltd.)

After the vehicle has been launched and while it is descending to the seabed, the pipeline is located by side scan sonar. The vehicle moves toward it, with direction from the side scan data, until visual contact is established.

A numbered field joint on the pipeline is located and a position fix taken, referenced to surface navigation (or seabed long baseline navigation if required). The vehicle is now piloted along, while the support ship maintains station overhead, and the pipeline and a continuous video tape is produced which shows the state of the pipe, any damage, the pipe trench, etc. All of this information is continuously recorded on video tape and referenced to time (which is displayed on the TV screen), field joint numbers, and geographical positions. At points of interest still photographs may be taken for greater resolution.

In addition to the video tapes the final results can be presented to the client in the form of a "pipe sheet" drawing which shows state of burial, any damage to the pipe, suspensions, etc.

3.1.1.b "As Laid" Inspection of Cables (P. Gaudillere, 1978, SESAM)

Charting of cables "as laid" is accomplished (using an RCV-225) as follows: A minipinger is installed on the vehicle to work with a surface-oriented acoustic system installed on the support ship. The position of the vehicle with respect to the ship is updated approximately twice per second; using the ship's heading and position as given by gyro and a range-finding system, the UTM coordinates of the vehicle are thusly obtained. All data is put into a mini-computer for automatic computation or plotting, computations can also be made with a pocket programmable calculator. The relative position accuracy of the ROV is found to be better than ±5m (16 ft) when used with a Motorola Mini-Ranger system. When the support ship is equipped with a joystick control (as are most dynamically positioned vessels) the task of keeping the support ship directly over the vehicle is greatly simplified. Attempts have been made to operate the support ship in an automatic mode (dynamic positioning), but software must be modified to gain smoother reactions from the thrusters. All visual data can be recorded on tape to provide a permanent record of such factors as abrasion, burial depth, suspended sections, links and coils. Since the RCV-225's depth sensor is capable of measuring depth to ±0.1m (0.3 ft) accuracy, it is sometimes positioned to permit rapid measurements of cable or pipe suspensions or depth of scouring around such structures.

3.1.1.c Structure Inspection (NDT)

A major portion of structural inspection consists of merely looking at the structure and recording the observations on videotape or photographically. Such observations, on steel jacketed structures, may consist of: 1) assessing potential damage to members due to ship impact, storms or earthquakes; 2) noting the presence or absence of anodes; 3) locating and identifying debris which is caught on or rests against the structure and 4) assessing the degree of scouring (or absence of such) at the platform's foundation.

The foregoing describes typical inspection activities in U.S. waters, however, in the English and Norwegian sectors of the North Sea government regulations regarding periodic certification of offshore structures require knowledge of the structure beyond that which can be obtained from visual observations. To supply such information several ROV operating companies have developed and employ a variety of Nondestructive Testing (NDT) techniques. One of the more progressive firms in this area of ROV application is England's Sonarmarine Ltd. The entire ROV system (SMT 2) is designed specifically for application from deep-water production platforms and operates as an independent unit from the platform with its own launch/retrieval system, power supply and operations modules. The "package" is certified by Lloyds Register of Shipping to operate from a production platform and conforms with the safety requirements of platform operators. The following list of NDT instrumentation has been developed for their vehicle and is offered for inspection services:

Video Cameras

The three cameras mounted on the vehicle are used for inspection work. One of the cameras, a wide-angle S.I.T. low-light design, is mounted on a tilt mechanism and used principally by the pilot. It operates in very low light conditions and obtains video data in murky conditions. The second camera is a vidicon design and is mounted either on a pan and tilt mechanism or in a manipulator. One unit obtains high definition video of specific standard features. The third camera, a neuvicon design, can be interchanged between viewing positions as conditions dictate or mounted in a stern position as a navigation aid when working in a platform. Two 3/4 inch cassette recorders are available-one operating continuously to record the complete dive profile, the other to record specific data required by inspection engineers.

Color photographs of specific features can be taken using a stereoscopic camera pair fitted on a pan/tilt unit. On-site processing is available.

C.P. Probe

The C.P. probe checks the level of protection of the platform's sacrificial anode system. A silver/silver chloride reference is held in the jaw of one of the two manipulators and is connected via the umbilical to a high impedance digital voltmeter. The circuit is completed by attaching the other side of the voltmeter to the platform. The potential values are displayed on the video monitor. (The French company SESAM, also provides this service from their RCV-225).

Marine Growth Clearance

A water jetting gun with integral pump operates from any depth to provide a high pressure water jet to remove growth. The pump feeds a reaction jet and delivers pressure of up to 351 kg/sq cm (5,000 psi) at a flow rate of 38 l. (10 gals) per minute. The gun reportedly cleans to bare metal on an inspection point in seconds.

Sand Suction

A suction horn gives the ability to clear sand from around a pipe or similar object on the seabed and allows underside inspection of spool pieces, etc.

Ultrasonic Measurement

An ultrasonic wall thickness gauge, developed by Sonarmarine, has a probe held in a manipulator and deployed against the structure. The thickness of the structure is presented on a CRT display and also on digital display or an X-Y plotter.

Radiographic Inspection

SMT 2 places an isotope source and a photographic plate around a riser for a specified time and then recovers them. The data is used to detect flaws or cracks in the riser.

Under the direction of the platform surveyor, the operators of SMT 2 deploy these capabilities at structure locations in accordance with an agreed-to inspection schedule.

3.1.2 Monitoring

The distinction between inspection and monitoring was made earlier in this chapter. It is significant to reiterate that more than ninety percent of all tasks now being performed by ROVs fall into these two categories. The primary tools and instrumentation used to monitor various undersea tasks are the depth sensor, and closed circuit TV. The following constitutes some of the work ROVs monitor:

Grouting operations
Piling installation
Structure alignment/orientation checks
Measure and control of cable length during installation
Observation of pipeline pull-in procedures
Pipeline weighting procedures

The following discussion elaborates on several of these tasks. Monitoring of grouting operations consists of straightforward observation of the procedure as it is taking place to assure that no more grout than is needed is pumped to ensure, for example, that a skirt pile sleeve is full. At times the ROV can perform other tasks than monitoring during grouting operations. Peterson (1978) reported an unusual application of RCV-225 during installation of a 20cm (8 in) grouting pipe through a skirt pile from 0 to 116m (380 ft) in a Gulf of Mexico structure. The original lines had become plugged and the new line had to be positioned between the bell guide and the skirt pile. The weight of the pipe caused it to hang just outside of the bell guide. Pushing on the pipe with the RCV-225 caused the pipe to swing and the moment it was in position over the bell guide it was lowered. This application avoided shutting down operations in order to mobilize a diving bell system.

3.1.2.a Piling Installation (D. Michel, 1978, Taylor Diving Co.)

The following description is taken directly from the above reference and describes the application of one of Taylor Diving's RCV-225s during installation of the Cognac platform in 309m (1,015 ft) water depth in the Gulf of Mexico.

"One area in which RCV visual information was particularly useful was in lowering and stabbing of piles. Even though sophisticated acoustic devices gave precise positioning and rate of closing information to the operators, visual contact with the 70-ton pile closing on the bell guide made the project a lot easier. As the pile, held by the elevator, was lowered, the RCV was moved up to the elevator to determine proper attitude and assure personnel that winches were synchronized. Then it was moved back to the bell guide to assist in the final line-up and stabbing.

Once each pile was stabbed, a pile hammer developing more than 500,000 ft/lbs of force was used to drive it into the sea floor. This was a very critical stage and presented another important task for the RCV. Proper slack had to be maintained in two six-inch diameter hoses supplying air and two cables lowering the hammer. This was accomplished by constant visual check with the RCV. A second assignment performed was monitoring depth to which the pile had been driven."

3.1.2.b Structure Alignment/Orientation Checks

There are a wide variety of tasks which ROVs conduct within this category. The following represent two of the more sophisticated endeavors.

In 1978 Martech International's RCV-225 was used during installation of Petrobras' subsea production system in the Garoupa field offshore Brazil. Martech's portion of the work was conducted in conjunction with an RS-7 (Honeywell) Positioning System to position and inspect the system's Manifold Center (MC). The vehicle performed a number of survey tasks during this operation, the following are those tasks falling into the category of monitoring:

- -Confirmation that MC hydraulic umbilical was intact throughout the operation.
- -Confirmation that lowering lines and orientation lines were free from entanglement during swingdown and positioning operations.
- -Inspection and observation of the MC above the sea floor, including depth measurement just prior to final azimuthal rotation and lowering to sea floor.

- -Observation and confirmation of attitude of the MC after touchdown including visual close inspection of MC base skirt penetration into sea floor around the complete perimeter.
- -Observation and confirmation of release of the lowering bridle including visual check of each sling at release.
- -Visual observation and confirmation of release of the hydraulic umbilical from the MC.
- -Visual observation and confirmation of hydraulically operated flood valves to allow final flood-down during ballasting and to insure that valves were closed when ballasting was complete.

A further application of an RCV-225 by Taylor Diving during installation of the Cognac platform's Jacket Base Section (JBS) was described by Michel (1978). Similar to the Martech work described above, Taylor Diving's role was not restricted to only monitoring during this installation; survey and diver assist tasks were conducted also; these are discussed in subsequent sections. The RCV's role during installation of the JBS was to follow it as it was lowered to the bottom and check its depth, attitude and orientation. A visual study was performed to determine sea floor impact. The RCV was first "flown" (guided through the water) around the bottom of the JBS to determine sea floor penetration. A second check was made by setting the RCV down on top of each leg and using depth readings from the RCV's on-board pressure transducer to determine how level the structure was. Electronic sensors on the JBS transmitted all of this data to the control room. The RCV's task was to verify JBS readings. In one case an electrical umbilical carrying JBS data malfunctioned. The RCV served as an alternate source of information.

3.1.2.c Cable Installation (Gaudillere, 1978)

A major factor during cable installation (or flexible pipes) is to synchronize the speed of the lay barge with the speed of the winch from which the cable is reeled. If the winch is too slow excess tension is created which can damage the cabling; if it is too fast, excess cable is laid which can make loops which may turn into kinks which cause difficulty during subsequent burial operations. SESAM employed the RCV-225 from the cable lay vessel to monitor the touchdown point. By providing TV monitors on the bridge and for the winch operator, coordination between ship and winch speed was made possible for a smooth and uniform cable lay.

3.1.2.d Pipeline Pull-in Procedures (Gaudillere, 1978)

SESAM has used the RCV-225 to observe pipe pull-ins through "J" tubes and tunnels. The vehicle observes the pulling cable and approach of the pulling head. This permits careful monitoring of the re-entry pipe, and the stopper clamped on it can be stopped within 2cm (1 in.) of a pre-determined position thereby avoiding excess pull and its consequent damage.

3.1.2.e Pipeline Weighting (Gaudillere, 1978)

Pipes may be buried or anchored on the seabed by concrete blocks. A large quantity of these blocks have been installed in the Frigg Field, where SESAM's RCV-225 has been employed. The blocks, weighing from 10 to 20 tons, are lowered by a crane from the vessel on which the RCV is operated. The lowering procedure stops before the blocks reach the bottom, and the RCV is used to check the height of the block above the seabed to assure that there is sufficient clearance for the block to be placed over the pipe. The RCV is then landed on the pipe and provides a visual reference as the crane rotates to bring the block exactly above the pipe. A diver is used to align the block to the pipe and the crane driver, who uses a monitor in his cabin, only need lower the block from the picture in front of him without requiring orders from a third party. With a slightly different design of the block it is felt that this task can be performed without divers.

3.1.3 Survey

Surveying can consist of merely observing the bottom through TV or, in addition, mapping the bottom and sub-bottom acoustically with an echo sounder, side scan sonar or sub-bottom profiler. Such operations are conducted to survey pipelines or cable routes or sites for emplantment of structures. In some instances, such as pipe trench profiling, the survey is conducted subsequent to the excavation of a trench to assure that it meets specifications.

In some instances the ROV is utilized to confirm results obtained through conventional surface-oriented surveying techniques. Michel (1978) reported using the RCV-225 (during installation of the Cognac jacket base section described earlier) to perform a complete bottom survey prior to setting the JBS. A survey ship previously ran grid patterns over the area with towed side scan sonar. Taylor Diving's RCV-225 was subsequently used to make a complete visual check of the area in case items protruding from the bottom had been overlooked.

Peterson (1978) of Martech International reports similar utilization of their RCV-225 in the Gulf of Mexico where the RCV was used to inspect the bottom before a drilling platform was launched. The purpose was to look for depressions or obstructions that would prevent the platform from sitting level. Once the platform was set, it was inspected to see if it was level on the sea floor. In another instance a platform was set in 130m (425 ft) of water. The RCV was used to locate level bottom and the correct depth of water, since the original site was too shallow. The RCV searched for the correct depth as the barge was moved to deeper water.

In the previous section (3.1.2.b) Martech International's utilization of the RCV-225 in the Garoupa field for structure alignment/orientation checks was described. The vehicle was also used to conduct bottom surveys during this operation. Each time the derrick barge (which laid the manifold) was positioned a bottom survey was conducted. Visibility at the 112m (368 ft) water depth was in excess of 60m (197 ft) during daylight hours. The RCV-225 was guided to target center by tracking it with a Honeywell RS-7 positioning system. Two acoustic tracking beacons were used, one on the remote vehicle and the other on the vehicle deployment cage. The remote vehicle deployment winch system was mounted on the port side of the barge approximately 12m (39 ft) aft of the bow, thus remote vehicle travel to target center was about 30 to 80m (98 to 263 ft) depending on bottom current conditions during the mission.

Video tape recordings were made of all bottom surveys to build a library of the conditions. All debris was located and marked with relation to target center.

The preceeding surveying examples employed only the TV camera and depth sensor. J. Westwood (1978) of the Sub Sea Surveys Ltd. describes pipe trench profiling surveys that reach a higher level of sophistication in terms of data acquisition and treatment. Sub Sea Survey's pipe profiling system works on the principle of a high resolution echo sounder profiling the seabed below the submersible and a high precision micro processor-based pressure sensor to measure the vehicle's up-down motion. Data from both sensors is fed via the submersible's umbilical to a DEC PDP 11 computer. The data is programmed to remove vehicle motion, plot out the shape of the pipe trench and then stored for future use. In practice, the submersible is "flown" across the pipeline and a profile of the pipe plotted in real time onto a plotter. The advantage of this system, according to Westwood, is the absence of a "stored air" reference with all its inherent drift problems. Additionally, data is available onboard in real time and in a format suitable for further computer analysis. Owing to the high operating frequency of the echo sounder (750kHz) and the very high precision depth measurement sensor, total system accuracies of centimeters are obtained.

A further surveying application of an ROV was conducted by the National Water Research Institute (formerly the Canadian Center for Inland Waters) in conjunction with the Geological Survey of Canada to survey a potential under-ice pipeline route for Panarctic Ltd. (Pelletier, 1977 and Roe, 1977). The site was located at a gas well in the vicinity of Drake Point on the east coast of Melville Island (Lat. 77N; Long. 108W). The pipeline route ran from 37m (120 ft) water depth to shore over a seabed overlain by ice-covered waters. The proposed route was 1,219m (4,000 ft) long and considered too risky for divers. A 5 X 6m (16 to 20 ft) hole was cut through the ice to deploy the vehicle (TROV). Equipment on TROV included a sub-bottom profiler and a side scan sonar, in addition to basic equipment such as TV, 35mm still cameras, etc. The operation was conducted in temperatures of -45°C and the work was conducted from inside a heated work tent. A major objective was to note and chart the presence of gouges in the seafloor caused by wind-driven ice dragging along the bottom. Such moving masses could destroy a pipeline and possibly other sea floor installations that it contacted.

3.1.4 Diver Assistance

While Remotely Operated Vehicles have replaced the diver in several work areas, they are also significantly augmenting his work capabilities and efficiency in others. Although no ROV has been specifically designed as a diver assist vehicle, they are proving quite adaptable to this chore. This is particularly true of the smaller vehicles, such as the RCV-225, which can easily be pushed out of the way by the diver if they inadvertantly interfere.

Based on the current activities of industrial firms such as Taylor Diving, SESAM and Martech International, the following tasks are being conducted in support of diving activities:

Diving support ship positioning assistance
Continuous monitoring of the diver in terms of safety
Initial diving gear check out for leaks
Augment surface understanding of diving conditions
Precise location of dive site prior to diver deployment
Evaluate diver site conditions in terms of safety
Provide mobile, independent light source
Inspection of potentially diver-hazardous areas
Inspection of area too small for the diver
Assist diver in monitoring of equipment installation
Monitor/inspect diver's work
Document diver's work photographically or with video TV

To exemplify the ROV's application to the above tasks, three work instances are presented.

a) Taylor Diving Co., Cognac Platform Installation, Gulf of Mexico (Michel, 1978)

During all deep diving operations, the RCV-225 accompanied the divers. During each diving bell run, the launcher was lowered to working depth first and the RCV moved in place to monitor the bell's descent. While the diver was preparing to exit the bell, the RCV was moved to the work site and personnel topside made a pre-survey of the upcoming task to insure the diver had proper tools, etc.

As the diver left the bell, the RCV aimed toward it. This accomplished two things. First, it provided a visual target (the vehicle's lights) to which the diver could swim. Secondly, it allowed barge personnel to observe the diver. As the diver arrived at the work site, the first task was to move the RCV behind him, checking his diving gear (much as a buddy diver would do).

Tremendous amounts of time were saved. Visibility at 305m (1,000 ft), even in clear water, is poor due to a complete lack of sunlight penetration at extreme depths. A diver carrying a hand light can see about 9m (30 ft) at best. The RCV on Cognac provided a clear field of view up to 122m (400 ft) away. The RCV's silicon intensified target camera produces a usable picture with as little as .002 foot-candles of light. This feature, plus the onboard compass, allowed the RCV to maneuver almost directly to an object that might take a diver hours to find. Another time-saving feature was the extreme maneuverability of the RCV, particularly on a vertical axis. Speed is 1.7 knots forward, 1 knot reverse, 1 knot port or starboard and .5 knots up or down. A diver saturated at 305m cannot safely ascend more than a few meters above this depth.

On one occasion, a burning umbilical was fouled at the 152m (499 ft) level. The RCV which had been observing the diver quickly ascended to 152m and the RCV operator directed barge personnel to take up and relieve tension on certain cables and hoses to the JBS, thereby freeing the rig. Had the RCV not been on board, the alternatives would have been to saturate another team of divers in the second chamber or decompress the saturated divers to 152m. The latter method would have taken five days.

b) SESAM, General North Sea Work (Gaudillere, 1978)

SESAM has been operating their RCV-225 with various diving companies in the North Sea. The following description of its works is taken from the above reference.

> "The first time divers hear of or see the RCV-225 they despise it. They are scared, and they don't like the 'spy.' But it doesn't take long before they ask for it at each dive. The vehicle is so small and light that it is not a danger. They just push it away if it comes too close (this is not the case with other types of vehicles).
>
> Much diving time is saved in using the RCV to search for the exact place to work. The vehicle is sent first, and the place is identified by people on the surface without ambiguity. The diver is then sent out of the bell and can go straight to the job by looking for the lights of the vehicle. With diving bells which can accommodate only two divers there is only one out at a time and having the RCV watching makes the diver feel much safer. (It is not only a feeling because he is really not alone anymore.) The RCV is even used to give the diver some light to the job he is working on. As a light source it can be placed right on the work. The work can be checked after completion and corrected as necessary from the surface."

c) Martech International, Sub-Sea Valve Inspection, Gulf of Mexico (Macdonald, 1978)

After mooring the ship in the area indicated by the surveyor, TREC was launched and dived to the sea floor. Based on surface positioning information and the Honeywell RS-7 positioning system, the TREC was directed on a course to intersect the pipeline. Once the pipe was in sight it was "flown" until the valve was located. TREC was then positioned in accordance with instructions from the diving supervisor. The RS-7 mini-beacon on the TREC then was used as a reference point which permitted mooring cables to be adjusted such that the bell launching system was directly over the valve. The bell was then lowered which maintained a one-atmosphere environment. The beacon on the bell was used to direct mooring adjustments until the position of the bell and TREC were near-coincident. The divers were able to see the TREC lights and they then commenced bell pressurization which was followed by exit and inspection. The TREC maintained position and acted as a known reference point for the dive.

In view of the fact that these applications of ROVs are incidental to their intended utilization, it is impressive to review their accomplishments. Indications are that as more experience is gained through application of vehicles in the diver assist mode, their role in deep, saturation diving will increase.

3.1.5 Search/Identification

Tasks within this category have included the following:

Location and identification of lost equipment and materials
Location and identification of acoustically-located objects
Debris identification and location
Location of sub-bottom pipeline taps

In many aspects search and identification tasks are similar to surveying, in that the tools and techniques are identical. The primary difference is that search and identification tasks involve investigation of man-made artifacts, surveying encompasses both man-made and natural objects and features. In many instances the task involves no more than straightforward visual inspection using TV and compass, in others it is more sophisticated. J.D. Westwood of Sub Sea Survey Ltd. described a typical search/identification mission conducted in the Norwegian sector of the North Sea. The following account is largely extracted from his paper (Westwood, 1978).

The aim of search/identification surveys is to determine the extent of debris remaining from the drilling operations and abandoned well sites which may prove destructive to fishing equipment. Such surveys are required by the Norwegian Petroleum Directorate (NPD). They require each oil company to: 1) conduct a side scan survey within a 2km square around the site center, in the case of wells drilled by semi-submersible rigs, and a 600m square for jack-up platforms, and 2) visually inspect the seabed over a 200m square centered on the well position. This survey being a 'grid search' with 20m spaced lines. It is also necessary to visually inspect items seen on side scan outside this 200m square.

Initially, the abandoned well sites are located by towing a magnetometer. Strong magnetic anomalies can be observed even when the wellheads have been removed and the casings cut off below the seabed. This is followed by a side scan survey of the 2km square area. A local navigation net is established by laying three transponders around the edges of the site. These are calibrated by one of the established methods.

Using the acoustic navigation system the ship is brought to the dive position and the submersible launched. It dives to the seabed and is piloted into position to begin the survey. The vehicle is driven over the predetermined 200m line space grid until an item of debris is encountered. The item is examined and sized using the vehicle's TV cameras and manipulator, the results being recorded on video tape. If necessary, still photographs are taken, and an item of interest is numbered and plotted onto the site chart. This process is continued until the site has been completed. If items are discovered near the edge of the site the survey grid is extended to provide coverage beyond that point. In practice some items plotted are quite insignificant, however, even a tin can can be a good position marker and when re-encountered can provide a check on the accuracy of the navigation system.

Using the vehicle's manipulator and specially developed tools, lifting lines can be attached to items of debris which are then winched up onto the support ship. All of these operations are carried out without anchoring the ship which continually moves along with the submersible. Video monitors on the bridge display TV from the seabed and a communications net connects pilot, observer, navigator, deck and the ship's helmsman.

Onboard the support ship preliminary charts are plotted out showing the seabed coverage of the side scan survey and submersible TV survey. Upon returning to shore, results from the preceding work period are reprocessed, video tapes copied, titled and annotated and final reports produced. These results are used in discussions with the NPD to determine which items are likely to constitute a hazard to fishing and therefore warrant removal.

3.1.6 Installation/Retrieval

Work within this category have included the following tasks:

Collection of small-sized artifacts
Debris recovery assistance (attach lift lines, provide guidance, etc.)
Lost equipment and component recovery assistance
Provide real-time depth measurements during equipment installation
Assistance during Blowout Preventer (BOP) installation (visual observations, depth and orientation measurements)
Cable burial by water jetting

Much of the assistance ROVs provide during installation of hardware has been described earlier under monitoring and diver assistance tasks. Additional work involves variations on this theme, such as monitoring the depth, orientation and attitude of structures and pipelines as they are being installed and after they have been installed. While virtually all ROVs are capable of only limited assistance during the installation phase, one, Ametek Straza's SCARAB, is specifically designed to play a major role in support of submarine cables.

The SCARAB system is designed to assist in repair and surveillance of submerged telephone cables. It can locate, unbury, attach, cut, recover and rebury a malfunctioning cable to depths of 1,828m (6,000 ft). In addition to closed circuit TV and obstacle avoidance sonar, SCARAB carries the following equipment:

Cable locator: magnetometer probes employed to locate a buried cable fault,
Cable deburial: a dredger nozzle and a 35hp suction pump can be deployed on the mechanical arm to debury the cable down to 1.2m (4 ft) under the seabed,
Cable gripper: two, of which at least one is attached to a surface lift line and, after the proper grip has been obtained, the gripper can be ejected. (The cable can be recovered by either a lift line to the ship or by clipping a lift line to the vehicle's umbilical.)
Cable cutter: mechanical cutters are carried in the manipulators which are capable of cutting telephone cable or rope up to 10cm (4 in) diameter,
Cable reburial: a special jet nozzle powered by a 35hp pump and a wheel assembly are located beneath the vehicle frame which are used to rebury the cable.

Retrieval assistance by ROVs is limited to providing an evaluation of the *in situ* conditions and attachment of guidance lines for subsequent attachment of lift lines. Present vehicles simply do not have the power to lift loads of more than a few kilograms to the surface and their propulsive power is inadequate to physically tow and position the large diameter wire rope or hawsers required to retrieve large objects from the seabed. In spite of these handicaps several vehicles have been used to provide assistance - along the lines mentioned - in retrieval of lost or abandoned components.

3.1.7 Cleaning

Cleaning activities preparatory to NDT inspection as conducted by Sonarmarine Ltd. were described in Section 3.1.1.c. In this section cleaning as an independent function is addressed.

The only ROV known to be designed exclusively for hull cleaning is SCAMP. The vehicle is manufactured by Winn Technology Ltd., Kilbrittain, Ireland, and is marketed in the United States by Butterworth Systems, Inc. Florham Park, New Jersey (Veccia, 1979). The vehicle measures 1.8m (6 ft) in diameter and holds three large, rotating brushes. Propulsion is derived by three traction wheels which are held against the ship's hull by an impeller with a force of 454kg (1,000 lbs). This provides a traction effect of 204kg (450 lbs) which permits use of the vehicle in currents up to 3 knots (5.5km/hr). The vehicle can be directed to advance, stop and reverse or can be directed to hold a parallel line of motion. It is remotely controllable or can be controlled by a diver.

The primary employment of SCAMP has been in the cleaning of large ship hulls which is generally performed while the carrier is unloading or at anchor. A unique hull coating has been developed by the Ship Research Institute of. Norway which is physically reactivated at intervals of 12 months using the SCAMP vehicle fitted with specially designed brushes. Pigmented with toxic cuprous oxide, the reactivation points are applied in layers to the ship's hull during dry dock. Small amounts of the toxin are released as the ship transits. After approximately one year the toxic effectiveness of the outer layer weakens to the point where it no longer inhibits marine growth. At this point the SCAMP abrasively removes the ineffective top layer of paint and exposes the still-active anti-fouling surface beneath. Color change built into each layer of paint verify that reactivation (i.e., removal of the ineffective layer) has been achieved.

Unlike all other ROVs SCAMP does not carry closed-circuit television as part of its standard equipment, but can employ TV if necessary.

3.2 Military Tasks

Military applications of ROVs closely parallel those of the industrial sector, but are reduced in scope. Although details of some military applications are not publically available, the following categories represent those which are:

Inspection
Survey
Search/Identification/Location
Retrieval

Reflecting an interest in deep, as well as the shallow waters, military vehicles are the deepest diving ROVs. In the industrial sector the ORCA, and the RCV-150 and 225 at 1,829m and 2,012m (6,000 ft and 6,600 ft) respectively, are the deepest diving vehicles. (It should be noted that industrial applications have not yet proceeded beyond 914m depth.) The U.S. Navy's CURV III is designed for 6,000m (19,685 ft). However, the remaining military ROVs, of which there are about ten, are designed for operations in less than 762m (250 ft) of water.

Another area in which military application differs from industrial application is in the use of manipulators. Very few (less than 5 percent) of the industrial tasks involved the use of manipulators. The military, on the other hand, utilizes some form of manipulation in at least 25 percent of its work. A representative sampling of such applications is presented in the following discussion.

3.2.1 Inspection

The following tasks within this category have been reported:

Aircraft crash assessment
Sunken craft identification/assessment
Hardware inspection

3.2.1.a Aircraft Crash Assessment

In March 1977 a U.S. Navy A-7 aircraft crashed in 104m (340 ft) of water off Japan. The pilot apparently failed to separate from his ejection seat and deploy his parachute, and was subsequently drowned. The Supervisor of Salvage was called into locate, examine and, if possible, retrieve the ejection seat for an accident investigation.

A side scan sonar search of the area revealed the presence of numerous sonar targets in the area. The sea floor area searched was relatively clean and flat, and afforded a distinct advantage to the search efforts. The Navy's ROV DEEP DRONE was used to identify the sonar targets and examine and recover the ejection seat. A CTFM-compatible transponder was deployed on the bottom which was used to track the vehicle's position as it conducted the search/identification task. The second of two targets turned out to be the ejection seat. The pilot remained strapped to the seat. DEEP DRONE attached a grapnel to the seat which was lifted to the surface by the support ship. On the following dive DEEP DRONE retrieved the bottom-mounted transponder.

Other tasks included assessment of a commercial airline crash off Venezuela in 183m (600 ft) of water, and assessment of a helicopter crash in 40m (130 ft) of water off Sitka, Alaska. Normally a surface towed side scan sonar would have been used to locate the wreck, but in the Alaskan assessment the bottom was so irregular that the vehicle's CTFM sonar was used instead.

3.2.1.b Sunken Craft Identification Assessment

In November 1975 the ore carrier S S EDMUND FITZGERALD sunk during a storm in Lake Superior. There were no survivors or no explanation for the cause of the sinking. The sinking was so rapid and unexpected that no one was able to successfully abandon ship. Arrangements were made by the Coast Guard with the Navy to use CURV III for an assessment. Surface-deployed side scan sonar and magnetometers located a potential target, but there was no positive identification. CURV III identified the sonar target as the EDMUND FITZGERALD by reading the ship's name and home port on the stern in 182m (530 ft) of water. Subsequently, 12 dives were made to further investigate the wreck and over a total of 56 hours bottom time and 13,184m (43,255 ft) of video tape was recorded for shore-based accident investigation.

3.2.1.c Hardware Inspection

There are a variety of hardware inspection tasks which military vehicles are called upon to perform. These reported tasks generally involve inspection of underwater tracking or surveillance ranges with their associated hardware components. In many instances it is difficult to separate inspection tasks from other tasks since the vehicles are called upon to do more than merely observe. CURV I, for example, conducted an inspection of stakepiles at the Naval Ocean Systems Center's Pop-Up Range. The task involved cleaning (using a rotating brush held in the manipulator) the stakepiles to determine the extent of corrosion and subsequent photography of the cleaned sections. Subsequently, CURV I was employed to assist in the drilling and grouting operations for installation of new stakepiles. This work involved providing continuous monitoring of the operations to enable the engineers to view and document the proceedings. At one point a drill bit stuck and CURV I provided close-up television coverage of adjustments necessary during attempts to remove the drill bit.

In a subsequent task involving overhaul of the Navy's Azores Fixed Acoustic Range (AFAR) CURV III provided a variety of assistance. These tasks included: 1) rigging one of the acoustic towers so that it could be lifted from the sea floor; 2) cutting various electric cables from 38 to 89mm (1.5 to 3.5 in.) diameter; 3) retrieving these cables from the sea floor; 4) sonar mapping (i.e., surveying) of acoustic tower sites, and 5) inspecting the range once all the other tasks had been completed.

Although these inspection tasks are similar to those of the industrial community, there is no reported application of military ROVs to conduct NDT-type inspections such as are performed on offshore production platforms.

3.2.2 Survey

Reference was made in the above section to a sonar survey performed by CURV III to select a site for installation of acoustic towers in the AFAR range. During the SEALAB project of the sixties CURV I was used to perform bottom surveys for selection of installation sites. The survey included visual examination of the bottom, bottom slope and strike measurements, collection of bottom samples and indirect bottom strength measurements performed by observing the amount of sediment stirred up by the manipulator.

Unlike the industrial sector, military surveying tasks do not require the high degree of navigational accuracy or detailed bottom feature measurements. Although the capability to perform to industrial standards can be made available, the need does not appear to exist.

3.2.3 Search/Identification/Location

Within this category are a variety of incidents where objects of exclusive interest to the military are detected initially by surface-oriented techniques and, subsequently, acquired (on TV), identified and their position fixed by an ROV. Since a great portion of this work is considered as classified by the military, details regarding both the techniques involved and the objects sought are not available.

One of the major tasks within this category involves the location, identification, and, if feasible, the neutralization of underwater ordnance. In Section 2.1 a brief description ot the PAP-104's capability to locate, identify, and neutralize explosive ordnance was given. Over 128 of these vehicles have been constructed and delivered to various NATO Navies. Initial detection of underwater ordnance relies upon surface techniques; the ROV is dispatched after surface detection has found a potential target.

The U.S. Navy (Naval Ocean Systems Center, San Diego) has embarked on the development of a mine neutralization vehicle (MNV) of its own design. The prototype vehicle (Advanced Development Model) was constructed by NOSC and is intended to be deployed from a minesweeper. The MNV will be used to classify and neutralize sea mines previously detected by sonar. A high resolution scanning sonar and TV system will allow relocation and classification of the target mine. The umbilical cable is automatically stored, played out and reeled-in by the handling system as the situation requires, power for the vehicle is from the surface ship. In April 1978 a contract was awarded to Honeywell Marine Systems Center and Hydro Products to develop two engineering development models of the MNV. Further details of the vehicle are not available owing to military classification.

3.2.4 Retrieval

Probably the most frequent tasks military vehicles conduct is within this category. The objects retrieved include drill bits, torpedos, bombs, ships and manned submersibles. In virtually all instances the vehicles are used to attach lift lines from a surface ship to the object since they do not have the grasping capability nor the lift capability required to bring the object to the surface. Some examples of the scope of work conducted by the U.S. Navy's CURV vehicles are given below to indicate the nature and scope of retrieval tasks.

3.2.4.a Explosive Ordnance

In early 1966 an H-bomb was lost in the sea off Spain when two U.S. Air Force aircraft collided. The bomb was located by a manned submersible in 869m (2,850 ft) of water. Owing to the danger of entanglement within the shroudlines of a parachute attached to the bomb, the Navy's CURV I - instead of a manned vehicle - was dispatched to attach lift lines. Two lift lines were successfully attached, on the third attachment dive CURV became entangled and it was necessary to retrieve both it and the bomb concurrently.

While CURV's H-bomb retrieval was undoubtedly the most dramatic of ordnance retrievals, the bulk of its work has been the more mundane task of retrieving torpedos in Navy test ranges. Since the first operational days in the mid-sixties, the CURV vehicles have retrieved hundreds of torpedos from a variety of shallow and deep depths. In such retirevals the vehicle "homes" on an acoustic pinger in the torpedo and once the torpedo is visible on TV, attaches a lift device from the surface. This work continues to be the bulk of the U.S. Navy's ROV employment.

3.2.4.b Hardware Recovery

In many instances recovery of various components connected with tracking ranges has been accomplished. One such instance, reported by Smith (1968), involved retrieval of the 317kg (700 lb) transponders from the San Clemente Island range. Prior to this recovery all hardware recovered was "cooperative", that is, they were equipped with 9 and 45 kHz pingers for CURV to home on. These transponders were "uncooperative", in that they carried no pingers and CURV located them by finding and following electric cables attached to the units. A specially designed hook was attached to the transponders for recovery. Significantly, in both instances CURV became entangled in the lines after ejecting the hook and - reminiscent of the H-bomb recovery - it was necessary to retrieve CURV and the transponder together.

Another incident involved CURV III's participation in recovery of a nuclear generator (a Radioisotope Thermoelectric Generator or RTG) from 716m (2,350 ft) of water west of San Diego. The operation is particularly interesting because it typifies many of the problems encountered with both military and industrial ROVs. Recovery attempts began in 1972. The first attempt was unsuccessful for unspecified reasons. On the second attempt a surface buoy line severed CURV's control cable. Since the vehicle is positively buoyant it floated to the surface 14 hours later at almost the precise point ten miles south that had been computed from prevailing sea currents. On a subsequent attempt both hydraulic lines that open and close the vehicle's manipulators were broken and required repair. On the next try the compass malfunctioned and caused another aborted dive. Finally, the vehicle was able to attach a four-inch braided nylon line to the RTG for eventual recovery.

3.2.4.c Vehicle/Vessel Recovery

Some of the more dramatic ROV tasks have been in the retrieval of manned submersibles. However, retrieval of other vessels and large-scale devices takes place with far more regularity, but with less public attention. Examples of these types of endeavors are given below.

In 1978 the U.S. Navy's DEEP DRONE was dispatched to assist in salvaging a 13m (41 ft) Coast Guard boat off the coast of Oregon. The boat rested in 96m (315 ft) of water and the weather was severe during the duration of the operation. DEEP DRONE's task was to attach an 18cm (7 in.) hawser to the craft so that it could be retrieved by the surface. Surface conditions were so rough that a launch/retrieval scheme involving 4.5m (15 ft) outriggers had to be fabricated on the scene that would hold DEEP DRONE away from the support ship to prevent it from colliding with its support ship when being lowered or lifted to and from the water.

Rescue of personnel from stricken submarines is another area in which the Navy has employed an ROV, but only in a simulation mode. For shallow water rescue a McCann Chamber would normally be employed. The chamber is positively buoyant and winches itself down to the submarine by reeling in an escape hatch cable which is released on a buoy from the submarine. In the event that the buoy is not released or has failed to deploy the haul-down cable, alternate means must be employed, e.g., divers, manned submersibles. In October 1977 the Navy's DEEP DRONE demonstrated the capability to perform this wire rope attachment function.

Although the vehicle is in the prototype stage, the Naval Ocean Systems Center, San Diego, has developed a Solid Rocket Booster (SRB) Dewatering System for the National Aeronautics and Space Administration. The system, referred to as a Nozzle Plug (NP), is designed to dewater expended SRBs jettisoned during space shuttle launches. Briefly, the specifications of the NP are:

Length: 4.3m (14 ft)
Diameter (OD): 0.8m (2.5 ft) min.
2.1m (7 ft) max.
Buoyancy: +120kg (265 lbs)
Weight (in air): 1,497kg (3,300 lbs)
Operating Depth: 53m (175 ft)
Speed: 2 knots (4km/hr) horizontal
2.5 knots (4.6km/hr) vertical

The SRBs assume a spar (upright) mode when in the water and they require a log (horizontal) mode for towing to port for refurbishment. The NP is launched from a support ship and maneuvered on the surface to the SRB where it dives to inspect the SRB casing using its TV system. The NP operator visually acquires the nozzle opening by the same TV system. The Plug is then positioned beneath the SRB and, at the appropriate time, uses its vertical and horizontal thrusters to drive it up into the Nozzle throat. When the NP has docked, indicator lights on the surface console show that it is seated and locking arms are deployed to hold it in position. Dewater air is activated through the umbilical cable and a pressure differential is attained which forces the water out. As the water leaves the SRB it raises out of the water and, becoming unstable, falls into the log mode. At this point a sealing bag is inflated on the NP to prevent loss of air and return of water. Dewatering continues until the SRB is emptied. The umbilical cables are then disconnected from the ship and both the SRB and NP are towed to port where the NP is removed and refurbishment begun.

Assistance in recovery of stricken or trapped manned submersibles by U.S. Navy ROVs has occurred on two occasions. The first incident involves the submersible JOHNSON-SEA-LINK, the second involves the PISCES III.

In June 1973 the JOHNSON-SEA-LINK (J-S-L) became entangled in the rigging of a scuttled destroyed at 110m (360 ft) depth off the coast of Florida. Divers attempted to free the submersible but strong currents resisted their efforts. A manned submersible was dispatched but equipment malfunctions caused it to abort the dive. Approximately 32 hours after entanglement a Remotely Operated Vehicle (Plate 3.1) developed by the U.S. Naval Ordnance Laboratory to inspect undersea hardware, carried a grapnel hook which it affixed to the J-S-L. A line from the hook to the surface ship pulled the submersible free of the hulk.

Another submersible retrieval incident occurred in August 1973 when the submersible PISCES III sank to the bottom at 480m (1,575 ft) depth southwest of Cork, Ireland. The objective in this incident was to attach lift lines to the vehicle to pull it to the surface. Three lift lines were eventually attached to the submersible, two were attached by sister-vehicles and the third by the U.S. Navy's CURV III.

PLATE 3.1 On 18 June 1973 this ROV, operated by the U.S. Naval Ordnance Laboratory pulled the manned submersible JOHNSON-SEA-LINK I free of its entanglement in a scuttled destroyer at 107m (350 ft) depth. Equipment includes a CCTV, light, compass and two thrusters. The grapnel was affixed for the submersible recovery. (Courtesy U.S. Naval Ordnance Laboratory, White Oak, Maryland)

3.3 Scientific/Research Tasks

The application of ROVs by the scientific/research community has been minimal. In the U.S. only two applications of ROVs to scientific tasks have been reported. The first application was by the Environmental Protection Agency during August 1974 involving inspection of a radioactive waste disposal site off the California coast. The second was the use of a SNOOPY vehicle by NOAA's Manned Undersea Science and Technology Office in conjunction with a study of herring spawning studies off the northeast coast in November 1975. The Harbor Branch Foundation, Ft. Pierce, Florida; have been developing a scientific/ research ROV capability with their CORD vehicle, but at this time the CORD has not yet conducted studies in this area.

Only three countries, England, Finland, and Canada, are known to be operating ROVs as scientific/research vehicles. The Institute of Geological Sciences at Edinburgh employs the CONSUB 1 system; the Geological Survey of Finland (Geologinen Tutkimuslaitos) at Otaniemi has, since 1969, used their PHOCAS vehicle, and the National Water Research Institute at Burlington, Ontario operates a TROV vehicle for scientific purposes.

The work which has been conducted to date can be categorized as Inspection and Survey. In many instances reports of ROV activity deal mainly with the manner in which the vehicle performed operationally, and does not provide details of the work conducted. For this reason many of the following work examples are brief.

3.3.1 Inspection

In 1946 an area 41 to 70km (22 to 38 miles) offshore began receiving containerized radioactive wastes. Until 1959, when land burial of wastes were initiated, 47,750 containers were dumped in this area in water depth from 91m (300 ft) to 1,828m (6,000 ft) deep. In 1974 the Office of Radiation Programs, Environmental Protection Agency, conducted a study using the U.S. Navy's CURV III to: 1) determine the feasibility of surveying a waste dumpsite with an ROV, 2) obtain photographs of the containers (i.e., 55 gal. drums) to determine the degree of corrosion and fouling, and the relative abundance of organisms, and 3) obtain sediment samples adjacent to both intact and breached containers known to contain radioactive wastes. (Some of the containers held chemical munitions). The site selected was at the 914 (3,000 ft) depth contour. Over a five day at-sea period CURV III completed four successful dives for a total of 31 hours 55 minutes bottom time. Hundreds of color photographs of selected targets were taken along with sediment cores and grab samples at various sites. Although several operational areas were in need of improvements, the vehicle conclusively demonstrated its ability to perform such surveys at great depths (EPA, 1975).

Other work in this category includes archeological investigations by the Rebikoff Underwater Institute. Such investigations have been conducted in the Mediterranean and off the coast of Florida and the Bahamas. Specific details are not available, but the main ROV capabilities utilized were the TV camera and photographic cameras. These investigations were conducted by the ROVs SEA SURVEYOR and SEA INSPECTOR.

3.3.2 Surveys

Surveys, as conducted in the academic community, are more qualitative and less quantitative than the industrial community. Typically, these surveys involve visual reconnaissance of the bottom, collection of grab samples and photography. The English CONSUB 1 is also capable of obtaining hard rock cores, a capability found only on that vehicle.

In virtually all survey applications ROVs are used to confirm interpretations drawn from data previously obtained through conventional surface techniques, or to fill in details not attainable by conventional means. An example of this latter application was the study of pack ice thickness and configuration by the Finnish vehicle PHOCAS.

During the years 1974 through 1976 the Institute of Geological Sciences conducted a series of survey operations with CONSUB 1 at various locations offshore England. Results of these operations was to provide a basis of comparison between the capabilities of remotely operated vehicles and manned submersibles as survey platforms. According to Eden et al (1977), in most instances the remotely operated vehicle is competent to achieve results equivalent to manned vehicles on the continental shelf, and at significantly lower operating costs.

3.4 U.S. ROV Utilization

In late 1978 a survey was conducted of civilian U.S. ROV operators to ascertain the degree of utilization of these vehicles during the Fiscal Year 1978 period (1 October 1977 through 30 September 1978). At that time there were 11 operators who represented a total of 27 ROVs. Only three of the operators responded to the survey questionnaire (Taylor Diving Co., Martech International and Rebikoff Underwater Products), but they operate a total of 15 ROVs which was somewhat greater than half of the vehicles operating. The responses from these three companies are summarized in Table 3.2. The total dive days of all 15 vehicles is 2,007. Significantly, all were in support of - or aimed at the industrial market, and all were funded by the private sector.

These ROV utilization figures are interesting when compared against the activities of the thirteen civilian operational manned submersibles for the same period. During FY 1978, U.S. manned submersibles operated a total of 510 dive days, of these 122 (23%) were funded by the federal government; 123 (24%) by a private research foundation and 265 (51%) by private industry. The tasks conducted by manned vehicles are almost equally divided between scientific/research (43%) and industrial (46%).

TABLE 3.2 ACTIVITIES OF U.S. REMOTELY OPERATED VEHICLES (1 OCTOBER 1977 to 30 SEPTEMBER 1978)

Operator	ROV	Date Month/Day/Year	Mission	Location of Mission	Number of Diving Days	Max. Depth (Meters)
Martech International	RCV-225(2ea)	10/77-11/77	Inspection	Gulf of Mexico	1,220[1]	61-152
	RCV-225(2ea)	12/77-9/78	Inspection	Offshore Brazill		61-152
	RCV-225	3/78-9/78	Inspection	Gulf of Mexico		61-152
	TREC	4/78-9/78	Inspection	Gulf of Mexico		61-152
	TREC(2ea)	5/78-9/78	Inspection	Gulf of Mexico		61-152
	TREC	6/78-9/78	Inspection	Gulf of Mexico		61-152
Rebikoff Underwater Products	SEA INSPECTOR (DR 330-2)	1/77-9/78	Training	Ft. Lauderdale, FL	16	50
	SEA INSPECTOR	8/77-9/78	Training/ Demonstration	Cannes, France	6	70
Taylor Diving and Salvage	RCV-225(#3)	11/77	Inspection	Gulf of Mexico	2	116
	RCV-225(#3)	1/78-3/78	Inspection	North Sea	60	320
	RCV-225(#3)	6/78-9/78	Monitoring	North Sea	94	156
	RCV-225(#4)	5/78-9/78	Monitoring	Tasman Sea	150	140
	RCV-225(#5)	4/78-9/78	Monitoring	Gulf of Mexico	153	314
	RCV-225(#6)	6/78-9/78	Monitoring	Gulf of Mexico	84	314
	RCV-225(#7)	7/78-9/78	Inspection	North Sea	67	152
	RCV-225(#9)	10/77	Inspection	Gulf of Mexico	9	314
	RCV-225(#10)	12/77-5/78	Monitoring	Tasman Sea	146	140

[1] A daily breakdown of diving days was not attainable.

4.0 PROBLEMS ENCOUNTERED

The information in this chapter was obtained through personal interviews with a total of 20 operators and builders representing 51 operating vehicles. A secondary source was from published documents (trade journals, transactions, proceedings, etc.). Since the content of this chapter is somewhat critical of the ROV field, individual operators and builders are not identified with their vehicle's problems, except in those instances where the information has been published and is public record.

The following problem categories are listed in decreasing order of occurrence. Table 4.1 lists the problem areas identified in this study and the number of operators who encountered the problem. It was not possible in all instances to obtain all the details on each problem area since several operators - owing to time constraints - simply stated that a particular problem had occurred, but was subsequently corrected.

4.1 ENTANGLEMENT

By far the most prevalent problem today's operator encounters is entanglement of the umbilical cable or the vehicle itself. Entanglement in its most mild form can result in merely a short delay until the problem can be worked out by the operator. In its more serious forms it can lead to abandonment of the vehicle for several months until it can be retrieved or its complete loss.

The means of entanglement are numerous as the following litany of entanglement incidents demonstrates;

Operator A - Cable tangled with surface buoy mooring, cut umbilical, vehicle later resurfaced and was retrieved.
Cable fouled on ships propeller, cut umbilical, vehicle lost.
Operator B - Cable wrapped around mast of sunken ship, pulled free.
Vehicle caught within structure of sunken ship, pulled free.
Operator C - Cable fouled on bottom structure, vehicle abandoned and retrieved three months later by divers.
Operator D - Vehicle flew under submerged cable and fouled.
Cable wrapped around submerged buoy mooring line.
Cable fouled around surface buoy mooring line.
Cable cut by unknown object on the bottom.
Vehicle fouled on its own umbilical.
Operator E - Vehicle fouled on discarded cable.
Operator F - Cable fouled in support ship's propellers.
Cable caught on submerged piling.
Operator G - Vehicle caught in subsea manifold, subsequently recovered.
Operator H - Cable fouled and ruptured by polypropelene mooring lines of marker buoys (100 such incidents in 18 months operation).
Vehicle caught in corner of structure, later recovered by divers.
Vehicle propeller fouled by monofilament fishing lines caught in structure.
Cable fouled in structure, subsequently was intentionally severed, vehicle caught in monofilament line while ascending, later freed by divers.

TABLE 4.1 ROV PROBLEMS REPORTED

Problem	Number of Operators
Entanglement	18
Electrical Connectors	12
Vehicle Disturbs Sediments, Obscures Visibility	11
Cable Ruptured by Abrasion	10
Electrical Interference in Cable	8
Support Ship Cannot Station-Keep	6
Compass Affected by Structure	6
Ship Power Surges Affect Vehicle Operations	5
Current Required Aborting Mission	5
Sea State Required Aborting Mission	5
Vehicle Damage During Launch/Retrieval	2
Vehicle Station-Keeping Inadequate	2
Manipulation Inadequate	2
Vehicle Payload Inadequate	2
Human Engineering Inadequate	2
Vehicle Lost Due to Low Surface Freeboard	1
Electrical Shocks Due to Inadequate Grounding	1
Vehicle Maneuverability Inadequate	1
Water Visibility Required Aborting Mission	1
Television Resolution Inadequate	1

Operator I - Cable wrapped in anchor line it was inspecting, support ship pulled away inadvertently and broke cable.
Vehicle propeller fouled by monofilament fishing line.
Cable tangled with marker buoy mooring line.
Cable cut by polypropelene mooring line.
Operator J - Cable fouled in support ship's anchor chain. Anchor had to be retrieved to free cable.
Vehicle tangled by abandoned lines on fixed structure.
Operator K - Vehicle tangled by abandoned fishing lines on structure.
Cable fouled in support ship's propeller and severed.
Cable fouled, resultant kinking caused short circuit.
Operator L - Cable wrapped around bottom-mounted navigation transponder.
Cable fouled (twice) in support ship's propellers.
Operator M - Cable wrapped around support ship's anchor chain.
Operator N - Cable caught in support ship's propeller (three separate occasions).
Operator O - Cable fouled on SALM (Single Anchor Leg Mooring) mooring line, vehicle abandoned for eight weeks, subsequently retrieved by manned submersible.

