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Underwater Security Vehicle

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ADMINISTRATIVE INFORMATION

The work described in this report was performed from April 1991 to September 1991. It was performed under project no. MS04 01, accession no. DN309087, and program element 600328D. The responsible organization was the Defense Nuclear Agency, Hybla Valley Federal Building, Washington, DC 20305. The study was performed by Code 532 of the Naval Ocean Systems Center (NOSC), San Diego, CA 92152-5000.

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RBT

EXECUTIVE SUMMARY

OBJECTIVE

The objective of the Underwater Security Vehicle (USV) program was to evaluate the feasibility of using an underwater remotely operated vehicle (ROV) system to aid in underwater security. The USV system is to be used to assess designated contacts in a near-shore environment, augmenting existing security systems such as the Waterside Security System (WSS).

RESULTS

A series of demonstration tests were conducted to evaluate the capabilities of various commercially available ROVs. Based on the available systems and mission requirements, a specification was developed for the USV proof-of-concept system. The system procured was the Benthos SUPER SeaROVER vehicle with the Smiths Hi-Scan 600 sonar.

For 2 months, tests were run to determine the general operating parameters of the system. The system performed well overall, aptly demonstrating its capabilities to acquire, track, and intercept diver targets.

In addition to the formal testing, the capabilities of the USV system were demon-·ated during the Coast Guard MDZ/PIDR OPS 91 harbor defense exercise on [illegible] August 1991. The USV system was successfully used to detect, track, intercept, illuminate two diver targets before they reached their objective. These operations w[illegible]e [illegible]ished in an actual security setting, at night, against aware and evasive targets.

The USV system tests and its performance in the Coast Guard harbor defense exercises demonstrated that a ROV can be used effectively for assessing and intercepting underwater threats in a security environment.

RECOMMENDATIONS

Test results determined that a wide-angle sonar and navigation system would be invaluable additions to the USV system. In an operational environment, the following issues should also be considered: launch and recovery, operator display, and integration with the Waterside Security System. Incorporating these recommendations would increase the effectiveness of the USV as a security asset.

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

1.0 INTRODUCTION

1.1 OBJECTIVE

The objective of the Underwater Security Vehicle (USV) program was to evaluate the feasibility of using an underwater remotely operated vehicle (ROV) system as an aid to underwater security. The USV system shall be used to assess designated contacts in a near-shore environment, augmenting existing security systems such as the Waterside Security System (WSS).

1.2 APPROACH

The USV program was originally defined as a 4-year effort for developing an integrated USV/WSS demonstration system. In the first year (FY 89), mission requirements were established and existing systems were assessed for their suitability for the mission. In FY 90, commercial systems were demonstrated and evaluated, and the procurement documentation was prepared for the development system. In May 1990, the program was reduced to a 3-year effort, eliminating the planned design, development, and integration aspects. FY 91 saw the delivery of system hardware and the proof-of-concept demonstration.

1.3 NEED

An underwater security system is required to prevent underwater threats to critical waterside or waterborne assets such as weapon depots, loading areas, power plants, ships, and submarines. Threats may be swimmers, scuba divers, and swimmer delivery vehicles. Current systems cannot fully deal with underwater threats; and in many critical areas, absolutely no provision exists for underwater security. A system such as WSS, for example, can detect an underwater target, but cannot fully assess and classify it. Use of a ROV can fill the gaps in existing systems without exposing humans to hazardous conditions or to routine, repetitive tasks.

A number of concepts were evaluated to address the need for underwater security. Four were developed based on threat analyses and investigation of Fleet requirements (Fletcher, 1991). By direction of the program sponsor at the Defense Nuclear Agency, the USV would be developed as an assessment adjunct to the WSS system. Based on the scope of the effort, the USV program was instructed to use commercially available, off-the-shelf equipment for the proof-of-concept demonstration.

1.4 MISSION DESCRIPTION

The USV is intended to be an adjunct to the WSS or other security system. Figure 1 depicts the USV system concept, showing how the vehicle would be used as an additional sensor carried on a patrol boat responding to a target detected by another system. Figure 2 depicts the operational sequence planned for the USV system. Once the WSS or other sensors make a contact, the USV will be taken out on a patrol boat or other support craft and deployed at the contact location. The operator will reacquire the target on the vehicle sonar and use the information to vector the vehicle into visual-contact range of the target. Video from the USV will be used by the operator to assess the target and to determine the appropriate course of action. The current USV has no initial detection or response capability, being intended solely as an aid to target assessment.

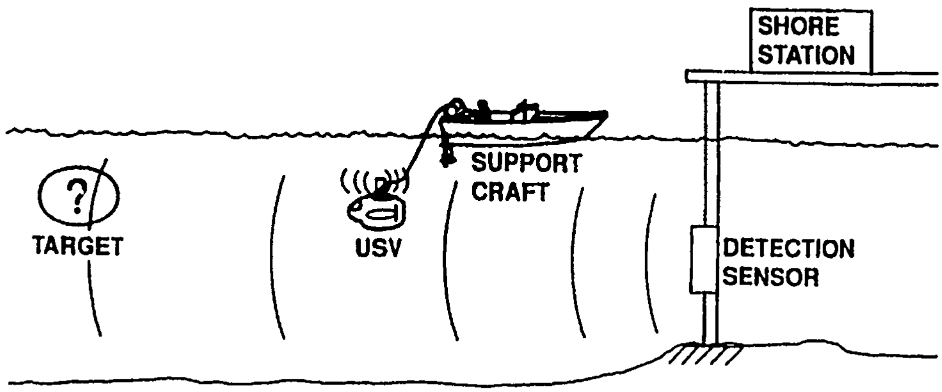


Figure 1. USV system concept.

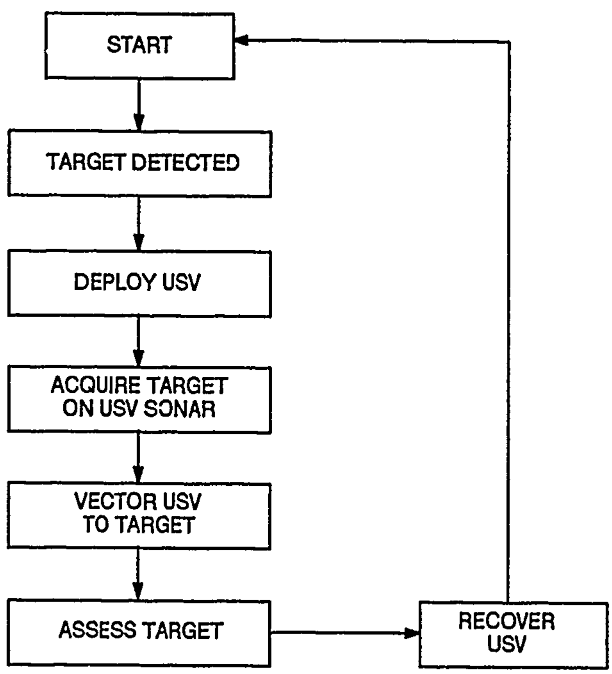


Figure 2. USV operational sequence.