The foregoing incidents are but a sampling of the many instances of cable and vehicle entanglement. Others have occurred which have not been documented, but reveal even more the vast potential for fouling every time a tethered vehicle is deployed. For such reasons several operators not only carry spare cables, but backup vehicles as well. While an exact count is difficult to obtain, at least 12 ROVs have been lost; in virtually every instance it was due to cable or vehicle fouling. Such incidents have prompted one operator to refuse work which requires the vehicle to operate around or within fixed, upright structures.

The causes of entanglement are varied and no single factor appears to be overriding. Operator error undoubtedly plays a large role. While the operator may be aware of the vehicle's position, he may not be aware of the umbilical's and it may have drifted into a compromising situation. Equally significant are the entanglement situations derived from discarded debris and lines. Several operators reported that fixed structures, particularly those which have been installed for a period of several years or more, are literally festooned with snagged monofilament fishing tackle from fishing activities of the crew. In a similar vein, the bottoms of harbors and other areas of high marine activities are likewise cluttered with a wide variety of debris. In such circumstances, there is little the operator can do to avoid entanglement other than to dive where visibility is adequate. Propeller guards help the situation somewhat, but are not always a positive solution. In some instances the power supply can be identified as the cause of entanglement, this is discussed in a later section, but, several incidents have occurred where the vehicle's power was temporarily interrupted and, by virtue of its positive buoyancy, it ascended into a structure and fouled. An additional factor is the water current which carries the umbilical into a structure while the vehicle itself remains outside.

In many instances several of the above factors work together to produce the entanglement and subsequent abandonment of the vehicle. An example of this is the experience of Operator O, where the vehicle was abandoned for two months. In this incident the vehicle was launched from an anchored support ship. As it was in the process of inspecting an oil transmission line, its power supply was interrupted and it drifted between the line it was inspecting and another line immediately adjacent. When power returned to the vehicle the tide had turned and the two lines were pushed together and prevented retraction of the ROV. Not wishing to chance withdrawal of the vehicle through the two transmission lines, the operator called in the services of a manned submersible. The manned submersible inspected the situation and found it could not lift the ROV. A tanker was coming in to the SALM and this forced the manned vehicle to leave. Before leaving it cut the ROVs umbilical. Two months later the vehicle was retrieved. The incident demonstrates that several factors caused final abandonment. It also substantiates that ROV operators are as subject to Murphy's Law as is the rest of the marine community.

As a result of the potential for entanglement, ROV operators have adopted several operating procedures to minimize the problem. One such (employed by vehicles with subsea launchers - such as the RCV-225) is to enter structures on the horizontal plane. If work above or below this plane is necessary, the vehicle retraces its course out of the structure and then its launcher is positioned higher or lower so that the vehicle can continue operating in the horizontal plane only. Another procedure is to work on a structure only at slack tide or to work on the down-current or leeward side of the structure so that the umbilical will be forced away from the structure. The design of the vehicle system can be of considerable assistance. Some vehicle systems employ underwater launchers or clumps which hold the greater portion of the cable in the vertical plane and allow the vehicle to operate from the launcher on a short (150m or so) umbilical. This procedure is helpful toward decreasing the possibility of entanglement with the support ship's screws, but entanglement of the shorter umbilical still occurs. Streamlining or fairing the vehicle to avoid entanglement is a somewhat uncertain (in terms of effectiveness) solution, since fully faired vehicles have been entangled and the number of times the vehicle avoided entanglement owing to its fairings is undeterminable.

At this point in time there is no infallible method of avoiding cable entanglement, and as long as the vehicle must rely on the umbilical cable for power, control and data transmission, the ROV will be "hoisted on its own petard." Because the very features which the ROV cable provides - long duration, unlimited power, real-time data transmission - are purchased at the ever-attendant risk of cable entanglement.

4.2 ELECTRICAL CONNECTORS

Almost half of the operators contacted expressed dissatisfaction with the performance of ROV electrical connectors (i.e., where the umbilical cable connects with the vehicle). The scope of this study precludes conducting a failure mode analysis of connector malfunctions. Consequently, only the highlights and occurrence of such malfunctions were solicited.

There is no particular failure common from vehicle-to-vehicle. Indeed, some operators expressed no connector problems with a particular vehicle of a series (e.g., the RCV-225 or the TROV/TREC or the SCORPIO series) while other operators owning vehicles of the same series were quite dissatisfied. The cause or causes of the problems are difficult to assess. Some operators categorically place the blame on lack of quality control at the manufacturing level, others accept the problem as being brought about by poor handling techniques or lack of knowledge on their part. A common complaint is poor (unreliable) potting techniques at the termination. Two operators have gone so far as to devise their own potting procedures and rebuilding the connectors. The problem can be severe when splicing of the termination is required which can take, in one instance, from 30 to 36 hours.

A specific complaint was that the soft metal sealing surfaces were damaged during handling and were not suitable for field conditions. Further, the complexity of the connectors was too great for field conditions and required more care than could be given during at-sea operations. To correct this problem. one operator has begun an in-house training program specifically designed for instruction in the maintenance, repair and handling of electrical connectors.

In only one instance did the surface connectors provide problems. In this instance the winch slip rings were identified.

4.3 SEDIMENT DISTURBANCE

When working on or near the bottom several vehicle operators have confronted, the problem of obscured visibility from sediment clouds produced by the ROVs propeller wash. All but a few, ROVs operate a few kilograms positively buoyant when submerged. In order to descend the vertical thrusters are employed. In this instance the prop wash is directed above the vehicle and does not disturb the sediment. The most common circumstance under which sediment disturbance is a problem is when the vehicle reverses thrust when it is on or immediately near the bottom. Sand and hard rock bottoms do not present this problem, silt and clay (i.e., mud) bottoms are critical. The sediment cloud produced can interrupt the operation for some period of time depending upon the strength of the prevailing current and the settling rate of the sediment. To combat this problem, operators try to work facing into the current such that the disturbed sediment will be carried downstream.

No one vehicle appears to be immune from encountering this problem occasionally. In some instances two different operators will have two different experiences working with the same vehicle under similar or near-similar circumstances. Obviously, pilot experience and expertise is a major factor in determining the degree of bottom disturbance.

At times it is necessary to work when on-going related activities result in extensive bottom disturbance (e.g., pipe trenching). Tasks such as trench profiling have been carried out in zero visibility, since the entire sequence of the operation depends upon acoustic transmission for navigation and data collection, and does not require remote observation.

4.4 CABLE RUPTURE

A variety of factors can be identified which result in rupturing of the umbilical cable. Many of these are produced when the cable is entangled or fouled as described in section 4.1. The overriding factor is mechanical abrasion by synthetic lines, the bottom or a structure. Since most cables are negatively buoyant, their first action is to drag. Floats can be and are attached to keep the cable suspended. This procedure is satisfactory when the vehicle does not work from a launcher where the floats would interfere with the reeling in process when the vehicle docks.

The most commonly identified rupturer of umbilical cables is polypropelene line. Such line is commonly used, for example, as buoy mooring lines for marking pipeline right-of-ways. When an ROV is deployed to inspect the route, trench or pipe itself the umbilical inadvertently chafes against the polypropelene. Since the umbilical cable's outer sheathing is less tough than the polypropelene line it is frequently chafed through to rupture. The problem can be quite severe, indeed, one operator of several vehicles reported as many as 100 cables ruptured in this fashion over an 18 month period. In this particular instance replacement of the umbilical - though not always required - costs $3,000 (U.S.).

Polypropelene line is not the only cause of mechanical abrasion. Also mentioned are the sea bottom, structures (metallic and concrete), wire rope mooring cable and anchor lines.

In virtually all present day deployment of ROVs the vehicle is deployed from the surface. Consequently, the vast majority of the cable is suspended in the water column and relatively immune from abrasion. However, one operator deploys his vehicle from a manned submersible when it is sitting on the bottom. With this technique almost the entire length of the negatively buoyant cable can be subjected to bottom abrasion. Attachment of floats is impractical owing to their interference with the reeling-out/reeling-in procedures.

4.5 ELECTRICAL INTERFERENCE

Problems with electrical interferences between the varied control, power, data and video transmissions in the umbilical cable were revealed by several operators. Interestingly, all but one of these operators employed vehicles built by non-industrial manufacturers (i.e., academic institutions, research foundations, government laboratories). Operators of industrially-built vehicles acknowledged minor interference in the early models, but those problems were subsequently corrected.

The most repeated interference effect is on TV signal transmission. This problem, when it does occur, is almost always caused by the propulsion units. The video picture is then, at best, subject to periodic fluttering; at worst, it is completely blocked out. This latter situation occurs with one operator when the paid out cable length reaches about 1km (3,168 ft). In one instance it is not the surge of propulsive power itself, but is caused by the invertors used for speed control. The result in this case, is interference with not only the video signal, but the sonar and data telemetry as well. The operator has minimized the interference, but cannot fully suppress it.

While electrical interference is not a common problem from operator-to-operator, it is the type of problem that is a major crisis to the one undergoing the experience. It is the feeling of several operators that the problem has not really surfaced at this stage of ROV employment. Since the predominant utilization of vehicles is for observation, the opportunities for interference are relatively limited. However, when the vehicle is equipped with an array of instrumentation (e.g., scanning sonar, side scan sonar, sub-bottom profiler, echo-sounder, etc.) which is operating concurrently, the interference problem may become more serious. One operator, who had no interference problems with the vehicle as an observation platform, experienced a variety of interference problems when a side scan sonar and sub-bottom profiler were added to its capabilities.

4.6 SUPPORT SHIP STATION-KEEPING

Several ROV operators have had missions abruptly terminated when the support ship could not maintain station above the vehicle. In such circumstances the vehicle has been pulled off-station (intentionally and unintentionally) which required subsequent repositioning with an attendant loss of time to regain the station. The loss of time and the inconvenience can be substantial as the following excerpts from one operator's daily log demonstrates:

> 1050: Vehicle on bottom.
> 1145: Vehicle pulled off station by ship. Depth 855m.
> 1220: Back on station. Resumed operation.
> 1245: Lost holding position.
> 1610: Resumed position.
> 1720: Lost holding position.
> 1815: Start recovery of vehicle.

What is merely an inconvenience can turn more serious. In the same operation the vehicle fouled in an anchor and the surface ship dragged it and the anchor some 150m (492ft) until the vehicle broke free. Fortunately, the cable did not part before the vehicle freed itself.

In almost every incident of this nature the cause was ascribed to the surface ship's lack of a bow thruster. (The incident from which the above logs were quoted involved a single-screw. sea-going tug.) All open ocean ROV operators agree that twin screws would be best, but such vessels are not readily available. A support ship with a dynamic positioning system is considered as the ideal platform, but the cost is prohibitive. One negative aspect of dynamic positioning was indicated by the possibility of the support ship inadvertently moving or activating a particular thruster at a critical juncture in the operation which could foul the cable and/or the vehicle.

The above comments apply to "live boat" type operations. Vessels which deploy the ROV when they are moored or anchored do not, obviously, require a bow thruster.

4.7 COMPASS PERFORMANCE

The performance of magnetic compasses on ROVs is not always satisfactory. Two problems were revealed by vehicle operators: 1) the compass does not react quickly enough to course changes, and 2) and compass is affected by close proximity to metallic structures.

In the first instance only one operator was affected by this problem. During survey runs along pre-planned tracks it was occasionally required to change course, when this did occur the reaction time of the compass was so slow that the operator intentionally bottomed the vehicle and waited until the compass settled on a particular heading. Vehicle heading was then incrementally adjusted until the correct compass heading was attained. The survey was then resumed along the proper course.

Compass unreliability around metallic structures is a problem encountered by several operators. The distance from the structure at which the compass begins to be affected varies, in some instances it was unaffected until the vehicle made actual physical contact with the structure, in others the distance was 1m (3 ft) or less. The problem is treated differently from operator-to-operator. Some have added directional gyros to the vehicle and rely upon these as primary systems and the magnetic compass as a backup source. Other operators treat the problem as one they can work around and do not think it serious. Obviously, the nature of the work is a controlling factor. If the job requires, for example, inspection of a pipeline, then relatively broad compass inaccuracies are tolerable since the potential for entanglement is minimal. If, on the other hand, the task requires penetration and inspection of a steel jacket structure, where the chance for entanglement is high, then any compass inaccuracies are serious potential defects.

4.8 POWER SUPPLY SURGES

ROV power is supplied by either the support ship or from a generator dedicated to the system. There have been several incidents where interruptions or surges in ship supplied power has occurred which caused a delay and, ultimately, termination of the operation.

As a general practice, most commercial operators provide their own power generator which is dedicated to ROV utilization. Ship's power is considered as a backup or emergency source. This arrangement evolved through problems created by surges in ship's voltage or by complete loss of ship's power. The problems created by voltage surges can be substantial. In one instance power to the ROV was lost for four hours; during which time the vehicle surfaced and was subsequently pounded against the platform resulting in $100,000 worth of repairs. Another power failure ended with the vehicle surfacing under its support ship resulting in damage to it and its umbilical. In other instances components were sensitive to power surges and ran the danger of being destroyed by unregulated voltages. One manufacturer revealed that the lights they were using (supplied by a sub-contractor) were sensitive to changes of ±5 volts and could be seriously damaged by such small power changes. As a consequence of such realized and potential experiences the employment of a power generator dedicated to the ROV has become a relatively standard procedure.

4.9 CURRENTS

The major problems created by water currents are cable drag, reduced vehicle maneuverability and cable entanglement. While only a few operators have been forced off the job by currents, virtually all are restricted by currents to when, where and at what depth they can operate. Typical current speeds under which ROVs can operate range from 1 to 2¼ knots (2 to 4km/hr). One operator claimed higher operating ranges of 4 to 5 knots (7 to 9km/hr) current speed. Since the majority of vehicles are sensitive to fairly low current speeds, their work schedule is often modified to operate during slack tide. This is particularly true around structures when the current can have a significant vertical component in addition to its horizontal component.

Water current influence on cable drag is obvious; in several instances the drag was sufficient to restrain the vehicle from reaching and maintaining the operating depth required. One solution to this problem has been to work the vehicle from a short tether attached to a heavy clump or from a submerged launcher. In this instance the clump or launcher may be placed on the bottom and the vehicle works within the radius of its tether. Additionally, some operators work in a "live boat" fashion and tow the launcher or clump while the vehicle keeps apace with the surface ship and the major portion of cable drag is imparted to that section between surface ship and clump. A somewhat unique approach is taken by the Harbor Branch Foundation. The vehicle, CORD, grasps the clump with its manipulator as it is being towed. When an object of interest is observed the vehicle releases its hold on the clump, the clump is bottomed, and the vehicle works around the clump on a short tether.

One problem encountered when the vehicle is working from a towed clump is that the clump will undergo heave-induced vertical excursions almost in a 1:1 ratio with the motion of the surface vessel. The result is a periodic shortening and lengthening of the vehicle's tether which could either pull the vehicle off station or produce an excess of tether which might entangle. To circumvent these possibilities one operator uses a heave-compensated winch which permits the clump or launcher to remain at near-constant depth as it is being towed.

4.10 SEA STATE

All commercial ROV operators can deploy their systems up to and including Sea State 4. Many exceed this limit and claim to have operated in State 6 and as high as State 8. The later performances have taken place from a semi-submerged vessel. Since these sea states are equal to - and often exceed - the average sea states where most ROVs are operating, there are very few incidents where surface conditions have forced aborting operations. Unlike manned vehicles, deployment of ROVs does not jeopardize human life and, therefore, operations in sea states higher than their manned counterparts is common.

One restriction placed on ROV operators is directly brought about by increasing sea state. Insurance underwriters will not assure the vehicle beyond, in one instance Sea State 4. In this respect sea state has limited the application of ROVs, but the number of occurrences and the extent of the problems are difficult to quantify.

One possible reason that underwriters are reluctant to provide coverage in higher sea states is the difficulty encountered in safely bringing a surfaced ROV sufficiently close to a rolling/pitching ship for retrieval. One operator inflicted damage to his vehicle when the support ship rolled and drew the ROV under its hull where it collided with the vessel as it rolled in the opposite direction. A more potentially damaging factor is launch/retrieval of the vehicle in high sea states, this is discussed in the following section.

4.11 LAUNCH/RETRIEVAL DAMAGE

Coincident with the effects of high sea states is the damage inflicted upon ROVs when they collide with the support ship during the launch/retrieval process. There are several instances where such damage has occurred, and it primarily occurred during the retrieval process.

Most damage occurring during the launch/retrieval procedure is minor, resulting in bent guard frames. One operator, however, in addition to bending the vehicle's guard frames, cracked the upper buoyancy chamber which caused significant delays and expensive repairs. A more recent North Sea incident resulted in virtually a total loss of the vehicle.

Those vehicles which are deployed from an undersea launcher are in a somewhat better position in this respect since the launcher also acts as a protective framework. However, the launcher itself can be damaged to an extent requiring delay of the operation with attendant costs for repairs.

While the major components of most ROVs are ruggedly designed, some of the sub-components are not, and severe jolts can render them inoperative. To avoid such shock-induced damage, one manufacturer has shock-mounted the more sensitive components, such as the television pan/tilt mechanism.

4.12 VEHICLE STATION KEEPING

Station-keeping with respect to the vehicle implies its ability to hover at a particular spot in the water column or to maintain a constant altitude above the bottom when underway.

Undoubtedly the most obvious culprit is the ROV pilot, and in several instances the pilot's lack of experience or expertise was identified as the weak link in the system. Several other aspects, in addition to pilot competency, of the ROV system were also identified as inhibiting the vehicle's ability to station-keep.

A frequent problem encountered by operators of small vehicles is the vehicle's inability to remain in one spot within relatively slow currents. The low mass and particularly, the low horesepower of the vehicle is seen as causing the problem. It is significant to note that operators of the same vehicle viewed them differently in regard to demonstrating an adequate station-keeping ability. The controlling factor is the nature of the work. For most inspection/documentation tasks there is no need for complete and total stability, some vehicle drifting is tolerable. But when inspection of structures for hairline cracks or corrosion is the task, even the slightest vibration can be intolerable. Not only do such vibrations make TV viewing difficult, but they can also cause still photographs to be out of focus.

Another factor causing loss of station-keeping ability was ascribed to the thruster's power sharing. One operator stated that when vertical thrust was applied, forward thrust was automatically reduced. The result is a constant jockeying back and forth to maintain station in the presence of even moderate currents.

The situation is helped somewhat on vehicles fitted with variable ballast systems, providing the system can be cycled rapidly. In one instance the operator abandoned this approach in favor of dynamic - rather than static - vertical control owing to the slow reacting time of the variable ballast system.

Several vehicles couple the data from a downward-looking echo sounder with servos to control the vehicle's vertical thrusters to maintain a constant distance-above-the-bottom. This technique performes satisfactorily over level sea bottoms, but where the bottom is steeply sloping (45 degrees or more) the system does not perform adequately since the returning echo is reflected away from the vehicle's transducer.

In one instance the operator decided to rely upon a more positive means of station-keeping than thrusters. A technique for holding the vehicle to a structure by limpet-like devices was developed for holding station while the vehicle cleaned prior to conducting non-destructive testing.

4.13 MANIPULATION

In view of the limited call for manipulative tasks by industrially-oriented vehicles, few operators expressed dissatisfaction with ROV manipulative capabilities. One operating firm was of the opinion that tooling for the manipulators required development in order to begin employing ROVs to their full potential as manipulative vehicles.

In another instance, the lack of a 3-dimensional perspective on current TV monitors was identified as the causative factor for the limited success and/or application of ROV manipulative devices.

Lack of sophistication (i.e., degrees-of-freedom) in ROV manipulators was not seen as an inhibiting factor since the excellent maneuverability of most vehicles could serve to place the manipulator in the proper orientation. In essence, ROV manipulation is considered more as an adjunct to the vehicle rather than a major capability.

4.14 PAYLOAD

Vehicle payload (herein defined as the capability of the vehicle to accommodate instrumentation in addition to those components routinely carried on a dive) was considered inadequate in only one instance. In this case the operator considered that at least 45kg (100 lbs) of additional payload was required to meet all the tasks requested.

In view of the fact that over 90 percent of all work conducted is observation and documentation, video or photographic, the need for additional carrying capacity is somewhat academic. Concern was expressed, however, in terms of the present vehicle's capability to perform more varied tasks, such as surveys, which required the addition of more equipment. The problem is not so pressing with the larger vehicles, particularly those with variable ballast systems, which can accommodate additional mass and bulk without sacrifice to the vehicle's buoyancy and maneuverability.

4.15 HUMAN ENGINEERING

The term "human engineering" herein refers to the adequacy of the design and layout of the vehicle controls and data displays. Adequacy is measured in the ability of the pilot to efficiently operate the vehicle and rapidly comprehend the data he is receiving which is related to vehicle control.

Problems in this area are not severe enough to cause cancellation or abortion of missions. They do influence the efficiency with which the pilot can control his vehicle and attain a successful mission.

In one instance the operator experienced difficulty in controlling the vehicle simply because the control surfaces were too close together. Separation of various controls, particularly vehicle attitude controls, was desired in order to avoid bumping and accidentally activating one control when another was desired. This is not a problem on control panels where the vehicle has a single joystick control.

Another control problem was expressed by an operator whose vehicle was controlled solely from within a van. In this instance a portable control consolette was desired during the launch/retrieval procedure so that the pilot could (from the deck) directly view the relationship and proximity of vehicle-to-support ship. This procedure would also help coordinate actions between pilot and winch operator since both could view the same scene at the same time and communicate directly with each other rather than through an intermediary.

Dissatisfaction with the display location of various data was expressed by another operator. The suggestion was made that critical vehicle control and attitude data, such as depth, heading and altitude, should be displayed on the pilot's TV monitor. This arrangement would allow the pilot to keep his eyes on the TV instead of turning away from it to view another part of the console. This is particularly critical when the vehicle is working around or within a structure and intense, full-time concentration is necessary. The same operator felt that digital compass displays were not satisfactory, and that analog displays were more easily comprehended and retained by the pilot.

A North Sea operator of one of the larger vehicles felt that the pilot lacked a feeling of rapport for the vehicle and the ambience in which it was working. He suggested that, perhaps, head-coupled TV and servo-controlled operator's chairs that would reflect the vehicle's attitude might give the operator a better feeling for the overall conditions under which the vehicle was operating.

The same North Sea operator, whose vehicle conducts bottom and pipeline surveys, felt that efficiency could be improved by physically separating the pilot from the data collection/display instrumentation. During such surveys, in addition to the pilot and other operating personnel, a large number of support personnel also occupy the van where the pilot is working. Consequently, the ambient noise and congestion distracts the pilot so that he cannot maintain full-time concentration on the TV monitor and the control/display console.

4.16 VEHICLE FREEBOARD

All ROVs have a freeboard which is not much more than a few centimeters. Under routine conditions the lack of substantial freeboard does not represent a problem. But when the vehicle has surfaced without its umbilical, visually locating it on the surface is made extremely difficult in all but the calmest of seas. In one instance the vehicle's tether broke during recovery and visual contact with the vehicle could not be maintained during the time it took to get the support ship underway. Consequently, the vehicle was lost for a period of some 60 days until it was found washed up on the beach.

Virtually all vehicles have a flashing strobe light which aids in location. Some have an acoustic pinger which is self-powered and remains submerged although the vehicle itself has surfaced. Such devices can aid in locating the vehicle, but they are time-limited in duration and sea state limited in effectiveness. Several vehicles have been lost owing to their low visibility on the surface although it was a safe assumption that at least one of these devices was operating. The surface location problem is obviously enhanced when the sea state increases since the amount of time the vehicle or its light is visible from the support ship is significantly reduced.

One potential solution to this problem has been to advance the concept of a negatively buoyant vehicle instead of a positively buoyant one. The argument is made that if it is necessary to cut the vehicle's umbilical, it is better for the vehicle to sink and remain in one known underwater location rather than surface and be subjected to the vagaries of wind, sea and currents. The argument is not without merit since several vehicles have been left on the bottom until fairer weather allowed a submerged pickup and retrieval by either a diver or a manned vehicle.

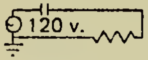
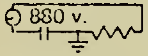
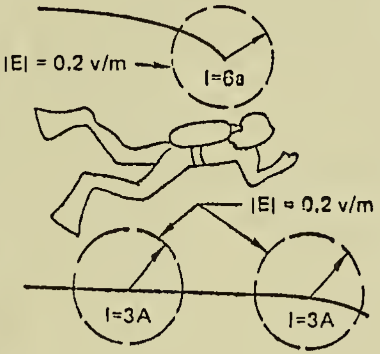
The lack of freeboard is, of course, only seen as a problem primarily by those operators who have lost a vehicle on the surface. But it is a potential problem to all. One operator is actively working on this problem and is investigating a variety of surface locating aids, such as self-inflating, self-activating balloons, radio beacons or pyrotechnic signals, to solve this problem.

4.17 ELECTRICAL SHOCKS

There is only one reported incident where the deck crew of an ROV sustained electrical shocks in the course of operations. In this incident the shock was no more than a tingling sensation (perhaps 1 to 3 milliamps AC) and at no time reached, what is termed, a "let-go current", of 9 to 16 milliamps AC. The immediate solution was to wear rubber-lined gloves when handling the vehicle on deck. A subsequent solution will involve installation of a ground strap on the vehicle as it is retrieved aboardship.

Figure 4.1

OUTLINE OF ELECTRICAL SHOCK HAZARDS ANALYSIS FOR U. S. NAVY "SNOOPY"
(based on analysis by R. A. Marrone, Naval Undersea Center, San Diego, 23 October 1974)

ITEMS ANALYZED			Electric Field Model	Diver Current Limit	Shape & Size of Area Exceeding Diver Limit	Remarks
Part	Operation	Possible Fault				
Cable	On-Deck Handling	Crewman's hand around coax power cable (no damage)	Capacitive Coupling	10 ma (see Remarks*)	None, unless transformer insulation and isolation transformer fail.	(*10 ma AC is "Let-go" value for 99.5% of population) Max. current is 12 μa and is below level of sensation unless noted double failure occurs.
		Crewman's hand around coax power cable with nick in cover exposing shield.	Direct contact	10 ma (see Remarks*)	None, unless transformer insulation and isolation transformer also fail.	Max. current is 0.36 ma and is below level of sensation unless noted triple failure occurs.
Cable Con-nector	Diver in Water	Leaky connector (one pin)		10 ma (see Remarks*)	None	Max. current in sea water is 12μa. Fault requires leakage of oil-filled pressure-balanced connector.
Cable	Diver in Water	Nick in cover exposing shield.		10 ma (see Remarks*)	None	Max. current in sea water is 0.36 ma.
		Current to sea water thru two conductors: a. Cable severed	Current dipole, $\|E\| = f(r)^3$	10 ma (see Remarks*)		Based on diver conductivity of 0.2 mhos/meter, a field of 0.2 volts/meter will induce the 10 ma limit current. a. Field strength falls below 0.2 volts/meter everywhere outside a sphere of 0.17-meter radius centered on end of severed cable
		b. Cable nicked to expose center conductor in one place and again to expose shield in another place far away	Current monopoles, $\|E\| = f(r)^2$			b. Field strength falls below 0.2 volts/meter everywhere outside of spheres of 0.55-meter radius centered at each fault The situations require double failures: one, for a fused circuit to carry twice its rated 3-amp current load for more than a few seconds; and two, for the noted cable failures to occur.

All other potential Diver-electric field contacts are prevented by insulation, plus the isolation transformer, plus oil-filled pressure-balanced connectors and harnesses.

(Courtesy of the Marine Board, Assembly of Engineering, National Academy of Sciences)

In 1976 the National Research Council published an analysis of potential electrical shock hazards related to the U.S. Navy's ROV SNOOPY.[1] Two situations were developed to illustrate under what conditions a hazard may exist: 1) cable handling by shipboard personnel, and 2) submerged diver operations with the vehicle.

The results of these analyses are tabulated in Figure 4.1; following are the conclusions:

> "Under normal operating conditions, the NAVFAC SNOOPY Vehicle System poses no electrical shock hazard to shipboard personnel or divers. However, in the rare occurrence of the current monopole produced by widely separated immersion of both cable conductors a possible hazard will exist within 0.5m (1.6 ft) of such cable, the potentially hazardous region is limited to approximately 0.25m (0.8 ft) from the break. Some additional margin exists in these estimates in that the fields will continue to fall off with distances comparable to diver dimensions in a region free of other conductors. Such additional conductors would tend to distort the external fields resulting in larger and smaller field intensities at given distances from faults, but these are very difficult to model. Unfortunately, in problems of this complexity, carefully instrumented testing is frequently prescribed to justify or replace the estimates obtained by modelling."

Although the ROV community has reportedly only one incident where electrical shocks did occur, the results of the National Research Council's analysis have a potentially wider application. The use of ROVs as diver assist vehicles does bring the diver and the vehicle in close proximity underwater. It is in this circumstance that consideration should be given to electrical shock considerations. Since the above analysis was conducted only on the SNOOPY, the results do not necessarily apply to other vehicles, analyses must be conducted on a case-by-case basis.

4.18 MANEUVERABILITY

Problems related to lack of vehicle maneuverability fall into two areas: vehicle bulk and power/thrust distribution. In the first area the operator reported that the bulk of the vehicle prohibited it from operating within the close confines of a structure (e.g., the junctions between "K" joints and other multi-nodal configurations). This restriction applies, however, only to a specific class of vehicles since some can work in areas where even the diver cannot fit.

The second area, power/thrust distribution, also applies only to two specific vehicles, not to the field at large. In one instance the problem was outlined

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[1] Underwater Electrical Safe Practices, 1976, Panel on Underwater Electrical Safe Practices, Marine Board, Assembly of Engineering, National Research Council, National Academy of Sciences, Washington, D.C., 66p. with Appendices.

in Section 4.12 since it also affects the vehicle's station-keeping capabilities. The difficulty was encountered when thrust to the horizontal propulsion is inadvertantly reduced by activation of the vertical propulsion. The result being to make smooth vehicle control difficult, if not impossible.

In another instance maneuvering of the vehicle (i.e., course changes) was not possible if the vehicle was required to work broadside to a current of greater than 1 knot. In order to turn, the vehicle thrust to one of the two stern-mounted propulsers had to be reduced. When this reduction took place the vehicle lacked the power required to maintain its course in the current and was set with the current accordingly. A solution to this problem was to be attained by addition of a lateral thruster to assist in holding station under such current conditions.

4.19 WATER VISIBILITY

Water visibility or clarity acts as a major factor in the successful and safe deployment of an ROV. Since well over 95 percent of all tasks undertaken to date depend upon remote viewing, the ability to see the object of interest is, obviously, critical. As an example, one operator was forced to abandon a project in the mouth of Cook Inlet, Alaska, because there was no underwater visibility available owing to fine-grained, suspended material in the water column.

The effects of reduced visibility are varied. In two instances the operators inflicted damage to their umbilicals when the cables fouled on an object on the bottom, the fouling was ascribed to lack of visibility. In another operation the vehicle collided with a wreck and suffered minor damage owing to reduced visibility and a malfunctioning forward looking sonar. To reduce the amount of backscatter in turbid water, one operator has mounted his photographic (strobe) lights on a 2 to 3m (6 to 10 ft) long boom, inadvertently the boom lights collided with a structure outside of the viewing range and were broken.

The visibility conditions under which industrial ROVs operate depend upon the nature of the work and the accuracy and reliability of the vehicle's positioning system. Several operators have successfully operated in 1m (3 ft) visibility, in one instance the minimal requirements were only that visibility allowed looking off about 1m to either side of the vehicle to safely maneuver. Conventional obstacle avoidance sonars provide assistance in detecting and acquiring or avoiding targets or structures under reduced visibility, but they are of no assistance when the vehicle is 1 or 2m from the structure since the outgoing pulse cannot be differentiated from the return.

4.20 TELEVISION

Section 2.1.7.a described the types of closed circuit television systems currently employed on ROVs. Overall the performance of these systems is considered satisfactory and in only one instance was an operation cancelled owing to poor TV performance. The following comments summarize the ROV operator's experience and opinions of currently used television systems.

Reliability - Satisfactory

Resolution - Adequate for the work now being performed. Some operators felt that greater resolution (800 lines was suggested) would be helpful.

In most instances it was agreed that photographic documentation would not likely be replaced by video tape since TV does not compare in quality of resolution with photographic film.

Color - Color TV is not a standard capability on conventional ROVs. The poor quality of color rendition was ascribed as the overriding factor. Several operators feel that color would be useful, especially for non-destructive testing, but there was no pressing demand for it at present. The operator of a scientifically oriented vehicle did see an immediate need for color television since a great deal of geological and, particularly, biological identification is based on color.

3-Dimensional TV - 3-dimensional television is commercially available for ROVs. Only one operator felt it was necessary at present, although several felt that it might be helpful in conducting manipulative tasks. The overall opinion was that the added complexity and loss of resolution which accompanies adaption of a 3-dimensional system were not worth the cost.

4.21 OTHERS

Almost all ROV operators had a particular problem with their vehicle that was peculiar to their design or the operation they were conducting. These problems are difficult to place and quantify in the foregoing discussion, consequently, they are dealt with in this category. Conversely, all operators place a high value on the need for - and lack of - experienced, qualified personnel, and on the need for reliable systems. The personnel problem is outside the purvey of this technical assessment, however, since the human component of the ROV system is as critical as the most important electrical or mechanical component, some discussion of this aspect cannot be ignored. Following are qualitative discussions of specific technical problems and human element considerations.

4.21.a Reliability

A pressing need for greater system reliability was expressed, particularly in system electronics. It is felt that a reduction in technology and increase in reliability would benefit the entire field. Since no more than two or three years field operations have been undergone by most vehicles, many of the problems accompanying the first vehicles are still present. A thorough, practical shakedown of each vehicle was suggested as a remedy to many of the problems the operator would confront subsequent to obtaining the vehicle. It is felt, by some, that an increase in reliability would permit a reduction in the size of the field party and, consequently, a decrease in operational costs.

4.21.b Growth Potential

Although most operators are satisfied with the present capability of vehicle systems to accumulate and transfer data to the surface, some are working toward increasing the data quantity and expressed the need for improvements. Specifically, the multiplexers currently in use do not have as high a data rate as the operator desires to increase the capability of his system. The lack of more broader band multiplexers was seen as inhibiting the growth of the field.

A requirement for increased power to the vehicle and its instrumentation and tools was also seen as inhibiting vehicle growth. Current procedures to correct this problem (i.e., supply more power) would entail increasing the diameter of the cable. This solution is unacceptable since it results in increased cable drag and weight.

4.21.c Sonar

Since the ROV market is relatively new and, in terms of other markets, relatively small, components, such as obstacle avoidance or scanning sonars, are obtained from equipment available for other vehicles - particularly manned submersibles. In the case of scanning sonars, one operator stated that they are too heavy and large for small ROVs, expensive and do not provide the required resolution. Further, the range of available scanning sonars has been dictated by the needs of manned vehicles. This range (500m or more) is not required by ROVs where a maximum range of 100m (328 ft) is thought to be adequate.

4.21.d Communications

Successful open sea operations of an ROV system relies upon dependable, continuous and clear communications between, at a minimum, the support ship's master, the vehicle pilot, the winch operator and the ship/vehicle navigator(s). Several incidents have occurred where the communications network broke down and the ROV was lost or severely damaged. In one instance the vehicle's cable was fouled around the anchor chain of a buoy it was inspecting. Instead of mooring the support ship to the buoy during the inspection (permission was requested, but denied) the support ship maintained station by its thrusters. Through a misunderstanding on the part of the ship's Master the support ship backed down and snapped the umbilical cable. In another incident the vehicle was inspecting a structure to which the support ship was moored by its stern. The vehicle surfaced near the bow of the vessel which at this time was swinging close to the structure. To avoid collision with the structure the bow thrusters were activated. The ROV was sucked into the thrusters and sunk. The vehicle's acoustic beacon was tracked for 18 hours, but was subsequently lost. In both instances the cause was ascribed to lack of communications between members of the ship's crew and members of the vehicle's crew.

4.21.e Personnel

Industrial operators are almost unanimous in decrying the lack of - and need for - qualified and experienced personnel. The type of personnel sought varies, but those with a good electronic background and experience in undersea operations and shipboard handling techniques are most desired. Obviously, a person with experience in operations and maintenance/repair of the operator's particular vehicle is ideal, but since the industrial field is so young, this type of individual is a rarity.

No two operators have similar training programs. Some rely solely on on-the-job training, others have formal in-house courses of from one week to three weeks duration which include the areas of operations, maintenance and repair. One operator also sends his personnel to a course prepared by the manufacturer of his navigation system for two weeks of instruction in operations and repair. A number of operators also send their key personnel to classes set up by the vehicle's manufacturer for formal training. The cost of training can be expensive, one operator's staff of ROV operators and maintainers increased from 23 to 75 individuals over an 18 month period.

No precise agreement could be reached regarding how long it takes to train a person to the point where he can be considered fully qualified in all aspects of the operation. But a period of one year or one diving season seemed to be indicated. A period of two years was quoted as the amount of experience necessary before an individual could be considered qualified as an ROV crew leader or operations supervisor.

The problem becomes more difficult during the winter season when few opportunities are available to work (unless the operator is fortunate enough to obtain jobs in the southern hemisphere). During this period the ROV crew must still be employed - and carried as overhead - until the summer diving season commences. Unfortunately, at just about the time an individual is fully trained, he (or his wife) have decided that long, uncomfortable periods at sea are not satisfactory and employment is sought elsewhere in land-bound pursuits. So, the recruitment problem is virtually near-constant.

Several operating companies feel that it would be possible to keep qualified personnel in spite of the long sea-going periods if the time and length of the job could be specified in advance, perhaps six to eight months. Under this arrangement the sea-going personnel could plan their lives with some degree of consistency. But such long lead times are not possible, two to three weeks (and sometimes days) are more likely.

The problem is an extremely difficult one for the industrial operator, and no immediate solution is foreseen. Unlike the diving industry, where there is a degree of commonality between techniques and equipment, the wide variation in design and capabilities between ROVs does not particularly lend itself to establishing schools for ROV operators who will be qualified across the board to operate and maintain one specific vehicle.

The foregoing problems represent ROV performance primarily in the industrial field. Table 4.2 presents a summary of these problems, and includes the causes of the problems; their results and solutions. Although this list appears formidable, it is important to emphasize that they are not preventing ROV operators from accomplishing the job. In spite of many obstacles, the primary tasks of observation and photographic/TV documentation are being accomplished.

In the course of this study, each ROV operator was queried regarding what he considered to be immediate research/development required to increase the capabilities and/or efficiency of present operations. The replies, in virtually every instance, reflected the particular operator's current problems and did not deal much beyond the practical aspects of ROV operations. While each operator did reflect a relatively unique set of problems, a consensus opinion - regarding research and development for the field at large - is that day-to-day problems are enough to keep them busy; the problems are still being identified, and just keeping up with the system is all the research and development they can handle at present. The following recommendations are, therefore, more in the form of improvements on present technology rather than new research and development programs.

TABLE 4.2 PROBLEMS/SOLUTIONS SUMMARIES

Problem	Causes/Results	Solutions Applied
Entanglement	1. Operator error 2. Debris 3. Power supply interrupted 4. Water current 5. Structure	2. Dive with good visibility; Propeller guards 5. Operate vehicle in horizontal plane; Operate vehicle at slack tide or on down-current side; Operate from launcher with short umbilical
Electrical Connectors	1. Lack of quality control 2. Poor handling techniques 3. Lack of operator knowledge 4. Poor potting techniques 5. Metal sealing surface too soft 6. Connectors too complex/sensitive for field operations	Various
Sediment Disturbance	1. Propeller wash (reverse thrust) 2. Lack of pilot experience	1. Operate at slight positive buoyancy; use vertical thrusters to descend; Work facing current
Cable Rupture	1. Fouling or entanglement 2. Mechanical abrasion 3. Bottom drag	3. Floats to keep cable suspended
Electrical Interference	1. Propulsion unit affects TV and video transmission as well as other equipment	Various
Support Ship Cannot Station-Keep	1. Lack of bow thruster on support ship	1. Bow thruster
Compass Performance Unreliable	1. Lack of quick response time 2. Affected by metallic structures	2. Directional gyro

TABLE 4.2 PROBLEMS/SOLUTIONS SUMMARIES (Continued)

Problem	Causes/Results	Solutions Applied
Power Supply Surges	1. Support ship overload	1. Dedicated generator
Currents	1. Cable drag 2. Reduced maneuverability	1. Operate at slack tide; Work from short tether attached to clump/ launcher; Live boating with clump/ launcher; Manipulator holds clump while being towed; Heave compensated surface winch with clump
High Sea State	1. Insurance limitation on deployment to State 4 2. Vehicle damage by collision with support ship 3. Shock damage to vehicle components	1. Upgrade launch/retrieval technique 2. Use underwater launcher 3. Shock-mount sensitive components
Vehicle Station-Keeping Inadequate	1. Pilot inexperience 2. Lack of control in currents 3. Power tradeoff forward/vertical thrust	1. Pilot training 2. Increase thruster power and/or relocate thruster 3. Use of limpet-like device to hold vehicle to structure
Manipulation Inadequate	1. Need additional tooling 2. TV lacks 3-dimensional capability	Various
Payload Inadequate	1. Limits vehicle's capability to perform additional tasks	1. Use larger vehicles; Use variable ballast system
Human Engineering Inadequate	1. Reduces pilot efficiency 2. Control surfaces too close together 3. Vehicle control surfaces located in van, difficult to control vehicle when adjacent to support ship	2. Separate controls; Use single joy stick 3. Use portable unit during launch/ retrieval

TABLE 4.2 PROBLEMS/SOLUTIONS SUMMARIES (Continued)

Problem	Causes/Results	Solutions Applied
Human Engineering Inadequate (Continued)	4. Critical control information located too far from TV monitor 5. Digital compass display unsatisfactory 6. Lack of pilot ambience with vehicle 7. Distraction of pilot by support personnel	4. Display on TV monitor 5. Use analog display 6. Use head-coupled TV or servo-controlled chair 7. Isolate pilot
Lack of Vehicle Freeboard	1. Surface visual location difficult	1. Use additional surface locating aides; Flashing strobe light; Acoustic pinger; Make vehicle negatively buoyant
Electrical Shocks	1. Effects on crew handling vehicle 2. Cable handling 3. Submerged diver operations	1. Wear rubber-lined gloves; Install ground strap to vehicle
Maneuverability Lacking	1. Bulk prevents operation within structure 2. Power/thrust distribution reduces vehicle control 3. Current pushes vehicle off course	3. Add lateral thruster to improve station-keeping
Water Visibility Restriction	1. Suspended material in water	1. Mount strobe light on boom; Obstacle avoidance sonar
Television Shortcomings	1. Need greater resolution 2. Quality not as great as photographic documentation 3. Color rendition of poor quality 4. Cost-benefit tradeoff to acquire 3-dimensional TV	Various

a) Greater thruster power to maneuver and position heavy lift lines at great depths,
b)*Stronger, abrasion-proof tether
c)*More power to vehicle
d)*More thruster power
e)*Lighter weight cable
f) Fast acting crane for launch/retrieval
g) High definition color TV
h) Fiber optic link for TV signal transmission
i) Accurate, inexpensive, inertial guidance underwater navigation system
j) Increase data handling capability

*With no increase to cable mass

5.0 CURRENT ROV RESEARCH AND DEVELOPMENT

Current research and development in tethered, free-swimming ROV technology is being funded and conducted by a variety of sources; these include federal governments of several nations and private industrial sources. In several instances the project is funded jointly by the government and industry, with the work being carried out by the industrial partner. This is particularly true in the United Kingdom where the Offshore Supplies Office of the Department of Energy is, by charter, an active participant in several projects directly and indirectly related to ROV technology.

This chapter attempts to describe various projects related to ROV research and development throughout the world. Most of the work now underway is concentrated in the U.S., Canada, England, France and the Federal Republic of West Germany. Not all of the projects are discussed herein in the same detail. The reasons vary, but are primarily related to the degree of confidentiality assigned by the various investigators. All U.S. Government funded programs are described in detail owing to this government's liberal policy regarding information obtained through public funds. Other governments do not subscribe to this position and in some, but not all, instances cannot provide a great deal of information since it may compromise their industrial partner's sense of confidentiality (i.e., competitive position). In instances where the investigator is solely industrial, even fewer details are available.

5.1 PROGRAM FOR THE PROGRESSIVE REPLACEMENT OF MAN UNDERWATER (U.K.)

Most of the ROV research and development programs deal with specific components or aspects of technology. The Government of England, however, has embarked on a program which deals with the field in its entirety, the following section describes this program as it was presented by the Department of Energy's Mr. David Partridge in a March 1979 London seminar sponsored by the Society for Underwater Technology.

> "A large variety of remotely manned submersibles have now been built, some with Offshore Energy Technology Board (OETB) support, and a small proportion of these have demonstrated the ability to perform useful work for the offshore industry, particularly video inspection. It is clear that as oilfield development moves into deeper water, and as social pressures to reduce reliance on hazardous occupations such as diving are likely to increase, there will be a greater need for remotely operated vehicles to perform underwater engineering tasks. The systems to carry out some of these tasks will inevitably be considerably more complex than those carried by today's vehicles; implying high development costs. Unfortunately the volume of work gained by the industry today does not generate sufficient income to finance expensive developments, neither can operators or equipment suppliers afford the overheads to support the conceptual thinking and design necessary to meet long term future requirements.
>
> This situation has been recognized by the Department of Energy which has therefore constituted a new advisory group within the OETB framework. The 'Advisory Group on the Technological Developments Necessary

for the Progressive Replacement of Man Underwater' (AGPRMU) is Chaired by Sir Herman Bondi; Chief Scientist of the Department of Energy.

The Advisory Group has the following terms of reference. To advise the Chief Scientists of the Department of Energy on the R and D support necessary to assist the development of the technology required for underwater engineering to move towards the progressive replacement of man underwater by remotely controlled systems. The Advisory Group will formulate and oversee the implementation of a co-ordinated and integrated program of R and D to make possible the achievement of the objective of moving towards the eventual progressive replacement of man underwater. A first task will be to determine a broad framework for action which can then be presented to the OETB for ratification.

Thereafter, it is intended that this should lead to the formulation of detailed R and D proposals. It is clear that there will need to be a significant amount of longer-term research, a large part of which might have to be wholly funded by the Department. The Advisory Group's help will be sought on the definition of such projects.

Much of the technology relevant to the remit of the Advisory Group may already exist within other branches of engineering science. Thus a major function of the Group will be to bring about cross fertilization with other engineering industries, in particular aerospace. In order to facilitate this, membership of the group is drawn not only from the offshore engineering industry, but from a wide range of organizations in Government, Aerospace, the Academic World, etc. Practical input from people with underwater experience is, of course, of prime importance.

The Group first met in January, and has recently held its second meeting. It is, therefore, too early to comment on the strategy or work program that may emerge. It is possible only to speculate on areas where the Group might concentrate activity.

It is probable that vehicles will become increasingly specialized; designed to perform single tasks or small ranges of tasks. A systems design approach should, therefore, be adopted, analogous to that employed in aerospace projects. However, a number of problem areas will be common to many tasks; navigation, power and propulsion, data transmission, the operator interface, and system reliability spring readily to mind.

The navigation problem may involve fixing the vehicle position accurately in a geographic reference frame, or be restricted to determining position relative to a ship or structure. For the latter purpose acoustic systems have traditionally been used, but lately inertial navigation has begun to make an impact. Acoustic systems suffer from the problem that seawater is a variable medium, and pose problems of signal reflection. Inertial navigation systems have been regarded as too expensive and have operational difficulties arising from the need to update regularly. There is a need to understand more fully the potential of both systems with reference to the performance required for particular types of task. It is possible that the answer may lie in a hybrid approach; in any event it is probable that a greater degree of integration of the vehicle's navigation and control systems is required.

Nearly all vehicles built to date receive power and transmit data through an umbilical. The diameter of the umbilical which governs the drag it creates and therefore the propulsive power required by the vehicle is partly determined by the diameter of the core which carries the power. Minimization of vehicle power requirements through increased propulsive efficiency, etc, therefore can lead to reduction in umbilical drag which in turn reduces vehicle power consumption. Efforts devoted to improving propulsive efficiency and to low power on board systems are therefore indicated. Umbilical diameter is minimized if efficient data transmission at high data rates requiring few transmission lines is used. Fibre optics offer a possible solution, but the mechanical properties of the fibres when continuously flexed and the matching of their modulii to the other cable materials require study. The effects of umbilical drag can be reduced by operating the vehicle from an underwater garage, or eliminated if free swimming vehicles can be developed.

The first stage, which has proved difficult in the past, is to provide sufficient onboard power to ensure useful mission durations and at the same time retain maximum maneuverability. Conventional batteries do not appear to hold the answer. Other, more expensive battery systems may have greater capacity per unit volume but these often have problems in production and disadvantages in use. Hydrocarbon power packs utilizing a Stirling or Rankine engine have been suggested but could have problems due to the size and weight of the propulsion unit with fuel and oxidant for long duration missions. It might also be worthwhile examining once again the prospects of using 100 percent hydrogen peroxide as a fuel. Until a proper study of power requirements involving power packs, recharging, and measures to reduce power requirements has been carried out, a sound approach to the problem will not be possible.

A further problem is through water transmission of information. For manned free-swimming submersibles information density requirements are relatively low and the method of communication has traditionally been acoustic. Acoustic methods have problems in this application however because of diffraction and distortion effects in thermal layers, shadow zones and low propagation velocity. Band width is too narrow to transmit all sensor, control and video data at present needed for unmanned operation. Electro magnetic transmission underwater is often dismissed because the attenuation rates are so high at useful frequencies. However, although far-field radiation will not propagate through sea water, near-field radiation may be a possibility within a limited envelope (say 100 meters).

The operator station is the area which has been most neglected in remote control systems. The whole rationale of manned submersibles depends on the need to have the human being close to and moving round the worksite, so he can get a 'feel' for it. This feel is removed in the present operator stations which at best are not much more than one or two monochromatic TV screens and a joystick. With such a system unless the operator is very familiar with the equipment and the task being performed it is almost impossible for him to get much gross spatial orientation from what he sees and even less appreciation of details is achieved. The way information is presented to the operator and the spectrum of options he has when reacting to this information ultimately defines the effectiveness of the operator station.

If remote operation is to be developed successfully, at the very least color vision with good definition is required, with some means of regenerating perspective and providing easily understandable data displays. The ability to store information and reassess it during the mission as well as later would be useful. For some tasks non-visual data, e.g., tactile, may be necessary. Experimental psychology may provide help to determine the optimum station/operator interaction. It may prove possible through simulation of the undersea environment to put the operator on a par with a diver on the spot. There is probably much to learn from the technologies and methodologies developed for the advanced aerospace simulators.

In the past poor vehicle reliability has caused some potential customers to doubt the value of remotely manned submersibles for offshore work. There is clearly great scope for applying reliability engineering techniques to such vehicles. Reporting of incidents and modes of failure, provision of testing facilities, and transfer of experience from other industries are essential to improving reliability of underwater vehicles, and are areas where Government help could be given.

It is of course possible to meet the most exacting requirements providing that sufficient resources are devoted to R & D. However, we recognize that in the offshore industry equipment has to demonstrate that it can work cost effectively before it becomes acceptable to the customers. Thus, the eventual capital and operating costs of systems will be kept firmly in mind in the event of major R & D programs being undertaken so that resulting equipment can find practical use in the market."

5.2 UNTETHERED VEHICLES

Section 2.4 described work in this area being conducted by the Naval Ocean Systems Center (NOSC) and the University of New Hampshire (both supported by the U.S. Geological Survey); the Naval Research Laboratory, Herriot Watt University and CNEXO. Summations of these programs are as follows:

NOSC - Developing a robot test-bed, untethered vehicle which will permit demonstration of improved ROV system technology. Communication with the submerged vehicle will be pursued through acoustic and/or fiber optic links from the surface.

University of New Hampshire - Developing an untethered vehicle which will automatically follow a pipeline using an acoustic array as a sensing element. Subsequent development will involve design of an optimum vehicle pipeline navigation system; design/fabrication of a two-way acoustic telemetry link and development of an thru-water acoustic vehicle control device.

Naval Research Laboratory - Development of a pre-programmed, untethered, low drag submersible designed initially for scientific data collection. Ultimate vehicle capabilities include a 6,000m (20,000 ft) depth capability; a precise navigation capability combining inertial navigation with OMEGA or doppler sonar; on-board data processing capability, pattern recognition and artificial intelligence and a mechanical manipulator.

Heriot Watt University - Development (over a 5 year period) of an untethered vehicle which will operate from a tethered vehicle at a depth to be specified. TV signals (1 picture/second), command/control functions, and other data will be transmitted from the untethered vehicle, ROVER, to the tethered vehicle, ANGUS 003, thru-water.

CNEXO - Have developed and are now testing EPAULARD, a 6,000m depth-capable, untethered vehicle designed to conduct exploratory missions of the ocean floor. The vehicle operates in a pre-programmed mode and stores data (photographs and echo-soundings) for surface processing.

In support of untethered vehicle technology, the Departments of Ocean Engineering and Electrical Engineering of the Massachusetts Institute of Technology are conducting research into underwater communication systems for untethered vehicles and submerged sensors. The program began in July 1978 and is headed by Dr. Arthur B. Baggeroer. The following program description has been extracted from Dr. Baggeroer's proposal to the MIT Sea Grant Program which is the major funder of this research.

> "The overall goal of the research is to build an underwater communication system which implements the results of modern communication theory using micro-processors. It will operate as a 'modem' providing data transmission at the highest rate consistent with the operating environment. In this way it should be able to serve a diverse number of needs. The system is intended primarily for use with near vertical paths, and it should be able to work at medium rates (>1 kbit/sec) at long ranges ($>$ 3 km) and at high data rates ($>$ 10 kbit/sec) at short ranges ($<$ .5 km). It should also be able to respond flexibly to changes in the operating environment by modifying the data encoding, the frequency, and power level of the transmitters.
>
> Four separate topics on modern communication theory will be investigated for possible implementation.
> i) compression of data from sources using algorithms from speech and image processing,
> ii) block and convolutional encoding procedures,
> iii) adaptive array processing methods for improvided directivity to reduce required power levels and reverberation,
> iv) use of a receiving station on a cable link employing fibre optics.
>
> In the first year of the program the following system components will be designed: data source, encoding and modulation, transmitter, channel, receiver, demodulation and decoding and data user. This work includes specifying the algorithms and simulating them on a general purpose computer to test their effectiveness before committing them to a hardware design. The algorithms will also be "sized"

to determine the speed and memory requirements of the microprocessors before purchasing. The design of the physical housing and hydrophone analysis will also be undertaken during the first year. The feasibility of the fibre optic link will be investigated by contacting the vendors (ITT and Corning) which have supplied this technology to the Navy.

The second year will primarily be devoted to construction of the actual hardware and the programming of microprocessors. Preliminary testing in shallow water will be done during the summer of the second year. During the third year, the results of the preliminary testing will be used to develop a final design which will then be tested and documented.

During each year important research questions must be answered. In the first, there is a need to determine how best to match the results of modern communication theory to the underwater environment. The field is far behind that which is available for electromagnetic communications. Microprocessor and fibre optic technology should be exploited to its fullest extent if a low power, high speed modem is to be obtained.

Because of its diverse needs, the proposed research will utilize resources from several groups - the Departments of Ocean and Electrical Engineering at M.I.T. and personnel from the Woods Hole Oceanographic Institution. Ocean Engineering Department will be concerned with the transducers, or hydrophones, and the physical properties of the fibre optic cable. The Electrical Engineering Department will focus on the communication theory, the microprocessors, and the electrical aspects of the fibre optic cable. Personnel at Woods Hole will be responsible for the construction of the physical housing of the transmitter and receiver as well as the power network and the connection of the microprocessors within them.

The following time and event program is scheduled.

Activity	Projected Time Schedule
Selection of algorithms for implementing communication theory algorithms with microprocessors for acoustic systems.	Winter 1977 - Summer 1978
Determine fibre optic system feasibility	Winter 1977 - Summer 1978
Complete computer simulation of algorithms based upon acoustic channel models in literature	Spring - Winter 1978
Complete timing specifications for microprocessor requirements	Spring - Winter 1978
Select fibre optic table and system components	Summer - Winter 1978
Construct first prototype of acoustic system	Fall 1978 - Fall 1979
Construct fibre optic systems	Winter 1978 - Winter 1979

Activity	Projected Time Schedule
Complete first testing of prototype in shallow water using R/V Edgerton	Fall 1979 - Spring 1980
Test Optical system in shallow water	Fall 1979 - Spring 1980
Redesign based upon first testing	Winter 1979 - Summer 1980
Second testing in deep water (aboard WHOI vessel)	Spring - Fall 1980
Test optical system in deep water (aboard WHOI vessel)	Spring - Fall 1980
Final design and testing of both acoustic and optical systems	Summer - Winter 1980
Final testing of acoustic and optical systems	Winter 1979 - Winter 1980

5.3 DIVER ASSIST VEHICLES

There are two programs aimed at enhancing the capabilities of ROVs as diver assistance vehicles. The first is being carried out by Dragerwerk AG/ZF, the second by the Office of Ocean Engineering, NOAA.

5.3.1 Dragerwerk System

This work is funded by the European Economic Community (EEC). The work is being conducted by Dragerwerk AG/ZF, Herion-System, Technik and has as its goal the development of a diver assistance vehicle for underwater inspection and maintenance duties. The project will develop an underwater support vehicle capable of providing electrical, hydraulic and pneumatic energy, to hold various inspection and work tools and aid communication between divers and the topside supervisor. The purpose of the vehicle is to increase diver efficiency.[1] No further details are available.

5.3.2 Office of Ocean Engineering, NOAA

The Office of Ocean Engineering's program is aimed at conceptual configurations of a Remotely Operated Diver Assist Vehicle (RODAV) designed for assistance in NOAA-related diving activities. Since a major portion of NOAA diving is scientifically-oriented, the RODAV should differ from a commercially-oriented vehicle in several respects.

The first step of this program involves an analysis of all operations and tasks now performed by NOAA divers to define precisely what is being done, how frequently, and to what degree of success. The objective is to rank the various tasks in an order of priority and to identify areas where the diver's performance

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[1] Ocean Industry, October 1978

can be improved with ROV assistance. Consideration will also be given to projected diving requirements over the next five years.

Based on the prioritized needs and deficiencies developed from the preceeding step, performance boundaries will be developed within which the operational parameters of the vehicle will be defined. Such parameters will include, but are not limited to, the following:

Electrical power (for diver tooling)
Speed
Maneuverability
Payload
Viewing capability
Lighting
Position accuracies
Emergency life support capacity
Tool carrying arrangements

An evaluation will also be conducted to define the characteristics of NOAA diving platforms and vessels that will impinge upon various characteristics of the diver assist vehicle, such as launch/retrieval capability (vehicle weight), ship's power, station-keeping characteristics, open deck space, enclosed space, navigational aids, etc.

When the performance characteristics of the RODAV have been defined, comparison of present and planned vehicle capabilities will be performed to identify what areas of technology are in need of development to produce a NOAA mission-oriented vehicle. It is possible that no individual vehicle can perform all of the desired tasks and still remain within a size small enough that it does not threaten the diver. Consequently, a trade-off analysis will be conducted which considers, at minimum, cost of technology developments vs priority of development vs impact on vehicle mass.

Conceptual configurations of at least two of the most promising configurations will be provided. A preliminary breakdown of costs to develop and deliver a prototype system will be estimated based on 1979 rates and delivery schedules.

5.4 ROV INSTRUMENTATION

There are a variety of developmental programs being pursued by industrial concerns regarding instrumentation and tooling for ROVs. Some of these programs are aimed at development of simple devices such as grinders, cutters, brushes, etc., which can be deployed by a specific ROV. Others involve development of more sophisticated technology, such as radiographic inspection equipment, underwater jetting devices, etc. Details of these programs are not attainable since the company does not wish to divulge a potential competitive edge. Two instrumentation development programs for which details, to lesser or greater degree, are available and being conducted by Chansiter Investment Ltd. and NOAA's Office of Ocean Engineering.

5.4.1 Chanister Investment Ltd.

This program is also funded by the EEC and involves development of advanced sea bed instrumentation. The project seeks support for the development of a wide range of instruments and equipment applicable to underwater engineering tasks. The hardware will be used on an ROV (as the base for development of prototype equipment) and on other types of manned and unmanned vehicles whether or not they are remotely controlled. The project aims at making systems generally available for underwater inspection and maintenance. Further details are not available.

5.4.2 Office of Ocean Engineering, NOAA

The projects described in this section are being supported in varying degrees by the Office of Ocean Engineering and involve cooperative efforts with other organizations as noted. The instruments under development are for application from towed vehicles, as well as from tethered, free-swimming vehicles.

5.4.2.a Digital Side Scan Sonar

NOAA/OOE has initiated the development of an advanced digital side scan sonar at the Jet Propulsion Laboratory (JPL), Pasadena, California, with combined NASA/NOAA funds in association with a NASA/JPL "Advanced Ocean Technology Development Platform (AOTDP)." The development, in addition to using improved sonar components, will incorporate digital processing techniques to provide the advantages of speed, programability, communication capability, reliability, accuracy, and compactness. Included as a primary objective of the development is the application of computer image processing to earth resources remote sensing to provide benefits similar to those realized in the application of space program image processing techniques. Direct mapping of seafloor morphology and deposits from sonar images is desireable since such surveys could be executed more rapidly and more economically than by present conventional techniques. System design and hardware development were started in the last quarter of 1977 and system integration and bench test began in the fall of 1978; initial field tests at sea will start in mid-1980. High resolution side scan sonar would be used in NOAA projects to provide images of the sea bottom and aid in characterizing the bottom terrain for basic information needed in implementing programs in ocean pollution, ocean dumping and sea bed disposal.

5.4.2.b Remote Sea Bed Sampling and Analysis

The purpose of this program is to develop advanced techniques which will facilitate remote sampling and *in situ* analyses of the sea bed to expedite assessments of environmental quality. These include metal pollutant content, sea bed transport, mineral constituents and physical properties relative to bottom strength and stability.

The program, currently funded by NOAA and under development at the University of Georgia's Center for Applied Isotope Studies, is to fabricate a system that enables continuous or selective sampling of the sea floor surface followed by on-line shipboard analysis. The project involves developing an experimental system in a two phase effort. This system will consist of three subsystems: (1) a continuous seafloor sediment retrieval system; (2) a shipboard sample preparation system and (3) a shipboard multi-element analysis system. Phase I, began in the middle of 1978 and involved the development of the retrieval and sample preparation units and the performance of an at sea test/evaluation in clear waters to enable visual and photographic documentation of the undersea mechanisms. The field tests were successfully conducted in June 1979 with the prototype system in shallow waters off the Florida coast. The system demonstrated the capability for underway collection (maximum 30 second sampling interval) and shipboard processing/storage (35mm diameter, dewatered and dried wafers coated for preservation on a strip chart).

Phase II of this project will involve the development of shipboard analytical capabilities to enable on-line analysis of samples, followed by at sea tests of the total system. After these two phases are completed all of the test results and system improvements will be incorporated into a design suitable for a tethered or untethered vehicle configuration depending on how the system functions are subdivided.

5.4.2.c Sub-Bottom Profiling

The goal of this program is to develop advanced techniques for profiling the sub-bottom structure of the sea bed by non-intrusive techniques. It is anticipated that NOAA missions related to ocean dumping, environmental assessment and mineral resource assessment will benefit by this technology.

The project, referred to as time delay spectrometry and initiated at the Jet Propulsion Laboratory, shows promise for improved performance in sub-bottom profiling resolution and penetration depth. An experimental system has been developed and undergone limited testing. The system employs advanced transmission and signal processing using a frequency modulating or "chirp" technique. The entire system is packaged into a towed vehicle configuration. NOAA's Office of Ocean Engineering supported this project with the joint cooperation of NOAA's National Ocean Survey in conducting evaluation tests at sea to obtain high quality data for correlation with soil properties derived by coring. If the results are promising, this concept can be developed into a modular unit for incorporation into towed vehicle systems.

5.5 MANIPULATION

Industrial use of manipulators on ROVs is, as discussed previously, minimal. Consequently, advanced research in this area (on the part of the commercial operator) is not a high priority item, and the most sophisticated commercial manipulative system is represented by that present on Saab Scania's ORCA (see Section 2.1.7.d).

In the academic/government community active research and development in underwater manipulative systems is being conducted by the Department of Mechanical Engineering MIT, with funding from the Office of Naval Research. The results of this work through July 1978 are presented by Sheridan and Verplank (1978) in the report Human and Computer Control of Undersea Teleoperators. The authors define "teleoperators" to be general purpose submersible work vehicles controlled remotely by human operators and with video and/or other sensors, power and propulsive actuators for mobility, with mechanical hands and arms for manipulation and, possibly, a computer for a limited degree of control autonomy.

The objectives of the study are as follows:

- Survey and analyze undersea tasks appropriate to accomplishment by teleoperators.
- Analyze constraints in the undersea environment and technological constraints of submersible vehicles, communication and control systems which most significantly mediate teleoperator control - parimarily the man-machine aspects.
- Investigate and define theories of operator control performance applicable to remotely controlled systems. Develop taxonomic and mathematical models of man-machine interactions in undersea teleoperation (inspection, vehicle control, manipulation), particularly those pertaining to supervisory control - where man controls computer on slow time scale while computer controls teleoperator on fast time scale.
- Recommend specific laboratory simulation experiments with human subjects and software developments to explore and demonstrate various supervisory control modes, and measure teleoperator performance.
- Perform some of the above experiments and apply some of the above models. (This is planned for follow-on phases of the present contract.)

The following is an abstract of their work to date as presented in the July 1978 report:

> "This is a review of factors pertaining to man-machine interaction in remote control of undersea vehicles, especially their manipulators and sensors. Emphasis is placed on human operator control of such teleoperator systems as a function of degree of automation sensor-control integration and task demands for underwater search, object recovery and manipulation. Models of operator-computer performance are considered, particularly with respect to human supervisory control of semi-autonomous systems.
>
> Sections of the report discuss: teleoperated submersible vehicles or work platforms; undersea tasks and how they can be analyzed; relative roles of human and computer or other control elements; control hardware (sensors, communication, propulsion, manipulation, control station) and how it affects the human controller; control software for computer-aided manipulation, including a review of various languages and algorithms presently available; human operator performance in manipulator control (a review of what we now know); present and prospective theoretical models of supervisory control; and finally, the needs for research in this area."

As of late 1978 a laboratory model of a manipulative system has been fabricated which is capable of measuring human input (such as the unscrewing of a nut and its subsequent replacement on the bolt) and then duplicating this action without the need for human intervention.

5.6 POWER

Virtually all electrical power for tethered ROVs is supplied from a surface generator through an umbilical. Untethered vehicles presently rely upon lead acid or silver zinc batteries for power, and have an operating duration of 4 to 5 hours, the primary user of this power is the propulsion system. In order to deploy an untethered vehicle which will provide capabilities comparable with tethered vehicles, a higher energy density power source must be made available. To this end the Continental Group Inc. of New York has developed a lithium battery or power cell which can be packaged for ROV application or from a manned submersible. The first application will be in a manned vehicle, the AUGUSTE PICCARD, where the power cell will be installed in late 1979 and will provide 1.2 mWH of electrical energy. A subsequent phase will see installation of a lithium power cell supplying 36 mWH.

The lithium power cell is an electrochemical system which combines high energy lithium anodes with simple iron cathodes in a highly ionized aqueous electrolyte. The anodes are solid lithium, rolled, cast or extruded from basic ingots. The cathodes are commercial iron or steel screening. Adding aqueous electrolyte to this lithium-iron combination makes a highly efficient cell. Lithium ions go into solution, releasing electrons which travel through the external circuit to release hydroxyl ions and hydrogen at the cathode. The lithium hydroxide solution which results from this activity forms the aqueous electrolyte. The electrolyte, produced by normal cell activity, is circuited through the cells to remove heat and the polarizing products of the electrochemical reaction, and to bring water into the reaction zone to maintain and control cell output. It can achieve high energy and power densities over a wide range of operating and environmental conditions. Lithium and water are consumed at room temperature in a cell in which voltage and power output can be controlled independent of the electrical load, within the limits of cell capacity. The power and voltage capability does not degrade during any given discharge cycle, or from cycle to cycle throughout the life of the system. Replacement of the lithium anodes readies the battery for reuse, which is limited only by the life of supporting equipment such as pumps, motors, and valves. The system also consumes substantial quantities of water, but in a marine system this is neither a cost nor logistic penalty because the water is drawn from the ambient environment.

Of the 3820 Whr/lb of lithium released (theoretical energy density of the basic lithium-water couple) during the electrochemical reaction up to 2500 Whr/lb of lithium can be delivered from the cell. (The remainder appears as heat in the circulating electrolyte from which it is subsequently removed.) High values of specific energy are achieved by operating at high cell voltage (and electrolyte molarity) with a corresponding low power density. As with most energy/power systems, there is a tradeoff between maximum energy and maximum power density, and the two characteristics achieve maximum values at different operating points. The lithium-water cell is typically operated at a cell voltage of 1.25 V which yields moderate values of both specific energy and power. However, cell operating characteristics can be tailored to fit specific requirements. Total system energy and power densities depend greatly upon the specific application.

Continued development of the basic power cell led to electrochemical systems which utilize active cathodes. One of these involves the addition of hydrogen peroxide as a reactant to the electrolyte. The peroxide eliminates the evoluation of hydrogen gas and converts it into usable water for dilution purposes. The changes required from the basic lithium water system are the addition of a thin silver or palladium plating to the iron screen cathode and a system for introducing the perioxide solution to the main electrolyte stream as required by power demands on the battery. The addition of hydrogen peroxide essentially doubles the power and energy that a system can deliver for the same weight of lithium consumed. Approximately 1.1kg (2.5 lbs) of hydrogen peroxide are required per pound of lithium consumed; in practical systems where the peroxide utilization is less than 100 percent if 1.4 to 1.8kg (3 to 4 lbs) of 80 percent peroxide per pound of lithium is used.

The marine application of the lithium power cell has been directed into three utilization modes: a deep-ocean power source, a self-contained deep-ocean power source and a small marine power source.

Deep Ocean Power Source - The deep-ocean power source application uses the lithium-water couple as a 3.75kW submersible power source for use at ocean depths up to 6,096m (20,000 ft). To date, a subscale power module complete with all ancillary pumps, valves, heat exchangers, and pressure compensation components has been tested at 6,096m (20,000 ft) depths. The application of this power source for 15kW submersible power source has been investigated. The design shows the complete system installed in a 66cm (26 in.) diameter pod. As conceptualized, the system uses four modules (installed in a 66cm (26 in.) diameter cylindrical pod) designed to provide a 20 hour operation and has an estimated dry weight (exclusive of the pod) of 408kg (900 lbs). Much of the system weight is associated with ancillary components which are not altered as operating time is increased. Hence, the system weight does not increase rapidly.

Self-Contained Deep-Ocean Power - The submersible power supply described above uses seawater from the environment and rejects hydrogen. For some applications, it is desirable to provide a self-contained power source which has a minimal interaction with its environment. The lithium-hydrogen peroxide couple can form the basis of such a system. The three-module system was designed to produce 15kW at 105 V and deliver 150kWhr. Treated seawater and hydrogen peroxide are carried onboard in reservoirs. The reaction products from battery operations are returned to and stored in these same reservoirs, separated from the primary liquids by flexible membranes in each tank. This closed-system type of operation maintains the system at essentially constant buoyancy. The only minor change in buoyancy results from the venting overboard of small amounts of gases which occur from nonstoichiometric operation. Other configurations are also available.

Small Marine Power Source - A prototype version of a small marine power source was built and successfully tested. A laboratory brassboard model of a unit has been used to verify performance capability of the design approach. The battery fits within a hull which is suspended below the ocean's surface by a float. Water for dilution and cooling are drawn from the surrounding ocean. The hydrogen gas and excess electrolyte are rejected to the ocean. The battery weight 23kg (50 lbs) including all the subsystem components necessary for self-sustained operation. The cell stack uses 10 cells and operates at 12.5 V (For one specific application, a DC-DC converter is used to provide the 50 V output required by the system.) It generates sufficient power and energy to delivery up to 500 W and 4000 Whr to the load as well as run its pumps and activate its valves. The overall system energy density for this small power source is seen to be 80 Whr/lb of system weight, energy density will double with the addition of hydrogen peroxide oxidizer.

5.7 NAVIGATION

The navigation systems described in Section 2.1.12 all rely upon acoustic, thru-water transmission. An inertial navigation system, called HASINS (High Accuracy Submersible Inertial Navigation System), has been developed by Ferranti Ltd., which has been demonstrated aboard a manned submersible and is under consideration by several ROV operators as having application to remote vehicles. The system is attractive because it does not rely upon acoustics and, therefore, has potential for working within a structure and not be subject to the effects of reverberation as are the acoustic-based systems. The manned submersible demonstration, conducted in early 1977, involved the measurement of seven positions along a 259m (850 ft) line and demonstrated a total error of 20cm (8 in.).

The system and demonstration tests performed are described by Stankoff and Tait (1977). The following description of the system and its operation is taken from their report.

> "Essentially the Inertial Navigation System (INS) comprises three gyroscopes and three accelerometers. These instruments are held on an orthogonal triad, with one accelerometer and one gyroscope pointing north-south (N/S), another set (E/W) and the third set vertical. This triad, called a cluster is mounted on gimbals. With a motor and synchro on each gimbal, the total arrangement has, with an appropriate servo system, the ability to be gyro-stabilised. This implies that the cluster will remain pointing in one direction irrespective of the motion of the gimbals.
>
> At switch-on, an INS must perform two processes. The first is levelling: here the cluster is aligned to the local vertical. Output signals from the accelerometers become error signals in servos which drive the gimbal motors. Only when N/S and E/W accelerometers detect zero gravitational acceleration is the cluster level. The cluster is levelled to within a few seconds of arc from the horizontal plane. The second process is gyrocompassing alignment - the object is to point the N/S accelerometer to True North. This is effected by measuring a component of the earth's rotation detected by the E/W gyroscope. With a knowledge of the latitude at the point of alignment, this rate is a measure of the misalignment of the cluster from True North. The cluster is then precessed until this error is zero. Alignment to North is accurate to within a few minutes of arc. Both these processes are automatic and require about 10 minutes to complete.

Having the cluster levelled and aligned to North, the N/S accelerometer detects only accelerations in a N/S direction. Likewise the E/W and vertical accelerometers are pointing E/W and vertical respectively. An acceleration in the N/S direction would be detected by the N/S accelerometer and if this acceleration was integrated, it would produce a velocity in the N/S direction. An integration of this velocity would result in a displacement N/S. Similarly, if accelerations occured in the E/W and vertical directions, double integration in both channels would produce displacements E/W and vertical.

Since it is necessary that the cluster always points North and is aligned to the local vertical, there is a coupling between the N/S accelerometer and the E/W gyroscope. This coupling between the instruments becomes the basis of a feed-back loop and is called a Schuler loop. One property of this loop is that it has a natural period of 84 minutes. Thus any instrument errors, scaling errors, computing errors, misalignment errors, etc., manifest themselves usually as velocity errors whose period is 84 minutes.

A typical inertial system has errors in position of 1 NM (1.8km) in one hour. The velocity error associated with the position error has a long period. It is this fact which offers a solution to the problem of attaining centimeters accuracy. The solution takes the form of sampling the Schuler loop velocity error frequently. The oscillation can, in short time intervals, be adequately represented by a low order function: $a + bt + ct^2 + dt^3$ where, a, b, c and d are constants and t is time. This simple model can then be used to represent the Schuler velocity errors. The accuracy of the model depends on two factors: (a) the frequency of sampling and (b) the accuracy and resolution of velocity error measurement. The first factor is influenced by the mode of operation, and the second factor depends critically on some standard of velocity with which to compare the error velocity. The standard velocity chosen here is zero velocity - stopped. This has a unique quality of being absolute and capable of infinite resolution. In practise, therefore the inertial system has to be stopped every minute say, and the error measured. A model is constructed to represent the error velocity and the net system velocity is inferred from the model velocity and measured velocity. Laboratory experiments were completed with the system stationary on a bench, the error velocity was sampled at various times and the resultant positional error logged. The error is about 3cm (1.1 in.) for one minute time intervals, 15cm (5.9 in.) for two minutes and 80cm (32 in.) for three minutes.

The INS is fully contained in one unit measuring 38cm x 33cm x 30cm (15 in. x 13 in. x 11 in.). The system also has a unit called GENIE (General Electronic Navigation Interface Equipment). Its purpose is to convert the basic INS into an accurate navigation system suitable for submarines. Fundamentally, it receives velocity information from the INS, and with its own computer performs the processes necessary to model the error velocity, and integrates to produce displacements. Displacements N/S, E/W and vertical are calculated to around 1mm and displayed to 1cm. The Control and Display Unit (CDU) is the means for controlling and displaying the results of the total system. Another use of the GENIE is to provide the vehicle with both a computing capability and also a source of control and steering signals."

5.8 PIPELINE INSPECTION SYSTEM INTEGRATION

The Marseille-based firm INTERSUB is in the final stage of developing an ROV pipeline inspection system which integrates various of the instruments listed in Section 2.1.7 onto an ROV and then further integrates the ROV, the navigation system and the support ship into a single operating entity. Significantly, where all commercial and most government ROVs operate from a support ship of opportunity, INTERSUB has dedicated and converted a ship to sole support of its inspection system.

The basic components of this system can be divided into three main parts: 1) the support ship; 2) the underwater vehicle; and 3) the equipment.

The Support Ship: INTERSUB FIVE was converted to operate both an unmanned, tethered underwater vehicle and a manned submersible. The ship is 57m (187 ft) long, 11.5m (38 ft) wide and has a draught of 4.8m (16 ft) with twin screws, gill jet bow and stern thruster and full dynamic positioning. There is accommodation for 30 and a ship's crew of 16 with two computers and space to process all data and produce drawings onboard.

Underwater Vehicle: The vehicle is a TROV specially designed for pipeline inspection using INTERSUB DEVELOPPEMENT survey equipment. It has a diving depth of 900m (2,953 ft), weighs 2,700kg (5,952 lbs) with dimensions of 300cm x 132cm x 165cm (118 in. x 52 in. x 65 in.). The propulsion is provided by four 440v motors with variable pitch screws in kort nozzles, the two longitudinal thrusters are 10hp while the vertical and transverse are 7hp. The umbilical is 1,067m (3,500 ft) in length and controlled by a winch comprising level winder, reel, water tank, slip rings and hydraulic drive. The reel accommodates 1,219m (4,000 ft) and is situated in a water tank to keep the cable cool.

Equipment: To carry out a full inspection the following equipment will be mounted on the unmanned tethered vehicle:

a. Short Base Navigation System: The Simrad HPR Short Base Navigation System is an acoustic system which provides an accurate position of the vehicle in real time, relative to the support ship axis.

   The sea state and structure of the water will also affect the accuracy of the equipment. The Short Base System is interfaced with a Surface Navigation System through a computer with a plotter giving the coordinates of the vehicle in real time.

   Any Surface Navigation System can be used such as Pulse 8, Hi-Fix, Argo, Trisponder or Syledis, etc. The total error using Syledis is better than ± 5m (16 ft).

b. Doppler Sonar: The Doppler Sonar continuously measures the speed of the vehicle in relation to the longitudinal and transversal axis. This measurement when integrated with time and a gyro compass thus enables the distance run by the vehicle to be known with high accuracy in relation to a specific reference points.

c. Pipetracker: The pipetracker enables the submersible to locate and follow a buried pipe to a depth of burial of 3m ± 10cm (10 ft ± 4 in.) depending upon the size of the pipeline. The system induces eddy currents in the metallic mass of the pipe and measures the resulting field which gives the location of the pipe both vertically and laterally.

d. Continuous Seabed Profiler: The continuous seabed profiler, which combines an Echo Sounder and a Pressure Sensor, uses the surface sea level to give a continuous seabed profile related to absolute depth.

e. Trench Profiler: The continuous sector scanning trench profiler produces a profile of the seabed every 25m (82 ft) at a normal survey speed of about one knot (1.8km/hr). The 140 degree sector scan cycle lasts about 60 seconds which includes data recording. The effective scan width is about 20m (66 ft) with the profiler 4m (13 ft) above the seabed.

f. Current Density: The INTERSUB Current Density System measures the D.C. currents produced by the anodes which vary between 25mA/m^2 and 500mA/m^2. This gives a curve showing current density along the pipeline whether it is buried or not.

g. Cathodic Potential Readings: This system using Ag/agCl reference cells achieves either direct measurement in contact with the bare metal areas or indirect measurement using two separated reference cells.

h. Leak Detection: This system,which is not yet fully proven at sea, includes a fluorometer leak detector system that continuously measures the hydrocarbon content of the seawater. The system, combined with an acoustic hydrophone to monitor the noise level, allows very small leaks to be accurately pin-pointed.

i. Optical Systems: The vehicle is fitted with three Sub Sea Systems CM8 Newvicon cameras, two of them are located in the front of the vehicle (one on pan and tilt, one on tilt) while the third one,placed on pan and tilt on the rear of the vehicle,allows a visual control of the umbilical and pipe tracker. The cameras have two functions: one allows the surface controller to see where the vehicle is going; the second provides a visual record of the inspection.

For detailed photographic work on specific areas of interest, color stills are taken using a benthos 372 still camera.

j. Computer System: Figure 5.1 shows the inter-relationship of the instrumentation. The sensors continuously transmit information to the computers on the surface. This information is collected at the

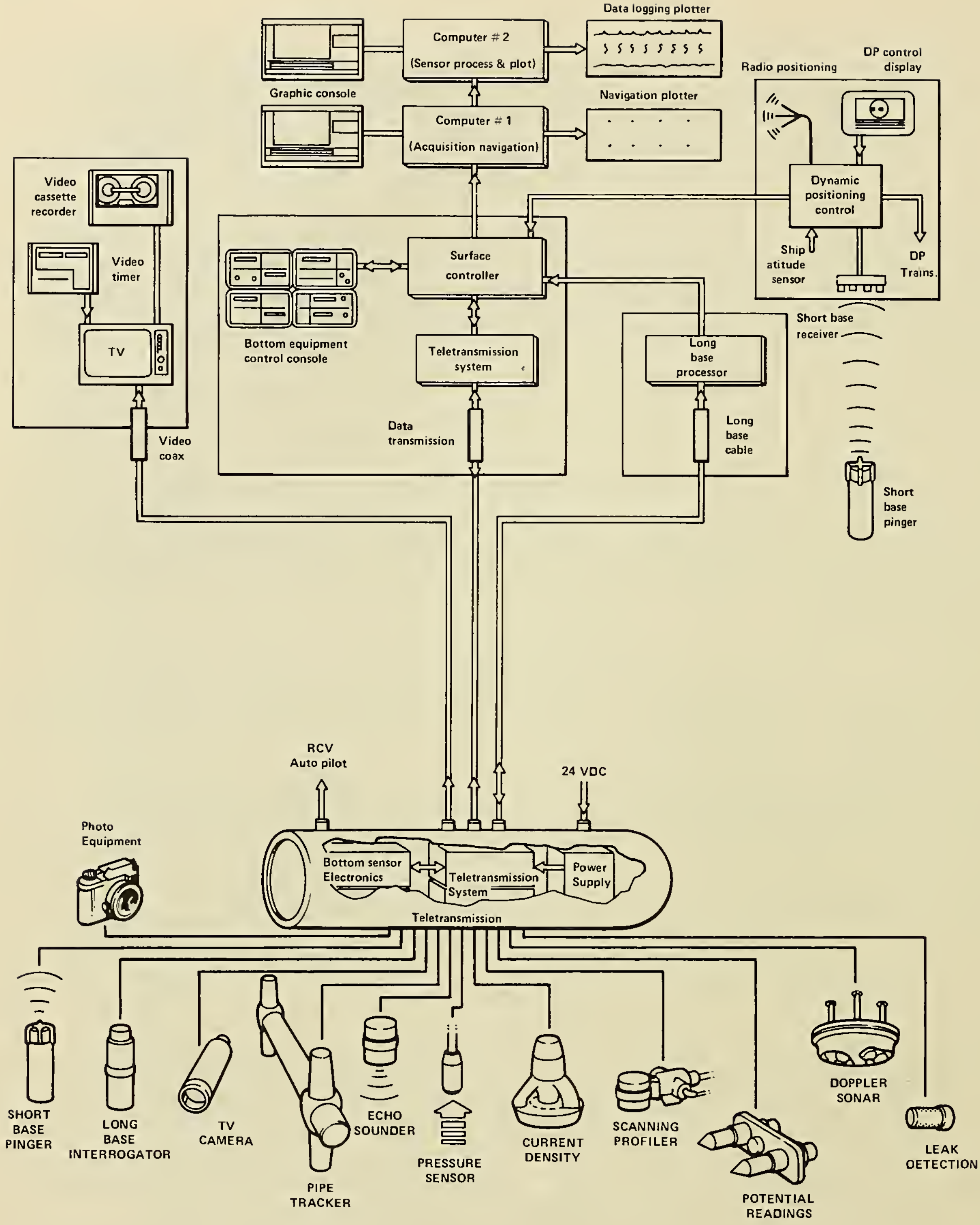

FIGURE 5.1 BLOCK DIAGRAM OF THE INTERSUB PIPELINE SURVEYING SYSTEM'S INSTRUMENTATION AND SURFACE PROCESSING
(Courtesy of Intersub, Marseilles)

same time as the other relevant data on the surface (short base, surface navigation) by the first computer which provides in real time a plot of the vehicle's position, thus allowing the route to be plotted point by point.

This information is then passed to the second computer which processes in real time, the data from the different sensors, calibrates them, corrects them, inter-relates them if necessary and finally plots them in the form of curves as a function of the distance run.

Pipeline Inspection Operation

The support ship is positioned in the immediate vicinity over the pipeline to be surveyed and launches the tethered vehicle. The vehicle is then dived to the seabed and controlled via the umbilical. When in position over the pipeline all systems are tested and recorders checked to ensure no malfunction. Figure 5.2 depicts the major system components at this point in time.

The vehicle is now electronically locked onto the pipeline via the pipetracker coupled to an automatic pilot which ensures that the vehicle follows along and directly over the pipeline. The active SIMRAD short base navigation system interfaced with the G.E. dynamic positioning ensures that the ship remains directly over the underwater vehicle. Offsets can be fed into the system to allow for umbilical drag.

The inspection vehicle now moves along the pipeline controlling the support ship where all data received from the sensors via the umbilical is being recorded and processed in real time. The only endurance limitations to the system are weather, maintenance and operator fatigue. To quote average pipeline distances inspected per day can be misleading as distances covered will depend upon conditions experienced: bottom tidal stream, rock dump areas, requirements for detailed inspection of specific areas, surface sea state, debris, pipe covers and all the other conditions that will affect the rate of advance.

The content of the final report depends upon the client's requirements. It usually contains, but is not limited to, the following information:

Pipeline - geographical location
UTM/DECCA lattice or similar
Mile posts/KP from start
Contractors joint number
Scale
Anodes
Bathymetry/Sub-bottom profiles
Isobathic curves
Cautions/obstructions
Current density - condition of anodes
Cathodic potential
Compass rose
Tidal stream: surface/sub-surface
Trenching details: top of pipe, bottom of trench, mean sea bed level

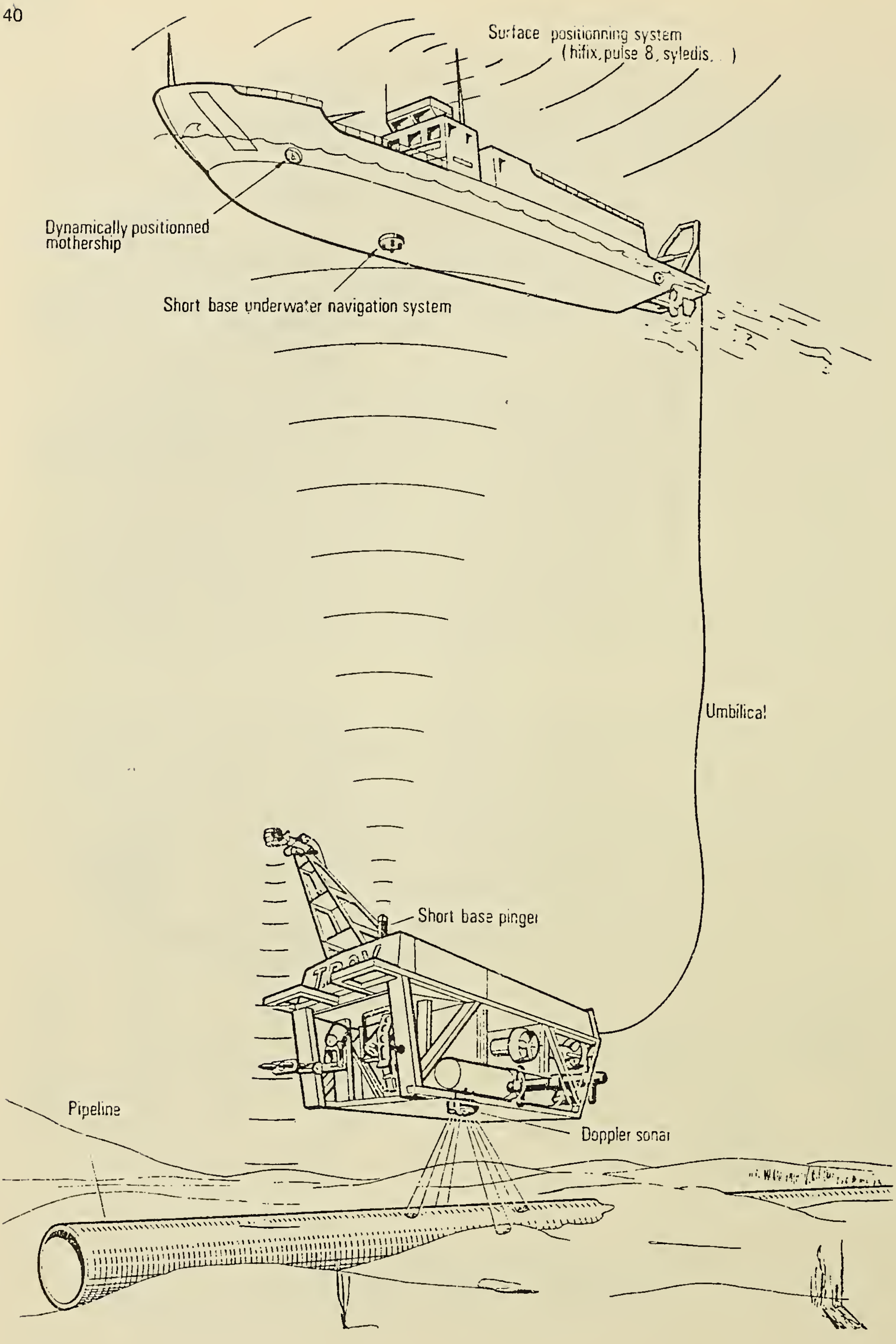

FIGURE 5.2 MAJOR COMPONENTS OF THE INTERSUB PIPELINE SURVEYING SYSTEM
(Courtesy of Intersub, Marseilles)

5.9 TETHERED MAINTENANCE VEHICLE

Exxon Production Research Company is developing a Tethered Maintenance Vehicle (TMV) designed to perform observation and manipulative tasks on facilities and equipment associated with a deepwater marine production riser system (Teers, 1979). The maintenance system consists of the TMV, interchangeable tool packages, a launch/recovery system, a control van and auxiliary surface support equipment.

The TMV is rectangular shaped with an open framework design. It measures 2.1m (7 ft) high, 2.4m (8 ft) wide and 5.7m (18¼ ft) long, and will weigh approximately 11,793kg (26,000 lbs). Ten thrusters will maneuver the vehicle, these are powered by two 100hp hydraulic pumps which also power the tool packages. Two 2200 VAC, 3-phase electric motors drive the hydraulic pumps and they receive their power from a surface generator through an umbilical cable. Additional power for all vehicles and tool package subsystems is provided through separate conductors in the umbilical where a transformer in the TMV's distribution system transforms 600 VAC, 3-phase to 120 VAC, 1-phase power. Five TV cameras constitute the optical viewing system. The TMV also contains a station-keeping system for tasks that do not require extensive shifting of payload. A variable buoyancy system can accommodate up to 1,814kg (4,000 lbs) of payload.

A guidance system receives target information from transponders mounted on the riser. The system permits the TMV to close and dock with the desired riser attachment point. Once at the desired attachment point the tool package attaches the system to the riser for performance of the maintenance task. Since the hydraulic thrusters produce considerable noise, a composite noise signature of the TMV hydraulic components was prepared which will be used to design the guidance systems acoustic components to assure that they will not interfere with the hydraulically-generated noise.

Three tool packages have been designated:

> Hose Replacement Tool Package - to replace production hoses weighing up to 1,814kg (4,000 lbs) in water,
> Swivel Replacement Tool Package - to replace flowline swivels weighing up to 4,762kg (10,500 lbs) in water, and a
> General Purpose Tool Package - to perform maintenance tasks such as inspection, cleaning, anode replacement, and buoyancy module replacement.

Each tool package can be rigidly attached to the riser by three attachment arms which also provide the initial alignment. A force-feed-back manipulator on each package will perform all manipulative tasks.

Two modes of TMV operation are envisioned: a free-flying mode and a suspended mode. According to Teers (1979), the techniques employed will be as follows:

> "When operating in the free-flying mode the TMV will be capable of supporting a 1,814kg payload while moving freely in the water to the work site. During this operation, a cable depressor (clump weight) will be installed on the tether cable. The cable depressor will

> maintain the position of the tether cable below the workboat and will allow the TMV to operate away from the cable depressor without the danger of the tether cable becoming entangled in the riser. The TMV, cable depressor, and payload will be maneuvered to the desired depth; then the TMV's propulsion system will move the system horizontally until the tool package can attach to the riser. In this mode, the variable buoyancy system will be used to compensate for changes in payload, such as releasing a replacement production hose after it has been connected.
>
> When operating in the suspended mode, the TMV will be suspended from the launch and recovery system's heave compensator by the tether cable. Since the TMV itself will be neutrally buoyant, the load on the tether cable will only be the payload weight plus the TMV dynamic loads (which will be minimized by the heave compensator). The TMV and payload will be lowered to the desired depth where the TMV's propulsion system will move the system horizontally until the tool package can attach to the riser. The maximum in-water payload for this mode is 4,762kg."

Current plans include continued development of the TMV to fabrication and testing. Testing of the launch/retrieval system and general purpose tool package will follow. Extensive offshore tests are planned to prove the systems effectiveness before it is employed on an actual riser maintenance mission.

6.0 RECOMMENDED RESEARCH AND DEVELOPMENT

The preceeding chapters attempted to portray a field of marine technology which is extremely dynamic and, in the main, reponsive to clients with ever-changing, virtually unpredictable needs. Unlike other areas of marine technology which have, to varing degrees, a long-term performance record for analysis, the Remotely Operated Vehicle field is virtually an overnight phenomenon. In merely three years the number of vehicles has tripled. The growth and application has been so dynamic that the operators - a traditional source for obtaining future development requirements in related fields - are so totally involved in day-to-day problems that they have little, if any, time to devote to future market requirements. The growth of this field is inextricably bound to development of offshore oil and natural gas resources - the ultimate client and source of future vehicle capability requirements. But, this field is as dynamic as the ROV field itself, and introduction of new exploration, development and production techniques also introduces new and varied applications for ROVs. As a consequence of these dynamics there are no clearly defined design goals or ROV capabilities objectives which will serve to satisfy future requirements with 100 percent assurance.

A further consideration, in regards to recommending research and development programs, is that present ROVs - in spite of their problems - are accomplishing the work they have set out to do. Except in a few areas, such as cable rupture and entanglement, there are no outstanding deficiencies in vehicle performance. This situation is clouded, however, by the fact that ROVs are being used primarily to conduct tasks which call upon their most fundamental capabilities - observation and videotape/photographic documentation. Indeed, one major manufacturer of ROVs stated that the vehicles have nowhere realized their full potential, and that they have the potential for accomplishing an even wider variety of tasks as now designed. A case in point is manipulative capabilities. The fact that approximately only 5 percent of the tasks call for manipulative capabilities is not necessarily because ROVs lack the capabilities required, it is simply that there is no strong demand for this function at present.

The foregoing summation is made to emphasize the point that it is difficult to provide a clear-cut, well-defined research and development program in a field as new and as dynamic as remotely operated vehicles. The problem is further complicated if the program attempts to address itself accross the board of the wide variety of ROV users. On the one hand is the commercial and military user who is entering an era of specialized vehicles, on the other hand is the potential scientific user who hardly knows what an ROV is. For these, and other reasons, the research and development program recommended is addressed separately to: 1) the commercial/military segment and 2) to the scientific/research community, although the latter will obviously benefit from developmental improvements by the former.

The recommended programs are presented in two categories: immediate and long term. By "immediate", the objectives are to increase the performance of existing vehicles. Many of these programs are not development programs as such, but are projects aimed at improving present capabilities instead of developing entirely new technology. "Long term" programs are those which require heavy investment of funds and a more extensive research effort than those programs identified as "immediate".

6.1 IMMEDIATE RESEARCH AND DEVELOPMENT PROGRAMS (Commercial and Military Sector)

6.1.1 Cable Technology

Umbilical cable rupture and breakage through abrasion on man-made and natural objects is a major cause of ROV malfunctions. Development of a stronger, abrasion-proof cable is required which does not incur a penalty of greater mass or greater drag.

Development of light weight cable is also required. In this instance there must be no degradation to the cable's data handling capability. Further exploration into fiber optics should continue and be accelerated and the mechanical properties of fiber optics when continuously flexed should be investigated. This technology is critical to meet the increasing demands for greater depth of operation.

Techniques for modifying existing, negatively-buoyant umbilical cables into positively buoyant cables needs to be developed which do not interfere with reeling-out and reeling-in procedures. Although deployment of ROVs from subsurface platforms (i.e., manned submersibles) is minimal at present, it is likely that future applications via this mode will increase - particularly if under-ice operations are required. Present day vehicles are limited in the distance they can "fly" upward from a bottom-mounted deployment platform by the weight of cable they can lift.

Inspection of cables on towed vehicles is accomplished primarily by visual examination of the outer sheathing. There are no rapid techniques available for conducting a non-destructive examination of the inner strength members. A non-destructive examination technique should be developed to provide relatively rapid examination of the strength members for cable lengths of 6,000m and more.

6.1.2 Television

Although color television is not in great demand at present, it is inevitable that there will be a demand for it in the future. There are several manufacturers of underwater color TV. A technical assessment of the various models is required to identify their level of color rendition, resolution and adaptability to the underwater environment. Color TV for scientific missions is imperative and there are developmental models which reportedly can provide an image equal to - and perhaps better than - that obtained via direct viewing. One such model is a prototype color TV manufactured by RCA which was used in the spring of 1979 to depths of 3,000m by the manned submersible ALVIN. According to several of the scientists who participated in this mission, the TV image was of such excellent quality that the scientists preferred viewing the monitor rather than directly through the submersible's viewports.

A serious shortcoming in television viewing is the lack of dimensional data on objects being viewed. Virtually every undersea task requires an estimate of some object's size or dimensions. With present TV there is no method of doing this accurately. (One operator has affixed two narrow beam lights 22cm distant from each other, the light beams are recorded on the videotape and provide an estimate of object size in two dimensions.) There is a need for a system which can automatically and accurately determine the size of an object viewed on the TV monitor. Initially, the system might view and videotape the image in 3-dimensions for subsequent size determinations using photogrammetric techniques. Ultimately, a real-time readout and storage of dimensional data is preferable.

6.1.3 Surface Location Techniques

A number of ROVs have been lost after their cable has been severed (intentionally or unintnetionally) and the vehicles safely reached the surface. Since the freeboard of all ROVs is no more than 10 to 15cm (and commonly less), visually locating the vehicle in calm waters is difficult; when the sea state is 2 or greater it is almost impossible. Several vehicles have self-powered, flashing lights to aid in location, however, in 1 to 2m high seas the light will appear intermittently and loses its effectiveness. A surface locating device is required that is light weight, of minimal dimensions and low power drain. The device should combine a variety of sensors to aid in location; at a minimal these should be an acoustic pinger, a radio beacon and a flashing light. Other items which should be considered are some form of pyrotechniques (smoke or flares), and dye disperents which would activate upon surfacing in an emergency condition. The emergency devices should be designed to aid in location from aircraft, as well as from ships. An operating duration of at least 72 hours is required.

6.1.4 Thruster/Power Module

The assistance of ROVs in debris recovery and object retrieval is increasing. However, their performance is limited in the size of cables and lines they can attach because they lack the propulsive power to move and maneuver heavy lines to the point of attachment.

In another vein, operations under strong, tidally-induced currents are hampered by lack of thruster power and the mission is often rescheduled to work during periods of slack tides. This procedure prolongs the operation and increases its cost.

An obvious solution would be to increase the power supplied to the thrusters and, concurrently, increase thruster horesepower. The solution, however, increases cable size, which leads to greater drag.

There is a requirement, therefore, for occassional increased electrical power and thrust, without incurring penalties in cable size. The solution can be obtained by design of a thruster module which is powered by an independent, submersible power source. The source can be batteries which provide high energy for short periods. The module should be designed for easy attachment to a rectangular, open framework structure such that it would augment vehicle thrusting power when the task calls for thrust beyond that required for routine operations. The first step in this project should involve determining the feasibility of such a module in terms of an available power source, adaptability to the field at large and sizing the power requirements based on the projected work tasks.

6.1.5 Diver Assist ROV

The application of ROVs as diver assist vehicles was quite fortuitous. There was no intent on the part of the designer to conduct the type of diver-assist services which several of the vehicles (particularly the RCV-225) are now providing. Since this type of function will undoubtedly continue, and will probably increase, there is a need for a vehicle designed specifically for diver assistance in the commercial field.

The first step in this program should involve an analysis of the tasks commercial divers perform to identify the support services required. Aspects of assistance such as: safety, navigation, location, additional electrical, pneumatic and hydraulic power, tooling, emergency breathing air/gas communication (diver-to-surface) and supplemental lighting should be, at a minimum, considered in the design. Similar to the NOAA program for a diver assist ROV for scientific use (Section 5.3.2), this program should aim at one or, perhaps, several concept designs in areas of support for inspection and maintenance, repair, construction and exploratory drilling.

6.1.6 Acoustic Imaging

In many inshore areas and coastal areas, and during various phases of constructional/installation, water visibility is so poor that closed cirucit television viewing is impractical. As an alternative an acoustic imaging system is required which can provide picture information of objects of interest under conditions where television is ineffective.

There are acoustic imaging systems used in various military endeavors and those which are also available commerically (EMI Electronics Ltd., Surry offers such a system). These technologies - as far as can be determined - have not been deployed from an ROV. As a first step the commercial systems and, to the degree possible, the military systems, should be evaluated for application from an ROV. The results of these evaluations should be made available to the user community. If the results show the need for improvement, a research and development program should be initiated to provide an instrument which will provide the required resolution and ROV compatibility.

6.1.7 Heave Compensation

Towed vehicles (and tethered, free-swimming vehicles in certain modes) are subject to vertical excursions imparted by heave of the surface support ship. The heave imparted can be significant. (According to Dr. F. M. Speiss, Scripps Institute of Oceanography, the vehicle motion can be 1:1 or at least 1½:1 of the ships motion.) The resultant effects on photography and television viewing are to periodically bring the cameras into and out of focus.

In one instance, mechanical accumulators aboard the support ship are used to modify the effects of heave. The technique is not entirely satisfactory since the accumulators cause mechanical degradation of the cable. A cable accumulator is required which can be used on or just above the towed vehicle. With this arrangement any degradation of the cable can be corrected by removing several feet from the end. If the fish is lost due to cable failure at the accumulators, then only a few feet of the cable will be lost rather than the entire length.

6.1.8 Reliability/Performance

In an emerging field of technology, such as Remotely Operated Vehicles, it is not unusual for vehicles of such diversity to encounter problems in reliability. Indeed, it would be unusual if all vehicles did work flawlessly. There is no program which could be invoked that would correct the malfunctions of such a wide variety of vehicles and vehicle components. There is, however, a need for dissemination of information between operators and manufacturers regarding the types of failures encountered, the failure mode, and the corrective action employed. There is no such service now available, and the participants in this field must rely upon word of mouth for an exchange of information.

A program is required which would periodically canvases the operators of ROVs to obtain information regarding their vehicle's performance and modifications and/or innovations they have introduced to increase performance of the vehicle and its supporting systems and instrumentation. Several times in this assessment reference has been made to the dynamics of this industry. The only practical method of staying abreast of developments is to actively maintain contact with the operators and manufacturers on an international basis. Consequently, two services could be supplied which would be critical and invaluable towards exchange of technological information: 1) description and a critique of worldwide vehicle performance, and 2) a current status report of worldwide research and development activities in Remotely Operated Vehicle technology.

6.2 IMMEDIATE RESEARCH AND DEVELOPMENT PROGRAMS (Scientific/Research)

The U.S. scientific community has had considerable experience with towed vehicles, particularly Scripps Institute of Oceanography, The National Marine Fisheries Service and Woods Hole Oceanographic Institution. Experience with free-swimming tethered vehicles, however, is extremely limited, the only known user being the Environmental Protection Agency. As a consequence, the effectiveness of tethered, free-swimming ROVs as scientific research vehicles has not been demonstrated. There are, therefore, a variety of unanswered questions regarding the suitability of ROVs to scientific/research applications. In view of the fact that one-atmosphere manned submersibles are employed in a variety of governmental research, it is likely that a tethered, free-swimming ROV can perform a number of these tasks without human intervention and less expensively. First, however, an evaluation of an ROV toward this application should be performed.

6.2.1 Scientific Indocrination

It is recommended that an ROV be leased and employed to conduct scientific investigations under actual field conditions and in the same program as are manned submersibles. While many of the operational and functional considerations of a scientific/research ROV will parallel those of a commercially-employed vehicle, there are considerations which are unique to the scientific user. The following aspects should be specifically evaluated.

control/maneuverability (over flat and steeply sloping bottom)
pursuit/capture capability
data quality
data telemetry rate
viewing quality (resolution/range)
three-dimensional viewing

- color TV quality/usability
- natural visibility limits
- organism detection/location techniques (sonic)
- navigation/positioning
- sediment disturbance
- vehicle effects on organism behavior
- manipulation/sampling effectiveness
- scientific observor's durational limits

The results of the field experience will be used to evaluate the potential of ROVs for augmenting or substituting for manned vehicles in various scientific/ research programs.

6.2.2 <u>Instrumentation</u>

There are two areas where instrumentation research and development programs have been identified for application from towed vehicles, these are in fisheries hydroacoustics and biological sampling/assay.

6.2.2.a Fisheries Hydroacoustics

A National Marine Fisheries Service document "Organization and Management Philosophy of the National Fisheries Engineering Laboratory" dated 31 March 1978 outlined some of the technological needs for fishery stock assessment and the problems in hydroacoustics technology. While fish school location, size and direction of movement can be acoustically obtained, a means for determination of fish species is the major advancement needed. In order to increase sonar performance, by avoiding surface and ship noise and reducing reverberation problems, it is desireable to operate the hydroacoustic systems from a towed vehicle. Based on apriori information, such as fish migration and behavioral patterns, seasonal variations, depth constraints, etc., it is possible to isolate some species. However, in most situations multi-species prevail at the same location, and specie identification is difficult.

The initial task required is to make an assessment of the state-of-the-art by reviewing the mission and operating requirements; examine the available technology and research underway and planned; identify the critical problems and deficiencies and formulate a technical development plan to conduct the research necessary. The engineering research tasks identified in the assessment study should be presented in the technical development plan. The most critical areas should be assigned priorities and the next step will involve carrying out the most critical engineering research identified in the technology assessment study/workshop.

6.2.2.b Biological Sampling/Assay

The National Marine Fisheries Service's towed vehicle RUFAS relies heavily upon photographic records to conduct bio-assays of organisms. Frequently the photographs contain a variety of organisms in addition to those of interest. Visually identifying, discriminating, and counting the organism of interest from those which are not is arduous and time-consuming, and hundreds of photographs are taken on one survey run. Frequently it is desired to collect representative samples of the organisms under investigation, the only known sampling capability at present is a device for collection of near-bottom plankton from the towed vehicle DEEP TOW.

Two programs are required to address the requirements for biological sampling and assay. The first program is to consult with pertinent NOAA program investigators to establish the desired capabilities of an ROV sampling/storage device for planktonic, nektonic and benthic organisms. Following this a prototype sampling system(s) should be designed and constructed and field-tested on existing ROVs to assess its effectiveness. The second program, a parallel effort, should assess the state-of-the-art in photographic pattern recognition and adopt or modify the most promising of these techniques to bio-assays in accordance with NMFS requirements.

6.3 Long-Term Research and Development Programs

6.3.1 Untethered Vehicle Technology

There are several factors which make the concept of an untethered ROV attractive: 1) the major cause of present vehicle operational delays and loss is cable entanglement; 2) the depth of offshore oil and gas exploration and exploitation is steadily increasing (exploratory drilling took place in 1,324m of water off the west coast of Africa in 1978, several wells are now being drilled in water depths in excess of 1,000m off the east coast of Canada), consequently, the umbilical cable lengths required to operate in these depths will introduce severe drag problems and potentially greater entanglement problems, and 3) exploratory drilling is proceeding in areas where an ice cover can be anticipated for the majority of the year (e.g., the Davis Strait), which precludes support by surface-dependent techniques during the winter months.

Sections 2.3, 5.2, and 5.6 identified programs which are currently involved in research and development of technologies supportive of untethered vehicle development. There is, however, no U.S. program which plans to capitalize on these future developments by ultimately bringing the end products together into a prototype operational vehicle combining real-time, thru-water television transmission, a mission-oriented operational duration and significant operating depth. If the technological problems now being addressed are successful, other problems remain. These include vehicle command/control techniques, navigation, launch/retrieval and integration of the individual components and sub-systems into an operational unit.

6.3.2 Manipulation

If the current deep-water drilling projects result in a commercial discovery beyond 450m there is no diving capability available to deploy a diver at these depths. The only means available are ROVs and manned vehicles. While the GE-designed manipulators on ORCA (see Section 2.1.7.d) are a great step forward in manipulation technology, they are not equivalent to human dexterity. The work at MIT in manipulation is also impressive, but it too falls short of the mark when compared to the human. A manipulator with menory should find application to many maintenance/inspection projects, but much of the diver's work entails repair, and in this type of work no two repair tasks will be absolutely identical. Consequently, the ability to conduct repetitive manipulative tasks without human intervention does not provide a major advantage.

It is recommended that a program be initiated which seeks to: 1) tabulate the variety of tasks which divers now perform and will perform in support of development and production of deep (greater than 400m) offshore oil and gas; 2) identify which of these tasks can be performed only by human intervention; and 3) commence design of a manipulative system which will possess the dexterity and force-feed back information required to substitute for the diver.

6.3.3 Navigation

Current acoustic navigation/positioning systems provide adequate information external to a structure. However, inside a steel-jacketed structure reverberation caused by the structure members limits use of acoustic techniques to the external members. A navigation system is required which will permit vehicle positioning within the interior of a structure. Several alternatives to long and short acoustic baseline techniques are available which may provide the positional data required. Inertial guidance has already been mentioned, it should be investigated for application to structure navigation, if it is unacceptable, the reasons should be identified and made available to the ROV community. Another technique could involve imparting memory to the ROV in which the coordinates of nodal points are imparted into a computer which directs the vehicle to various points inside the structure. High accuracy doppler sonar - where the acoustic pulses are reflected off a specific member - may also offer an alternative technique. These and other techniques, should be investigated and evaluated with the ultimate goal of providing in-structure navigational data for inspection and maintenance tasks.

6.3.4 Free-swimming/Towed Vehicle

Towed vehicles are constrained from performing a great number of additional tasks by virtue of their inability to stop, maneuver independently of the surface, and collect samples or perform manipulative functions. In several applications, such as geological/biological surveying, and waste site disposal investigations, selective sampling and detailed site investigations are also required, but vehicles are unable to conduct this function.

It is recommended that a program be initiated to provide a concept design for a towed vehicle capable also of maneuvering (freely-swimming or bottom-crawling) and manipulative tasks within an area of at least 50m radius independent of the surface support ship's movement. The design should - as one option - attempt to incorporate these features into an existing vehicle such as RUFAS II or DEEP TOW. It would also delineate surface support ship maneuvering requirements and shipboard component and cable requirements needed to accommodate these additional functions.

APPENDIX A

ORGANIZATIONS CONTACTED

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ORGANIZATIONS CONTACTED

Canada

Bedford Institute of Oceanography
Dartmouth, N.S.

Horton Maritime Explorations Ltd.
No. Vancouver, B.C.

International Submarine
Engineering Ltd.
Port Moody, B.C.

National Water Resource Institute
Burlington, Ontario

Finland

Geloginen Tutkimuslaitos
Otaniemi

France

Centre d'Etudes et de Recherches
Techniques Sous-Marine
Toulon

Centre National Pour L'Exploitation
des Oceans
Brest and Toulon

Comex Services
Marseille

French Navy
Toulon

Intersub
Marseille

Sesam
Paris

Societie Eca
Meudon

Ireland

Winn Technology
Kilbrittain, Cork

Italy

Technomare S.p.A.
Venice

Gay Underwater Instruments
Trezzano Sul Navigalio

Sub Sea Oil Services S.p.A.
Milan

Japan

Hitachi Construction Machinery Co. Ltd.
Tokyo

Kitachi Shipbuilding and Machinery Co. Ltd.
Osaka

Japan Marine Science and Technology Center
Yokosuka

Komatsu Ltd.
Tokyo

Mitsui Ocean Development Engineering Co. Ltd.
Tokyo

Netherlands

Skadoc Submersible Systems
Yerseke

Norway

Myren Verksted A/S
Oslo

Kvaerner Brug A/S
Oslo

Sweden

Atlas Copco A.B.
Stockholm

United Kingdom

British Aircraft Corp.
Bristol

United Kingdom (Continued)

British Oxygen Co.
Crawley, West Sussex

Heriot Watt University
Edinburgh, Scotland

Hunting Surveys Ltd.
Boreham Wood, Herts

Institute of Geological Sciences
Edinburgh, Scotland

Land and Marine Engineering
Bromborough, Merseyside

Marine Unit Holdings
Richmond, Surrey

Offshore Supplies Office
Glasgow

OSEL Group
Gt. Yarmouth, Norfolk

Sonarmarine Ltd.
Ashford, Middlesex

Submarine Television Surveys
Aberdeen

Sub Sea Surveys
Barrow-in-Furness, Cumbria

U.D.I. Group
Aberdeen

ULS Marine Ltd.
Stonehouse, Glos.

Underwater and Marine Equipment Ltd.
Farnborough, Hants

Underwater Security Consultants
London

Vickers Oceanics Ltd.
Leith

Union of Soviet Socialist Republic

Institute of Oceanology USSR
Moscow

United States

Ametek Straza
El Cajon, CA

Applied Physics Laboratory
University of Washington
Seattle, WA

AT&T Longlines
Bedminster, NJ

Butterworth Systems
Florham Park, NJ

The Continental Group
New York, NY

Environmental Protection Agency
Washington, DC

Harbor Branch Foundation
Ft. Pierce, FL

Honeywell Marine Systems
Seattle, WA

Hydro Products
San Diego, CA

International Nickel Co.
Seattle, WA

Jet Propulsion Laboratory
Pasadena, CA

Kraft Tank Co.
Kansas City, MO

Maui Divers of Hawaii Ltd.
Honolulu, HA

Marine Physics Laboratory
San Diego, CA

Martech International
Houston, TX

Massachusetts Institute of Technology
Cambridge, MA

Naval Facilities Command
Washington, DC

United States (Continued)

Naval Ocean Systems Center
San Diego, CA

National Oceanic and Atmospheric Administration
- Ocean Dumping Program, Wash., DC
- Office of Marine Mining, Wash., DC
- Office of Sea Grant, Wash., DC
- Outer Continental Shelf Assessment Program, Boulder, CO
- Southwest Fisheries Research, La Jolla, CA
- Pacific Marine Environmental Laboratory, Seattle, WA
- Office of Ocean Engineering, Rockville, MD
- National Marine Fisheries Service, Bay St. Louis, MS

Naval Oceanographic Office
Bay St. Louis, MS

Naval Research Laboratory
Washington, DC

New England Ocean Services
Boston, MA

Ocean Systems Inc.
Houston, TX

Oceaneering International
Santa Barbara, CA

Perry Oceanographics
Riviera Beach, FL

Rebikoff Underwater Products
Ft. Lauderdale, FL

Remote Ocean Systems
San Diego, CA

Smit Lecler Inc.
Harvey, LA

Supervisor of Salvage, U.S. Navy
Washington, DC

Taylor Diving and Salvage Co.
Belle Chasse, LA

University of Georgia
Athens, GA

University of New Hampshire
Durham, NH

West Germany

Dornier Systems GmbH
Friedrichshafen

Gesellschaft fur keenforfchung
Karlsruhe

VFW Fokker
Bremen

APPENDIX B

BIBLIOGRAPHY

APPENDIX B

BIBLIOGRAPHY

Anderson, V.C. et al 1970 RUM II - Remote underwater manipulator (A program report). Proc. 6th Annual Conf. and Exposition. Mar. Tech. Soc., Wash., D.C., V. 1, p. 717-731 (preprint).

Anon. 1976 Remote-controlled manipulator vehicles: a new capability in offshore diving. Ocean Ind., V. II, n. 4, p. 369-370.

----- 1977 TOM 300 makes 'remote' Mediterranean debut. Offshore, December, p. 2.7.

----- 1977 The tethered vehicle method takes the diverless inspection approach. Offshore, September, p. 198-200.

----- 1977 Computer-controlled submersible. Ocean Industry, November, p. 75.

----- 1977 A-7 Found Off South Korea. Foreplate, V. 8, No. 4, p. 18-19.

----- 1977 Unmanned sub does good job as cp monitor on Montrose. Offshore Services, December, p. 18-19.

----- 1978 Martech conducts unique installations. Offshore, September, p. 142 & 145.

----- 1978 Global Round-up of unmanned submersible fleet. Offshore Engineer. October, p. 89-93.

----- 1977 F-14 Salvaged from North Atlantic. Faceplate, September, p. 17-20.

----- 1978 SPIDER/SNURRE: the story of 2 support units. Offshore, January, p. 66.

----- 1978 SPS: producing oil by remotely controlled tools. Offshore, January, p. 64.

----- 1978 Underwater vehicles not a substitute for divers - they complement them. Offshore Engineer, May, p. 95-98.

----- 1978 Improving the performance of a Remote Control Vehicle. Ocean Industry, April, p. 74-76.

----- 1978 Unmanned success story (CETUS). Offshore Services, October, p. 26 & 72.

Banzoli, V. et al 1976 New concept of underwater, remote controlled tracked vehicles for deep water trenching operations. Proc. Offshore Tech. Conf., Houston, TX, V. 1, p. 647-664.

Benton, R.D. *et al* 1971 RUFAS II Phase One. Mississippi State Univ. Rept. No. 1ET-71-01, Universities Marine Center, Ocean Springs, MS, 78p.

Biber, O. and Aril, B. 1979 A new trenching system for deep water pipelines. Proc. 11th Ann. Offshore Tech. Conf., V.III, p. 1939-1952.

Bircham, J. and Skidmore, G. 1976 Operational use and techniques with an unmanned, cable controlled submersible in the North Sea environment. Proc. 1976 Offshore Tech. Conf., V. III, p. 1049-1056.

Blasco, S.M. 1978 Probing with TROV. GEOS, Winter, p. 13-15.

Blidberg, D.R., Allmendinger, E.E. and Sideris, N. 1978 The development of an unmanned, self-controlled, free-swimming vehicle. Proc. 10th Ann. Offshore Tech. Conf., V. III, p. 1589-1598.

Bline, D.B. and McDonald, W.M. 1976 Development of an unmanned deepwater pipeline repair system. Proc. Offshore Tech. Conf., Houston, TX, V. III, p. 732-739.

Brundage, W.L. and Patterson, R.B. 1976 LIBEC photography as a sea floor mapping tool. Proc. Oceans '76, Mar. Tech. Soc., Wash., D.C., p. 8B-1 thru 8B-11.

Busby, R.F. 1977 Unmanned submersibles. in, Submersibles and Their Use in Oceanography and Ocean Engineering, edited by R.A. Geyer, Elsevier Scientific Pub. Co., Amsterdam, p. 23-58.

Cameron, G. and Hay, J. 1979 Practical considerations and applications for wheeled seabed work vehicles based on operational experiences of the world's first commercial seabed vehicle. Proc. 11th Ann. Offshore Tech. Conf., V.III, p. 1929-1938.

Dessurault, J.G. 1976 "BATFISH" A depth controllable towed body for collecting oceanographic data. Ocean Engineering, V. 3, p. 99-111.

Eden, R.A., McQuillin, R. and Ardus, D.A. 1977 U.K. experience of the use of submersibles in the geological survey of Continental shelves. in Submersibles and Their Use in Oceanography and Ocean Engineering, Elsevier Scientific Publishing Co., Amsterdam, p. 235-278.

Environmental Protection Agency 1975 A survey of the Farallon Islands 500-fathom Radioactive Waste Disposal Site. Tech. Note ORP-75-1, Office of Radiation Programs and Office of Water Program Operations, Wash., D.C.

Estabrook, N. and Wheeler, H. 1975 Development of deep-ocean work system. Proc. Ocean '75, Mar. Tech. Soc., Wash., D.C., p. 573-577.

Francois, R.E. 1973 The unmanned Arctic research submersible system. Mar. Tech. Soc. Jour., V. 7, p. 46-48.

Fugitt, R.B. 1975 Design and operation of two remotely manned undersea vehicles. Proc. Ocean '75, Mar. Tech. Soc., Wash., D.C. p. 870-876.

Gaudillerp. P. 1978 SESAM RCV Operations. Personal Communication to Hydro Products Corp.

Gennari, J.J. and Bridge, R.B. 1974 Naval Research Laboratory Deep Ocean Search and Inspection System. NRL Rept. No. 7733. Wash., D.C. 32p.

Gray, W.E. and Fike, J.W. 1979 Operational Experiences with remote manipulator systems. Proc. 11th Ann. Offshore Tech. Conf., V.III, p. 1953-1965.

Heine, D.R. and Suh, S.L. 1978 An experimental nodule collection vehicle design and testing. Proc. 10th Ann. Offshore Tech. Conf., V. II, p. 741-750.

Holmes, R.T. and Dunbar, R.M. 1975 Sea-bed surveying by remote control. Proc. Oceanology International '75, Brighton, England 17-25 March.

----- 1978 Operational experience with the remotely manned A.N.G.U.S. submersibles. Proc. 10th Ann. Offshore Tech. Conf., V. III, p. 1977-1988.

Hoyt, J.W. 1970 Biological collecting with a remote-controlled underwater vehicle. Jour. Mar. Tech. Soc., Jan-Feb., p. 65-66.

Jacobsen, L.R. and Jalbert, P.E. 1976 Unmanned cable controlled subsea vehicles - status and potential in the offshore oil industry. Proc. 1976 Offshore Tech. Conf., V. III, p. 1037-1048.

Johnson, H.A., Verderses, A.J. and Hansen, R.J. 1976 A "smart" multi-mission unmanned free-swimming submersible. Naval Eng. Jour., p. 84-95.

Johnston, J.R. 1979 Remote control vehicle update. Proc. 9th Ann. International Diving Symposium, Assoc. of Diving Contractors, New Orleans, LA, p. 65-74.

Jue, M.F. et al 1974 An automatic terrain-following control system for deep-towed submersibles. Proc. Offshore Tech. Conf., Houston, TX, V. 1, p. 747-754.

Kawasaki, H. et al 1972 Development of underwater bulldozer systems. Proc. 8th Annual Conf. and Exposition, Mar. Tech. Soc., Wash., D.C. p. 669-680.

Kettle, M. 1978 Working underwater - the role of atmosphere diving systems and unmanned vehicles: uses, experience to-date and future prospects. Jour. Soc. for Underwater Tech., V. 4, n. 2, p. 5-10.

LaPuzza, T. 1976 Work Systems Package: Deep Ocean Work By Remote Control. Sea Technology, V. 17, n. 10, p. 38-40.

Lange, J.P. and Biemann, W.G. 1975 Development of components for an in-situ analysis system for the exploration of manganese nodules. Proc. 7th Ann. Offshore Tech. Conf., Houston, TX, p. 585-592.

MacDonald, M.D. 1978 TREC unit allows new diving mobility. Offshore. September 1978, p. 152 and 154.

McCord, M. 1975 A multiplex system for a small remotely manned submersible. Proc. Ocean '75, Mar. Tech. Soc., Wash., D.C., p. 361-364.

Michel, D. 1978 Deepwater applications for remote controlled vehicles: Cognac and beyond. Ocean Resources Engineering, n. 4, V. 12, p. 28-31.

Mickelsen, P.W. 1970 SEA DRONE I and the unmanned system. 6th Annual Conf. and Exposition, Mar. Tech. Soc., Wash., D.C., V. 2, p. 837-845.

Noakes, J.E. et al 1975 Surveillance system for subsea survey and mineral exploration. Proc. Offshore Tech. Conf., V. I, p. 909-914.

Normack, W.R., Hess, G.R. and Spiess, F.N. 1978 Mapping of small scale (outcrop-size) sedimentological features on modern submarine fans. Proc. 10th Ann. Offshore Tech. Conf., V. 1, p. 593-598.

Osborn, H. 1976 Remote control vehicles service underwater telephone lines. Sea Technology, February 1978, p. 14-15.

Pelletier, B.R. 1977 The unmanned submersible. Geological Survey of Canada (unpublished manuscript).

Peterson, K. 1978 Three months with RCV-225, S/N 016. Seahorse, V. 10, n. 3, p. 7.

Pollio, J. 1972 Remote underwater systems on towed vehicles. Photogrammetric Engineering Jour. Amer. Soc. of Photogrammetry, V. XXXVIII, n. 10, p. 1002-1008.

Rebikoff, D. 1967 The case for the unmanned underwater systems Sea Frontiers, V. 13, n. 20, p. 130-136.

----- 1976 Underwater photogrammetric survey of man made structures. Sea Tech., November, p. 33-35.

Robertson, R. 1976 Unmanned submersibles adapt to varied roles in the offshore. Offshore, August, p. 53-55.

----- 1977 Exxon's Subsea Production System - producing oil/gas by remote control. Offshore, October, p. 72-81.

Roe, J.T. 1977 TROV Arctic Trials, Melville Island, Northwest Territories, March 7 to March 25, 1977. Dive Unit Report, National Water Research Institute, Burlington, Ontario.

Roe, J.T. and Sandilands, R.G. 1975 TROV Operations 1975, Test Report. Canada Centre for Inland Waters. Environment Canada (unpublished report).

Sandilands, R.G. and Sly, P.G. 1976 TROV Operations In Georgian Bay, July 1976 - With Underwater Photographs. Unpublished Report, Canadian Center for Inland Waters, 12p.

Schooley, G.C., Mullen, C.T. and Johnson, D. 1975 A new family of tethered underwater remote controlled work vehicles. Proc. 7th Ann. Offshore Tech. Conf., V. III, p. 667-677.

Scottish Council Development and Industry 1978 United Kingdom Oil and Gas. An assessment of Related Inspection Maintenance and Repair Opportunities. Aberdeen, North East Office, 35p.

Sheridan, T.B. and Verplank, W.C. 1978 Human and Computer Control of Undersea Teleoperators. Mass. Inst. of Tech., Cambridge, Man-Machine Systems Lab., 185p.

Skidmore, G. and Bircham, J. 1975 Development of an unmanned cable controlled submersible vehicle for surveying and sampling exposed subsea rock shelves. Proc. Offshore Tech. Conf., V. III, p. 127-138.

Smith, H. D. 1968 Useful underwater work with CURV. Jour. Mar. Tech. Soc., V. 2, n. 10, p. 19-23.

Spiess, F.N., Lowenstein, C.A. and Boegman, D.W. 1978 Fine grained deep ocean survey techniques. Proc. 10th Ann. Offshore Tech. Conf., V. II, p. 715-724.

Stricker, P.A. 1978 Active/passive motion compensating crane for handling a remote unmanned work system. Proc. 10th Ann. Offshore Tech. Conf., V. III, p. 1599-1608.

Spiess, F.N. et al 1976 Fine scale mapping near the deep sea floor. Proc. Ocean '76, Mar. Tech. Soc., Wash., D.C., p. 8A-1 through 8A-9.

Stankoff, A. and Tait, R.A.R. 1977 Underwater survey using an inertial navigation system. Proc. Offshore Tech. Conf., V. II, p. 61-68.

Talkington, H.R. 1972 Why man? National Acad. of Engineering, Marine Board Workshop, Airlie House, VA., Wash., D.C.

----- 1974 The U.S. Navy participation in the rescue of PISCES III. Mar. Tech. Soc. Jour., V. 8, p. 63-67.

----- 1976 Manned and Remotely Operated Submersible Systems: A Comparison. Naval Undersea Center, San Diego, CA., Rept. No. NUCTP511.

----- 1978 Undersea work systems research and development. Proc. 10th Ann. Offshore Tech. Conf., V. III, p. 2409-2416.

Teers, M. 1979 An unmanned, tethered, maintenance vehicle for deepwater production riser maintenance. Proc. 11th Ann. Offshore Tech. Conf., V. III, p. 1905-1912.

Tiemon, A. 1972 Exploration by unmanned submersibles. Conf. Paper, Oceanology International '72. Brighton, England, p. 252-257.

Turnage, G.W. and Seabergh, W.C. 1979 Trafficability and stability analysis of bottom crawling work vehicles. Proc. 11th Ann. Offshore Tech. Conf., V. III, p. 1913-1928

Vigil, E.A. et al 1975 Deep sea survey system. Trans. Offshore Tech. Conf. Paper No. OTC 2240, p. 915-922.

vonReibnitz, G. 1972 Cable controlled sea bottom measuring vehicle. Conf. Paper, Oceanology International '72, Brighton, England, p. 274-277.

Watanabe, S. and Homma, J. 1973 System design of ocean space robots for measurement OCEANS 73 IEEE International Conf. on Engineering in the Ocean Environment. Seattle Wash. 25-28 Sept. 1973, p. 265-268.

Westwood, J.D. 1978 Commercial applications of remotely controlled vehicles. Jour. Soc. Underwater Tech., V. 4, n. 3, p. 13-19.

Widditscn, H.R. 1973 SPURV-The First Decade. Applied Physics Lab.-UW 725, University of Washington, 32p.

Wilkins, G.A., Hightower, J.D. and Rosencrantz, D.M. 1975 Lightweight cables for deep tethered vehicles. Proc. Ocean '75, Mar. Tech. Soc., Wash., D.C., p. 138-147.

Yastrebov, V.S. and Stefanov, G.A. 1978 Underwater Robot/Manipulator Development. Marine Tech. Soc. Jour., V. 12, n. 1, p. 3-9.

Vadus, J.R. 1976 International status and utilization of undersea vehicles, Inter Ocean '76 Conference at Dusseldorf, Germany, June.

----- 1977 Summary of Characteristics, Status and Use of Undersea Vehicles Worldwide, in Submersibles and Their Use in Oceanography and Ocean Engineering, edited by R.A. Geyer, Elsevier Scientific Pub. Co., Amsterdam, p. 353-369.

Veccia, F. 1979 Underwater hull cleaner smooths out problems associated with hull fouling. Offshore, April, p. 119-122.

APPENDIX C

FREE-SWIMMING, TETHERED VEHICLES SPECIFICATIONS

ANGUS 002

(A Navigable General purpose Underwater Surveyor)

Operating Depth: 984 ft (300m)
Dimensions (LxWxH): 74 in. x 41 in. x 51 in. (225cm x 127cm x 135cm)
Weight (dry): 1,543 lbs (700kg)
Speed: (Max. Surface) 1.5 knots (2.8 km/hr)
(Max. Operating Current) 1.0 knot (1.85 km/hr) at 300m
Structure: Open tubular aluminum framework supports and encloses all components. Eight inch (20cm) diameter polypropylene floats are contained within a glass reinforced casing atop the vehicle.
Buoyancy: Positive buoyancy is provided by polypropylene floats and parts of the tubular framework which is pressure compensated.
Power Requirements: All electrical power is supplied by a 3-phase 415/240 V, 50Hz, 20 kVA diesel generator.
Propulsion: Two, 4 and one half hp horizontal thrusters mounted p/s on the stern, and four, 1 and one half hp vertical thrusters ducted within each corner of the upper casing.
Instrumentation: Two TV cameras, one 35mm still camera, one Super 8 cine camera, two 600 watt quartz halogen lights of infinitely variable intensity, hydrophone (25 kHz), wide band hydrophone (0-200 kHz), magnetic compass, echo sounder, pressure transducers, two 160 joule daylight strobe lights.
Navigation: A two-transponder relative positioning system provides repeatability of less than 2 meters (6.6 ft) on a 1 km (0.5nm) baseline.
Shipboard Components: Diesel generator, Earth Leakage Protection Unit (circuit breakers), control console, (CCTV monitor, compass repeater, roll and pitch indicators) buoyancy and trim meters, depth readout, voltage and current monitors, cable reels (400 meters/1,312 ft total), navigation control console and transponders are essential.
Support Ship Requirements: Any craft in excess of 12 meters (39 ft) length and equipped with a derrick capable of lifting the vehicle.
Operation/Maintenance Crew: Two: one engineer, one technician
Total Shipping Volume: 783 cu ft (22cu m)
Total Shipping Weight: 3.5 tons (3.2t)

Status: Operational
Builder: Dept. of Electrical & Electronic Engineering
Heriot-Watt University
Scotland

ANGUS 003

Operating Depth: 984 ft (300m)
Dimensions (LxWxH): 95 in. x 57 in. x 57 in. (241cm x 145cm x 145cm)
Weight (dry): 1.1 ton (1t) (provisional)
Speed: (Max. Surface) 3.5 knots (6.5m/hr) (provisional)
(Max. Operating Current) 2 knots (3.7km/hr) at 300m (provisional)
Structure: Open tubular aluminum framework supports and encloses all components. Plastic floats are enclosed within a glass reinforced fairing atop the vehicle.
Buoyancy: Eight and six inch (20 and 15cm) diameter plastic fishing floats provide the major portion of positive buoyancy. The vehicle will be slightly positive at maximum operating depth.
Power Requirements: 3-phase, 240/440 V, 50 Hz. Can operate from ship's power or a portable generator.
Propulsion: Two, 6 hp, reversible induction motors with Kort nozzels provide horizontal propulsion. Four, 2hp, reversible induction motors provide vertical propulsion. Four 1.25 hp, reversible induction motors with Kort nozzels provide lateral propulsion.
Instrumentation: One TV (fixed) for piloting, one TV on pan/tilt mechanism for observing. Cine camera (8 or 16mm). Still camera (35mm). Absolute and differential pressure transducers, wideband hydrophone (0-200 kHz), up and down looking echo sounders, water temperature thermometer, obstacle avoidance sonar (provisional), magnetic compass.
Navigation: A bottom-mounted, two-transponder relative positioning system combined with Doppler sonar provides repeatability of plus or minus 2m (6.6 ft) on a 1 km (0.5nm) baseline.
Shipboard Components: Diesel generator, earth leakage protection unit, control console (CCTV monitor, compass repeater, roll and pitch indicators, buoyancy and trim meters, depth readout, voltage and current monitors, cable reels), navigation control console, and transponders.
Support Ship Requirements: Not specified.
Operating/Maintenance Crew: Not specified
Total Shipping Volume: Not specified
Total Shipping Weight: Not specified

Status: Under construction
Builder: Dept. of Electrical and Electronic Engineering
Heriot-Watt University
Scotland

BOCTOPUS

Operating Depth: 2,170 ft (661m)
Dimensions (LxWxH): 126 in. x 84 in. x 66 in. (320cm x 213cm x 168cm)
Weight (dry): 2,000 lbs (907kg)
Speed: 0.5 kts (0.9km/hr) at 1,150 ft (350m) in 2 kt (3.7km/hr) current.
Structure: Rectangular-shaped open steel framework encloses and supports all components. Top half of vehicle is enclosed by a fiberglass fairing.
Buoyancy Control: Dives with 20 lbs (9kg) positive buoyancy which is provided by spheres enclosed in the fiberglass fairing.
Power Requirements: Total power of 33 KVA is supplied by a dedicated diesel generator.
Propulsion: Five thrusters total. Two (10hp each) horizontal thrusters located aft on the keel. Two (4hp) vertical thrusters located port/starboard amidship. One (3hp) lateral thruster located on the keel forward.
Instrumentation: Echo sounder, two television cameras (one fixed; one on pan/tilt mechanism), magnetic compass, pressure/depth gage. Vehicle is designed to accomodate and transmit data from a side scan sonar and sub-bottom profiler. Optional equipment includes cine and still camera and manipulator.
Navigation: Magnetic compass, transponder, pressure/depth indicator.
Shipboard Components: Diesel generator, hydraulic crane and winch, control cabin.
Support Ship Requirements: Launch/retrieval system, bow thruster, twin screws.
Operating/Maintenance Crew: Four
Total Shipping Volume: 2,154 cu ft (61 cu m)
Total Shipping Weight: 12.5 tons (11.3t)

Status: Operational
Builder: BOC, Limited
London, England

CETUS

(Computerized Exploration. and Technical Underwater Surveyor)

Operating Depth: 1,500 ft (457m)
Dimensions (LxWxH): 96in.x60in.x48in. (244cm x 152cm x 122cm)
Weight (Dry): 2,000 lbs (907kg)
Speed: (Max. Surface): 4.2 knots (7.8km/hr).
(Max. Operating Current): 1.6 knots (3.0km/hr) at 1,500 ft.
Structure: Rectangular, open aluminum (N8) framework encloses and supports all components. Syntactic foam blocks are attached to the top of the framework.
Buoyancy: Positive buoyancy is provided by syntactic foam blocks. Variable buoyancy is provided by two trim tanks (one forward, one aft) which are blown by compressed air, a total buoyancy change of 420 lbs (190kg) is possible.
Power Requirements: 415V, 3 phase, 50Hz or 498V, 3 phase 60Hz.
Propulsion: Four thrusters, two horizontal, one vertical, one lateral. All are 4.3 hp, 940 rpm, 415V, electric 3-phase, variable pitch control.
Instrumentation: One fixed TV (for piloting) one TV mounted on pan/tilt mechanism (for observing), 35mm still camera, magnetic compass, directional gyro, echo sounder, pressure/transducer, magnetic gradiometer (for buried pipeline detection) and transponder. Two manipulators, both have four degrees-of-freedom, an extension of 36 in. (91cm) and a maximum working load of 200 lbs (91kg) at maximum extension.
Navigation: Two systems are used, a long and a short baseline. The long baseline system consists of three, bottom-mounted transponders deployed about 0.5nm (1km) apart. Relative ROV positions of plus or minus 3m (9.8ft) accuracy are obtainable. The short baseline system involves suspending one transponder from the ship's bow and one from the stern, both about 5m (16ft) below the water. A fish transponder is streamed and the round trip time for a pulse to travel from the fish to the ROV and back to the bow and stern transponders provide slant range. The arrival time differences at the bow and stern transponders is used to calculate angular bearing of the ROV relative to the ship. A work area range of about 500m (1,640 ft) is possible with the short baseline system, 23m accuracy is reported.
Shipboard Components: Control cabin, diesel generator (optional), cable winch. Support ship supplies crane for launch/retrieval crane, open deck space of 1,679 sq ft (156 sq m) for control cabin, winch, ROV and store cabin.
Operation/Maintenance Crew: Four (12 hrs), nine (24 hrs).
Total Shipping Volume: 1,655 cu ft (40 cu m) (approximate).
Total Shipping Weight: Not available.

Status: Three operational vehicles
Builder: ULS Marine Ltd.
Gloucester
England

CONSUB 1

Operating Depth: 2,000 ft (610m)
Dimensions (LxWxH): 107 in. x 72 in. x 57 in. (272cm x 183cm x 145cm)
Weight (dry): 3,000 lbs (1,361kg)
Speed: (Max surface) 2.5 kts (4.6 km/hr)
(Max Operating Current) 2 kts (3.7km/hr) at 2,000 ft. (610m)
Structure: Tubular aluminum alloy HE 130
Buoyancy: Two cylindrical, pressure-resistant, fiberglass cylinders provide a positive buoyancy of 40 lbs (18kg) when vehicle is submerged
Power Requirements: 240 V 50 Hz single phase 3 KVA, 415 V 50 Hz 3-phase 50 KVA (to the control cabin transformer). If the latter is not available a diesel generator can be used. Surface transformer converts supply voltage to 415 V/1000 V 3-phase for transmission to vehicle.
Propulsion: Two lateral and two vertical fixed, reversible thrusters. All are electro-hydraulically powered, 5 hp each, and capable of independent operation.
Instrumentation: Compass, inclinometer, depth gauge, two TV cameras (1 color; 1 black and white), stereo camera system, rock drill capable of taking a 0.5 in. (1.3cm) diameter, 5 in. (13cm) long core. Stereo and TV cameras are mounted on a pan and tilt unit which trains plus or minus 150 degrees in azimuth and tilts plus or minus 30 degrees to minus 90 degrees from the horizontal.
Navigation: Visual sighting, compass.
Shipboard Components: Control console (2 TV monitors; vehicle/instrument controls), transformer, system distribution box (connects transformer, ship junction box and consoles), ship junction box (terminates umbilical cable of support craft) and faking frame (for storage and deployment of umbilical).
Support Craft Requirements: Launch/retrieval system capable of supporting vehicle dry weight. Freeboard not to exceed 12 ft (3.7m). Deck space: 10 ft x 10 ft (3m x 3m) clear space with tiedowns for vehicle; area of 20 ft x 20 ft (6m x 6m) required for umbilical cable faking frame. Cabin space: 1) must be large enough to contain a 7 ft (2.1m) long bench for control console at which two operators sit, and must also provide a view of operational deck area; 2) bulkhead area 3 ft x 4 ft (0.9m x 1.2m) for distribution box; 3) deck space in cabin of 2 ft x 2 ft (0.6m x 0.6m) for transformer and 4) an access port of 5 in. (12.7cm) diameter is required for electrical service cables.
Operating/Maintenance Crew: Three to four
Total System Shipping Volume: Information not available
Total System Shipping Weight: 6,100 lbs (2,767kg) (approximate)

Status: Operational. Has conducted a variety of commercial and scientific in the U.K. offshore area.
Builder: British Aircraft Corp. Ltd.
Bristol, England

CONSUB 201 & 202

Operating Depth: 2,000 ft (610m)
Dimensions (LxWxH): 145 in. x 84 in. x 69 in. (368cm x 213cm x 175cm)
Weight (dry): 6,393 lbs (2,900kg)
Speed: (Max. Surface) 2.5 kts (4.6 km/hr)
(Max. Operating Current) 2 kts (3.7 km/hr) at 2,000 ft
Structure: Rectangular-shaped tubular aluminum alloy (HE 130) encloses and supports all components.
Buoyancy: Syntactic foam blocks provide positive buoyancy.
Power Requirements: 380/415/440 V 50/60 Hz 3-phase 125 KVA (to control cabin transformer)
Propulsion: Four fixed, reversible, electric thrusters with Kort nozzles each of 12.5 hp. A TV camera is mounted on a rotating platform stabilized in azimuth relative to rest of vehicle, the controls are arranged such that the vehicle will travel in the compass bearing in which the operator points the camera.
Instrumentation: Three TV cameras, stereo camera system mounted on a pan and tilt mechanism similar to CONSUB 1. Depth sensor, magnetic compass. side scan sonar, magnetic tracker, sub-bottom profiler, echo sounder, corrosion-potential probes, manipulator. In the event of power loss to the vehicle, a self-powered transponder and flashing light is activated. Nine, 1,000 watt quartz iodide lights.
Navigation: Visual sighting and magnetic compass. Vehicle space and electrical connectors are available to accommodate any of the conventional bottom-mounted or surface-tracking navigation systems.
Shipboard Components: Same as CONSUB 1 except that a mechanical cable handling unit replaces the faking frame.
Support Craft Requirements: Clear deck space (with tie-downs): 15 ft x 18.4 ft (4.6m x 5.6m) for vehicle; 20 ft x 6.5 ft (6m x 2m) for cable handling device. Derrick or crane capable of lifting vehicle with an outreach of 6.5 ft (2m) from the support craft. Two cabins, each 19.7 ft x 8 ft x 8.5 ft (6m x 2.4m x 2.6m). Station keeping requirements dependent upon depth of vehicle and strength of current.
Operating/Maintenance Crew: Four
Total Shipping Volume: 1,624 cu ft (46 cu m), not including optional diesel generator
Total Shipping Weight: 39,374 lbs (17,860kg)

Status: 201: Operational; 202: Construction
Builder: British Aircraft Corp.
Bristol, England

CORD I

(Cabled Observation and Rescue Device)

Operating Depth: 1,500 ft (457m); 2,000 ft (610m) goal

Dimensions (LxWxH): 68 in. x 41 in. x 55 in. (173cm x 104cm x 140cm)

Weight (dry): 720 lbs (327kg)

Speed: (Max. Surface) 5 kts (9km/hr)
(Max. Operating Current) 2 kts (3.7km/hr) at 1,500 ft

Structure: A U-shaped 10 in. (25cm) aluminum tube provides flotation and serves as storage and protection for the bulk of the electronics. The base of the vehicle consists of two rectangular oil-filled pods which serve as the hydraulic reservoir and as mounting locations for electronic and hydraulic components.

Buoyancy: U-shaped, 10 in. (25cm) diameter, pressure-resistant, aluminum tube provides positive buoyancy when surfaced. Buoyancy submerged can be controlled by plus or minus 15 lbs (6.8kg) through displacement of oil into and out of a soft bladder.

Power Requirements: 5 KW, 480 V 3-phase 60 Hz provided by an alternator in SEA GUARDIAN (its support craft) which is hydraulically powered by a 115 hp Ford diesel engine. A 0.35 in. (0.9cm) diameter, 1,850 ft (564m) long, armored, coaxial cable serves as the umbilical between support craft and vehicle.

Propulsion: Four hydraulically-powered, fixed, reversible propellers driven by a 3 hp hydraulic motor. Two thrusters supply forward-aft motion (thrust), one provides vertical motion (heave) and one provides lateral motion (yaw). All have continuously variable speed control.

Instrumentation: Television and light on pan & tilt mechanism (360 degrees azimuth; 110 degrees downward from the horizontal), current speed sensor, temperature sensor, echo sounder. Magnetic compass, pressure/depth transducer, scanning sonar (360 degree scan, 200 kHz search; 500 kHz local) with CRT display. Manipulator: hydraulically-powered, two degrees-of-freedom, scissors-type claw.

Navigation: CORD is equipped with a 25 kHz pinger which can be powered from the surface or is self-powered and pings at repetition rate of once/second. Its support craft deploys three hydrophones, one mounted on the starboard forward quarter, one amidships portside, and one on the starboard side astern. The three hydrophones receive the outgoing ping and onboard electronics process the signal by triangulation to provide a CRT display showing the pinger's position relative to the three hydrophones. Accuracy of CORD's position relative to its support craft had not been determined at the time of this study.

Shipboard Components: CORD is deployed from an aluminum surface utility craft, SEA GUARDIAN, which has the following dimensional characteristics:

Length:	23 ft (7m)	Speed (loaded):	8 kts (14.8km/hr)
Beam:	9 ft (2.7m)	Range:	60 nm (111km)
Draft:	2 ft 1 in. (0.6m)	Weight (loaded):	4.5 tons (4.1t)

All controls and displays for the operation and monitoring of CORD are aboard SEA GUARDIAN. Power is provided by a 115 hp Ford diesel engine which drives three hydraulic pumps which power the main hydrostatic transmission propulsion system, a 5 KW alternator and bow and stern thrusters as well as a line hauler and storage reel. A dynamic positioning system, within an enclosed cabin, maintains SEA GUARDIAN in position over CORD.

Support Craft Requirements: At present CORD can only be fully deployed and operated from SEA GUARDIAN.

Operating/Maintenance Crew: Three

Total Shipping Volume: 49.3 cu yd (37.5 cu m) approximate

Total Shipping Weight: 4.9 tons (4.4t) approximate

Status: Operational

Builder: Harbor Branch Foundation, Inc.
Ft. Pierce, Fl.

CURV II
(Cable-controlled Underwater Recovery Vehicle)

Operating Depth: 2,500 ft (762m)
Dimensions (LxWxH): 180 in. x 72 in. x 72 in. (457cm x 180cm x 183cm)
Weight (dry): 3,450 lbs (1,565kg)
Speed: (Max. Surface) 4 kts (7.4km/hr)
(Max. Operating Current) NA

Structure: Rectangular-shaped open aluminum framework encloses and supports all components. Syntactic foam blocks are affixed atop the framework.

Buoyancy: Syntactic foam blocks provide slight positive buoyancy submerged.

Power Requirements: 400 VAC, 120 VAC 3-phase 50 KW. A portable, 60 KW diesel generator supplies all power to the system.

Propulsion: Three, 10 hp, pressure-compensated, electric motors provide power to three propellers. Two provide forward-reverse motion and one provides vertical motion. All are capable of independent operation.

Instrumentation: Television (2 ea.), 35mm still camera, lights, altimeter, depthometer, magnetic compass, active and passive CTFM sonar (AMETEK Straza Mfg). Manipulator, hydraulically-powered, three degrees-of-freedom, circular-type (torpedo grasping) claw.

Navigation: By compass bearing and visual sighting. Can interrogate bottom-mounted transponder to obtain relative position. Can locate pinger and "home" in on target.

Shipboard Components: Control/display console (in a portable van), power supply (generator) and conversion equipment, and surface handling equipment.

Support Ship Requirements: Station-keeping capability and cable handling area away from screws. Deck space for seven items approximately 75 to 120 sq ft (7 to 11.2 sq m) each.

Operational/Maintenance Crew: Seven normally, ten in an emergency mission.

Total Shipping Weight: 26 tons (23.6t) (not including handling crane).

Total Shipping Volume: 4,500 cu ft (127.4 cu m). For operations to 1,500 ft (457m) the total system (not including handling crane) can be loaded aboard a C-141 aircraft. For emergency operations on unknown ship of opportunity two C-141s are required.

Status: Operational. Two identical CURV IIs are in operation, one at NOSC, San Diego and one at the Naval Torpedo Station, Keyport, Wa.

Builder: Naval Ocean System Center
San Diego, Ca.

CURV III

Operating Depth: 10,000 ft (3,048m)
Dimensions (LxWxH): 150 in. x 78 in. x 78 in. (381cm x 198cm x 198cm)
Weight (dry): 4,000 lbs (1,814kg)
Speed: (Max. Surface) 4 kts (7.4km/hr)
(Max. Operating Current) NA
Structure: Same as CURV II
Buoyancy: Same as CURV II
Power Requirements: Same as CURV II
Propulsion: Same as CURV II
Instrumentation: Same as CURV II
Navigation: By compass heading and visual sighting. The support craft, YFNX-30, is equipped with a Boat-Mounted Acoustic Locating Device (BALD) which monitors CURV III's relative bearing during a dive.
Shipboard Components: Same as CURV II
Support Ship Requirements: Same as CURV II. For local area operations, the YFNX-30 serves as its support craft. YFNX-30 has the following characteristics: Length 110 ft (33.5m), beam 34 ft (10.4m), draft 5 ft (1.5m), freeboard 6.5 ft (2m), speed 5.5 kts (10.2km/hr).
Operational/Maintenance Crew: Same as CURV II
Total Shipping Weight: Same as CURV II
Total Shipping Volume: Same as CURV II

Status: Operational
Builder: Naval Ocean Systems Center
San Diego, Ca.

DART
(DEEP ACCESS RECONNAISANCE TELEVISION)

Operating Depth: 1,200 ft (366m)
Dimensions (LxWxH): 37 in. x 18 in. x 12 in. (94cm x 46cm x 31cm)
Weight (Dry): 70 lbs (32kg)
Speed: 1.2 knots (2.2km/hr)
Structure: Rectangular configuration. PVC buoyancy cylinders located topside.
Buoyancy Control: Positive buoyancy provided by PVC cylinders. Vehicle is slightly positively buoyant when submerged.
Power Requirements: 2.5kw, 120 V, 60 Hz, single phase.
Propulsion: Four thrusters (2 forward, 1 vertical, 1 side) deliver 25 lbs (11kg) of thrust.
Instrumentation: CCTV (Panasonic 1350A), depth sensor, compass.
Navigation: Visual sighting and compass.
Shipboard Components: Display/control console, power supply.
Support Ship Requirements: Information not available.
Operating/Maintenance Crew: One.
Total Shipping Volume: Information not available.
Total Shipping Weight: Information not available.

Status: Operational. The first prototype of this vehicle was constructed in January 1979. Further design and performance details were not available at the time this study was conducted.
Builder: International Submarine Engineering Ltd.
Port Moody, B.C.
Canada

DEEP DRONE

Operating Depth: 2,000 ft (610m)
Dimensions (LxWxH): 84 in. x 54 in. x 48 in. (213cm x 137cm x 122cm)
Weight (dry): 1,600 lbs (726kg)
Speed: (Max. Surface) 3.5 kts (6.5km/hr)
(Max. Operating Current) 2 kts (3.7km/hr) at 2,000 ft (est.)
Structure: Two, pressure-resistant flotation tanks atop of - and enclosed within - an open, tubular aluminum framework.
Buoyancy: Positive buoyancy of 45 lbs (20kg) is provided by the flotation tanks when submerged. Negative buoyancy is dynamically-provided by the thrusters.
Power Requirements: 115 VAC 1-phase 2 KVA, 440 VAC 3-phase 10 KVA. Umbilical consists of a 3,000 ft (914m) long, 0.75 in. (1.9cm) diameter coaxial cable with strength member. A diesel motor generator provides all power required to operate the vehicle system.
Propulsion: Three thrusters, two are for forward-aft propulsion (thrust and yaw) and one is for vertical propulsion (heave). Each motor is fixed, reversible, shrouded by a Kort Nozzle and rated at three shaft horsepower at 1,725 rmp.
Instrumentation: Two TV cameras, one is fixed and one is mounted on a pan and tilt mechanism, 70mm still camera with strobe light, CTFM sonar with transponder interrogation and pinger location capabilities, altimeter, depth meter.
Navigation: The CTFM sonar is designed to interrogate a bottom-mounted (ATNAV) transponder and, using it as a benchmark, can conduct search patterns out to 3,000 ft (914m). The sonar can also interrogate more than one transponder to establish its position. A locator system aboard the surface craft can obtain the vehicle's relative range and bearing.
Shipboard Components: Control console, control cable and basket, support line and A-frame, vehicle locator, diesel motor generator, support spare parts.
Support Ship Requirements: Lift boom of one ton (0.9t) capacity, deck capstan for retrieval of umbilical, station-keeping ability if conducting underway oeprations.
Operation/Maintenance Crew: Four man (minimal - more depending on nature and length of task).
Total Shipping Weight: 5.5 tons (5t)
Total Shipping Volume: 4,000 cu ft (113 cu m). Packaged for shipment in two standard LD-9 air cargo containers.

Status: Operational, on standby for emergency calls.
Builder: AMTEK, Straza Division
El Cajon, Ca.

ERIC II

Operating Depth: 6,000m (19,685 ft)
Dimensions (LxWxH): Fish: 500cm x 300cm x 180cm (197 in. x 118 in. x 71 in.). Clump: 640cm x 370cm x 260cm (252 in. x 146 in. x 102 in.).
Weight (dry): Fish: 5t (5.5 tons)
Clump: 2.5 to 4t (2.75 to 4.4 tons)
Structure: Teardrop configuration overall. All components are enclosed within a fiberglass framing. A clump, PAGODE, is employed to protect ERIC II during launch/retrieval and to keep the umbilical taut while the fish operates from a 300m (984 ft) long cable between it and the PAGODE.
Power Requirements: Fish power (115 V single phase, 400 Hz, 100 KW max.) is supplied by a diesel generator.
Propulsion: Six thrusters provide six degrees of maneuvering freedom.
Instrumentation: Cine camera, scanning sonar, CCTV (head-following), gyrocompass and vertical gyro, echo sounder, depth sensor, two manipulators with force feedback.
Navigation: A bottom-mounted transponder navigation system (11 and 16 kHz) can provide fish position accuracies of plus or minus 5m (16.4 ft) with 20-second updates. The navigation computer simultaneously handles the ship and fish navigation.
Shipboard Components: Control/display console (in a portable van), cable and fish handling equipment, acoustic navigation equipment.
Support Ship Requirements: Dynamic positioning capability.
Operating/Maintenance Crew: Two operators are required to run the system. One operator controls the fish, the second operator maintains the support ship directly over the PAGODE.
Total Shipping Volume: Approximately 222 cu m (7,838 cu ft) not including the technical shelter or diesel generator.
Total Shipping Weight: Approximately 47.5t (52.4 tons) not including the technical shelter or diesel generator.

Status: Construction
Builder: CERTSM
D.C.A.N. Toulon
France

ERIC 10

Operating Depth: 500m (1,640 ft)
Dimensions (LxWxH): 400cm x 200cm x 200cm (158 in. x 79 in. x 79 in.)
Weight (dry): 2.8t (3.1 tons)
Speed: (Max. Surface) 4 kts (7.4km/hr)
(Max. Operating Current) 2.0 kts (3.7km/hr)
Structure: Rectangular shape composed of open aluminum framework which encloses and supports all components.
Buoyancy: The vehicle is 110 lbs (50kg) positively buoyant
Power Requirements: 60 Hz, 3-Phase, 440 VAC 60 KVA
Propulsion: Three thrusters, two provide thrust and yaw and one provides vertical motion. All thrusters are reversible; have continuously variable speed control (0 to 380 rpm) and are capable of independent operation.
Instrumentation: TV on pan and tilt mechanism, six lights, still camera, depth gauge, CTFM sonar, inclinometer (pitch; roll) downward-looking echo sounder, magnetic compass, magnetometer. One manipulator with five degrees-of-freedom, parallel jaws-type claw. Six, 400 watt quartz iodide lights. Two surface flashing lights.
Navigation: Compass heading, visual sighting and by interrogation of transponders with the CTFM sonar.
Shipboard Components: Control/Display console (in portable van), cable and reel winch, launch/retrieval crane, diesel generator.
Support Ship Requirements: Deck space for van and component storage.
Operation/Maintenance Crew: Five
Total Shipping Weight: 11 tons (10t)
Total Shipping Volume: 1,588 cu ft (45 cu m)

Status: Operational
Builder: Centre d'Etudes et de Recherches Techniques Sous-Marines
D.C.A.N. Toulon
France

EV-1

Operating Depth: 1,500 ft (457m)
Dimensions (LxWxH): 52 in. x 32 in. x 24 in. (132cm x 81cm x 61cm)
Weight (dry): Vehicle - 250 lbs (115kg)
Launcher (if used) - in design stage
Speed: (Max. Operating Depth) 0.5 knots (0.9km/hr)
Structure: Two syntactic foam cylinders strapped to a welded tubular steel frame support motors, camera/electronics pressure housing, and other associated hardware.
Buoyancy Control: Vehicle operates neutrally buoyant with additional buoyancy available for up to 40 lbs (18kg) of accessory equipment.
Power Requirements: 220 to 440 VAC 3-phase 60Kz 5 KW maximum.
Propulsion: Three fixed reversible hydraulic motors, one stern mounted, one lateral, and one vertical thruster, provide thrust, yaw and heave.
Instrumentation: Fixed TV camera, two, 250 watt tungsten halogen light, compass, pressure transducer for depth, leak detector, and hydraulic system temperature indicator.
Navigation: By compass heading and visual sighting.
Shipboard Components: Control console, power distribution package, winch.
Support Ship Requirements: Enclosed area for control console, 3-phase 60Hz 220 or 440 V generator.
Operating/Maintenance Crew: Two or three depending upon length of task.
Total Shipping Volume: 52.5 cu ft (1.5 cu m)
Total Shipping Weight: 10,251 lbs (4,650kg)

Status: Operational (two vehicles have been constructed)
Builder: Ocean Systems Division
Kraft Tank Co.
Kansas City, Mo.

FILIPPO

Operating Depth: 300m (984.3 ft)
Dimensions: Spherical shape nominal 65cm (26 in.) diameter.
Weight (dry): 86kg (189 lbs).
Speed: Can work at operating depth in 0.5 kt (0.9km/hr) current.
Structure: Two fiberglass hemispheres enclose all components. The hull is penetrated by two parallel windows oriented 30 degrees downward from the horizontal through which the TV camera and still camera view. A third window looks vertically upward.
Buoyancy Control: A droppable weight of 20kg (44 lbs) and a guard chain provide the vehicle with 0.5kg (1.1 lbs) negative buoyancy. When the chain rests on the bottom about 3kg (6.6 lbs) of positive buoyancy is obtained.
Power Requirements: Self-powered with rechargeable lead acid batteries. About 8 hours operational time is provided.
Propulsion: Four fractional hp electric motors provide forward/reverse, vertical and lateral movement and yaw control.
Instrumentation: Magnetic compass, depth sensor, TV camera, 55 watt halogen light. Optional equipment includes still camera and flood light and manipulator.
Navigation: Magnetic compass and visual.
Shipboard Components: Cable and winch 45kg (99.2 lbs) 54cm x 50cm x 40cm (21 in. x 20 in. x 16 in.) H x W x D. Control/display console weighing 10kg (22 lbs) and 54cm x 38cm x 32cm (21 in. x 15 in. x 13 in.) H x W x D.
Support Ship Requirements: Deck space of approximately 2.5 sq m (26.9 sq ft)
Operating/Maintenance Crew: One
Total Shipping Volume: Approximately 0.4 cu m (14.5 cu ft)
Total Shipping Weight: 130kg (287 lbs)

Status: Operational. Two vehicles constructed, two additional units under construction.
Builder: Gay Underwater Instruments
Trezzano Sul Naviglio
Italy

IZE

Details concerning the design and capabilities of this vehicle are not fully available. What details are available are presented below. IZE was built with financial assistance from the National Research Development Corporation.

Operating Depth: 500m (1,640 ft)
Structure: Rectangular-shaped, open aluminum framework. Pressure-resistant cylinders atop the framework provide buoyancy and house the electronics systems.
Instrumentation: CCTV mounted on a pan/tilt mechanism. One thallium iodide light, two, 250 watt, quartz halogen lights.

Status: Operational
Builder: Sub Sea Surveys, Ltd.
Barrow-in-Furness, Cumbria
England

MANTA 1.5

Operating Depth: 4,921 ft (1,500m)
Dimensions (LxWxH): 78 in. x 62 in. x 40 in. (198cm x 158cm x 102cm)
Weight (dry): 2,200 lbs (998kg)
Speed: (Max. Surface) 3 knots (5.5kt/hr)
(Max. Operating Current) NA
Structure: Frame Construction
Buoyancy: 11 lbs (5kg) positively buoyant underwater.
Power Requirements: 380 VAC 3-phase 50 Hz.
Propulsion: Four thrusters, two provide fore-aft thrust and yaw, two provide vertical motion (heave). All are fixed, reversible and 1.5 hp each.
Instrumentation: Television, lights (3 at 500 watts), manipulator with 5 degrees-of-freedom, capable of 10kg (22 lbs) lift capacity and has various types of claws, side scan sonar.
Shipboard Components: Cable, control consol.
Shipboard Requirements: Information not available
Operator/Maintenance Crew: Three
Total Shipping Weight: 4 tons
Total Shipping Volume: 20 cu m

Status: Operational
Builder: Academy of Sciences USSR
Moscow

MURS-100
(MODEC Unmanned Remote-controlled Submersible)

Operating Depth: 328 ft (100m). Emergency dive to 492 ft (150m)
Dimensions (LxWxH): 100 in. x 74 in. x 49 in. (255cm x 188cm x 125cm)
Weight (dry): 1,984 lbs (900kg)
Speed: (Max. Surface) 2 kts (3.7km/hr)
(Max. Operating Current) 2.5 kts (4.6km/hr) at 328 ft (100m) depth.
Structure: An acrylic plastic, tear drop-shaped shell encloses and supports a pressure-resistant inner shell consisting of a transparent acrylic plastic hemisphere joined to a steel sphere. The inner shell contains a TV camera and its telemetry control unit and the thruster orientation units. Metallic skids support the vehicle on deck or when bottomed.
Buoyancy: The vehicle is 13 lbs (6kg) positively buoyant when submerged.
Power Requirements: 440 VAC, 60 Hz, 3-phase, 30 KVA.
Propulsion: Two, oil-filled, reversible thrusters are mounted port/starboard amidships (1 on each side). Each thruster can be rotated plus or minus 90 degrees in the vertical plane and each is rated at 2 hp (1.5 KW).
Instrumentation: One color TV with mirror pan and tilt unit. Eight 500 watt halogen lights, compass, inclinometer (pitch), depth gauge, speedometer, transponder, a bilateral, force feedback manipulator.
Navigation: Compass heading and visual sighting. A transponder on the vehicle is interrogated to provide slant-range and bearing from the support ship.
Shipboard Components: Control/display console; power panel, cable winch.
Support Craft Requirements: One (1) ton (0.9t) capacity boom with 6 ft (2m) outreach for launch/retrieval of vehicle. Deck space of 20 ft x 20 ft (6m x 6m).
Operation/Maintenance Crew: Three to four.
Total Shipping Volume: Approximately 989 cu ft (28 cu m).
Total Shipping Weight: Approximately 5 tons (4.5t).

Status: Operational.
Builder: Mitsui Ocean Development & Engineering Co., Ltd.
Tokyo, Japan

MURS-300

(MODEC Unmanned Remote-controlled Submersible)

Operating Depth: 300m (984 ft)
Dimensions (LxWxH): 266cm x 190cm x 163cm (105 in. x 75 in. x 64 in.)
Weight (dry): 2,400kg (5,291 lbs)
Speed: 3 knots (5.6km/hr) (maximum operating current)
Structure: Rectangular shaped, open metallic framework encloses and supports all components. A syntactic foam float is attached to the top of the framework.
Buoyancy: Syntactic foam provides positive surface buoyancy. Vehicle is approximately 10kg (22 lbs) positively buoyant when submerged.
Power Requirements: 22 VAC, 3-phase, 60Hz, 60 KVA.
Propulsion: Four thrusters, two horizontal, one vertical and one lateral. A 7.5 hp hydraulic pump provides power. Heading, depth and altitude are automatically controlled.
Instrumentation: Two TV cameras (1 color, 1 low light level black and white) mounted on a pan and tilt mechanism, 35mm still camera with strobe light, four 250 watt lights and two 500 watt lights, downward looking echo-sounder, depth gage, gyrocompass, trim gage, CTFM sonar, cable cutter. Two manipulators, one has 7 degrees-of-freedom 20kg (44 lbs) lift capacity, one has 5 degrees-of-freedom and 40kg (88 lbs) lift capacity. The 7 motion manipulator operates bilaterally with master-slave control.
Navigation: Visual, gyrocompass, ship-mounted vehicle tracking system.
Shipboard Components: Control/display console, power panel (inside portable van), cable winch.
Support Ship Requirements: Deck space for van and cable winch (21.4 sq m) power supply, lift device for submersible launch/retrieval.
Operating/Maintenance Crew: Two (operators only, maintenance crew not yet established).
Total Shipping Volume: 72 cu m (2,553 cu ft) (approximate)
Total Shipping Weight: Not available.

Status: Under construction.
Builder: Mitsui Ocean Development and Engineering Co., Ltd.
Tokyo, Japan

OBSERVER DL.1

Operating Depth: 600 ft (183m)
Dimensions (LxWxH): 11 ft x 8 ft x 10 ft (3m x 2m x 3m)
Weight (dry): 5.5 tons (5t)
Speed: Information not available.
Structure: Rectangular open metallic framework encloses and supports all components.
Buoyancy Control: Automatic buoyancy tank.
Power Requirements: Information not available.
Propulsion: Two propellers provide forward/reverse and yaw control.
Instrumentation: TV camera on pan and tilt mechanism, 2 spotlights, lifting arm w quick release hook.
Navigation: Visual sighting.
Shipboard Components: Control/display console, remote control panel, video tape recorder, telecom system connects pilot to winch operator, umbilical and carrier cables.
Support Ship Requirements: Information not available.
Operating/Maintenance Crew: Information not available.
Total Shipping Weight: Information not available.
Total Shipping Volume: Information not available.

Status: Operational
Builder: C.G. Doris
Paris, France

ORCA I

Operating Depth: 700m (2,297 ft)
Dimensions (LxWxH): 3.5m x 2m x 2m (11.5 ft x 6.6 ft x 6.6 ft)
Weight (dry): 2,721kg (6,000 lbs)
Speed: Information not available
Structure: Open, rectangular, metallic framework encloses and supports all components. Syntactic foam blocks are attached to the top of the frame.
Buoyancy Control: Syntactic foam is adjusted to provide a slight positive buoyancy.
Power Requirements: 440 V, 60 Hz/380 V, 50 Hz.
Propulsion: 6 Kw thrusters provide maneuvering in all translational and rotational motions. Automatic control of depth, altitude, pitch and roll.
Instrumentation: Two CCTV (one fixed and one on pan/tilt device). Tool rack with tools, sample basket, stereo-camera system. Three manipulators: one master-slave primary work unit; two rate controlled, work-assistance grabbers. Echo-sounder. Two directional hydrophones. Transponder. Depthometer. Direction Syro, Inclinometer.
Navigation: Automatic tracking from surface provides position reference accuracy of plus or minus 1 percent.
Shipboard Components: Control/display console and computer, master transformer. Umbilical cable and container, launch/retrieval equipment.
Support Ship Requirements: Deck space of 50 to 80 sq m (538 to 861 sq ft).
Operating Maintenance Crew: Information not available.
Total Shipping Volume: Information not available.
Total Shipping Weight: 10.9t (12 tons) not including launch/retrieval device.

Status: Operational
Builder: Saab-Scania
Aerospace Division
Linkoping, Sweden

PAP 104

Operating Depth: 100m (328 ft)
Dimensions (LxWxH): 2.7m x 1.2m x 1.3m (8.9 ft x 3.9 ft x 4.3 ft)
Weight (Dry): 700kg (1,543 lbs)
Speed: Can operate in 4 knot (7.2km/hr) current
Structure: Torpedo shaped vehicle with side thrusters and explosives carried on keel.
Buoyancy Control: Vehicle is positively buoyant when explosive charge has been released, it is slightly negative with charge. A guiderope is trailed from the vehicle which holds it at near-constant altitude.
Power Requirements: Battery powered (Lead acid, 32v, 145 amp-hr). Approximately 100 minutes of operating time is obtained on one battery charge.
Propulsion: Two electric motors, variable pitch propellers.
Instrumentation: CCTV, transponder, gyrocompass.
Navigation: The vehicle and its intended target (mine) are both located and tracked by a surface monitor until closure of both is obtained.
Shipboard Components: Main control/display console, video monitor, remote control unit.
Support Ship Requirements: Ship must be equipped with a sonar system capable of receiving the PAP transponder.
Operating/Maintenance Crew: Two
Total Shipping Volume: Information not available
Total Shipping Weight: Information not available

Status: 128 of these mine neutralization vehicles have been built and are operational.
Builder: Societe ECA
Meudon, France

PHOCAS II
(Photo Optical Cable-Controlled Submersible)

Operating Depth: 300m (984 ft)
Dimensions (LwWxH): 200cm x 80cm x 80cm (79 in. x 32 in. x 32 in.)
Weight (dry): 227kg (500 lbs)
Speed: 1.5 kts (2.8 km/hr) (submerged)
Structure: Rectangular-shaped, open, tubular aluminum framework encloses and supports all components.
Buoyancy: Fourteen, 20cm (8 in.) diameter Nokalon floats provide surface and subsurface buoyancy. Altitude near-bottom is controlled by a combination of a drag chain and pneumatically controlled variable ballast tank, extra floats can be added.
Power Requirements: 5 KW, 380/220 VAC (3 or single phase), 50 Hz.
Propulsion: Two, stern-mounted horizontal thrusters provide forward/reverse and yaw motion. Each thruster is powered by a one half hp electrical motor. Vertical (up/down) movement is obtained by the drag chain/VBT combination.
Instrumentation: TV camera, 35mm still camera (both mounted on a common tilt mechanism), downward looking echo sounder, 400 w thallium iodide light (TV), 160 ws strobe light (still camera), magnetic compass, depthometer, transponder interrogater. Manipulator with 3 degrees-of-freedom is being designed for collection of bottom samples.
Navigation: By visual sighting, magnetic compass and interrogation (bearing and range) of a transponder suspended from the support vessel.
Shipboard Components: Control/display console, 2 KVA (220 V, 50 Hz) generator, cable drum and winch, 9 KVA 3-phase diesel generator available.
Support Ship Requirements: Air supply of 140 cu ft (4 cu m) at 3,000 psi (211kg/sq cm), electrical power supply and one half ton containerized support and cabin space for navigation/control console of 7.6 cu ft (0.2 cu m).
Operating/Maintenance Crew: 1 operator, 1-2 for handling
Total Shipping Weight: No information available
Total Shipping Volume: No information available

Status: Operational
Builder: Geologinen Tutkimuslaitos
Otaniemi
Finland

PINGUIN B6

Operating Depth: 6,500 ft (1,981m)
Dimensions (LxWxH): 10.25 ft x 4 ft x 4 ft (3.1m x 1.2m x 1.2m) (approximate)
Weight (Dry): 3,584 lbs (1,626kg)
Speed: 2 knots (4km/hr) cruise; 7 knots (13km/hr) maximum
Structure: Torpedo shaped body encloses and supports all components
Buoyancy: Information not available
Power Requirements: Information not available
Propulsion: Six thrusters: 2 horizontal, 2 vertical, 2 lateral.
Instrumentation: CCTV, echo sounder, lights, forward-looking sonar.
Navigation: Information not available
Shipboard Components: Information not available
Support Ship Requirements: Information not available
Operation/Maintenance Crew: Information not available
Total Shipping Weight: Information not available
Total Shipping Volume: Information not available

Status: Operational
Builder: VFW Fokker
Bremen
West Germany

RCV-150

Operating Depth: 6,000 ft (1,829m)
Dimensions (LxWxH): 52 in. x 47 in. x 42 in. (132cm x 119cm x 109cm).
Operates from a launching unit on a 200 ft (61m) long tether cable.
Weight (dry): 45 lbs (204kg)
Speed: (Max. Surface) 2 kts (3.7 km/hr)
(Max Operating Current) 2 kts (3.7 km/hr) at 6,000 ft.
Structure: Tubular aluminum framework encloses and supports all components. Atop and port/starboard on the framework are two cylindrical, fixed buoyancy units composed of a high strength composite epoxy and two spherical, variable buoyancy tanks mounted forward/aft on the vehicle's centerline. Mesh screen guards enclose the port and starboard sides of the aluminum framework.
Buoyancy: The high strength composite epoxy provides 15 lbs (7kg) of positive buoyancy when the vehicle is submerged. Variable ballast tanks can provide plus or minus buoyancy when submerged.
Power Requirements: 220 or 440 VAC, 50/60 Hz, 3-phase
Propulsion: Four ducted propellers: 15 hp, two provide forward/reverse thrust and yaw rotation, one provides vertical thrust and one provides transverse or side motion. All thrusters are reversible. An automatic servo control system automatically corrects for external forces acting on the vehicle and automatically controls depth.
Instrumentation: TV camera (low light level) capable of being tilted plus or minus 90 degrees from the horizontal, 500 watt quartz iodide light, depth sensor, heading sensor, emergency pinger and flasher. A wide variety of optional equipment is available.
Navigation: By compass heading and visual sighting.
Shipboard Components: Control/display console, hand controller, winch, A-frame, hydraulic power supply, vehicle protective launcher.
Support Ship Requirements: Enclosed area for control/display console, deck space for vehicle and handling equipment, station-keeping capability and electric power supply (a diesel generator power source is optional).
Operation/Maintenance Crew: Three for an 8 to 10 hour period
Total Shipping Weight: 1,100 lbs (495kg), not including deployment unit, winch and cable, or handling equipment.
Total Shipping Volume: 252 cu ft (7.1 cu m), not including deployment unit, winch and cable, or handling equipment

Status: Four vehicles are under construction. None have been delivered to their purchasers as of November 1978.
Builder: Hydro Products
San Diego, Ca.

RCV-225

Operating Depth: 6,600 ft (2,012m)
Dimensions (HxWxD): 20 in. x 26 in. x 20 in. (51cm x 66cm x 51cm)
Launcher (HxWxD): 3.7 ft x 3.2 ft x 3.2 ft (1.1m x 1.0m x 1.0m)
Weight (dry): 180 lbs (82kg) Launcher (dry) 175 lbs (80kg)
Speed: (Max. Surface) 1.7 kts (3.1 km/hr)
(Max. Operating Current) 1 kt (1.8 km/hr) at 6,600 ft
Structure: A syntactic foam hull shaped into a prolate spheroid encloses the motors and the camera/electronics pressure housing.
Buoyancy: Vehicle is positively buoyant by 4 lbs (2kg)
Power Requirements: 220 VAC 3-phase 50 to 60 Hz or 440 VAC 3-phase 50 to 60 Hz (5 KW maximum).
Propulsion: Four oil-filled electric motors, two provide thrust and yaw and two provide heave, a forth motion (sway) is provided by the vertical thruster configuration. A desired depth and heading can be automatically maintained.
Instrumentation: TV camera (low light level) which is capable of being tilted plus or minus 90 degrees in the vertical, two 45 watt tungsten halogen lights, compass and depth sensor.
Navigation: By compass heading and visual sighting
Shipboard Components: Control/display console, power supply, hand controller, deployment unit (winch/skid/A-frame).
Support Ship Requirements: Enclosed area for control console.
Operation/Maintenance Crew: Two to three, depending upon length of task.
Total Shipping Weight: 5,555 lbs (2,520kg)
Total Shipping Volume: 285 cu ft (8.1 cu m)

Status: Twenty six of these vehicles were built by the end of 1978. Six more units are scheduled for production in 1979.
Builder: Hydro Products
San Diego, Ca.

RECON II

Operating Depth: 1,500 ft (457m)
Dimensions (LxWxH): 42 in. x 38 in. x 32 in. (107cm x 96cm x 81cm)
Launcher: 36 in. x 30 in. x 36 in. (91cm x 76cm x 91cm).
Weight (dry): 610 lbs (281kg) Launcher: 1,500 lbs (680kg)
Speed: (Max. Surface) 3 kts (5.6 km/hr)
(Max. Operating Current) 2 kts (3.7 km/hr)
Structure: Syntactic foam atop an open tubular framework which supports and encloses all components.
Buoyancy: Operates at neutral buoyancy. Descends/ascends by operation of thrusters.
Power Requirements: 220 VAC or 440 VAC 3-phase, 60 Hz.
Propulsion: Four fixed, reversible, hydraulically-driven, propellers, each provides 1 hp. Two provide thrust and yaw, one provides vertical motion and one provides side motion. All are capable of independent operation and have continuously variable speed control.
Instrumentation: TV camera, two 250 watt incandescent lights, magnetic compass, depth monitor, current meter. One hydraulically-powered manipulator with 14 inches (36cm) linear extension, 90 degree wrist rotation and cable cutting/scissors-type jaws.
Navigation: By compass heading and visual sighting, or acoustic surface tracking.
Shipboard Components: Control console, cable, transformer package. Tracking system optional. TV monitoring and recording equipment.
Support Ship Requirements: One and one-half ton (1.5t) winch, 2,000 ft (610m) of 8,000 lbs (8,629kg) wire rope, power supply.
Operational/Maintenance Crew: Three
Total Shipping Weight: 2,100 lbs (952kg) not including control console, umbilical bundle, or items listed under support ship requirements.
Total Shipping Volume: 65.8 cu ft (1.9 cu m) not including umbilical bundle.

Status: Operational
Builder: Perry Ocean Group
Riviera Beach, Fl.

RECON III

Operating Depth: 1,200 ft (366 m)
Dimensions (LxWxH): 56 in. x 28 in. x 24 in. (142cm x 71cm x 61cm)
Weight (dry): 308 lbs (140kg)
Speed: (Max. Surface) 2 kts (3.7 km/hr)
(Max. Operating Current) Information not available
Structure: Rectangular shape composed of tubular aluminum framework which encloses and supports all components.
Buoyancy: A syntactic foam block mounted atop the framework provides positive buoyancy. Vehicle operates at 5 lbs (2.3kg) positive buoyancy and descends/ascends by virtue of thrusters.
Power Requirements: 60 Hz, 3-phase, 220 V and 440 V, 15 KVA capacity required.
Propulsion: Three reversible electric thrusters, continuously variable speed control. Two are stern-mounted and provide forward/reverse thrust and develop a maximum thrust of 80 lbs (36kg). One is mounted amidships and provides vertical thrust of 40 lbs (18kg) maximum.
Instrumentation: CCTV mounted on a tilt mechanism which can orient the camera 10 degrees up and 90 degrees down. One mercury vapor, variable intensity, 400 watt light. Depth sensor (5 percent accuracy). Magnetic compass. Automatic depth keeping capability provided.
Navigation: Visual sighting and magnetic compass. The system is equipped to accommodate the Honeywell RS-7 digital acoustic positioning reference system. The RS-7 can display the vehicle's position and another known location relative to the support ship with a position accuracy plus or minus 1 percent of depth.
Shipboard Components: Control/display console, umbilical cable/winch, transformer package.
Support Ship Requirements: Approximately 40 sq ft (3.7 sq m) of deck space for the control station and 500 sq ft (46.5 sq m) for the winch and launch area. Total 540 sq ft (50.2 sq m).
Operational/Maintenance Crew: Three
Total Shipping Weight: 1850 lbs (839kg)
Total Shipping Volume: 136 cu ft (3.9 cu m)

Status: Operational (5 vehicles)
Builder: Perry Ocean Group
Riviera Beach, Florida

RECON V

Operating Depth: 1,200 ft (366m)
Dimensions (LxWxH): 75 in. x 36 in. 30 in. (191cm x 91cm x 76cm)
Weight (dry): 848 lbs (385kg)
Speed: (Max. Surface) 2.5 kts (4.6 km/hr)
(Max. Operating Current) Information not available
Structure: Rectangular shape composed of tubular aluminum framework which encloses and supports all components.
Buoyancy: A syntactic foam block atop the framework provides slight positive buoyancy when submerged.
Power Requirements: Three phase, 60 Hz, 208/240/480 V at 100 KVA minimum capacity.
Propulsion: Five reversible hydraulic thrusters. Two are stern-mounted and provide 150 lbs (68kg) forward and reverse thrust. Two are vertical thrusters mounted port/starboard amidships and one is a lateral thruster mounted amidships. The vertical thrusters provide 150 lbs of thrust; the lateral thruster 75 lbs. (34kg).
Instrumentation: CCTV mounted on a pan/tilt device can scan 270 degrees in azimuth and can tilt vertically plus or minus 80 degrees from the horizontal. Two, 250 watt tungsten iodide lights mounted on the pan/tilt mechanism. Magnetic compass. Depth sensor. Manipulator capable of four degrees of freedom which can grasp objects 4 in. (10.2cm) in diameter. Automatic hover and heading control. Display of cable twist and cable slack.
Navigation: Visual sighting and magnetic compass. The system is equipped to accommodate the Honeywell RS-7 digital acoustic positioning reference system.
Shipboard Components: Control/display console, surface control van (optional). Surface transformer package. Umbilical cable (tether). Handling system (slip ring winch, crane).
Support Ship Requirements: For operations in a live-boat mode (where the support ship is underway), the support ship must be able to maintain a maximum shipprint of 50 ft (15m) on the surface relative to the vehicle's position. Consequently, absolute control of the support vessel must be continuously maintained during vehicle submergence. Minimal live-boat surface propulsion requirements call for twin screws and a bow thruster.
Operational/Maintenance Crew: Three
Total Shipping Weight: 2050 lbs (930kg)
Total Shipping Volume: 136 cu ft (3.9 cu m)

Status: Operational
Builder: Perry Ocean Group
Riviera Beach, Florida

RUWS
(REMOTE UNMANNED WORK SYSTEM)

Operating Depth: 20,000 ft (6,096m)
Dimensions (LxWxH): Vehicle -132 in. x 57 in. x 60 in. (335cm x 145cm x 152cm); PCT -115 in. x 60 in. x 72 in. (292cm x 152cm x 183cm)
Weight (Dry): Vehicle -7,000 lbs (3,175kg); PCT - 5,500 lbs plus or minus 300 lbs (2,495kg plus or minus 136kg).
Speed: Design goal of 1.5 knots; actual performance to be determined during development tests.
Structure: Vehicle: Rectangular shape composed of open angular aluminum framework supporting and enclosing all components, syntactic foam blocks are affixed to the top of the framework. PCT (Primary Cable Termination): Rectangular shape composed of open, angular aluminum framework which encloses and supports a winch for the vehicle's buoyant, 850 ft (259m) long tether and four thrusters for stationkeeping.
Buoyancy: Syntactic foam provides the vehicle with 10 to 30 lbs (4.5 to 13.5kg) positive submerged buoyancy. The PCT is negatively buoyant by 3,500 plus or minus 300 lbs (1,588 plus or minus 136kg).
Power Requirements: All power, 60KW, is supplied by diesel-electric generators.
Vehicle Propulsion: A 15 hp hydraulic pump provides power to five thrusters: two for forward/reverse motion, two for lateral motion and one for vertical motion. All are reversible and continuously supply variable speed control.
Instrumentation: Black and white 525 line resolution TV (on pan and tilt can be manually positioned or head coupled); 70mm still camera; two manipulators, one seven degrees-of-freedom position control, the other a four degrees-of-freedom rate control grabber; high resolution preformed beam search/avoidance sonar with 1,000 foot range and two directional hydrophones for pinger tracking high frequency acoustic altimeter; digital magnetic compass.
Navigation: A real time CRT display of the support ship, vehicle and PCT positions can be obtained relative to three bottom-mounted transponders which are interrogated individually by each component. Relative position accuracies of plus or minus 40 feet (12m) are obtainable at maximum operating depth. A hard copy of the CRT-displayed data may be obtained at the operator's discretion.
Shipboard Components: Control/navigation van; maintenance van; near-surface navigation transducer with handling system; power generation equipment and a motion-compensated, deck handling system.
Support Ship Requirements: A minimum deck space of 700 sq ft (65 sq m) is required to accommodate all surface and underwater components.
Operational/Maintenance Crew: To be determined.
Total Shipping Weight: 82 tons (84.4mt)
Total Shipping Volume: Entire system can be air transported by three Lockheed C-141A aircraft or one C-5A aircraft.

Status: Undergoing sea trials and tests, estimated operational in 1979
Builder: Naval Ocean Systems Center
Kailua, Hawaii

SCAMP

Operating Depth: Can accommodate deepest draft ULCCs (Ultra Large Crude Carriers)
Dimensions (LxWxH): 6 ft x 1.7 ft (1.8m x 0.5m).
Dry Weight: 1,500 lbs (680kg)
Speed: 0.5 knots (0.9km/hr)
Structure: Principle structure is fiberglass canopy (platform with a central aperture for an impeller). Platform is mounted on three wheels and on the under side of the machine are located three wire brushes. The cleaning swatch is slightly less than the canopy diameter.
Buoyancy: The fiberglass canopy is injected with styrofoam to provide positive buoyancy.
Power Requirements: Power is supplied from a generator to a 15 hp submersible electric motor driving a duplex hydraulic pump. One unit of the pump drives the impeller, the second unit powers the wheels and the cleaning burshes.
Propulsion: Hydraulically driven motors powering three traction wheels, one of which provides steering.
Instrumentation: The SCAMP cleaning unit is connected by a coaxial cable to a control console on the support craft. This machine will advance, stop or reverse either by remote control from the console or by a local diver control. It can also be switched to automatic control to maintain a horizontal path on a vertical surface.
Instrumentation/Navigation: The control console reads out depth, machine attitude, and distance travelled.
Shipboard Components: Control/display console, diesel generator.
Support Ship Requirements: A variety of small surface craft
Crew: Variable, depending on scope of operation. Minimally one man required for console operation, one for coaxial cable tender control, one for diver tender (air support etc.) plus normal complement of crew required to operate surface craft.
Total Shipping Volume: Information not available.
Total Shipping Weight: Information not available.

Status: Operational at 14 worldwide locations
Builder: Winn Technology Ltd. for Butterworth Systems, Inc.
Kilbrittain
County Cork
Ireland
Operator/Point of Contact: Butterworth Systems Inc.
Florham Park, N.J.

SCAN

Operating Depth: 328ft (100m)
Dimensions (LxWxH): 24 in. x 24 in. x 14 in. (61cmx61cmx36cm) (approximate).
Weight (Dry): Information not available
Speed: 1 knot (1.75km/hr).
Structure: A disc-shaped, fiberglass fairing encloses and supports all components.
Buoyancy: Plastic spheres provide surface buoyancy. A free-flooding tank is blown free of water by compressed air to provide positive buoyancy to hold the vehicle against the hull of the vessel it is inspecting.
Power Requirements: AC power is supplied by a 7KVA, 420V, 50Hz, 3-phase portable diesel generator. DC power is supplied from a 12V battery.
Propulsion: Two hydraulically-driven wheels propel the vehicle along the hull surface.
Instrumentation: Two, pan/tilt-mounted TV cameras (a Vidicon for close viewing and a low-light TV for distance viewing), 35mm still camera, distance-travelled sensing unit.
Navigation: Visual location (on hull markings), dead reckoning by measurement of the x-y components of distance travelled. An acoustic positioning system can be used if required.
Shipboard Components: Control/Display console, diesel generator
Support Ship Requirements: Barge or small boat
Operation/Maintenance Crew: One
Total Shipping Volume: Information not available
Total Shipping Weight: Information not available

Status: Operational
Builder: Underwater Maintenance Co., Ltd.
Southampton
England

SCARAB I & II
(Submersible Craft Assisting Repair and Burial)

Operating Depth: 6,000 ft (1,829m)
Dimensions (LxWxH): 132 in. x 72 in. x 60 in. (335cm x 183cm x 152cm)
Weight (dry): 5,000 lbs (2,268kg)
Speed: (Max. Surface) 3 kts (5.6km/hr)
(Max. Operating Current) 0.5 kt (0.9km/hr) at 6,000 ft
Structure: Open tubular framework cage enclosing and supporting vehicle components.
Buoyancy: Cylindrical flotation tanks provide 50 lbs (23kg) of positive buoyancy when submerged.
Power Requirements: 480 VAC 3-phase 150 KW. Portable diesel (2 ea fully redundant) electric generator supplies all power requirements. A 10,000 ft (3,048m) long umbilical cable 1.4 in. (3.2cm) diameter powers and controls the vehicle.
Propulsion: Six, 5 hp each, electrical motors and one, 5 hp, hydraulic motor provide propulsive power.
Instrumentation: Two low light level TV cameras (one with zoom) on pan and tilt units, one 35mm still camera, lights, bottom contour following sensors, altimeters, depth sensors, magnetometer (for cable location). Two hydraulically-powered manipulators, 5 degrees-of-freedom, equipped with various devices for cable cutting and gripping. Dredge or jet pump to uncover and bury cables.
Navigation: 360 degree scanning CTFM sonar capable of interrogating bottom-mounted transponders or locating pingers for relative bottom positioning. Computer driven graphics display tracking unit on support craft for obtaining vehicle's relative range and bearing.
Shipboard Components: Power distribution unit, control/display console, navigation plotter, operator's chairs (three each), spare parts, diesel generators, cable, cable floats, vehicle locator unit and motion compensated launcher with cable storage reel.
Support Ship Requirements: Deck space for shipboard components and vehicle.
Operation/Maintenance Crew: Operator, assistant operator and observer.
Total Shipping Weight: 94,000 lbs (42,638kg).
Total Shipping Volume: Nine standard air freight containers hold all components. Volume of each container (LD-3) is 158 cu ft (4.5 cu m).

Status: SCARAB I - Presently on extended sea trials for acceptance.
SCARAB II - Awaiting completion of sea trials of I and then will begin its sea trials. Expect to complete trials in 1979.
Builder: AMETEK/Straza
El Cajon, California

SCORPIO

Operating Depth: 3,000 ft (914m)
Dimensions (LxWxH): 88 in. x 48 in. x 64 in. (223cm x 122cm x 163cm)
Weight (dry): Vehicle - 1,500 lbs (680kg)
Winch and Cable Reel - 7,000 lbs (3,175kg) maximum fully loaded with tether cable and with power distribution components.
Speed: (Max. Operating Depth) 1 knot against 1 knot current at depth (estimated).
Structure: Two pressure resistant flotation tanks atop of--and enclosed within--an open tubular aluminum framework. Electronics are housed in removable chassis drawers within the buoyancy tanks.
Buoyancy: Vehicle is positively buoyant. Negative buoyancy is dynamically controlled by verticle thruster.
Power Requirements: 440 VAC, 60 Hz, 3-phase, 50 KW. Umbilical cable is 3,500 ft (1,060m) long and 1.15 in. (2.9cm) diameter. Cable has 15 power conductors evenly distributed around the periphery surrounded with a grounding copper braid. Over the copper braid is a jacket of polyurethane, a Kevlar strength member and finally an outer jacket of polyurethane.
Propulsion: Four proportionally controlled high velocity, hydraulic thrusters each delivering 250 lbs (113kg) thrust; 2 axial, 1 vertical, 1 lateral.
Instrumentation: Underwater TV camera mounted on pan and tilt mechanism. AMETEK Model 250 CTFM sonar mounted on upper front frame for 360 degree search and obstacle avoidance. Sonar also tilts 90 degrees downwards for bottom search and survey. Hydraulic five-motion manipulator extends from bottom front frame. Automatic heading and depth control. Cable turns counter. Acoustic pinger and strobe flasher to assist in emergency subsurface and surface recovery. One 250w thallium iodide light and one 250w tungsten quartz iodide light.
Navigation: The CTFM sonar can assist in location and navigation to selected areas marked by an acoustic pinger or can locate submerged objects passively. A surface-ship mounted scanning hydrophone receives a continuously transmitted acoustic signal from the vehicle and displays vehicle slant range and bearing. Also works with acoustic bottom reference pingers giving bearing only.
Shipboard Components: Control console with portable control box for visual launch and recovery of vehicle, sonar, TV and locator displays, operator, bridge, winch station communications sets, power distribution unit, winch and cable reel and spare parts. Power generator and launching frame are optional.
Support Ship Requirements: Enclosed area for control console and operators (can be supplied as optional item). A suitable power source with a rating of 440 - 480 VAC, 60 Hz, 3-phase and 75 KW is recommended for operation of the vehicle and cable winch motors. A smaller (e.g., 50 KW) power rating is possible. A crane, boom or A/U frame is required to launch and recover vehicle (can be supplied as optional item); should have capacity to handle vehicle maximum weight of 2,000 lbs (907kg) which includes optional sensors/tools. Good station-keeping ability for live-boat operations. Deck space of 20 ft (6.1m) long by 12 ft (3.3m) wide required for vehicle, winch and flotation hose.
Operating/Maintenance Crew: Three man minimum. Four man recommended to allow rotation of stations and insertion of fresh man. Extended operations should have five to six man crew.
Total Shipping Weight: 10,000 lbs (4,536kg) maximum.
Total Shipping Volume: 600 cu ft (17 cu m) depending on spares quantities and optional shipping containers.

Status: Operational (4 units)
Builder: AMETEK, Straza Division
El Cajon, CA 92022

SEA INSPECTOR

Operating Depth: 1,000m (3,280 ft)
Dimensions (LxWxH): 334cm x 120cm x 61cm (132 in. x 47 in. x 24 in.)
Weight (dry): 140kg (309 lbs)
Speed: 5 knots (9km/hr) (surface)
Structure: Torpedo shaped metallic body with dive planes and stern-mounted propeller.
Buoyancy: All depth control is by dynamic propulsion.
Power Requirements: 4KW, 230VAC, 60Hz.
Propulsion: Stern-mounted reversible propeller and a hovering module with two ducted thrusters. Power is obtained from a 2 hp motor. Vehicle depth and azimuth can be automatically controlled.
Instrumentation: Color television system forward and a rearward-looking mini-TV to monitor cable fouling, depth gage, compass.
Navigation: Visually, compass bearing.
Shipboard Components: Display/control console.
Support Ship Requirements: Station-keeping ability required.
Operating/Maintenance Crew: One.
Total Shipping Weight: Approximately 160kg (353 lbs)
Total Shipping Volume: Approximately 2 cu m (70 cu ft).

Status: Two vehicles under construction.
Builder: Rebikoff Underwater Products Inc.
Ft. Lauderdale, Fl.

SEA SPY

Operating Depth: 1,000 ft (305m)
Dimensions (LxWxH): 50 in. x 26 in. x 23 in. (127cm x 66cm x 58.4cm)
Weight (dry): 225 lbs (102kg)
Speed: Forward - 1.3 kts (2.4km/hr)
Astern - 0.75 kts (1.4km/hr)
Transverse - 0.5 kts (0.93km/hr)
Vertical - 0.5 kts (0.93km/hr)
Performance subject to depth, length and type of umbilical.
Structure: A sealed, tubular, rectangular-shaped framework of H30 Aluminum Alloy with two parallel longitudinal flotation cylinders. CCTV camera, and lights, thrusters and accessories are within the framework limits.
Buoyancy Control: Vehicle is operated at about 2 lbs fixed positive buoyancy. Primary positive buoyancy is obtained from the two foam filled PVC cylinders providing 60 lbs (31.3kg) each. Lead ballast is used for adjustment, to provide for stability and allow for additional payload.
Power Requirements: 240 VAC single phase, 3 kW maximum.
Propulsion: Four thrusters: two forward/astern units longitudinally, one lateral, one vertical. All use 1/5 hp 2800 rpm 240 VAC induction motors. Gearbox reduction to 700 rpm at the propeller shaft. Propellers are adjustable pitch units except the vertical thruster which is variable pitch and controlled from the pilot's console.
Instrumentation: Remote reading magnetic compass and depth gauge, readouts at pilot's console. Thallium Iodide 250 w light and CCTV camera. Transponder.
Navigation: Normal payload includes a transponder which can be compatible with most sonar submersible plotting systems.
Shipboard Components: Pilot's control console 18 in. x 9 in. x 6 in. (45cm x 23cm x 15cm) including earth leakage safety cut-out unit. Separate CCTV monitor and TV recorder.
Support Ship Requirements: Minimum space and shelter for console and monitor etc. Power source for 240 VAC single phase 3 kW. Space for handling the umbilical. A crane, boom or "A" frame and winch required for launch and recovery.
Operating/Maintenance Crew: Three man minimum team, four men for 24 hour operation.
Total Shipping Volume: 17 cu ft (0.65 cu m)
Total Shipping Weight: 600 lbs (272kg). Volume and weight shown allows for a representative umbilical and some spares.

Status: One operational at Admiralty Underwater Weapons Establishment, Portland, Dorset, U.K.
Designers and Builders: Underwater and Marine Equipment Ltd.
Farnborough, Hampshire
England

SEA SURVEYOR

Operating Depth: 660 ft (200m): Optional 2,000 ft (606m) and 6,600 ft (2,000m).
Dimensions (LxWxH): 132 in. x 48 in. x 28 in. (335cm x 122cm x 171cm).
Weight (dry): 385 lbs (175kg).
Speed: (Max. Surface) 5 kts (9.3km/hr).
(Max. Operating Current) 3 kts (5.6km/hr) at 600 ft.
Structure: Torpedo-shaped metallic body with forward dive planes and stern-mounted propeller.
Buoyancy: All Depth control is by dynamic propulsion.
Power Requirements: 230 V 60 Hz 4 KW.
Propulsion: Stern-mounted, reversible propeller.
Instrumentation: TV camera, light depth sensor, gyrocompass.
Navigation: By compass bearing and visual sighting and artificial horizon (doppler sonar optional).
Shipboard Components: Display/Control console.
Support Ship Requirements: Station-keeping ability required.
Operation/Maintenance Crew: One.
Total Shipping Weight: Approximately 353 lbs (160kg).
Total Shipping Volume: Approximately 70 cu ft (2 cu m).

Status: Operational (2 vehicles)
Builder: Rebikoff Underwater Products, Inc.
Ft. Lauderdale, Fl.
Operator/Point-of-Contact: Rebikoff Underwater Products, Inc.
Ft. Lauderdale, Fl.

SMARTIE
(Submarine Automatic Remote Television Inspection Equipment)

Operating Depth: 984 ft (300m)
Dimensions (LxWxH): 27 in. x 23 in. x 19 in. (69cm x 58cm x 48cm)
Speed: Information not available
Structure: A free-flooding, elliptically-shaped fiberglass fairing encloses and supports all components.
Buoyancy: Vehicle has slight positive buoyancy underwater. Lead shot in tanks can be removed to obtain buoyancy adjustments.
Power Requirements: 440 V, 3-phase, 50 Hz. Current consumption is approximately 4.0 amps per phase for standard vehicle and control console.
Propulsion: A 3-phase, centrifugal pump pressurizes a central manifold. Butterfly valves, controlled by the computer, divert the water to six thruster jets to provide thrust, yaw, heave and sway. A computer automatically carries out the necessary calculations to activate the combination of thrusters required to obtain a particular motion.
Instrumentation: Three TV cameras, pressure/depth transducer, magnetic compass, gyro.
Navigation: Visual navigation in conjunction with computer processed magnetic compass and gyro position information. An artificial navigation target can be displayed on the monitor and can be used to keep the vehicle on course in the absence of visibility.
Shipboard Components: Control/display console, winch, cable, power supply, launch/retrieval system
Support Ship Requirements: Information not available
Operation/Maintenance Crew: Three (for 12 hrs); five (for 24 hrs).
Total Shipping Volume: Information not available
Total Shipping Weight: Information not available

Status: Two operational, one additional by February 1978
Builder: Marine Unit Technology, Ltd.
Plymouth
England

SMIT SUB-1000

Operating Depth: 1,000m (3,280 ft)
Dimensions (LxWxH): 2.2m x 2.2m x 1.6m (7.2 ft x 7.2 ft x 5.2 ft)
Weight (Dry): 700kg (1,543 lbs) (estimated)
Speed: 1.5 knots (2.8km/hr) at maximum operating depth
Structure: Circular-shaped, open, tubular aluminum framework supports and encloses all components. A circular-shaped block of syntactic foam is attached to the top of the structure.
Buoyancy: Positive buoyancy is provided by syntactic foam. The vehicle is slightly positively buoyant when submerged.
Power Requirements: 380/440 V, 3 phase, 50/60 Hz, 125 KVA maximum.
Propulsion: Two horizontal and two lateral thrusters of 300kg (661 lbs) thrust each. One vertical thruster providing 125kg (276 lbs). All thrusters are in Kort nozzles. Vertical thruster is servo-controlled by the depth sensor to control vehicle depth automatically or it can be controlled manually. One 4-axis joystick control.
Instrumentation: CCTV (SIT) with 140 degree fish eye lens, one CCTV on pan/tilt device, 35mm still camera, with 1,000 watt strobe light, two 250 watt quartz iodide lights, altitude sonar, CTFM sonar, sub-bottom profiler, side scan sonar, magnetic compass, pressure/depth sensor. Two manipulators.
Navigation: Compass heading and visual sighting. Provisions available to track vehicle with Honeywell RS-7 system.
Shipboard Components: Control/display console, launch/retrieval device, power source. (Except for the winch and vehicle, all Shipboard components are housed in three standard ISO shipping containers.)
Support Ship Requirements: Deck space of 55.9 sq m (601 sq ft) (minimum).
Total Shipping Weight: 28,500kg (62,830 lbs)
Total Shipping Volume: 129.5 cu m (4,573 cu ft) (approximate)

Status: Under construction. Scheduled for completion by August 1979
Builder: Skadoc Submersible Systems
Yerseke
The Netherlands

SMT 1 & 2 (TROV 2 & 5)

Operating Depth: 1,200 ft (366m)
Dimensions (LxWxH): SMT 1: 84 in. x 50 in. x 50 in. (213cm x 127cm x 127cm)
SMT 2: 108 in. x 50 in. x 50 in. (274cm x 127cm x 127cm)
Weight (dry): SMT 1: 2,200 lbs (998kg)
SMT 2: 3,300 lbs (1,497kg)
Speed: (Max. Surface) 5 kts (9.3km/hr)
(Max. Operating Current) 1.5 kts (2.8km/hr) at maximum operating depth.
Structure: Open, rectangular-shaped aluminum framework supports and encloses all components.
Buoyancy: Floodable ballast tanks emptied by compressed air. Syntactic foam (241 lbs/cu ft) atop framework provides positive buoyancy.
Power Requirements: A surface diesel generator supplies 55 KW, 440 V, 60 Hz power.
Propulsion: Four reversible thrusters, all 7 hp. Two provide forward-reverse thrust, one provides lateral movement and one provides vertical movement.
Instrumentation: Three quartz iodide lights, 500 w each. Echo sounder, CCTV with video recorder. Pinger. SS400ST tracking trench profiler (SMT-1 only). Strobe light. Two hydraulic manipulators, one with seven degrees-of-freedom and one of four degrees-of-freedom. Magnetic compass, depth sensor, corrosion-potential probes, ultrasonic thickness probes, radiographic inspection device, water jet cleaner, stereographic photography.
Navigation: By visual sighting and compass bearing. Both vehicles have the capability for positioning relative to bottom-mounted transponders.
Shipboard Components: Control/display console, diesel generator, reel winch, launch/retrieval crane.
Support Ship Requirements: (Approximate) deck space: 200 sq ft (18.6 sq m) open, 100 sq ft (9.3 sq m) enclosed.
Operating/Maintenance Crew: Seven
Total Shipping Weight: (Approximate) SMT-1: 6,125 lbs (2,778kg)
SMT-2: 7,225 lbs (3,277kg)
Total Shipping Volume: 1 1/2 A2 modules (will fit into a 747 aircraft)

Status: Operational
Builder: International Submarine Engineering Ltd.
Port Moody, B.C.
Canada

SNOOPY (ELECTRIC)

Operating Depth: 1,500 ft (457m)

Dimensions (LxWxH): 40 in. x 26 in. x 18 in. (101cm x 66cm x 46cm)

Weight (dry): 150 lbs (68kg)

Speed: (Max. Surface) 1 kt (1.8km/hr)
(Max. Operating Current) 1 kt (approximate)

Structure: Syntactic foam mounted atop an open, tubular, aluminum framework. Two, cylindrical, pressure-resistant, aluminum housings with plexiglass endcaps for housing electronics.

Buoyancy: Syntactic foam provides slight positive buoyancy when submerged.

Power Requirements: 115 VAC 60 Hz 1.2 KW umbilical cable consists of two small (RG-58) coaxial cables (one for power and control signals and one for video signal) and a strength member, married together.

Propulsion: Three fixed and reversible oil-filled thrusters each powered by pressure-compensated DC motors. Two are stern-mounted to provide forward-aft motion (thrust) and one is mounted amidships to provide vertical motion (heave). All motors have continuously variable speed control.

Instrumentation: TV camera and 8mm cine camera (in aluminum housings), quartz iodide light, magnetic compass, depth transducer.

Navigation: By compass heading and visual (TV) sighting.

Shipboard Components: Control console (TV monitor, vehicle and instrument controls), cable storage bin.

Support Ship Requirements: Small boat davit, 5 ft x 8 ft (1.5m x 2.4m) deck area, station keeping ability desirable.

Operating/Maintenance Crew: Two

Total Shipping Weight: 1,200 lbs (545kg)

Total Shipping Volume: Approximately 100 cu ft (2.8 cu m)

Status: Operational

Builder: U.S. Naval Ocean Systems Center
San Diego, Ca.

SNOOPY (NAVFAC)

Operating Depth: 1,500 ft (457m)
Dimensions (LxWxH): 46 in. x 28 in. x 24 in. (117cm x 71cm x 61cm)
Weight (dry): 300 lbs (136kg)
Speed: (Max. Surface) 2 kts (3.7 km/hr)
(Max. Operating Current) 1.5kts (2.8 km/hr) at 1,500 ft.
Structure: Similar to ELECTRIC SNOOPY
Buoyancy: Similar to ELECTRIC SNOOPY
Power Requirements: Similar to ELECTRIC SNOOPY. Umbilical consists of one cable (RG-58) and an auxiliary strength member.
Propulsion: Four, fixed and reversible thrusters. Two are stern-mounted to provide forward-aft motion (thrust), one is mounted amidships to provide lateral motion (sway) and one is mounted amidships atop the lateral thruster to provide vertical motion (heave). An automatic altitude/depth "hold" mode of operation is provided. CTFM Sonar (Ametek Straza Model 500).
Instrumentation: TV camera, super 8mm cine camera, quartz iodide light, magnetic compass, depth transducer.
Navigation: By compass heading and visual sighting
Shipboard Components: Control/display console, power converter box, power booster box, cable tank.
Support Ship Requirements: Station-keeping and handling crane
Operational/Maintenance Crew: Two
Total Shipping Weight: 1,370 lbs (621kg)
Total Shipping Volume: 111 cu ft (3.1 cu m) in five containers

Status: Operational
Builder: U.S. Naval Ocean Systems Center
San Diego, Ca.

SNOOPY (NOSC)

Operating Depth: 1,500 ft (457m)
Dimensions (LxWxH): 46 in. x 28 in. x 24 in. (117cm x 71cm x 61cm)
Weight (dry): 300 lbs (136kg)
Speed: (Max. Surface) 2 kts (3.7 km/hr)
(Max. Operating Current) 1.5kts (2.8 km/hr) at 1,500 ft.
Structure: Similar to ELECTRIC SNOOPY
Buoyancy: Similar to ELECTRIC SNOOPY
Power Requirements: Similar to ELECTRIC SNOOPY. Umbilical consists of one cable (RG-58) and an auxiliary strength member.
Propulsion: Four, fixed and reversible thrusters. Two are stern-mounted to provide forward-aft motion (thrust), one is mounted amidships to provide lateral motion (sway) and one is mounted amidships atop the lateral thruster to provide vertical motion (heave). An automatic altitude/depth "hold" mode of operation is provided. CTFM Sonar (Ametek Straza Model 500).
Instrumentation: TV camera, super 8mm cine camera, quartz iodide light, magnetic compass, depth transducer.
Navigation: By compass heading and visual sighting
Shipboard Components: Control/display console, power converter box, power booster box, cable tank.
Support Ship Requirements: Station-keeping and handling crane
Operational/Maintenance Crew: Two
Total Shipping Weight: 1,370 lbs (621kg)
Total Shipping Volume: 111 cu ft (3.1 cu m) in five containers

Status: Operational
Builder: Naval Ocean Systems Center
San Diego, CA

SNURRE

Operating Depth: 3,280 ft (1,000m)
Dimensions (LxWxH): 126 in x 75 in x 71 in (320cm x 190cm x 180cm)
Weight (dry): 2,425 lbs (1,100kg)
Speed: (Max. Surface) 1.5 knots (2.8 km/hr)
(Max. Operating Depth) NA
Structure: Rectangular shape, open aluminum tubular framework encloses and supports vehicle components. A syntactic foam block is affixed to the top of the framework.
Buoyancy: Vehicle has slightly positive buoyancy when submerged. Descent/ascent are dynamically controlled.
Power Requirements: 3-phase, 420 VAC, 40 KVA. Supplied by a diesel-electric surface generator.
Propulsion: Four thrusters total. Three provide forward and lateral motion and can be tilted from the horizontal plane upward to 90 degrees. One thruster is located in the center of the vehicle and provides vertical motion.
Instrumentation: TV (2 ea.) can be tilted 90 degrees upward and 20 degrees downward from the horizontal and are mounted to provide stereoscopic viewing; two 8mm cine cameras; two stereoscopic still cameras; two, 250 watt, quartz-iodide lights, depth gauge; altimeter (echo sounder); gyrocompass; two hydrophones receiving from 0-20 kHz; manipulator with cable-cutting capability.
Navigation: A three-transponder, bottom-mounted navigation system has been developed which will provide position accuracies of 2 to 5 meters (6 to 16 ft) relative to the transponders at a maximum range of 1,500 meters (4,921 ft).
Shipboard Components: Control/display console, diesel generator, cable winch, launch/retrieval facility.
Support Ship Requirements: Deck space for one 20 ft (6m) standard ISO container, 4 x 6 meter (13 x 20 ft) deck space for vehicle.
Operational/Maintenance Crew: Four to five for a 12 hour working day.
Total Shipping Volume: Two, 20 ft (6m) standard ISO containers.
Total Shipping Weight: Six tons metric (6.6 tons)

Status: Operational
Builder: Continental Shelf Institute
Trondheim
Norway

SPIDER

Operating Depth: 250m (820 ft) (Length of present umbilical cable)
Dimensions: Height: 2m (6.5 ft) Diameter: 2m (6.5 ft)
Weight (Dry): 2.3t (2.5 tons)
Speed: Vehicle is not designed to transit by its own propulsion. It is positioned over the work site by a surface platform.
Structure: Cylindrical shape
Buoyancy Control: By surface winch.
Power Requirements: 440 V, 60 Hz.
Propulsion: Three thrusters mounted in a 120 degree array girdle the equator of the vehicle, and orient it in the horizontal plane to perform work. Vertical motion is provided by a surface winch.
Instrumentation: Two CCTV, gyrocompass, depth gage, echo-sounder
Navigation: By gyrocompass and visual sightings
Shipboard Components: Control/display console, umbilical cable, umbilical handling system
Support Ship Requirements: 192 sq ft (18 sq m) of deck space
Operating/Maintenance Crew: Three
Total Shipping Volume: 1,280 cu ft (36.3 cu m)
Total Shipping Weight: Information not available

Status: Operational
Builder: Myrens Verksted A/S
Oslo, Norway

TELESUB 1000

Operating Depth: 2,000 ft (610m)
Dimensions (LxWxH): 55 in. x 31 in. x 27 in. (140cm x 79cm x 69cm)
Weight (Dry): 550 lbs (250kg)
Speed: (Max. Surface) 2.3 kts (4.2 km/hr)
(Max. Operating Current) 1.5 kts (at 1000 ft with no clump)
Structure: Rectangular shaped open tubular aluminum framework encloses and supports all components. Syntactic foam block is fixed to the top of the framework.
Buoyancy: Syntatic foam provides slight positive buoyancy when submerged.
Power Requirements: 200 or 440 VAC, 12KVA, 60 Hz.
Propulsion: Four, 1 hp (each), variable speed, reversible thrusters. Two provide thrust and one provides lateral motion. One provides vertical motion.
Instrumentation: CCTV, two 500 watt quartz iodide lights, compass, depthometer.
Navigation: Visual sighting, compass bearing.
Shipboard Components: Portable control box, power distribution unit, TV monitor, cable and cable bin.
Support Ship Requirements: Information not available
Operating/Maintenance Crew: Two
Total Shipping Volume: 38.4 sq ft (3.6m sq m)
Total Shipping Weight: 1060 lbs (480.8kg)

Status: Operational
Builder: Remote Ocean Systems Inc.
San Diego, Ca.

TOM 300

Operating Depth: 300m (984 ft)
Dimensions (LxWxH): 360cm x 170cm x 182cm (142 in. x 67 in. x 72 in.)
Weight (dry): 2900kg (6393 lbs)
Speed: Forward: 3 kts
Transverse: 1 kt
Upward: 1 kt
Downward: 0.5 kt
(Max. Operating Current) 1.5 kt

Structure: Open aluminum tubular framework encloses and supports vehicle components. The frame is protected by triangular rubber bumpers.

Buoyancy: Vehicle has slightly positive buoyancy, 30kg (66 lbs) when submerged. Descent/ascent are dynamically controlled.

Power Requirements: 220-380 VAC - 3 phases 35 KVA.

Propulsion: Four reversible, propulsion units of 3 hp. Two reversible, lateral thruster of 1.5 hp. One reversible, vertical thruster of 1.5 hp.

Instrumentation: One TV camera for piloting and one for observation. One still color camera, two 250 watt lights and six 500 watt Halogen lamp spot lights. One hydraulic manipulator with three degrees of freedom, 110 lbs. (50kg) lift capacity.

Navigation: Depthometer, altitude sensor, gyrocompass, magnetic digital compass.

Shipboard Components: Cabin containing control/display console. Cable storage drum and lifting system.

Support Ship Requirements: Information not available
Operational/Maintenance Crew: Four
Total Shipping Weight: 14t (15.4 tons)
Total Shipping Volume: 42 cu m (1,483 cu ft)

Status: Operational
Builder: COMEX
Marseille
France
THOMSON CSF - Division activite sous-marine-route du Coquet
Brest
France

TREC
(Tethered Remote Camera)

Operating Depth: 1,200 ft (366m)
Dimensions. (LxWxH): 45 in. x 35 in. x 38 in. (114cm x 89cm x 97cm)
Weight (dry): 350 lbs (159kg)
Speed:
(Max. Operating Current) 1.5 to 2 knots
Structure: Rectangular shape composed of open aluminum (6061-T6) framework which encloses and supports all components.
Buoyancy: A syntactic foam package (density 24 lbs/cu ft) is fixed to the top of the framework and provides neutral buoyancy in sea water. A variable ballast trim sytem is included which operates off compressed air.
Power Requirements: A diesel generator provides 8 KW, 120 V, 60 Hz, single phase power through an umbilical cable. The umbilical is 1,500 ft (457m) and comprised of 3 No. 8's, one (1) shielded twisted pairs and (3) three RG 58's.
Propulsion: Four thrusters, all are driven by 1.5 hp universal motors and all are reversible. Two are stern-mounted and provide forward/reverse thrust, one is mounted amidships to provide lateral movement and one is also mounted amidships to provide vertical thrust.
Instrumentation: CCTV (Panasonic low light level), echo-sounder, two lights (variable intensity control), manipulator (optional) with three degrees of freedom, 6 in. (15.2cm) claw opening.
Navigation: Visual sighting, magnetic compass, depth gage.
Shipboard Components: Control/display console (control: propulsion, light intensity, camera focus, manipulator functions, TV and video recorder controls; display: CCTV, depth, altitude), cable reel, launch/retrieval device.
Support Ship Requirements: Can operate from a variety of support ships or barges with a minimum deck area of 30 x 20 ft (9 x 6 m)
Operation/Maintenance Crew: Two
Total Shipping Weight: 120 cu ft (3.4 cu m)
Total Shipping Volume: 1,000 lbs (454kg)

Status: Six units are operational. Three more units will be built in 1979.
Builder: International Submarine Engineering Ltd.
Port Moody, B.C.
Canada

TROV-B1
(Tethered Remotely Operated Vehicle)

Operating Depth: 1,200 ft (366m)
Dimensions (LxWxH): 82 in. x 69 in. x 60 in. (182cm x 175cm x 152cm)
Weight (Dry): 1,130 lbs (513kg)
Speed: (Max. Surface) 3 knots
(Max. Operating Current) 1 knot (1.8km/hr) at 1,200 ft
Structure: Open, rectangular-shaped, aluminum framework encloses and supports all components
Buoyancy: Floodable ballast tanks emptied by compressed air
Power Requirements: 460 VAC, 60 Hz
Propulsion: Two 5 hp electric motors powering 2 main controllable pitch propellers. Vertical and lateral thrusters powered by 3, 1/8 hp electric motors.
Instrumentation: Television camera, two 55 watt quartz halogen lights, magnetic compass, echo sounder, transponder interrogator. Manipulator, hydraulically-powered, scissors-type claw, 4 degrees-of-freedom, 100 lbs (45kg) static lift capacity.
Navigation: By compass bearing and visual sighting. Can interrogate two bottom-mounted transponders concurrently for relative positioning using a Mesotech system.
Shipboard Components: Control/display console, cable winch, power pack for control console, spare power pack (batteries) for vehicle.
Support Ship Requirements: Various support ships with 4 tons (3.6t) of containerized support needing 400 sq ft (37 sq m) of deck space (including vehicle, winch and generator, air supply of 200 cu ft at 2,500 psi and electrical power supply of 460 V 60 Hz AC.
Operational/Maintenance Crew: Two
Total Shipping Weight: 2,900 lbs (1,315kg)
Total Shipping Volume: 103 cu ft (2.9 cu m)

Status: Operational
Builder: International Submarine Engineering Ltd.
Port Moody, B.C.
Canada

UFO 300
(UNDERWATER FLYING OBSERVER)

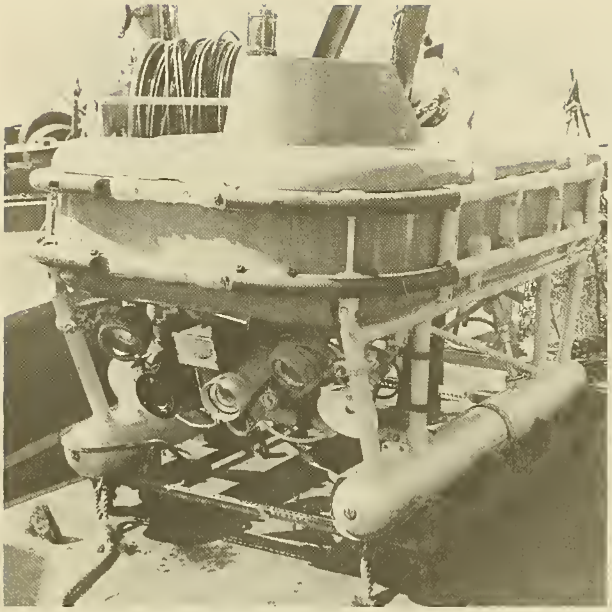
Operating Depth: 984 ft (300m)
Dimensions (LxWxH): Information not available
Weight (dry): 200 lbs (91kg)
Speed: 2 knots (4km/hr) fwd/rev; 1.75 knots (3.24km/hr) laterally and 0.4 knots (.7km/hr) in the vertical.
Structure: Molded syntactic foam encloses and supports all components.
Buoyancy: Information not available.
Power Requirements: Information not available.
Propulsion: Ducted impellers operating through 8 water jets provide forward/reverse, lateral and vertical movement.
Instrumentation: Low light TV camera, 2 quartz halogen lamps fitted to hull, still color camera. Cathodic protection read-out system provides depth and magnetic heading data which is superimposed on camera picture.
Navigation: Magnetic compass and gyroscopically controlled auto-pilot system operated through 3-axis joystick.
Shipboard Components: Control Console 10 ft x 8 ft (3m x 2m) containing VTR unit, video-edit facility, typewriter and control panel with TV display and monitor.
Support Ship Requirements: Information not available.
Operating/Maintenance Crew: Information not available.
Total Shipping Weight: Information not available.
Total Shipping Volume: Information not available.

Status: Was to be operational by mid 1979 status unknown.
Builder: Winn Technology Ltd.
Kilbrittain, County Cork
Ireland
Operator: Submersible Television Surveys Ltd.
Aberdeen
Scotland

UTAS 478

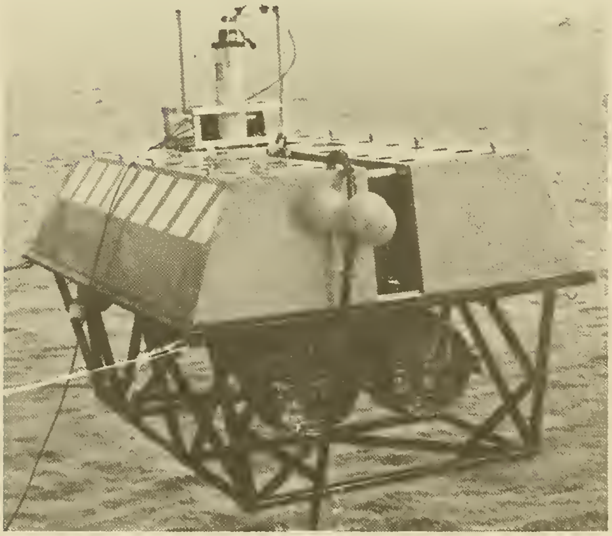
Operating Depth: 400m (1,312 ft)
Dimensions (LxWxH): 140cm x 55cm x 30cm (55 in. x 22 in. x 12 in.)
Weight (dry): 80kg (176 lbs)
Speed: 2.3 knots (4.2km/hr) (submerged)
Structure: Information not available.
Buoyancy: Information not available.
Power Requirements: Information not available.
Propulsion: 4 motors provide proportional translation, 2 operate on 100W, 2 operate on 50W.
Instrumentation: Low light level TV, pingers, one 100W light, thernometer, depth sensor, echo-sounder, magnetic compass.
Navigation: Visual sighting and compass.
Shipboard Components: Surface control box dimensions 70cm x 70cm x 30cm (28 in. x 28 in. x 12 in.). Electric winch operating on 24 VCC.
Support Ship Requirements: Information not available.
Operating/Maintenance Crew: Information not available.

Status: Unknown
Builder: GVS
Milan
Italy

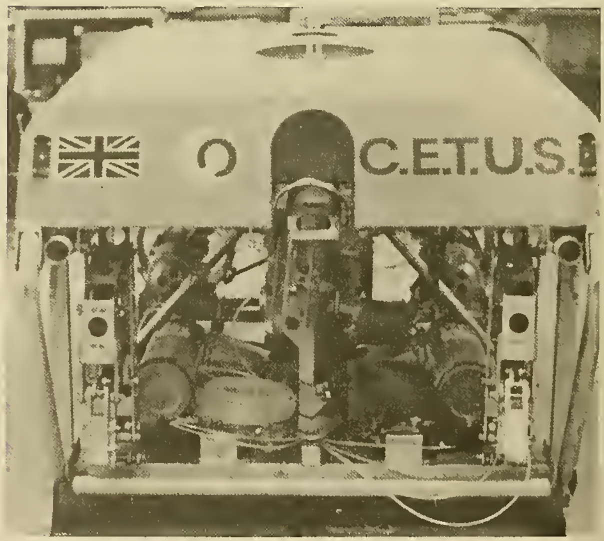


ANGUS 002
Courtesy of: Heriot-Watt University

ANGUS 003
Courtesy of: Heriot-Watt University

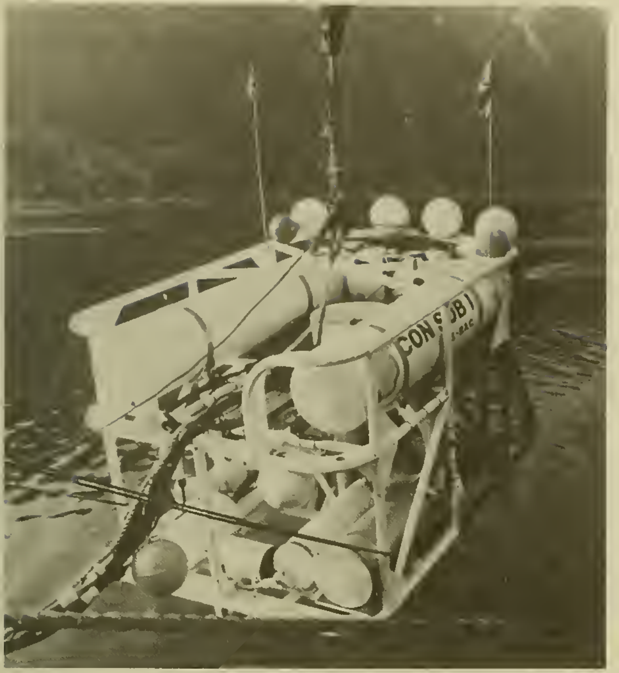


BOCTOPUS
Courtesy of: BOC, Limited



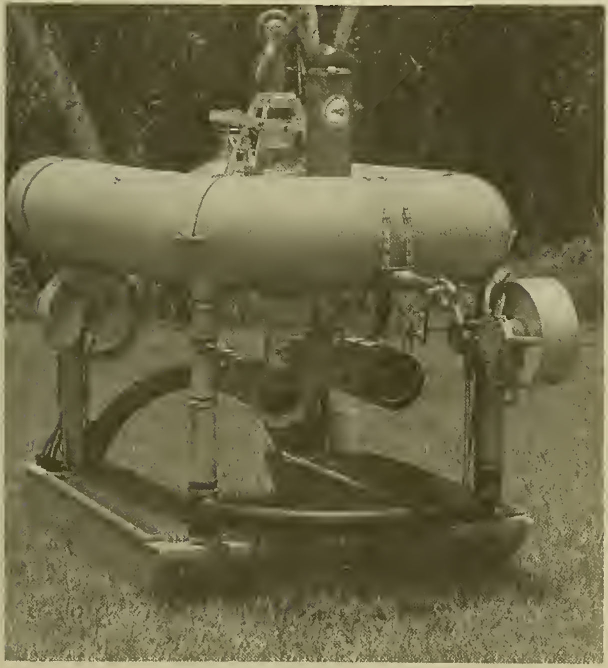
CETUS
Courtesy of: ULS Marine Limited

PLATE C-1

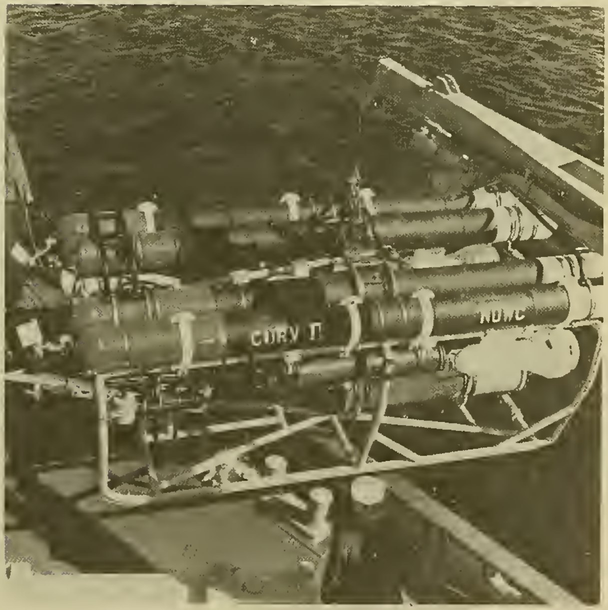


CONSUB 1
Courtesy of: British Aircraft Corp. Ltd.

CONSUB 201
Courtesy of: British Aircraft Corp. Ltd.

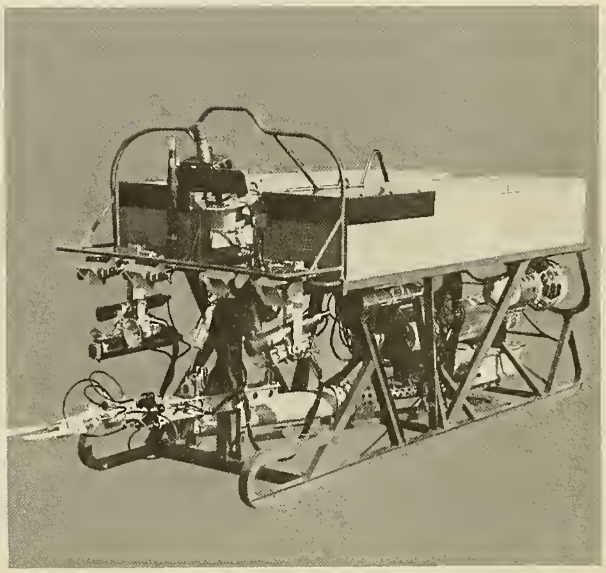


CORD I
Courtesy of: Harbor Branch Foundation, Inc.



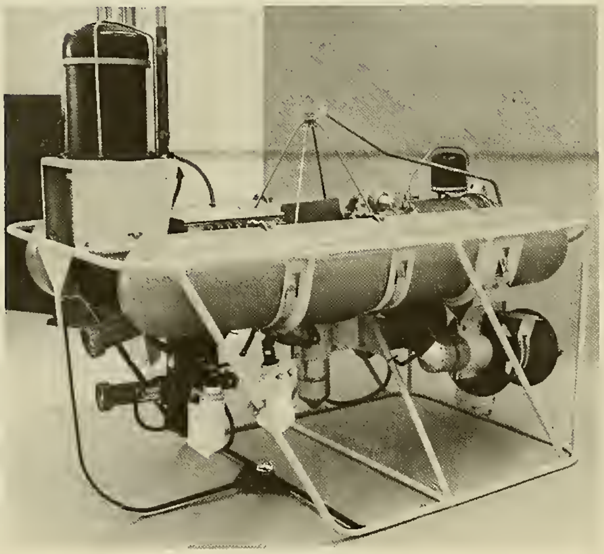
CURV II
Courtesy of: Naval Ocean System Center

PLATE C-2

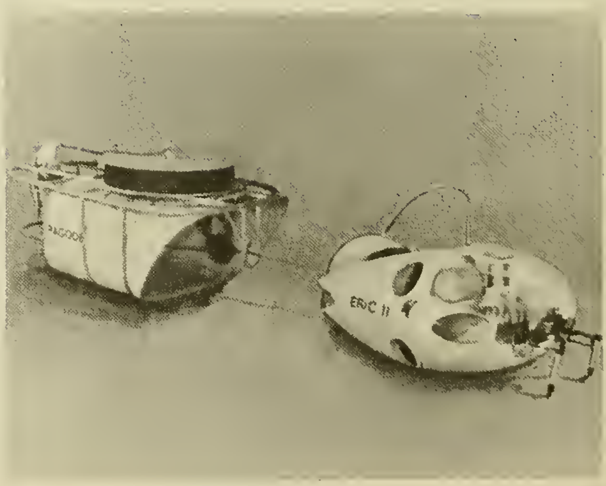


CURV III
Courtesy of: Naval Ocean Systems Center

DART
Courtesy of: International Submarine Engineering Ltd.

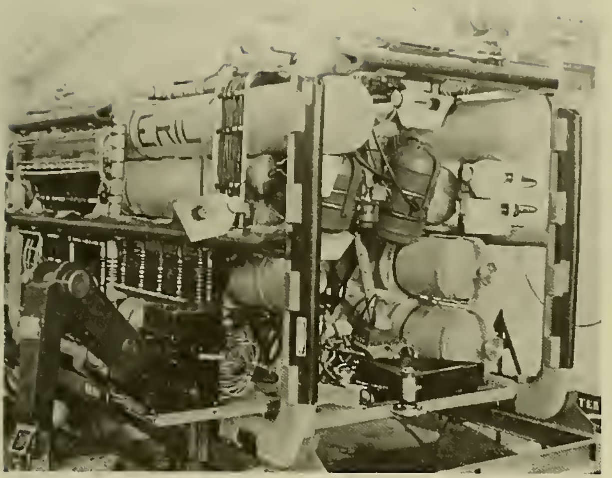


DEEP DRONE
Courtesy of: AMTEK, Straza Division

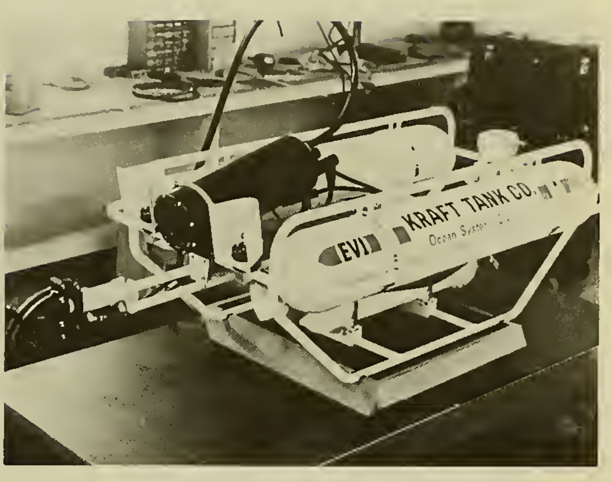


ERIC II
Courtesy of: Centre d'Etudes et de Recherches Techniques Sous-Marines

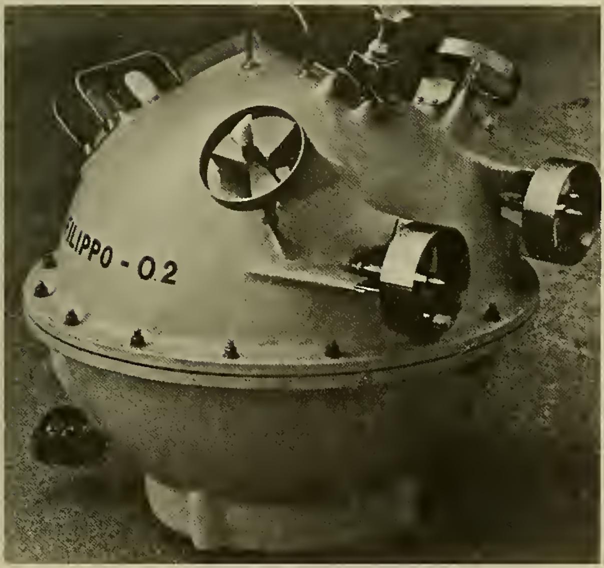
PLATE C-3



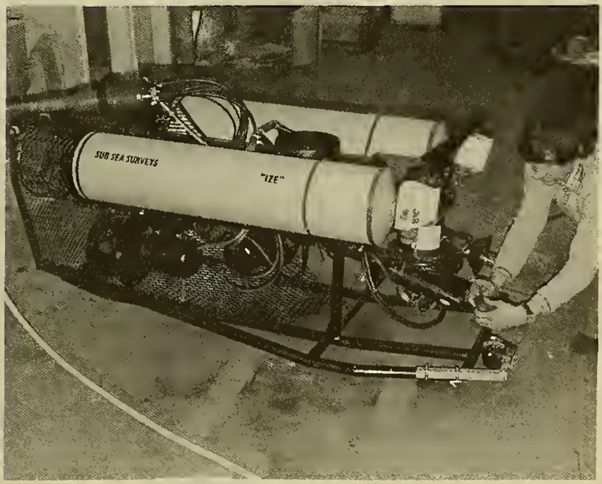
ERIC 10



EV-1
Courtesy of: Kraft Tank Company

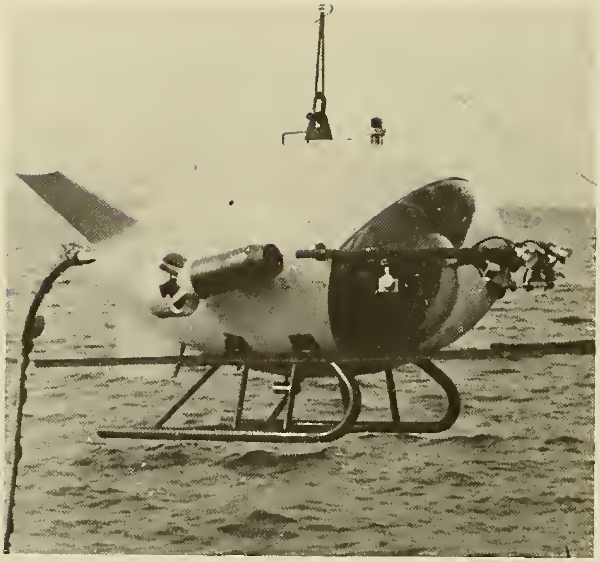


FILIPPO
Courtesy of: Gay Underwater Instruments

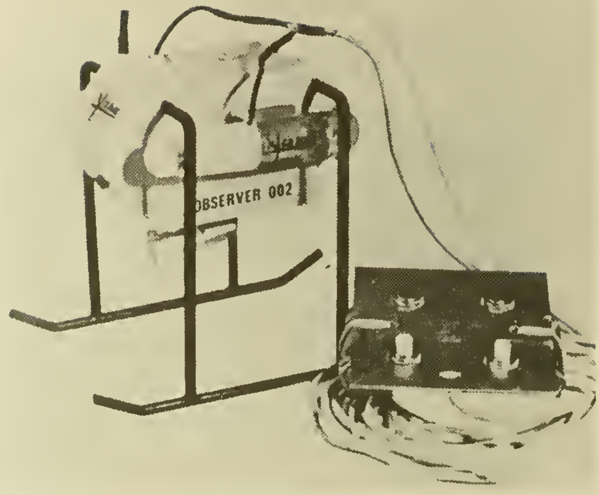


IZE
Courtesy of: Sub Sea Surveys, Ltd.

PLATE C-4

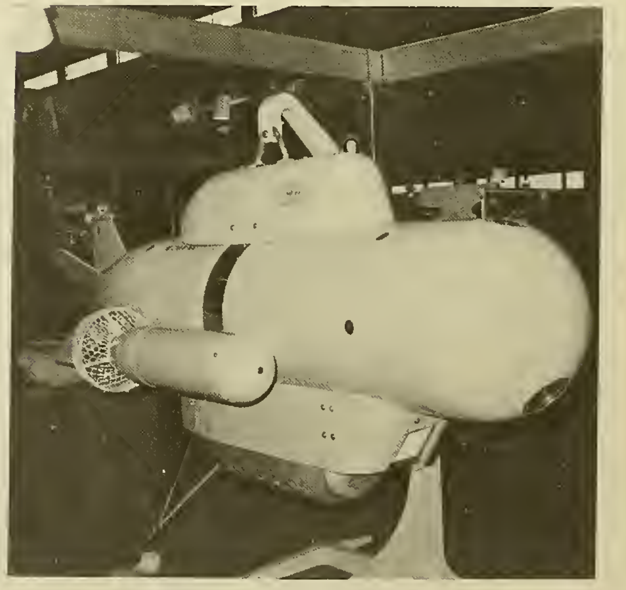


MURS-100
Courtesy of: Mitsui Ocean Development
and Engineering Co., Ltd.



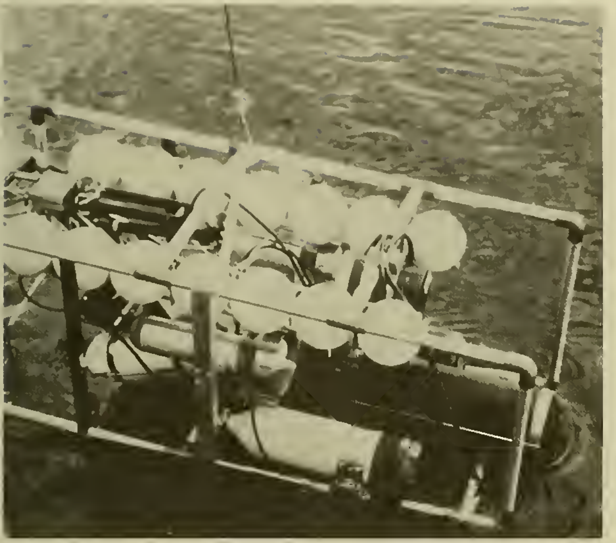
OBSERVER DL.1
Courtesy of: C. G. Doris

ORCA I
Courtesy of: Saab-Scania

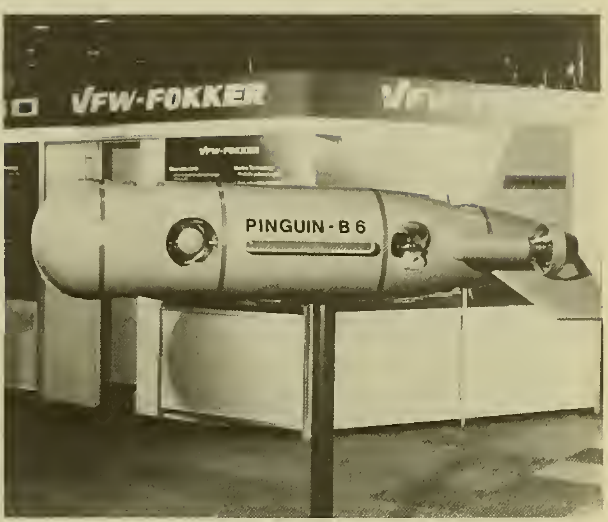


PAP 104
Courtesy of: Societie Eca

PLATE C-5



PHOCAS II
Courtesy of: Geologinen Tutkimuslaitos

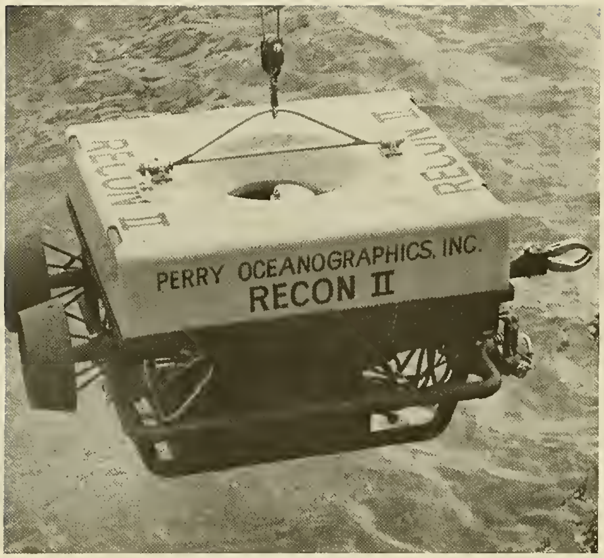


PINGUIN B6
Courtesy of: VFM Fokker

RCV-150
Courtesy of: Hydro Products

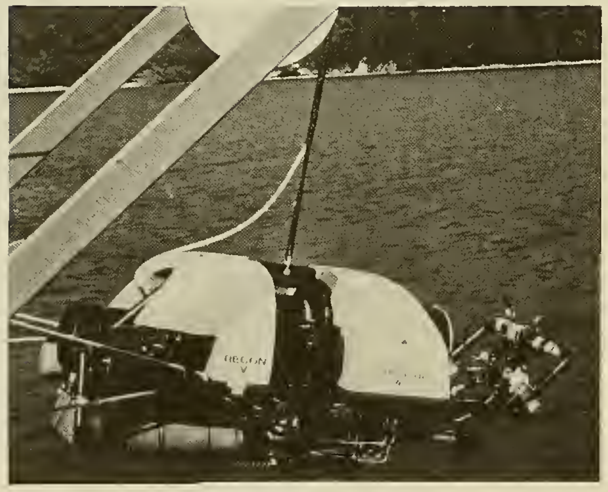
RCV-225
Courtesy of: Hydro Products

PLATE C-6

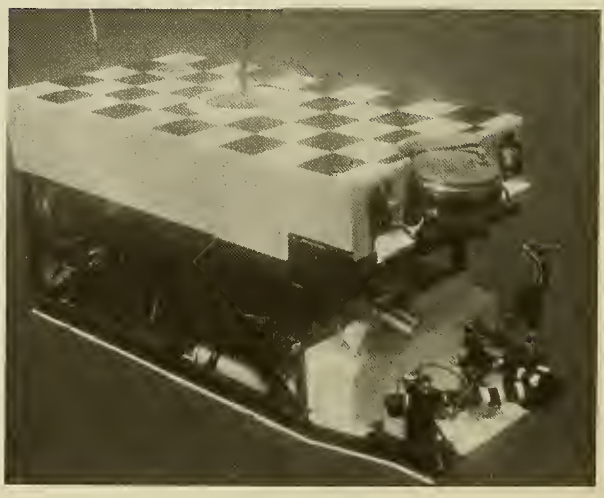


RECON II
Courtesy of: Perry Ocean Group

RECON III
Courtesy of: Perry Ocean Group

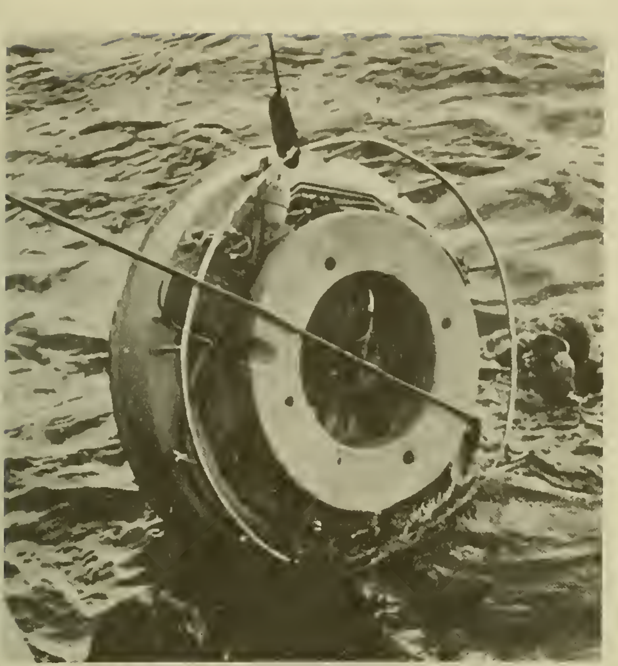


RECON V
Courtesy of: Perry Ocean Group



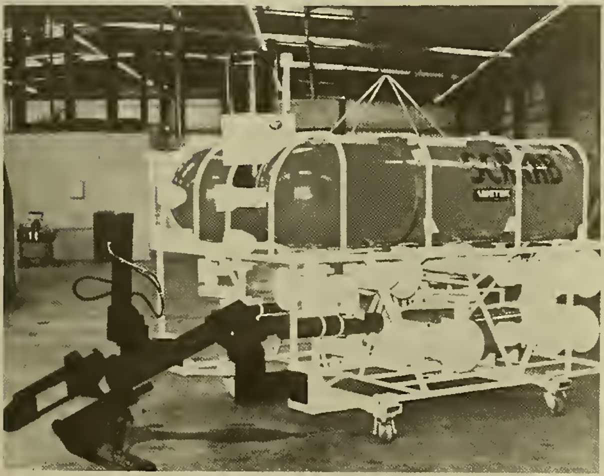
RUWS
Courtesy of: Naval Ocean Systems
Center

PLATE C-7

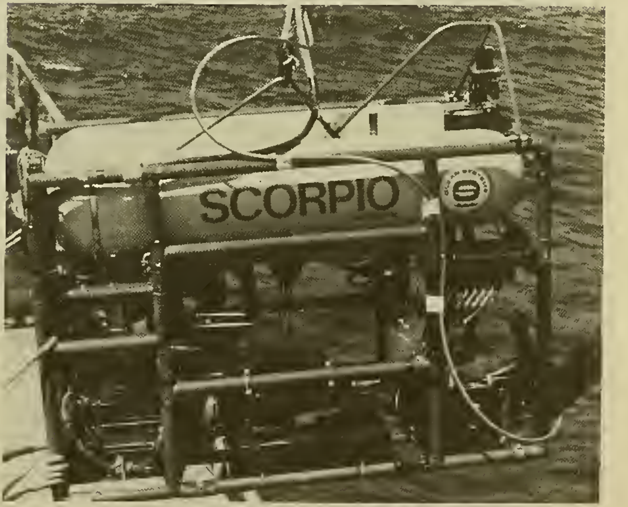


SCAMP
Courtesy of: Butterworth Systems Inc.

SCAN
Courtesy of: Underwater Maintenance Company, Ltd.

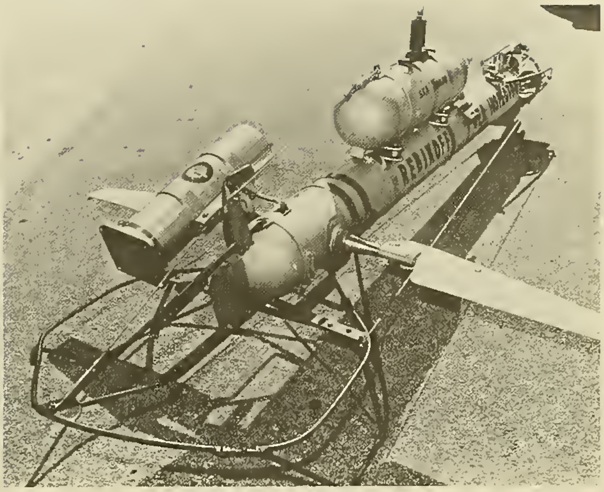


SCARAB
Courtesy of: AMETEK, Straza Division

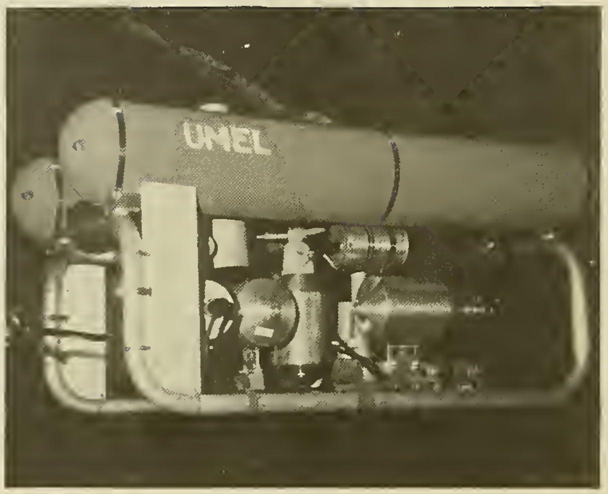


SCORPIO
Courtesy of: AMETEK, Straza Division

PLATE C-8

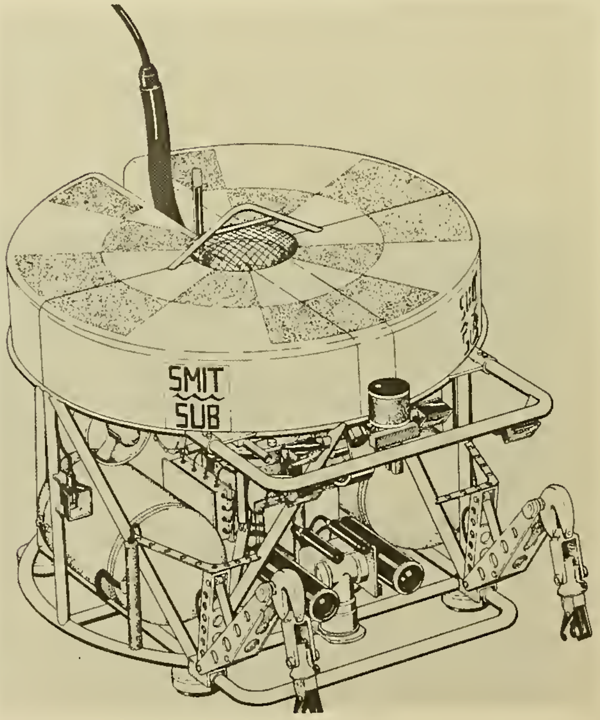


SEA INSPECTOR
Courtesy of: Rebikoff Underwater Products Inc.



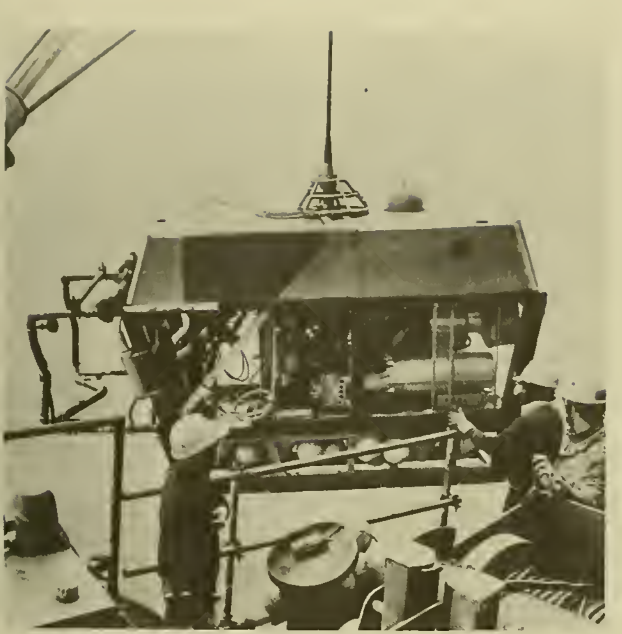
SEA SPY
Courtesy of: Underwater and Marine Equipment Ltd.

SMARTIE
Courtesy of: Marine Unit Technology Ltd.



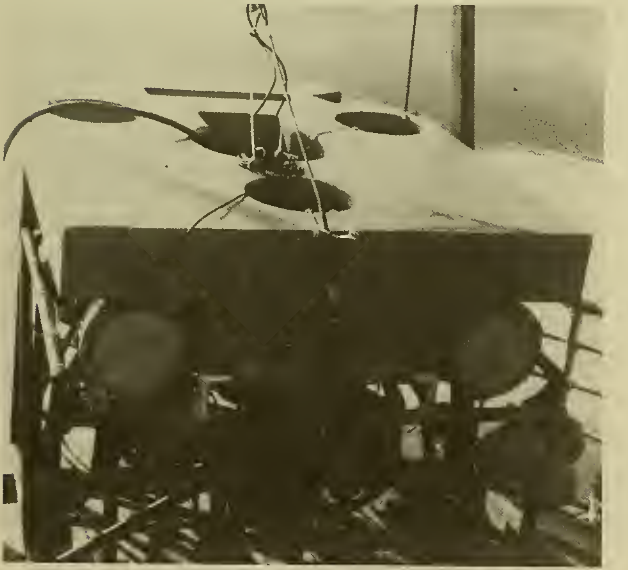
SMIT SUB-1000
Courtesy of: Skadoc Submersible Systems

PLATE C-9

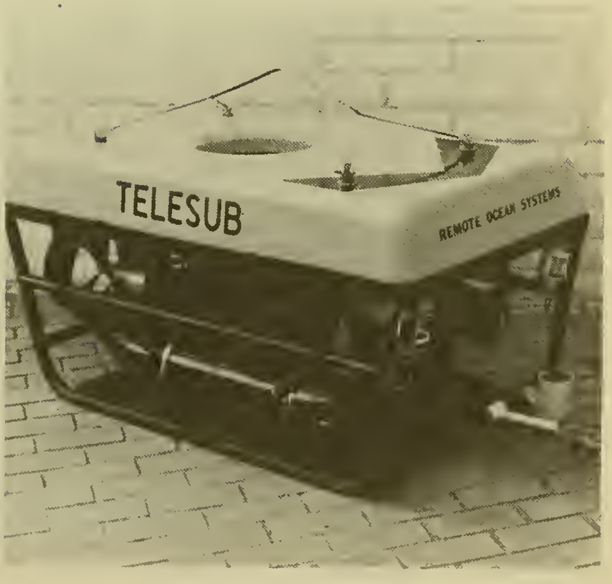


SMT 1
Courtesy of: International Submarine
Engineering Ltd.

SNOOPY
Courtesy of: Naval Ocean Systems
Center

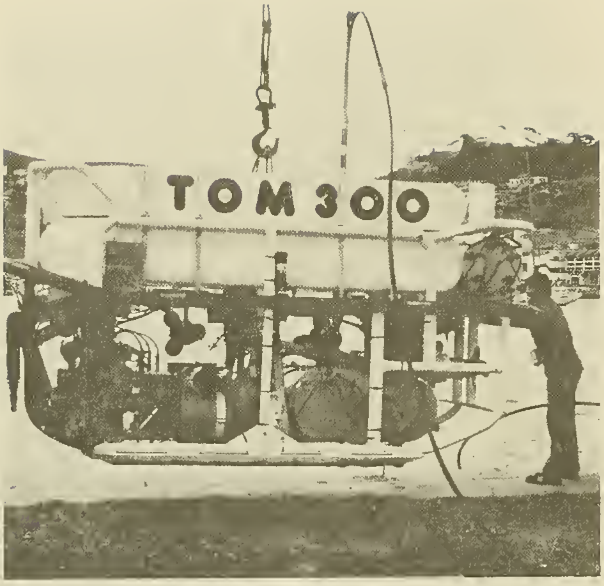


SNURRE
Courtesy of: Continental Shelf Institute

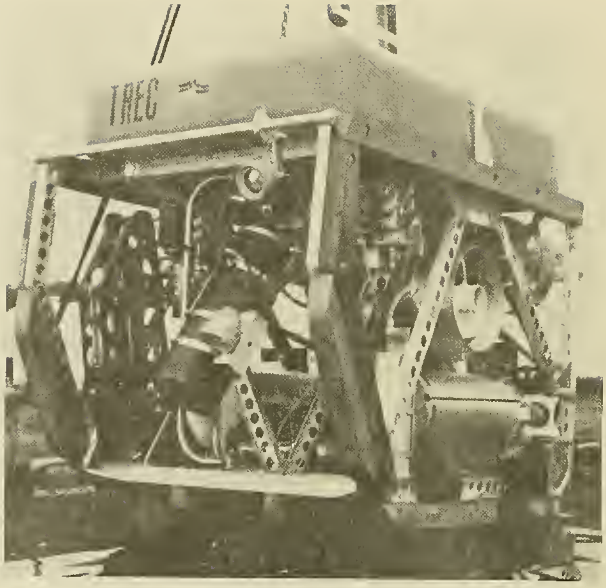


TELESUB 1000
Courtesy of: Remote Ocean Systems
Inc.

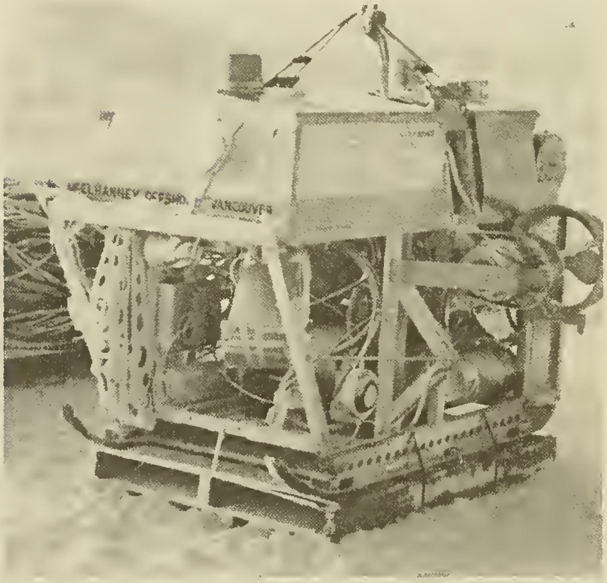
PLATE C-10



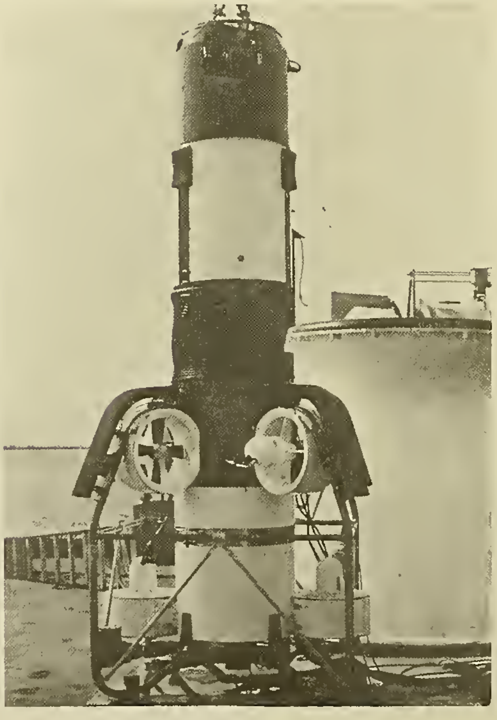
TOM 300



TREC
Courtesy of: International Submarine
Engineering Ltd.

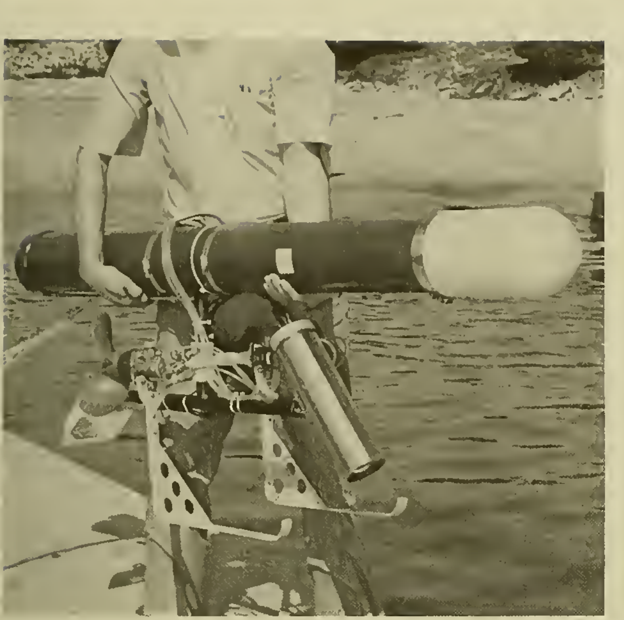


TROV-B1
Courtesy of: National Water Research
Institute, Canada



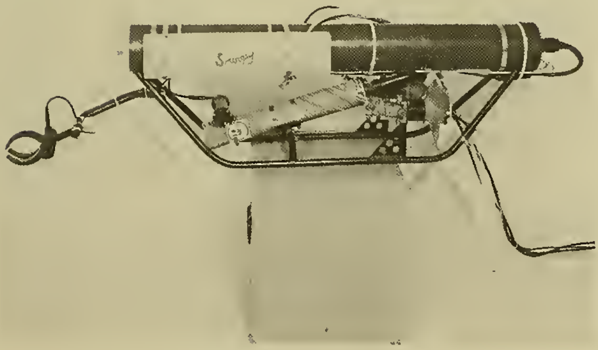
NOZZLE PLUG DEWATERING SYSTEM
Courtesy of: Naval Ocean Systems
Center

PLATE C-11

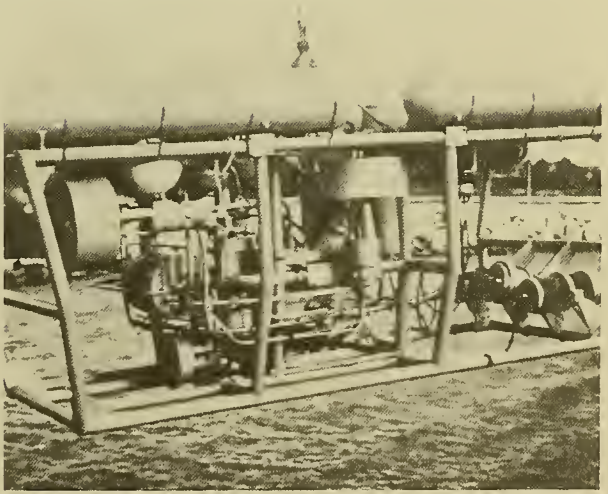


SCAT (Prototype)
Courtesy of: Naval Ocean Systems Center

SCAT
Courtesy of: Naval Ocean Systems Center



SNOOPY (Prototype)
Courtesy of: Naval Ocean Systems Center



SUB 2
Courtesy of: Atomic Weapons Research Establishment

PLATE C-12

APPENDIX D

BOTTOM-CRAWLING VEHICLE SPECIFICATIONS

GRANSEOLA

Function: Pipe trenching. Pipe diameter - 122cm (48 in.). Trench depth - 1.9m (5.9 ft)
Operating Depth: 46m (150 ft) maximum
Dimensions (LxWxH): 8m x 6m x 5.7m (26 ft x 20 ft x 18.7 ft)
Weight (dry): 9t (9.9 tons)
Speed: 152m (500 ft)/hr (average advance rate)
Power: Hydraulic. Two 450 hp AIFO 828 SRI eng. Surface diesel supplies power for the hydraulic unit.
Propulsion: Double clamp system hydraulically operated by a ram which alternately grasps the pipe.
Tools/Instrumentation: Hydraulic cutters in conjunction with a water suction system.
Navigation: Information not available.
Shipboard Components: Information not available.
Support Ship Requirements: Information not available.

Status: Operational.
Builder/Operator: INCOP (Industria Construsioni Oper Pubbliche)
Ancona
Italy

JH 160*

Function: Under water bulldozing.
Operating Depth: Shallow - 5m (16 ft).
Deep - 5 to 60m (16 ft to 197 ft).
Dimensions (LxWxH): Shallow - 6.2m x 4m x 2.8m (20.3 ft x 13.1 ft x 9.2 ft)
Deep - 7.2m x 5.1m x 4.2m (23.6 ft x 16.7 ft x 13.8 ft)
Weight: Shallow - 16t (18 tons) in air; 13t (14 tons) in water
Deep - 32t (35 tons) in air; 24t (26 tons) in water.
Speed: Shallow - 2 knots (3.7 km/hr)
Deep - 1.6 knots (3 km/hr)
Power: Shallow - Hydraulic. Powered by a 160PS/1,600rpm Hitachi B-60 diesel engine.
Deep - Hydraulic. Unit is driven by a 150kw, 3,300 V electric motor which receives it's power from a surface diesel engine.
Propulsion: Shallow & Deep - Caterpillar tracks. Both units have buoyancy tanks which are blown free of water and permit the vehicles to surface. On the surface they are towed to the work site.
Tools/Instrumentation: Shallow - Bulldozer blade and bottom ripper.
Deep - Bulldozer blade and bottom ripper. Gyrocompass, vertical gyro, transducer, depth meter, forward scanning sonar, hydrophone.
Navigation: Shallow - A sign pole attached to the vehicle protrudes above the water surface. The operator on the surface barge views the motion of the sign pole which indicates the inclination, direction and depth of the bulldozer and the blade position.
Deep - The acoustic positioner (transponder, interrogater and indicator) monitors the position and the crawling direction of the bulldozer. Position and direction are displayed on a CRT by a bright spot and an arrow. The forward-looking sonar monitors the bottom profile in front of the bulldozer, it is displayed on the CRT. A vertical gyro and gyrocompass indicate direction and pitch and roll angles. Steering is the same as a conventional bulldozer: two levers.
Shipboard Components: Shallow - Diesel engine, hydraulic power unit, air compressor, operating controls.
Deep - Diesel engine, electric generator, auxiliary generator, cable winch, air compressor, bulldozer hoisting winch, operating controls.
Support Ship Requirements: Shallow - The surface support ship is a self-powered catamaran capable of 2 knots (3.7 km/hr). It displaces 14t (15.4 tons), is powered by a 90 PS, 2,000 rpm diesel engine and has dimensions (LxWxH) of 10.5m x 6.2m x 1.3m (34.4 ft x 20.3 ft x 4.2 ft).
Deep - A non-self propelled barge of approximately 100t (110 tons) displacement with dimensions (LxWxH) of 16.5m x 10.2m x 1.8m (54.1 ft x 33.5 ft x 5.9 ft).

Status: Unknown
Builder/Operator: Hitachi Ltd.
Tokyo, Japan

*Two vehicles have been constructed, a shallow version and a deep version, in 1969 and 1971, respectively.

KVAERNER MYREN TRENCHING SYSTEM

Function: Pipe trenching. Pipe diameters 400 to 1,200mm (16 to 48 in.). Trench depth 2.5m (8.2 ft).
Operating Depth: 500m (1,640 ft)
Dimensions (LxWxH): 9.3m x 9.74m x 8.2m (30.5 ft x 31.95 ft x 26.9 ft).
Weight (Dry): 90t (99 tons).
Speed: 0.3 kts (500m/hr) (average advance rate)
Power: Hydraulic. Signals and power (6.6 kV) are transmitted through a 70mm (2.75 in.) diameter cable 550m (1,805 ft) long to five electrical motors on the vehicle before being converted to hydraulic power.
Propulsion: Eight thrusters (vertical and horizontal) are used to maneuver the vehicle into position on the pipe. Four pairs of wheels grip the pipe and propel the vehicle along it. Four spherical tanks provide positive or negative buoyancy by blowing or flooding sea water. The spheres are interconnected so that ballast water can be shifted from one to the other controlling inclination and enabling the machine to follow curved sections and avoid obstacles.
Tools/Instrumentation: Cutter head 1.8m (5.9 ft) high. CCTV, sonar (for docking on pipe and profiling the trench). Sediment from the trench is transported by a suction pump and is expelled to the side.
Navigation: Visually (CCTV) and by a surface acoustic tracking unit.
Shipboard Components: Display/control console, A-frame for launch/retrieval, power supply.
Support Ship Requirements: Dynamic positioning system. Launch/retrieval limits at present are 4m (13 ft) significant wave heights.

Status: Operational
Builder/Operator: Myrens Verksted A/S
Oslo, Norway

PBM

Function: Pipe trenching. Pipe diameters - 15 to 122cm (6 to 48 in.). Trench depth - 2m (7 ft), 4.5m (15 ft) can be reached by making several passes over the trench.
Operating Depth: 650m (2,132 ft) (Equipment can operate to depths equal to the power of normal air compressors to supply air, depths of 60 to 65m (197 - 213 ft) are easily obtainable.)
Dimensions (LxWxH): 6m x 1.8m x 3.5m (20 ft x 5.9 ft x 11.5 ft)
Weight (Dry): 10t (11 tons), can be made neutrally buoyant in water if required.
Speed: 50m (164 ft)/hr in sand. Work terminates in current speeds exceeding 1.6 knots (2.9 km/hr).
Power: Air compressors delivering 30,000 ltrs/min at 7 to 9kg/sq cm (100 to 128 psi) are satisfactory.
Propulsion: The machine moves along the pipe by means of a push-pull system which operates hydraulic clamps with internal rubber protection. The machine is locked around the pipe (by divers) and operates at neutral buoynacy to avoid applying great stresses to the pipe.
Tools/Instrumentation: A water jet cuts the sediment in front of the machine, cuttings are removed by air lift (shallow water) or by water pumps (deep water).
Navigation: Initial positioning and clamping to the pipe is directed by divers.
Shipboard Components: Control cabin, hydraulic power pack, high pressure water pumps, air compressors, umbilical winch and cable, electric power generator, handling system, workshop van.
Support Ship Requirements: For shallow water (less than 50m depth) in good weather: a small supply vessel equipped with a 20 ton A-frame, an eight-point mooring system, deck space adequate to contain the above equipment, shallow diving equipment and accommodations for 12 people. Deep water: larger craft with 50 ton A-frame, one deep-diving unit and accommodations for 25 people.

Status: Several PBMs (of different sizes and capabilities) are operational
Builder/Operator: Sub Sea Oil Services S.p.A.
Milan, Italy

RUM II
(Remote Underwater Manipulator)

Function: General inspection and recovery work
Operating Depth: 2,500m (8,202 ft)
Dimensions (LxWxH): 4.6m x 2.64m x 3.3m (15.1 ft x 8.66 ft x 10.8 ft)
Weight (Dry): 10.9t (12 tons) 6.1t (6.7 tons) in water
Speed: 0.85 knots (1.57km/hr)
Power: Electrical power (2,400 V, 60 Hz) supplied from a dedicated support ship, ORB (Oceanographic Research Buoy)
Propulsion: Two 7½ hp electric motors power two caterpillar tracks.
Tools/Instrumentation: Manipulator with six degrees-of-freedom plus grip, two CCTV on pan/tilt device, ten 500 watt quartz iodide lights, two scanning sonars, up/down-looking echo sounders, magnetic compass, transponder, depthometer, hydrophone.
Navigation: Visual sighting, magnetic compass, transponder for acoustic positioning.
Shipboard Components: Control/display console, cable handling and constant tensioning system, dynamic snubbing capability.
Support Ship Reqirements: RUM requires a special high voltage transmission line and cable tensioning system that is slip-ring connected and must be operated from its dedicated support platform ORB. The vehicle is launched/retrieved through a centerwell.

Status: Inactive. Has not operated since 1973.
Builder/Operator: Marine Physics Laboratory
Scripps Institution of Oceanography
La Jolla, CA

SEABUG 1

Function: General purpose inspection and manipulation tasks
Operating Depth: 1,000 ft (305m)
Dimensions (LxWxH): 12 ft x 6.5 ft x 5 ft (3m x 2m x 1.5m)
Weight (Dry): 1.75 tons (1.6t), 1.2 tons (1.1t) in water
Speed: 2 knots (3.7km/hr) (In 2 knot current and 1 in 6 gradients)
Power: Hydraulic. An armored cable 34mm (1.3 in.) diameter provides 440 V, 3 phase regulated power to the vehicle where it is converted into hydraulic power (25hp). Power is from a generator providing 60 KVA, 440 V, 3 phase, 50 Hz.
Propulsion: Four, 48 in. (122cm) diameter rubber tires trainable 45 degrees left/right. Maximum tractive effort is 2,800 lbs (1,270kg). Tip angle stability - 45 degrees.
Tools/Instrumentation: CCTV (3 ea), cable burying jetting equipment, two manipulators with three degrees-of-freedom, TV extender arm (2 degrees-of-freedom) 15 ft (4.6m) extension, trench profiler, side scan sonar, sector scan sonar, directional gyro, pitch/roll indicator, depth gage.
Navigation: Visual sighting, directional gyro, compatible with the ATNAV system. Can also be controlled in situ by a diver or manned submersible.
Shipboard Components: Display/control console, diesel generator, launch/retrieval system, slip-ring winch.
Support Ship Requirements: Deck space for shipboard components and vehicle handling system.

Status: Operational
Builder/Operator: UDI Ltd.
Aberdeen, Scotland

SEACAT

Function: Cable burial.
Operating Depth: 200m (656 ft)
Dimensions (LxWxH): 15 ft x 10.25 ft x 8 ft (5m x 3.1m x 2m)
Weight (Dry): 2,500 lbs (1,134kg), 1,000 lbs (454kg) in water
Speed: 60 to 180m (197 to 591 ft)/hr (average burial rate)
Power: Hydraulic. Electrical power supply: 415 V, 3 phase, 50 Hz, 60 KVA.
Propulsion: Caterpillar tracks. Vehicle has ballast tanks that are flooded on the surface to provide approximately 20 lbs (9 kg) negative buoyancy for descent to the bottom. On the bottom they are flooded fully to provide maximum in-water weight. A diver or a manned submersible controls the vehicle as it works.
Tools/Instrumentation: Trench cutting is performed by a specifically-designed high pressure water jet. All other instrumentation requirements are supplied by the attendant manned submersible.
Navigation: Supplied by the manned submersible
Shipboard Components: Diesel generator.
Support Ship Requirements: Launch/retrieval device, deck space for SEACAT, and umbilical. Since the vehicle is controlled by either a diver or a manned vehicle, the support ship must include one or both of these as its onboard capability.

Status: As of 10 November 1978 SEACAT was scheduled for future use as a land or shallow water (10 ft) trials vehicle to evaluate burial and pipe-following equipment and to act as a testbed for the next generation vehicle: SEADOG
Builder/Operator: British Underwater Engineering, Ltd.
Leith, Scotland

SL 3

Function: Pipe trenching. Pipe diameter - 50cm to 120cm (20 in. to 47 in.). Trench depth - 1.5m (4.9 ft) (depending on pipe diameter).
Operating Depth: 50m (164 ft) Minimum depth - 5m (16 ft)
Dimensions (LxWxH): 6m x 7m x 6m (20 ft x 23 ft x 20 ft)
Weight (Dry): 16t (18 tons), in water - 8t (9 tons)
Speed: a) Pipe OD - 0.5m (1.6 ft), trench width 2m (7 ft), Speed: 72m/hr (236 ft)
b) Pipe OD - 1.0m (3 ft), trench width 2.5m (6.2 ft), Speed: 58m/hr (190 ft)
c) Pipe OD - 1.5m (4.9 ft), trench width 3m (10 ft), Speed: 48m/hr (158 ft).
Power: Jetting power supplied by two, 150 KVA generators 440/380 V, 50 Hz, powering four 30hp each Robot pumps on the vehicle. Four, 600 cfm compressors.
Propulsion: Towed by surface barge. The SL 3 is a sled-type machine which straddles the pipe and is supported on the seabed by tubular skids. To guide the machine along the pipe are two side rollers at each end, one on either side of the pipe and two top rollers, one at each end.
Tools/Instrumentation: Four electrically driven pumps, provide pressurized water to water jets which fluidize the bottom sediment. The sediment is then removed and deposited away from the trench by airlift educators. Vehicle instrumentation includes a device to measure machine angle across the pipeline, water jet and air pressure indicators and amperage readings for water pump.
Shipboard Components: See "Power" for components.
Support Ship Requirements: Specially designed and dedicated barges support the operations of SL 3. The capabilities of one of these barges are presented in the description of TM III

Status: Operational
Builder/Operator: Land and Marine Engineering Ltd.
Merseyside, England

SUBTRACTOR

Function: General manipulative tasks
Operating Depth: 1,372m (4,500 ft)
Dimensions (LxWxH): 3m x 2.2m x 1.6m (8.2 ft x 7.2 ft x 5.2 ft)
Weight (Dry): 2t (2.25 tons)
Speed: 3 knots (5.5km/hr)
Power: 440 V, 60 Hz from support ship
Propulsion: Caterpillar tracks powered by one 15hp motor
Tools/Instrumentation: Hydraulically-powered manipulator with cutter, CCTV, two 600 watt lights, still camera, transponder
Navigation: By visual sighting and by interrogation of a vehicle-mounted transponder.
Shipboard Components: Control/display console, umbilical cable.
Support Ship Requirements: Power supply of 440 V, 60 Hz, space for containers of 15 sq m (160 sq ft), handling system for launch/retrieval of vehicle.

Status: Testing and refit, sea trials to 46m (150 ft) completed in August 1978
Builder/Operator: Maui Divers of Hawaii, Ltd.
Honolulu, Hawaii

TALPA

Function: Pipe trenching. Maximum pipe diameter - 122cm (48 in.).
Trench depth - 2.5m (8.2 ft)
Operating Depth: 46m (150 ft)
Dimensions (LxWxH): 8m x 8m x 5.3m (26 ft x 26 ft x 17.4 ft)
Weight (dry): 17t (18.7 tons)
Speed: 82m (270 ft)/hr (average advance rate)
Power: Hydraulic. Two 450 hp AIFO 828 SRI eng. Surface diesel supplies power for the hydraulic unit.
Propulsion: Hydraulically-operated tires grip and propel vehicle along the pipe.
Tools/Instrumentation: Hydraulic cutters in conjunction with a water suction system.
Navigation: Information not available.
Shipboard Components: Information not available.
Support Ship Requirements: Information not available.

Status: Operational
Builder/Operator: INCOP (Industria Costrusioni Oper Pubbliche)
Ancona
Italy

TALPETTA

Function: Cable burial. Trench depth - 1.1m (3.6 ft)
Operating Depth: 46m (150 ft)
Dimensions (LxWxH): 5m x 3m x 1.5m (16 ft x 10 ft x 4.9 ft)
Weight (dry): 2.5t (2.8 tons)
Speed: 152m (500 ft)/hr (average advance rate)
Power: Hydraulic. One 450hp AIFO 828 SRI eng. Surface diesel engine supplies power to the hydraulic unit.
Propulsion: Information not available.
Tools/Instrumentation: Information not available.
Navigation: Information not available.
Shipboard Components: Information not available.
Support Ship Requirements: Information not available.

Status: Operational.
Builder/Operator: INCOP (Industria Construsioni Oper Pubbliche)
Ancona
Italy

TM 102

Function: Pipe Trenching.
Operating Depth: 200m (660 ft)
Dimensions (LxWxH): 14m x 15m x 7m (46 ft x 39 ft x 23 ft) Vehicle is 22m (72 ft) wide with arms extended.
Weight (Dry): 193t (213 tons)
Speed: Information not available
Power: Supplied by generators aboard support ship to electric and hydraulic motors aboard the vehicle.
Propulsion: Caterpillar tracks. The vehicle has a sea water ballast system of 27t (30 tons) capacity which permit it to be towed on the surface to the dive site and lowered - by venting the ballast system - to the work site. Sensors on the vehicle keep it from making direct contact with the pipe. The vehicle can also employ its ballasting system to vary for different sediment conditions.
Tools/Instrumentation: Two, hydraulically-powered trenching arms with 90 degree movement and cutters. Two synchro feelers with 0 to 30 degrees vertical movement and plus or minus 15 degrees horizontal movement. CCTV. The machine is capable of backfilling the trench after the pipe has been laid.
Navigation: By visual contact (TV) and by sensors which relate the vehicle's position relative to the pipeline.
Shipboard Components: Control/display console, diesel generator, four hydraulic winches for tether handling.
Support Ship Requirements: Dedicated support ship: LOA-50m (164 ft), beam - 12m (39 ft), draft - 4m (13 ft), power supply consisting of one 1,300 hp and one 45 hp motor generator, space for three containers requiring 200 sq m (2,152 sq ft).

Status: Operational
Builder/Operator: Technomare S.p.A. (Societa per lo Svilluppo delle
Technologie Marine)
Venice, Italy

TM III*

Function: Pipe trenching. Maximum pipe diameter - 1.6m (5.2 ft) O.D. concrete. Trench depth - 1.6m (5.2 ft), width - 6.5m (21 ft)
Operating Depth: 75m (246 ft). Minimum depth - 3m (10 ft)
Dimensions (LxWxH): 7.5m x 8.5m x 6.5m (24.6 ft x 27.9 ft x 21.3 ft)
Weight (Dry): 95t (105 tons)
Speed: Fine sand: 120m/hr (394 ft)
Sand and silts: 100m/hr (328 ft)
Power: Two 1300hp diesel generators (960 KVA 230 V), two 100 KVA 440/300 V auxiliary generators, one 1200 CFM, 10.5 bar (152 psi) air compressor. One power cable reel.
Propulsion: Towed by surface barges. A pipe frame fits over the pipeline and rests on four coated rollers which permit the machine to run over the pipeline with minimal friction. Coated rollers are also located beneath the pipe to stop the machine from being pulled off the pipe as it is towed along by a surface barge.
Tools/Instrumentation: The vehicle has four electrically driven pumps capable of handling 12,000 gals. of water/minute. These are connected into a common manifold which direct the flow to main fluidizing jets on both ends of the vehicle. Two sand pumps transport the fluidized material from beneath the pipeline to jet discharges which blow the spoil away to the side of the trench.
Navigation: By surface means. The pipeline serves as guidance for the vehicle.
Shipboard Components: See "Power"
Support Ship Requirements: A specially designed pulling/jetting barge, L.M. BLADER, supports the vehicle, characteristics of this barge are as follows:
Length: 110m (361 ft), Beam: 30m (98 ft), Draft: 7.7m (25.2 ft)
DWT: 15,000
Anchorage System: Four double drum Skaggit winches with 750m (2,460 ft) of 50mm (2 in.) wire rope (87t max. pull) and eight 7.5t anchors.
Storm Anchor: One electrically-driven windless with chain and 5t anchor.
Accommodations: 80 berthing and full messing
Craneage: One Crawler Crane with 25m (82 ft) boom with maximum lift of 136t (150 tons). One Crawler Crane (deck travelling) of 60 ton maximum lift.
Navigational Equipment: Radar, Hi-Fix, Trisponder, Tellurometer

Status: Operational
Builder/Operator: Land and Marine Engineering Ltd.
Merseyside, England

*A smaller device, TM IV, is also operational and can trench pipe of 1.1m (3.6 ft) diameter in water depths of 50m (164 ft). TM IV is operationally similar to TM III, construction details are not available.

TRAMP

Function: General purpose inspection and manipulation tasks.
Operating Depth: Not available.
Dimensions (LxWxH): 6 ft x 3.7 ft x 3.8 ft (1.8m x 1.1m x 1.2m)
Weight (dry): 1,545 lbs (701kg)
Speed: Infinitely variable up to 1 knot (1.8km/hr).
Power: 25kw (550v, 3 phase AC, 40 to 90 Hz)
Propulsion: Six independently suspended drive wheels developing a pull of 1,500 lbs (680kg). Acceptable angle of vehicle roll is 36 degrees.
Tools/Instrumentation: CCTV (mounted on a manipulator), gyrocompass, scanning sonar.
Navigation: Visual sighting, gyrocompass.
Shipboard Components: Control/Display Console 72in. x 30in. x 66in. (183cm x 76cm x 167cm); launch module 12.4 ft x 5.4 ft x 4.5 ft (3.8m x 1.7m x 1.4m), umbilical cable.
Support Ship Requirements: Deck space for launch module and vehicle, and enclosed space for control/display console.

Status: The above specifications apply to TRAMP model 38 which is operational. A second, larger model TRAMP 88 has been partially constructed, but further work has been temporarily halted.
Builder/Operator: Winn Technology Ltd.
County Cork, Ireland

UNDERWATER BULLDOZER (D155W)

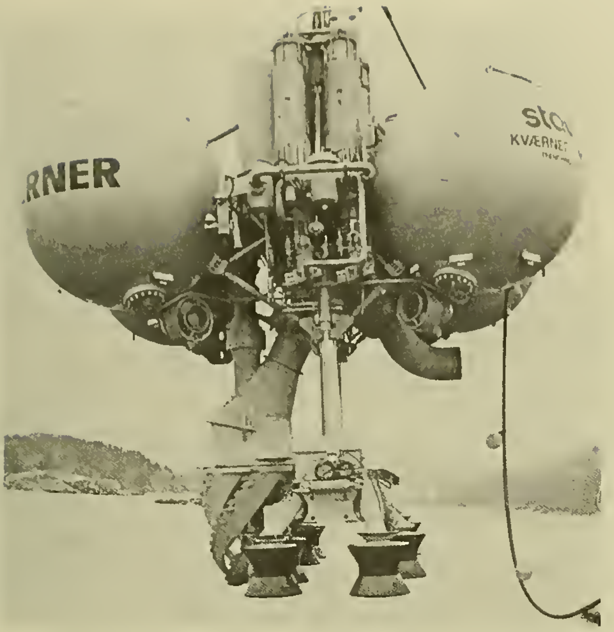
Function: Bulldozing, dredging
Operating Depth: 7m (23 ft)
Dimensions (LxWxH): 19.3m x 4m x 9.8m (30.5 ft x 13 ft x 32.2 ft)
Weight (Dry): 43.5t (47.9 tons), in water - 27.9t (30.8 tons)
Speed: Forward 1st 3.6km/hr (1.9 knots)
2nd 6.5km/hr (3.5 knots)
Reverse 1st 4.3km/hr (2.3 knots)
2nd 7.7km/hr (4.2 knots)
Power: Vehicle power is supplied from a submersible diesel engine (KOMATSU S6D155-4) providing 270hp at 2,000 rpm. A mast which protrudes through the water surface incorporates the intake and exhaust ducts.
Propulsion: Caterpillar tracks. Maneuvering controls can be by a remote radio control system or a wire control system. The radio control system has an effective control range of 50m (164 ft), it is a dual combination low-frequency unit transmitting from 141.68 to 141.96mHz.
Tools/Instrumentation: Bulldozing blade - 3.8 cu m (5 cu yd) capacity, parallelogram-type hydraulic ripper. Atop the mast is blue lamp which flashes when the vehicle inclines greater than 21 degrees. A yellow lamp flashes to warn that engine oil pressure, engine water temperature or torque converter oil temperature exceeds a safe level. A red lamp lights when incoming water in the engine housing rises to a point at which the train pump begins to operate and then flashes on/off when pump capacity is exceeded. A horn audibly warns the operator in all instances.
Navigation: By observing mast orientation.
Shipboard Components: Control system
Support Ship Requirements: None, operates from land-based control station.

Status: Constructed, but not available commercially as of 12 September 1978.
Operator/Builder: Komatsu, Ltd.
Tokyo, Japan

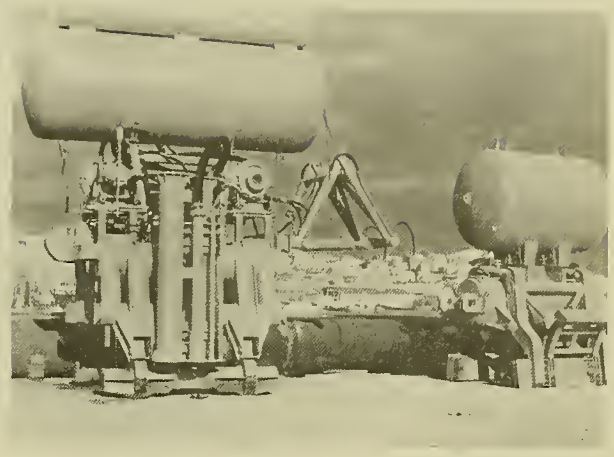
UNDERWATER TRENCHER

Function: Pipe trenching and excavation for construction foundations.
Operating Depth: 70m (230 ft)
Dimensions (LxWxH): 11.9m x 5.2m x 4.9x (39 ft x 17.1 ft x 16.1 ft)
Weight (Dry): 60t (66 tons), in water - 50t (55 tons)
Speed: 3km/hr (1.6 knots) (travelling speed on bottom)
Power: Diesel generator transmits 440 V, it is raised to 3,300 V, 60 Hz by transformer, this power is reduced to 440 V and 110 V when it reaches the vehicle.
Propulsion: Caterpillar tracks, driven by two hydraulic motors.
Tools/Instrumentation: Five blade cutter and dredge pump (discharges sediment 200m from cutter).
Navigation: A bottom-mounted, acoustic system consisting of three beacons which ping on surface command and a receiver (hydrophone) on the trencher which receives the three pings. Surface processing of this data provides a position based on (3-range) triangulation.
Shipboard Components: Display/control console, diesel generator.
Support Ship Requirements: Eighty (80) ton crane (minimum) for launching trencher. Deck space for crane and umbilical, and enclosed space for display/control console.

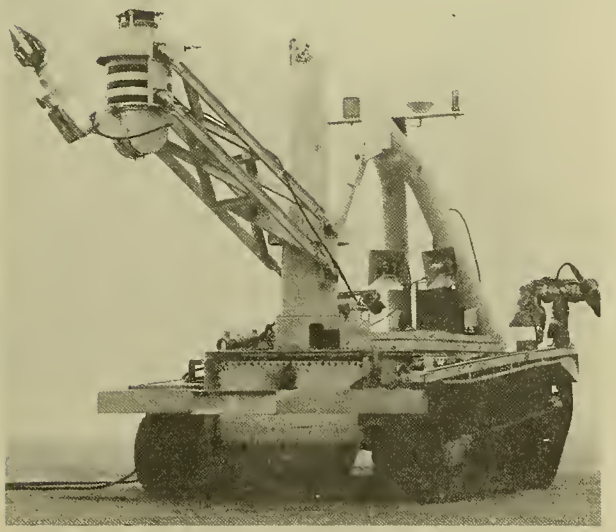
Status: Developed as a prototype machine in 1973. Demonstration experiments were conducted in 1975, it has not been used since and there are no plans for future work.
Builder/Operator: Sumitomo Heavy Industries, Ltd.
Tokyo, Japan



KVAERNER MYREN TRENCHING SYSTEM
Courtesy of: Myrens Verksted A/S



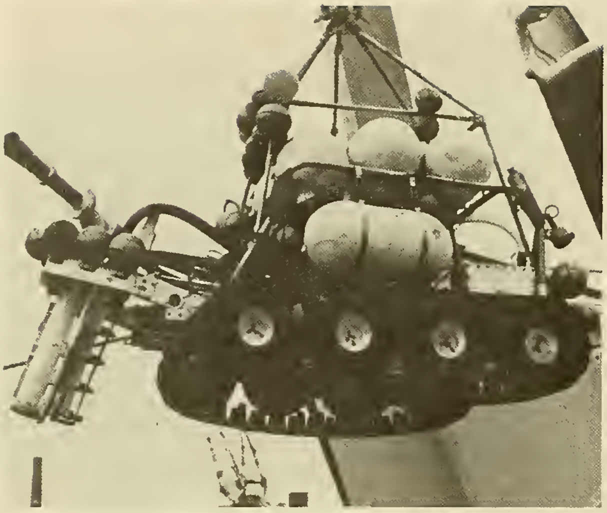
PBM
Courtesy of: Sub Sea Oil Services S.p.A.



RUM II
Courtesy of: Marine Physical Laboratory, Scripps Institution of Oceanography

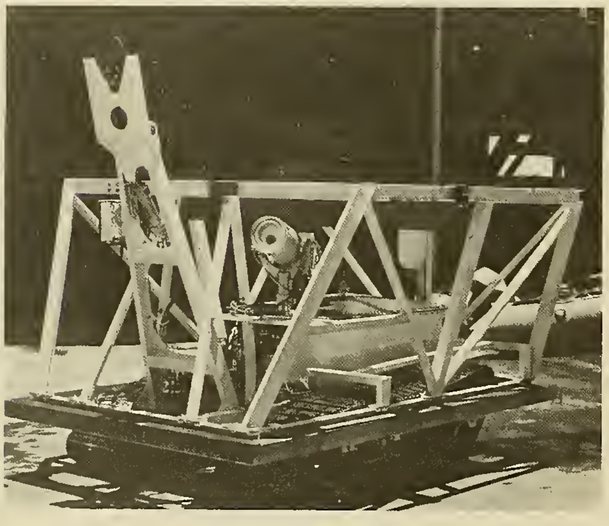
SEABUG 1
Courtesy of: UDI Limited

PLATE D-1

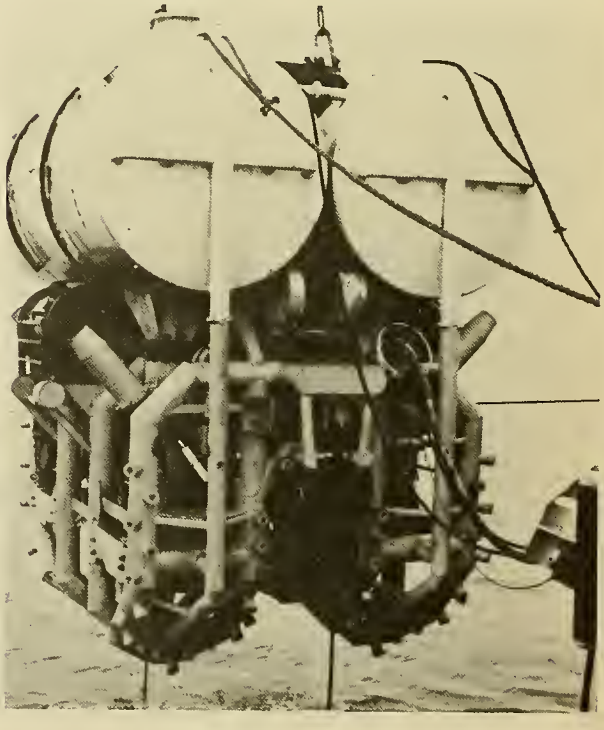


SEACAT
Courtesy of: Vickers Oceanics Ltd.

SL 3
Courtesy of: Land and Marine
Engineering Ltd.

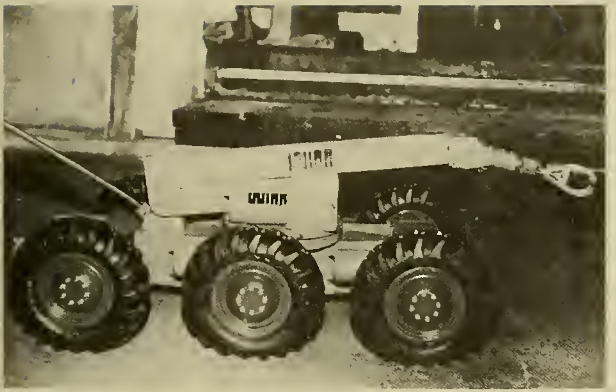


SUBTRACTOR
Courtesy of: Maui Divers of Hawaii, Ltd.



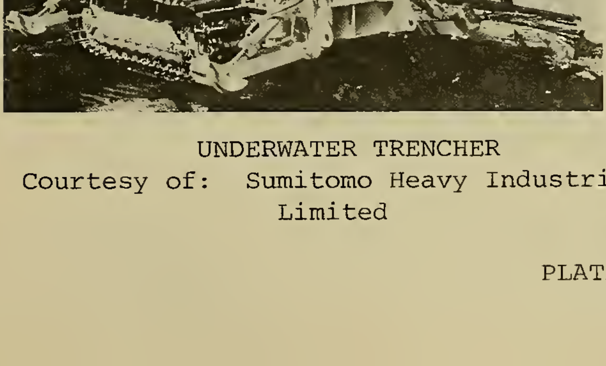
TM IV
Courtesy of: Land and Marine
Engineering Ltd.

PLATE D-2



TRAMP

UNDERWATER BULLDOZER
Courtesy of: Komatsu, Limited



UNDERWATER TRENCHER
Courtesy of: Sumitomo Heavy Industries, Limited

PLATE D-3

APPENDIX E

TOWED VEHICLES SPECIFICATIONS

ANGUS
(Acoustic Navigation Geological Undersea System)

Operating Depth: 20,000 ft (6,096m)
Dimensions (LxWxH): 14 ft x 6 ft x 5 ft (4m x 2m x 1.5m)
Weight (Dry): 4,800 lbs (2,177kg) (with sled)
Towing Speed: 0.75 to 1 knot (1.4 to 1.8km/hr)
Power: Self contained 30 V, 150ah (lead-acid) batteries.
Instrumentation: Benthos Survey Camera (color) (ranging from 15 sec to 1.5 min picture rates), Benthos 1500W/sec strobe with glass ball power pack and 2ea 750W/sec heads. 12kHz pinger for monitoring height off bottom using Gifft Recorder (7m standard height). Unit can also telemeter one variable to surface. Complete photo processing facility housed on deck mounted van (LxWxH: 14 ft x 8 ft x 10 ft) (4m x 2m x 3m) ready for viewing in 3.5 hrs (approximate). High resolution temperature sensor (0.2 degrees C full scale with foldover from 0 degrees C to 32 degrees C), information telemetered to surface via pinger.
Navigation: ACNAV (Woods Hole System similar to AMF ATNAV) with AMF acoustic devices and HP2100 computer.
Control: Intercom to winch operator for up/down motion. Height off bottom monitored via 12kHz bottom finding pinger and Gifft Recorder.
Support Ship Requirements: Ship of opportunity capable of providing suitable winch, deck space for fish and photo van plus lab space for computer and general maintenance.
Crew: Six

Status: Operational
Builder/Operator: Woods Hole Oceanographic Institution
Woods Hole, MA

BATFISH*

Operating Depth: Standard version 200m (656 ft), wide-winged version - 400m (1,312 ft)
Dimensions (LxWxH): Standard version - 1.3m x .075m x 0.9m (4.3 ft x 2.5 ft x 3 ft), wide-winged version - 1.3m x 1.25m x 0.9m (4.3 ft x 4.1 ft x 3 ft)
Weight (Dry): Standard version - 70kg (154 lbs), in-water - 20kg (44 lbs) wide-winged version - 85kg (189 lbs), 25kg (55 lbs in water.
Towing Speed: 5 to 15 knots (10 to 15km/hr)
Power: Information not available.
Instrumentation: Pressure transducer, conductivity/temperature/depth sensor, fluorometer, zooplankton counter. All environmental data is transmitted digitally to the surface. A bottom avoidance system has been employed which emits an audible alarm when the vehicle reaches a pre-determined altitude above the bottom, at this point the vehicle automatically begins to ascend. The vehicle is also equipped with a roll and yaw stabilizer and a depth servo-control system which activates the wings on BATFISH to cause it to ascend or descend within certain programmed rates and diving limits.
Navigation: Relies on surface positioning systems.
Support Ship Requirements: Cable winch and davit (for unfaired cable) or stern-mounted A-frame (for faired cable). The vehicle has been deployed from a variety of ships from 10m (33 ft) to 90m (295 ft) LOA.
Crew: Two to three.

Status: Operational.
Builder/Operator: The basic vehicle is built by Guildline Instruments Ltd., Smith Falls, Ontario, Canada. Some of the above instrumentation was constructed by the operator: Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.

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*The basic BATFISH towed body is manufactured by Guildline Instruments Ltd. Several units of two versions (standard and wide-winged) have been sold. The unit described herein, except where noted, is a standard version employed for oceanographic investigations by the Bedford I

DEEP TOW

Operating Depth: 6,096m (20,000 ft)
Dimensions (LxWxH): 2m x 0.75m x 0.5m (6.6 ft x 2.5 ft x 1.6 ft)(approximate)
Weight (Dry): 907kg (2,000 lbs)
Towing Speed: 1.5 knots (2.8km/hr)
Power: 120 and 440 VAC, 60 Hz, 20 amps, winch: 12kW, 440 V, 60 Hz, 3 phase.
Instrumentation: CCTV (uses strobe light for illumination and produces successive reproductions of individual exposures), side scan sonar, stereo camera system, proton-precession-type magnetometer, sub-bottom profiler (4kHz, 50 to 100m penetration typical), pressure/depth gage, speedometer, water temperature sensor, up/down-looking echo sounder, forward-looking (obstacle avoidance) sonar, plankton sampler (optional), magnetic compass, transponder.
Navigation: Bottom-oriented transponder positioning system providing 2 to 5m (7 to 16 ft) accuracy.
Support Ship Requirements: Must have installed winch or equivalent deck load carrying capability, ability to install crane, space for 2m x 3m (6 ft x 10 ft) storage and workshop van, at least 37 sq m (400 sq ft) of enclosed and dry lab area. Ship must have good low speed propulsion (diesel electric, cycloidal propulsion, variable pitch propellers, auxiliary low speed system, etc.) and bow thruster with enough horsepower to turn into a reasonable wind while maintaining a 4,536kg (10,000 lb) line pull at 1 to 2 knots. Almost any AGOR or AGSS should be satisfactory. Offshore drilling supply boats often satisfy all but the low speed capability, which could be provided by a pair of Murray-Tregurtha Harbormaster units, and the laboratory and living space requirements, which can be met with vans. Power: 20 amps of reasonably regulated 60 Hz 110 V single phase for the actual equipment. Crane has its own small diesel engine. Winch (if not normally installed) required 120 kW 440 V, 60 Hz, 3 phase power.
Crew: 13 for 24 hour operating capability, six of these must be experienced in DEEP TOW operations.

Status: Operational
Builder/Operator: Marine Physical Laboratory
San Diego, CA

DIGITOW

Operating Depth: 6,096m (20,000 ft)
Dimensions (LxWxH): 2.4m x 1.5m x 1.2m (8 ft x 5 ft x 4 ft)
Weight (Dry): 544kg (1,200 lbs)
Towing Speed: 1.5 knots (2.8km/hr)
Power: 120 VAC, single phase, 60Hz. Total continuous power supplied will be 3 Kw.

Instrumentation: Initial complement: Five sonars (up-looking, down-looking and transponder ranging), side scan sonar. An obstacle avoidance sonar will be added in the future. Future instrumentation capability includes: shallow and deep penetration sonar, water temperature sensor, pressure sensor, magnetometer (2), two normal angle and one wide angle still cameras with strobe, conductivity/dissolved soygen/sound velocity sensors, doppler sonar, CCTV. DIGITOW incorporates a micro-processor based all-digital data system. A downlink command capability of 1,000 bits per second will be provided, with an uplink data rate of 250,000 bits per second. Each instrument will be provided with a standard micro-processor based interface unit to accommodate unique requirements with software. Data from all instruments will be obtained digitally, transmitted up the coaxial cable and recorded on magnetic tape aboard ship. These data will be annotated accordingly and preserved as the original record.

and transponder ranging), side scan sonar. An obstacle avoidance sonar

Navigation: Not yet defined
Support Ship Requirements: Not yet defined
Crew: Not yet defined

Status: Final design is not fully completed. Some components of the vehicle are now under development.

Builder: Jet Propulsion Laboratory
California Institute of TEchnology
Pasadena, CA

DSS-125

Operating Depth: 6,096m (20,000 ft)
Dimensions (LxWxH): Fish: 234cm x 127cm x 122cm (92 in. x 50 in. x 48 in.)
Depressor: 201cm x 152cm x 234cm (79 in. x 60 in. x 92 in.)
Weight (Dry): Fish: 630kg (1,389 lbs), in water - 34kg (75 lbs).
Depressor: 1,678kg (3,700 lbs).
Tow Speed: 1.5 knots (2.8km/hr)
Power: 115 VAC, 60 Hz, 20 amps, or 220 VAC, 50 Hz, 10 amps. (Frequency stability of plus or minus 0.5 Hz required when video taping)
Instrumentation: CCTV (TC-125-SIT low light level with 10:1 200m lens), still camera (70mm), strobe light, magnetic compass, two 250 watt thallium iodide lights, two high intensity collimated spotlights (for estimating object size and vehicle altitude).
Navigation: Relies upon surface positioning system
Support Ship Requirements: Information not available.

Status: Operational. Two systems have been sold to a West German firm and two to a Japanese firm.
Builder: Hydro Products
San Diego, CA

GUSTAV

Operating Depth: 6,000m (19,689 ft)
Dimensions (LxWxH): 334cm x 281cm x 203cm (131.5 in. x 110.5 in. x 80 in.)
Weight (Dry): 1,361kg (3,000 lbs)
Tow Speed: 8 knots (15km/hr)
Power: 380 V, 60 Hz
Instrumentation: CCTV, still camera, strobe and floodlights, echo sounder, forward-looking sonar.
Navigation: Relies upon surface navigational systems
Support Ship Requirements: Deployed from R/V VALDIVIA which supplies electrical power. Containerized support requiring 4 sq m (43 sq ft) of deck area and 2.7t (3 tons) lift capacity.
Crew: Information not available

Status: Construction completed in 1975
Builder: Dornier-System GmbH
Friedrichshafen
West Germany

MANKA 01 (formerly EAS 01)

Operating Depth: 6,500m (21,325 ft)
Dimensions (LxWxH): 500cm x 279cm x 246cm (197 in. x 110 in. x 97 in.)
Weight (Dry): 4,500kg (9,921 lbs)
Tow Speed: 2.5 knots (5km/hr) Vehicle is towed in contact with the bottom.
Power: 110 V and 220 V, 50 Hz
Instrumentation: CCTV, forward-looking sonar, downward-looking echo-sounder, suction nozzel for in situ bottom sampling, onboard gamma radiation analysis system for determining concentrations of cobalt, nickel, iron and manganese.
Navigation: Relies upon surface positioning systems.
Support Ship Requirements: Information not available. Has been deployed from R/V VALDIVIA (see GUSTAV support ship requirements)
Crew: Four

Status: Towing cable parted during retrieval. Vehicle lost at sea. No plans to build replacement owing to present lack of commercial interest for in situ analysis of manganese nodules.
Builder: Kernforschungszentrum Karlsruhe GmbH
Karlsruhe
West Germany

NRL SYSTEM

Operating Depth: 6,096m (20,000 ft) (cable length is limiting factor)
Dimensions (LxWxH): 190cm x 79cm x 76cm (75 in. x 31 in. x 30 in.)
Weight (Dry): 1,134kg (2,500 lbs)
Tow Speed: 1 knot (2km/hr)
Power: Fish power is supplied by an onboard 20 amp, nickel-cadmium, 28 V battery. The battery is maintained in a fully charged condition throughout the towing operation by supplying current from the support ship through the 7,315m (24,000 ft) of cable.
Instrumentation: CCTV (slow scan), two 35mm still cameras (105 and 67 degree viewing angle), 70mm still camera, side scan sonar, proton precision magnetometer, altimeter (sonar). Roll, pitch, heading and speed sensors. Optional: water temperature sensor, pressure/depth, radiation detector, multi-sampling water bottles.
Navigation: A surface-oriented, short baseline system is used in conjunction with a responder on the fish. A bottom-oriented transponder navigation system is also available.
Crew: Six minimum at all times, 12 required for 24 hour continuous operations.
Support Ship Requirements: The system was designed to be employed from a dedicated ship, USNS MIZAR (T-AGOR II). It could probably be operated from other AGOR-type ships, having appropriate handling capability and characteristics, winch, computer, deck space, etc.

Status: Inactive (Maintained in a state of semi-readiness)
Builder: Naval Research Laboratory
Washington, D.C.

RAIE I
(Remorguage Abyssal d'Instruments pour l'Exploitation)

Operating Depth: 6,000m (19,685 ft)
Dimensions (LxWxH): 3m x 1.4m x 1m (10 ft x 4.6 ft x 3 ft)
Weight (Dry): 800kg (1,764 lbs), in water -
Tow Speed: 0.5 to 1.0 knot (0.9 to 2km/hr)
Power: 1.5 amps, 110 VAC (power supplied from surface is 400 VAC)
Data are digitized and transmitted through the cable every second.
Instrumentation: Two 35mm still cameras (Benthos Mod. 377), two 200 joules capacity strobe lights (Benthos Mod. 383), echo sounder (126 kHz) gimbal-mounted, pressure/depth gage (20m accuracy, 0-5 degrees C), magnetic compass transponder, pinger 12 kHz (for altitude/depth measurements). Camera can be manually operated or set to automatically expose at selected intervals.
Navigation: Compatible for operating with bottom-oriented systems or by transponder tracking from surface.
Support Ship Requirements: Has operated from R/V JEAN CHARLOT, will operate from R/V LE SUROIT in 1979. LE SUROIT has the following characteristics:

LOA: 56.34m (185 ft), Beam: 11m (36 ft), Draft: 4.5m (15 ft)
Loaded displacement: 1.09t (1.2 tons)
Maximum Speed: 14 knots (26km/hr)
Maximum Sea State for RAIE I operations: 4

Crew: Information not available

Status: Operational
Builder: Centre National Pour L'Exploitation Des Oceans (CNEXO)
Centre Oceanologique de Bretagne
Brest
France

RAIE II

Operating Depth: 6,000m (19,685 ft)
Dimensions (LxWxH): 3m x 1m x 1m (10 ft x 3 ft x 3 ft)
Weight (Dry): 600kg (1,323 lbs)
Tow Speed: 1.5 knots (2.8km/hr)
Power: Battery powered. Cable is for towing only, data obtained is recorded in the fish and played back aboard ship.
Instrumentation: Two, 35mm still cameras, two, 200 joules capacity strobe lights, echo sounder with gimbal-mounted transducer (126 kHz), pressure/depth gage, pinger (12 kHz) navigation transponder. If bottom is flat and the sea relatively calm, a 1t weight is suspended from the fish and dragged along the bottom to keep the fish at an optimum altitude.
Navigation: Compatible for operating with surface-oriented transponder tracking system.
Support Ship Requirements: Same as RAIE I.
Crew: Information not available.

Status: Operational
Builder: CNEXO
Centre Oceanologique de Bretague
Brest
France

RUFAS I
(Remote Underwater Fishery Assessment System)

Operating Depth: 91m (300 ft)
Dimensions (LxWxH): 3m x 2m x 1m (11 ft x 5 ft x 3 ft)
Weight (Dry): 453kg (1,000 lbs)
Tow Speed: 3 knots (6km/hr)
Power: 60 Hz, 110 VAC
Instrumentation: CCTV, still camera (35mm), two quartz iodide lights, echo sounder (downward-looking), dive planes (vanes) control roll, pitch and depth.
Navigation: Relies upon surface positioning system for geodetic positioning.
Support Ship Requirements: Power supply, at least 25 ft (8m) LOA, handling system. Has been using the NOAA research ship OREGON II, launch/retrieval through Sea State 5.
Crew: Three to four for 8 hour continuous operation.

Status: Operational
Builder/Operator: National Marine Fisheries Service
Southeast Fisheries Center
Bay St. Louis, Miss.

RUFAS II

Operating Depth: 732m (2,400 ft)
Dimensions (LxWxH): 3m x 1.7m x 1.1m (11 ft x 5.5 ft x 3.5 ft)
Weight (Dry): 454kg (1,000 lbs)
Tow Speed: 25 knots (11km/hr)
Power: 60 Hz, 115 VAC
Instrumentation: CCTV on pan/tilt device, still camera (35mm), stereo cameras, obstacle avoidance sonar, depth sensor, viewing lights, strobe lights, downward-looking echo sounder, roll and pitch indicators, directional hydrophone.
Navigation: Relies on surface positioning systems for geodetic positioning.
Control: Automatic bottom-following control system. Vehicle is guided by stern-mounted (port/starboard) dive planes.
Support Ship Requirements: Similar to RUFAS I
Crew: Three to four for continuous 8 hour operation.

Status: Undergoing modifications. Scheduled for operation in the summer of 1979.
Builder: Institute of Engineering Technology
Mississippi State University
State College, Miss.
Operator: National Marine Fisheries Service
Southeast Fisheries Center
Bay St. Louis, Miss.

S^3

(Seafloor Surveillance System)

Operating Depth: 1,829m (6,000 ft)
Dimensions (LxWxH): 3m x 2m x 1m (10 ft x 6 ft x 4 ft)
Weight (Dry): 317kg (700 lbs)
Tow Speed: 1 knot (2km/hr)
Power: 110 V, 50 Hz, 30 amp, single phase (dedicated electrical generator)
Instrumentation: CCTV (Pan/tilt control), two 1,000 watt quartz iodide lights, side scan sonar, sub-bottom profiler, magnetometer, bottom sampler (dredge-type) transponder.
Control: Two stern-mounted, servo-activated diving planes receive shipboard commands for depth control. Constant depth can be automatically maintained.
Navigation: Relies upon surface positioning systems to provide geodetic positioning.
Support Ship Requirements: The University of Georgia: R/V KIT JONES was used to support the prototype vehicle. It is a 65 ft (19m) Gulf Coast shrimping vessel with a stern-mounted A-frame which was used to tow S3.

Status: Inactive. Prototype developed and tested.
Builder: University of Georgia
Athens, GA

SEP

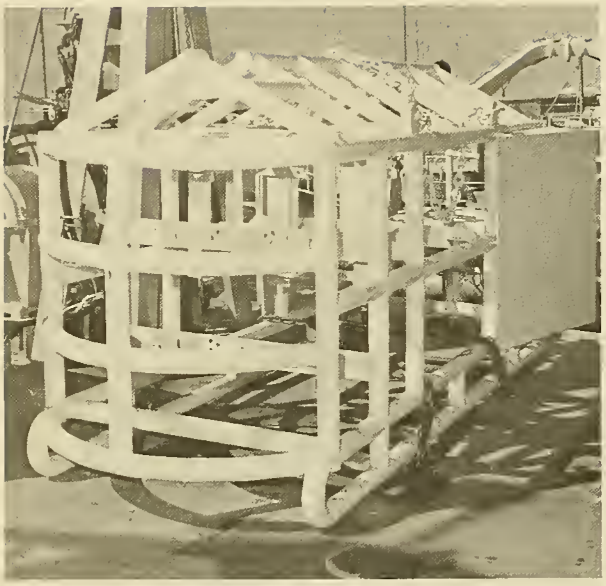
Operating Depth: 6,000m (19,689 ft) (Capable of greater depth, limited by cable length.)
Dimensions (LxWxH): 330cm x 160cm x 80cm (130 in. x 63 in. x 31.5 in.)
Weight (Dry): 1,361kg (3,000 lbs)
Tow Speed: 3 to 8 knots (6 to 15km/hr)
Power: 380 V, 60 Hz
Instrumentation: Echo sounder, forward-looking sonar, pinger
Navigation: Relies upon surface positioning system.
Support Ship Requirements: Deployed from R/V VALDIVIA which supplies electrical power and 4 sq m (43 sq ft) deck area for containerized support and provides 2.7t (3 tons) lift capacity. Handling system: stern A-frame. Capable of operating in Sea State 4 to 5.
Crew: Information not available.

Status: Scheduled operational by end of 1978
Builder: Dornier-System GmbH
Friedrichshafen
West Germany

TELEPROBE

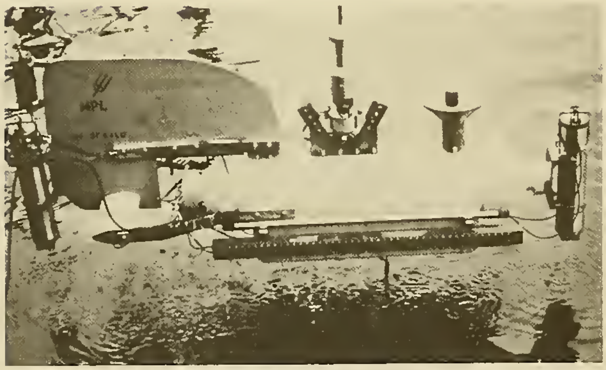
Operating Depth: 6,096m (20,000 ft)
Dimensions (LxWxH): 2m x 1.4m x 1.3m (8 ft x 4.7 ft x 4.4 ft)
Weight (Dry): 1,134 to 1,588kg (2,500 to 3,500 lbs) (Instrumented and ballasted)
Tow Speed: 3.0 knots (6km/hr)
Power: 50 amps, 120 V regulated.
Instrumentation: CCTV (slow scan), stereoscopic cameras (35 to 70mm), strobe lights, altitude/depth sensor, transponder, magnetometer, side scan sonar, obstacle avoidance sonar, heading sensor.
Navigation: Fish position is determined relative to the surface ship by interrogation of transponder on fish. Relies on surface ship positioning system for geodetic position. Also capable of positioning relative to a bottom-mounted transponder navigation system.
Support Ship Requirements: A specialized ship is necessary which has the following capabilities: bow thruster and active rudder, a winch system capable of handling a maximum of 9,144m (30,000 ft) of cable, a deck frame or stern A-frame for launch/retrieval of fish, a fair lead system usable with 0.68 in. cable and a 50 amp, 120 V, regulated power supply. Can operate into Sea State 6.
Crew: 15 minimum

Status: Operational
Builder: U.S. Naval Oceanographic Office
Bay St. Louis, Miss.

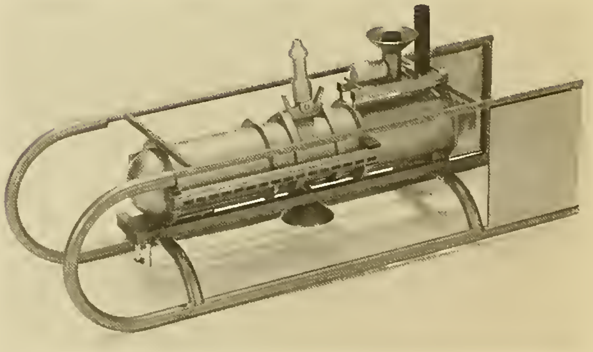


ANGUS
Courtesy of: Woods Hole Oceanographic

BATFISH
Courtesy of: Guildline Instruments, Ltd.

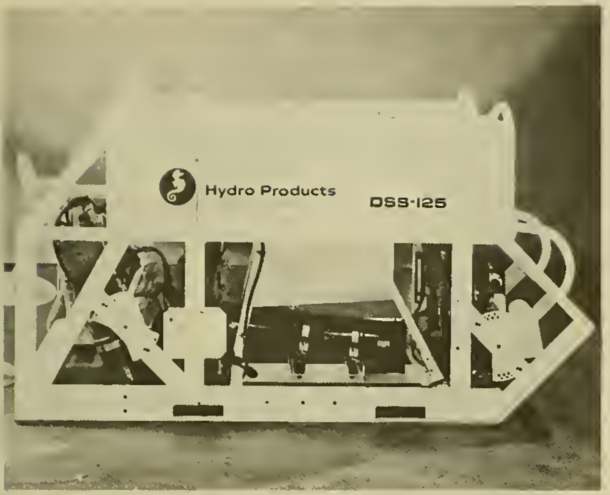


DEEP TOW
Courtesy of: Marine Physical Laboratory

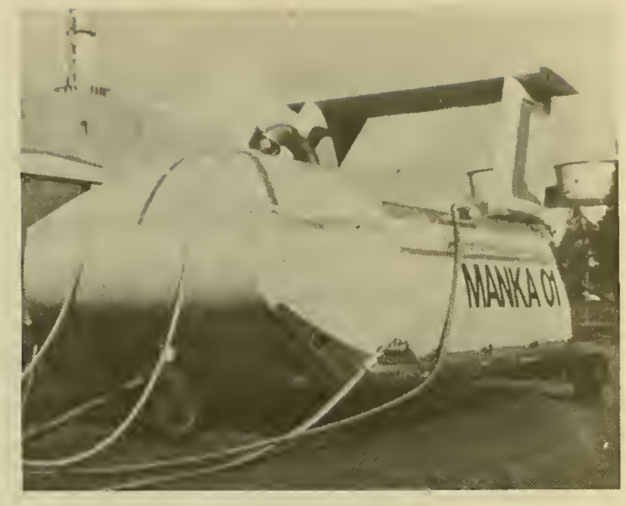


DIGITOW (Model)
Courtesy of: Jet Propulsion Laboratory

PLATE E-1

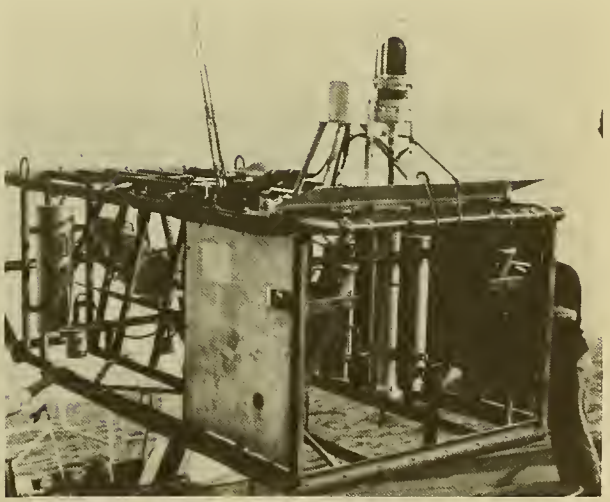


DSS-125
Courtesy of: Hydro Products



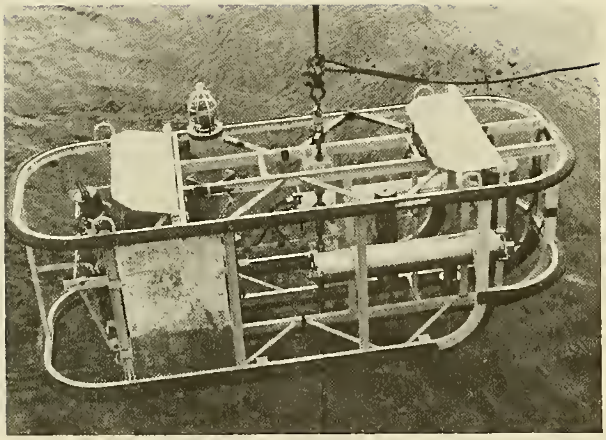
MANKA 01
Courtesy of: Kernforschungszentrum
Karlsruhe GmbH

NRL SYSTEM
Courtesy of: Naval Research Laboratory

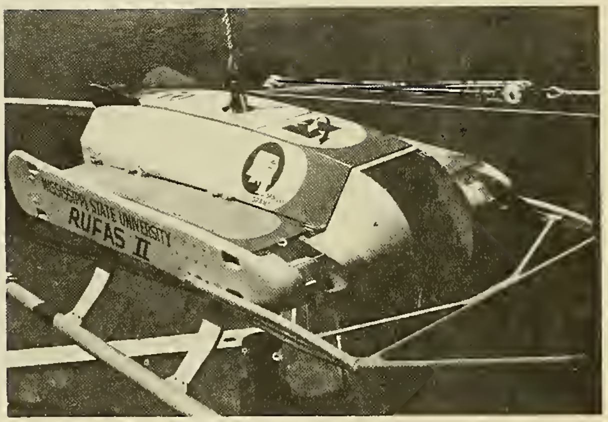


RAIE I
Courtesy of: Centre National Pour
L'Exploitation Des
Oceans

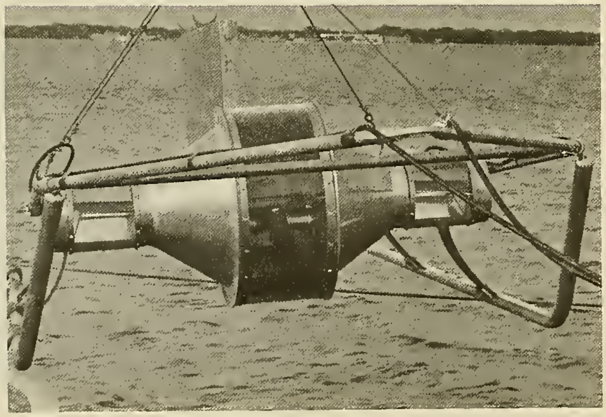
PLATE E-2



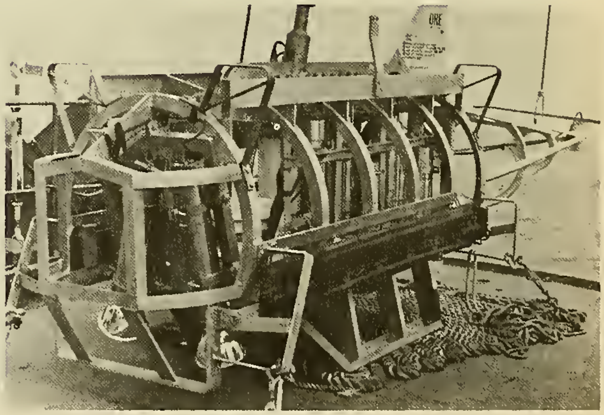
RAIE II
Courtesy of: Centre National Pour
L'Exploitation Des Oceans



RUFAS II
Courtesy of: National Marine Fisheries
Service



S^3
Courtesy of: University of Georgia



TELEPROBE
Courtesy of: U.S. Naval Oceanographic
Office

PLATE E-3

APPENDIX F

UNTETHERED VEHICLE SPECIFICATIONS

EPAULARD

Operating Depth: 6,000m (19,685 ft)
Dimensions (LxWxH): 4m x 1.1m x 2m (13 ft x 3.6 ft x 7 ft)
Weight (Dry): 3t (3.3 tons).
Speed: 1 and 2 knots (selectable) (2 and 4km/hr)
Structure: Detailed information not available. Electrical components will be housed in a pressure-resistant body, syntactic foam will provide positive buoyancy.
Power: Pressure-compensated, lead acid batteries providing 20KWH. A typical mission to 6,000m will last over a period of 12 hours and will entail: descent-1½ hours, traverse-8 hrs (at 2 knots), ascent-1½ hours, retrieve and refit for next dive-1 hr.
Command/Control: An 80kg (176 lb) descent weight and ascent weight will be used to expedite vehicle travel time to and from the bottom. Propulsion along the bottom will be provided by a 3-blade propeller. A 12m (40 ft) long, 80kg guide chain will be dragged on the bottom to control vehicle altitude. The vehicle's course will be pre-set prior to launch. Ascent/descent weights will be dropped by echo sounding information (acoustic command, internal timer or magnesium weak link will provide the same function in an emergency). Tracking of the vehicle will be based on interrogation of a vehicle-mounted transponder which will also transmit depth information. Four command signals can be transmitted to the vehicle: heading (can be coded in 5 degree increments); speed (emergency forward, stop, reverse); weight drop, and photographic function. Vehicle will answer that it has received these commands. Vehicle will measure and relate to surface its: heading, depth, altitude and weight condition. Various alarms (sent in code) will automatically be transmitted to surface; these include flooding, position malfunction, sonar malfunction. When an obstacle is detected vehicle will automatically stop and reverse. System is designed to operate over low relief bottom.
Instrumentation: 35mm still camera, strobe light, radio beacon (for surface) pressure/depth gage, transponder, echo sounder, obstacle avoidance sonar.
Launch/Retrieval: Vehicle will release a buoy with 20m (65 ft) of attached line as it approaches the surface. Support ship will hook line for retrieval.

Status: Under construction. Scheduled for sea trials in April 1979.
Builder: CNEXO
Base Oceanologique de la Mediterrance
La Seyne Sur Mer
France
and
Society ECA
Meudon
France

OSR-V and OSR-H*
(OCEAN SPACE ROBOT-VERTICAL)
(OCEAN SPACE ROBOT-HORIZONTAL)

Operating Depth: 250m (820 ft)
Dimensions (LxWxH): OSR-V: 4.3m x 2.0m x 1.75m (14 ft x 7 ft x 5.7 ft)
OSR-H: 4.4m x 0.86m x 2.0m (14 ft x 2.6 ft x 7 ft)
Weight (Dry): OSR-V: 2,600kg (5,731 lbs) (displacement). In water - plus or minus 45kg (99 lbs)
OSR-H: 1,600kg (3,527 lbs)
Speed: OSR-V: 3 knots (6km/hr) Climbing speed - 0.6 knots (1km/hr)
OSR-H: 2 to 5 knots (4 to 9km/hr)

Structure: OSR-V: Cylindrical pressure hull contains batteries, electronics and control device. The bow and stern are capped by a nose and tail cone, respectively. Above the pressure hull a fairing encloses and protects a current meter and surface detector. Skids are affixed to the underside of the vehicle for landing on the bottom.

Power: OSR-V: Silver oxide batteries, 100v and 24v, 256 amp-hrs. OSR-V is designed to conduct 35 up/down cycles under average current conditions of 3 knots and water depth to 100m (305 ft) OSR-H is designed to cruise at 3 knots horizontally for a 24 hour period. OSR-V is propelled by two, 5 hp electric motors which power two, stern-mounted (port/starboard) propellers.

Command/Control: OSR-V: The vehicle controls its position automatically on a pre-determined vertical (up/down) course. A sea-bottom base transmits acoustic pulses periodically which are received by two hydrophones on the OSR-V. The difference in reception time is used, together with depth and attitude (heading; inclination) information to calculate the vehicle's position. By using a trim adjusting device, a ballast tank and two propellers, the vehicle moves (diving or climbing) along pre-determined vertical lines. In the event that the vehicle generates an emergency signal, a support ship can transmit a climbing command to bring the vehicle to the surface.

Instrumentation: OSR-V: Current meter, water temperature sensor, water pressure sensor, conductivity sensor, turbidometer, pH meter, dissolved oxygen sensor. The data is stored aboard the vehicle until it surfaces, at this time it electromagnetically transmits the stored data to a mooring buoy which subsequently transmits the data to a shore-base.

Launch/Retrieval: Launched by a stiff-legged crane. Limits are Sea State 3.

Surface Support: The undersea vehicles are supported by a moored buoy, a surface ship and a land-base. The moored buoy serves to collect supporting data (current speed and water temperature) while the OSR-V is operating. The moored buoy further serves as a station to receive data from the vehicle when it surfaces and transmits the data to a land station where it is processed.

Status: Unknown (systems were constructed in 1974)
Builder: Mitsui Ocean Development and Engineering Co., Ltd.
Tokyo
Japan

SPURV I & II
(SELF-PROPELLED UNDERWATER RESEARCH VEHICLE)

Operating Depth: (SPURV I) 3,658m (12,000 ft)
(SPURV II) 1,524m (5,000 ft)
Dimensions (LxWxH): 3.1m x 0.508m x 0.508m (10.2 ft x 1.7 ft x 1.7 ft)
Weight (Dry): 454kg (1,000 lbs)
Speed: Max - 7 knots (12km/hr)
Low - 4 knots (7km/hr)

Structure: Cylindrical shape consisting of an aluminum, central cylinder and two spherogive end sections with nominal thickness of 2.54cm (1m). A free-flooding tailcone is attached to the aft section to provide a fairing about the propulsion system and to provide support for the rudder and elevator surfaces.

Power: Primary power is supplied by two sets of 16 silver-zinc cells (Yardney LR-90) connected in parallel through diodes to form a 24 volt, 200 ampere-hour supply. Under vehicle loads of about 40 amperes total the cells supply about 130 ampere-hours when new. Operating (running) time for both vehicles is 5.5 hours.

Command/Control: Commands to the vehicle require 12 binary bits in the transmitted acoustic data word, of which 4 are used for the command proper. The remaining 8 bits provide incremental depth or course changes referred to as depth or turn steps. The 4 command bits provide 16 commands which are listed below in decimal order. Some commands have alternative uses which are shown in parentheses.

0 Motor Off-Track only
1 Surface-Depth 1
2 Depth 2
3 Depth 3
4 Depth 4
5 Climb N steps (Start Climb Ramp)
6 Dive N steps (Start Dive Ramp)
7 Right turn N steps
8 Left turn N steps
9 Azimuth Program ON
10 Azimuth Program OFF
11 Depth Search ON
12 Depth Search OFF
13 Hold Ramp (Increase Fluorom. Sens.)
14 Reset Ramp (Decrease Fluorom. Sens.)
15 Spare

The 8 command step bits can provide up to 256 turn or depth steps every 10 seconds, somewhat more than the vehicle can follow. The command options available are, briefly, any one of 3 pre-selected depths from which incremental changes can be made, course changes relative to the initial gryo-retained course, and three programs: a long ramp-like depth change, a sawtooth-like depth search, and an azimuth program. The control system is broken down into azimuth, depth and run program subheadings.

Azimuth reference is established by means of a self-leveling, directional gyro obtained from a high quality aircraft autopilot. It can be adjusted for a drift rate of less than one degree per hour at most operating latitudes. The gyro is free in azimuth, its only load being a lightweight brush which grounds one of the segments of the split-ring commutator when the course error is large enough.

Prior to launch, the vehicle and ship are pointed in the desired direction and the system is nulled out by entering turn steps until one of the two gaps in the commutator coincides with the brush. Either gap will give a null; however, they yield reciprocal headings. The gaps in the commutator are about 4 degrees wide; hence the vehicle "follows" the gyro to within about 2 degrees. Rudder action is infrequent during straight runs, and power consumption is small. Rudder solenoid activation is recorded on the vehicle's tape recorder.

In broad outline all depth systems function in a similar manner: a reference voltage proportional to the desired depth is generated, a voltage proportional to the actual depth is provided by a sensor, and the difference between the signals constitute the error signal which drives the vehicle in the appropriate direction to reduce the error to zero. The error signal is limited in amplitude and combined with a pitch sensor signal to keep climb and dive angles within bounds.

In the SPURV system the depth sensor does not provide a voltage directly, but provides a digital number proportional to depth. The most significant 8 bits of the number are compared with a switch-selected digital reference. The resulting "coarse" error signal overrides others until the vehicle is within 30 meters of the desired depth. The lesser 10 bits are converted to an analog voltage and compared against a reference voltage to provide the "fine" error signal. The fine error is nulled when the depth error is less than 0.03m (0.09 ft).

A new count is generated 12 times a second. If properly stabilized before use by two days of warmup, the Vibrotron will be stable over a 6-hour period within 0.1m (0.3 ft) and its repeatability from day to day will be within 0.5m (1.6 ft).

Instrumentation: The standard nose probe package for SPURV for some years included three elements: a velocimeter (sound velocity), a quartz thermometer and a thermistor-controlled Wien bridge oscillator (WBO). All of the elements are individually packaged for depths up to 3,048m (10,000 ft) and they all generate frequencies which are measured and recorded in the instrumentation chassis.

The velocimeter is a sing-around type manufactured by Lockheed and has a resolution of 0.013 meter per second.

The quartz crystal thermometer is a relatively slow instrument of high accuracy. The crystal is made by Gulton (Model MET-2) and has a specified accuracy of plus or minus 0.01 degrees C over a 6-month period. The resolution of the thermometer is 0.00056 degrees C.

The thermistor of the Wien bridge oscillator is made by VECO (type Z32A91) and constitutes the resistive element in an oscillator designed at the Laboratory.

Another probe configuration contains a fluorometer developed at APL for detecting minute quantities of certain fluorescent dyes in water. The dyed water flows through the instrument's test cell where it is illuminated with light capable of exciting the fluorescence. The scattered fluorescent light is filtered out and focused onto a photomultiplier tube. The resulting current from the tube is amplified and converted to a frequency. The instrument can measure Rhodamine B dye concentrations ranging from 10 to the minus twelth to 20 to the minus sixth g/cu cm. It uses four overlapping ranges to cover this dynamic range. The fluorometers have been used successfully in three experiments:

Two diffusion experiments in the Pacific and a study in Puget Sound to measure tidal flushing of a bay for a proposed nuclear power plant.

All data are recorded internally on magnetic tape; some oceanographic and vehicle operation data can also be telemetered to the ship acoustically.

The data are converted to binary form and are sampled periodically. The more important data are sampled 12 times a second and most of the oceanographic data are recorded at this rate. Vehicle data are sampled at rates varying from 12 times a second to once a second.

There are several ways to display the data for study and analysis. In the older method the tapes are read directly into a photosensitive paper strip recorder. Vehicle tapes are also transferred to computer-compatible tapes, after which the data can be printed out or plotted using the IBM 1130 computer and its peripherals.

Tracking: Frequency diversity and frequency shift keying (FSK) are used in the tracking system. Transmission to the vehicle is at 20 and 22 kHz and the vehicle replies at 26 and 28.9 kHz. The lower frequency in each case is used for a 0 in the digital word. The frequency diversity prevents crosstalk problems when more than one device is being tracked. Although this system gives good performance with signal-to-noise ratios down to 6 dB, it is susceptible to multipath propagation.

The structures of the transmission and reply are as follows. There are 25 bits in a word, each bit 1 msec in length. The first 8 bits are used only for the correlation code which is used to accurately time the data loading. Bits 11 and 12 are identity or address bits which are used to permit selective tracking of up to 4 objects other than the vehicle. (Bit 9 alone serves as an identity code for the vehicle.) The command bits 13 through 24 are binary-coded with the most significant bits sent first. Bit 25 is a parity error-detection bit which is chosen so that there are an even number of 1's in the bits following the correlation code. If the parity of the command as received does not agree with the parity bit the command will not be stored or executed. Although every transmission to the vehicle includes command bits they usually simply reiterate the operating depth (D2, D3, or D4), and are essentially tracking pulses.

The reply code correlation and identity bits are the same as in the incoming transmission but telemetered data bits replace the bulk of the command bits.

Launch/Retrieval: A launch/retrieval crane is bolted and welded to the ship's railing and deck. Its boom has a reach of 5m (16 ft) from the side of the ship, its whip is 9m (30 ft) long and its capacity is 907kg (2000 lbs) at full reach.

For launch the vehicle is held a few feet above the surface by a launch bar which is tripped with a line from the deck. The vehicle is dropped with the ship underway at about 2 knots (4km/hr). On the vehicle's return to the surface the ship is maneuvered to within about 100m (328 ft) and the crane is used to launch the boat; the crew attaches the recovery bridle, tows the vehicle into range and attaches the crane's whip. With the boom fully extended the whip is used to pull the vehicle toward the ship with the boat crew stabilizing the operation. When the vehicle is close enough and the waves are favorable, the boom is quickly raised clear of the water. Further tightening of the whip snubs the bridle on the end of the boom and prevents swaying. After the vehicle is swung aboard and alid in its cradle the boat and crew are brought aboard. The whole operation takes from 15 to 30 minutes, depending upon how close to the ship the vehicle is brought up, and can be done safely in sea states up to 6 and winds up to 30 knots. The smaller AGOR ships are the usual operating base.

Status: Three vehicles are operational: two SPURV I's and one SPURV II.
Builder: Applied Physics Laboratory,
University of Washington
Seattle, Washington

UARS
(UNMANNED ARCTIC RESEARCH SUBMERSIBLE)

Operating Depth: 457m (1,500 ft)
Dimensions (LxWxH): 3m x 0.5m x 0.5m (10 ft x 1.6 ft x 1.6 ft)
Weight (Dry): 408kg (900 lbs)
Speed: 3.7 knots (6.8km/hr) (cruising)

Structure: Cylindrical shape composed of a pressure-resistant and filament-wound reinforced plastic hull and a floodable tailcone section which supports the vehicle control surfaces (rudders and elevators) and propeller. The vehicle is 9kg (20 lbs) positively buoyant when submerged.

Power: Silver zinc batteries supply all power. The batteries are divided into two sources of supply: a 260 ampere hour main battery and a 60 ampere hour reserve. The main battery provides the normal 10 hour run capability, the reserve provides slightly more than 2 hours running time.

Command/Control: A Vibrotron pressure transducer is used as the depth control sensor. The vehicle can be commanded to any one of four preset running depths, and can step up or down in small increments from any of the preset depths by means of acoustic command from the tracking station. Inputs from an obstacle avoidance sonar or an under-ice profiler will send the vehicle to the next lowest preset depth each time a step-down command is received from either unit. Roll control is provided by two linear activators which activate the vehicle's elevator control surfaces. The activators respond to a roll angle sensor mounted in the vehicle. Primary heading reference is obtained from a directional gyro. An initial heading is set before launching, heading changes (in 3 degree increments clockwise or counter-clockwise) during the run are acoustically commanded from the tracking station. The vehicle can also "home" on an acoustic source whtn it is observed (via an acoustic telemetry link) that the homing signal is above threshold level. The heading control curcuits then switch control of the rudder drive circuits to the output of the homing receiver. Stop "homing" can be commanded by acoustic link at any time and heading control reverts to the directional gyro. In the event that the vehicle does not receive a command for a period of 5 minutes a "loss of command" sensing circuit actuates a 180 degree turn in the azimuth stepping circuits, which reverses the vehicle's course for a period of 10 minutes. If command is still not received a homing search mode is activated. After one hour from loss of the first command signal the motor stops and the vehicle floats to the surface. Tracking of the vehicle (under-ice) is conducted by an array of four separate hydrophones which receive an acoustic pulse every 2 seconds from the vehicle which is referenced to a clock within the vehicle. Slant ranges to the hydrophones are determined by the velocity-time calculations. The hydrophone positions are monitored continuously by acoustic means with respect to a transducer baseline which serves as a base of reference.

Instrumentation: The primary purpose of UARS is to accurately profile the underside of ice. To conduct this task an acoustic profiling system is carried which measures and digitally records the under-ice profile

5 times a second on each of three separate, narrow, upward-looking beams to accuracies of 0.1m (0.3 ft). Other instrumentation includes an obstacle avoidance sonar (to detect and avoid collision with pressure ridges), a timed pinger (for tracking), an acoustic homing system (two hydrophones), and a self-powered pinger which will automatically activate and deploy itself on a mooring line for emergency location. Launch/Retrieval (Under-ice): The vehicle is lowered on a cradle through a hole cut in the ice. The cradle is negatively buoyant and UARS is buoyantly suspended from it by electromagnetically-operated latch pins which release and unmate the two assemblies underwater. Retrieval involves the use of a acoustic homing system in the vehicle which responds to a homing beacon centered in a capture net. Upon contact with the net a capture probe mounted in the nose of the vehicle firmly meshes with the net which is raised clear of the water.

Status: Inactive
Builder: Applied Physics Laboratory
University of Washington
Seattle, Washington

UFSS
(UNMANNED FREE-SWIMMING SUBMERSIBLE)

Operating Depth: 457m (1,500 ft)
Dimensions (LxWxH): 6m x 1m x 1m (20 ft x 4 ft x 4 ft)
Weight (Dry): Information not available.
Speed: 5 knots (9km/hr)
Structure: A flooded, low drag pressure hull (volumetric coefficient of drag of .007 at operating speed) encloses all necessary pressure vessels.
Power: Lead and batteries (125nm range) and, subsequently, lithium thionyl chloride batteries (1,000nm range). A stern-mounted free propeller provides propulsion. Rudder and dive planes provide pitch/yaw control.
Command/Control: An onboard microcomputer will be programmed to direct and guide the vehicle during its mission. Periodically it will surface to obtain OMEGA fixes. Acoustic tracking and telemetry will be used from the support ship to obtain data and to transmit override commands to the vehicle.
Instrumentation: Not specified. The vehicle has a 1.4 cu m (50 cu ft) payload capability to accommodate a variety of instruments.
Launch/Retrieval: Not specified.

Status: Under construction. First at sea tests scheduled for July 1979.
Builder: U.S. Naval Research Laboratory
Washington, D.C.

(UNNAMED)
NAVAL OCEAN SYSTEMS CENTER

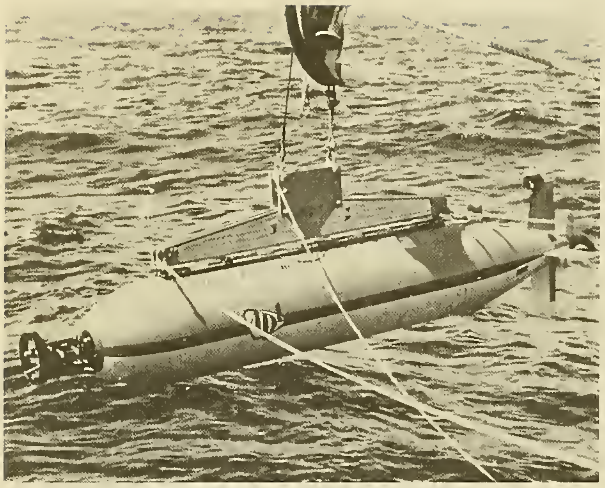
Operating Depth: 61m (200 ft) (capable of 609m)
Dimensions (LxWxH): 2.7m x 0.5m x 0.5m (9 ft x 1.7 ft x 1.7 ft)
Weight (Dry): 136kg (300 lbs)
Speed: 1.5 knots (3km/hr) (5 knots with fairing)
Structure: An expandable, rectangular metallic frame supports all components. Syntactic foam nodules atop the framework provide positive buoyancy (about 1 or 2kg submerged). Four cylindrical flasks contain all electronics. Two ¼hp stern propellers provide thrust, one, ¼hp vertical thruster is mounted amidship.
Power: Lead acid batteries providing 5 ampere hours can operate the vehicle for 1 hour duration.
Command/Control: The system is controlled by micro-processors which compares programmed altitude, heading, depth and run sequence input data with measured data coming from an on-board altimeter, gyro compass, depth sensor and clock. The microprocessor generates digital error signals between the programmed values, and issues error signals to the appropriate motor controllers. The motor controllers then power the DC motors which directly drive the propellers from a separate 24V battery supply. Later developments will include command/control of the vehicle via either an acoustic link or fiber optic cable.
Instrumentation: Compass, pressure/depth gage, downward-looking echo-sounder. The vehicle developmental emphasis is as a testbed for advanced sensor concepts. Present instrumentation only reflects that required for elementary control.
Launch/Retrieval: Not designated.

Status: Under development, pool trials were made in 1978.
Builder: Naval Ocean Systems Center
San Diego, CA

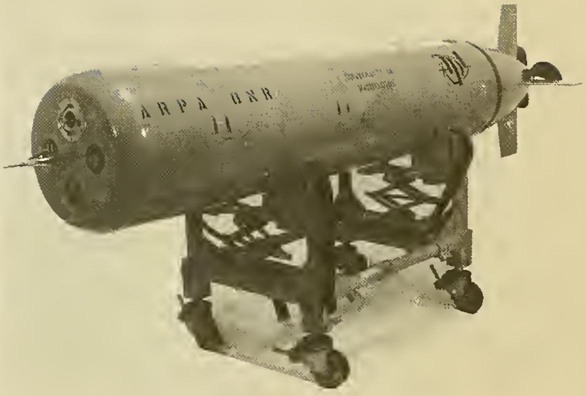
UNNAMED
(UNIVERSITY OF NEW HAMPSHIRE)

Operating Depth: 46m (150 ft)
Dimensions (LxWxH): 1.5m x 1.5m x 1m (5 ft x 5 ft x 3 ft)
Weight (Dry): 371kg (820 lbs)
Speed: 1.6 knots (3km/hr) (maximum sustained in still water)
Structure: Open framework structure consisting of 2.5cm (1 in.) OD 6062-T3 aluminum tubing with 0.6cm (0.25 in.) aluminum plating for corner brackets and mounting components and buoyancy structure. Buoyancy is obtained from two cylinders of urethane foam atop the vehicle which provide 5.3kg (11.7 lbs) of positive buoyancy submerged. A transducer ring is located on the underside of the vehicle which supports a circular array of 12 transducers.
Power: Eight, lead acid (automobile) batteries provide 7.5 KWH of power. A mission endurance of 4 to 5 hours is obtained under average conditions, six, 0.25ph, 17 lb (8kg) thrust electric motor/screw propellers. Five degrees of motion control are possible (roll is not attainable).
Command/Control: A sensor system (12 separate sonar systems in a clock-like configuration on the transducer ring) provides vehicle control information to an onboard microcomputer system. This system, in turn, has the function of making control decisions and gives control commands to the vehicle's thrusters for execution. A software system (developed to evaluate the present vehicle system) contains four modes: system monitor (permits a system checkout prior to vehicle launch), control override routine (overrides all automatic functions via umbilical cable), automatic altitude mode (controls z-axis thrusters to automatically position the vehicle at a predetermined height off the sea floor), and automatic pipe-following mode (contains all subroutines used to maintain vehicle orientation over a pipeline).
Instrumentation: The vehicle serves as a prototype testbed for pipeline inspection. Presently the emphasis is on vehicle control, inspection instrumentation will be addressed at a later date.
Launch/Retrieval: Procedures to be developed.

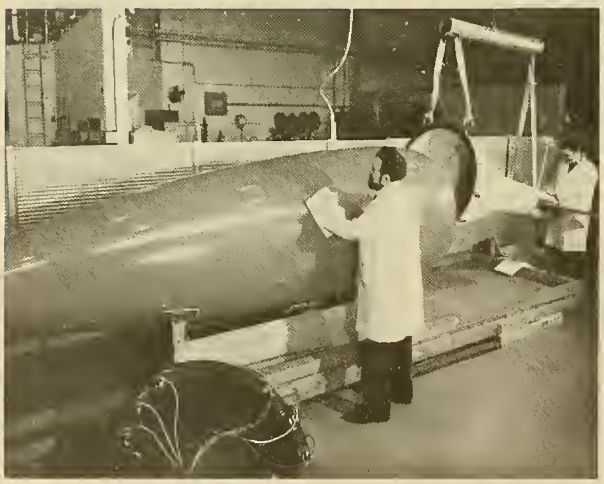
Status: Preliminary sea trials have been held, vehicle is still in development.
Builder: Ocean Engineering Department
University of New Hampshire
Durham, N.H.



SPURV
Courtesy of: University of Washington



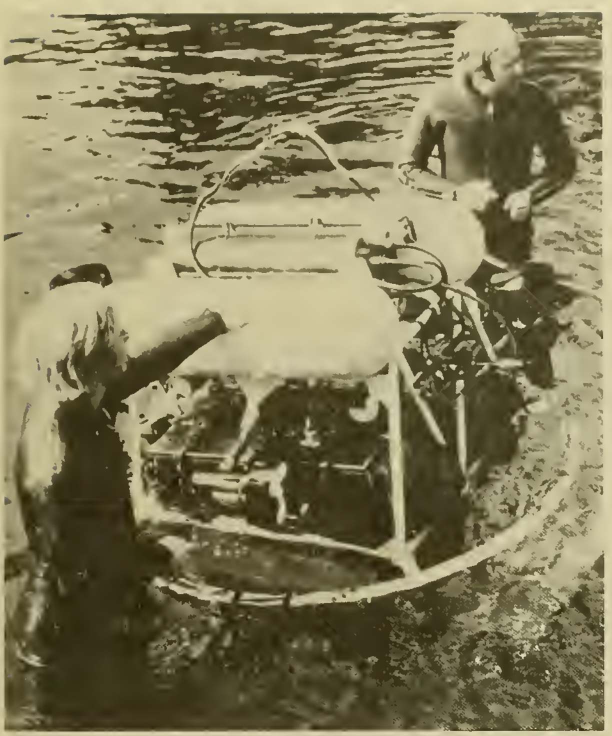
UARS
Courtesy of: University of Washington



UFSS
Courtesy of: U.S. Naval Research Laboratory

(UNNAMED)
Courtesy of: Naval Ocean Systems Center

PLATE F-1



(UNNAMED)
Courtesy of: University of New Hampshire

EPAULARD
Courtesy of: Centre National Pour L'Exploitation Des Oceans

PLATE F-2

ADDENDUM

1) Figure 2.1 is incorrect in the following areas:
   a) Only two (not six) RCV-150 vehicles have been constructed
   b) Two RECON III's have been constructed in 1979 and two more are scheduled for construction in 1980.
   c) The U.S. Naval Undersea Warfare Engineering Station, Keyport, Washington is scheduled to take delivery of the TROV 10 vehicle in November 1979, the vehicle will be redesignated URS-1 (Undersea Recovery System).

2) Technomare is in the process of finalizing TM 402, a bottom crawling vehicle designed specifically for trenching cable and small diameter pipe. It is capable of digging trenches up to 0.4m (1.3 ft) wide and 1.5m (4.9 ft) deep and buries pipe up to 0.3m (1 ft) diameter. The machine weighs 22 metric tons in air and is 11m (36 ft) long and 5.6m (18.4 ft) wide. It is propelled by caterpillar-like tracks and is powered and controlled from the surface. Development of this vehicle and its predecessor, TM 102, was provided by a grant from the European Economic Council.

3) The capabilities listed under Vickers Oceanics Ltd. (SEA CAT), now operate under the title of British Underwater Engineering.

4) Solus Ocean Systems has adopted and modified a color TV for application from its TREC vehicle. The device has been used for inspection of an oil platform in the Gulf of Mexico. Tapes from this system have been reviewed by Busby Associates and show good color rendition at ranges up to approximately 1m (3.2 ft) (under 400 watt quartz iodide lighting). Selected specifications of the color TV camera are:

Color System: NTSC-type output, phase and frequency separation system.
Vidicon Tubes: Single tube system, 25mm (1 in.) VIDICON with specially designed striped filter.
Scanning System: 525 lines, 60Hz, 2:1 interlaced.
Video Output: 1V p-p, 75 ohms through 12-pin camera cable connector.
Resolution: More than 230 lines (horizontal), more than 300 lines (vertical).
S/N Ratio: More than 40 dB (Y channel), 30 dB (chroma channel).
Audio Output: -20 dB/low impedance (through 12-pin camera cable connector).
Lens: Normal fixed lens 25mm, f 1.8 variable focus.

5) Additional details of the RCA color TV system discussed under Section 6.1.2 have been published in the July 1979 Institute of Electrical and Electronic Engineers publication Spectrum. The following is taken from that periodical:

> "A solid state camera with three charge-coupled devices (CCDs) as image sensors for each of the primary colors of television--red, blue, and green--has transmitted detailed color TV pictures from a submarine engaged in oceanographic exploration at 9000-ft depths. The prototype camera, specially configured by RCA's Electro Optics and Devices Div. for a National Geographic expedition, was mounted outside the submarine on a mechanical arm. Among the filmed marine life were pictures of giant eight-foot long tube worms that scientists say represent a basic division of the animal kingdom because of the novel anatomy. Each image sensor of the tubeless camera comprises a matrix of 512 x 320 elements for a total of 163,840

pixels. Present commercially available CCDs contain about 75,000 elements. RCA plans to introduce a compact version of the 5.5-lb camera for closed-circuit, audio/visual applications by the beginning of next year. In closed-circuit applications, CCD cameras provide instant turn-on and exhibit no image lag and no burn. Applications in home video-recorder systems are to follow as soon as design and manufacturing techniques are optimized to lower the price of the $8,000-camera.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1979 O—302-855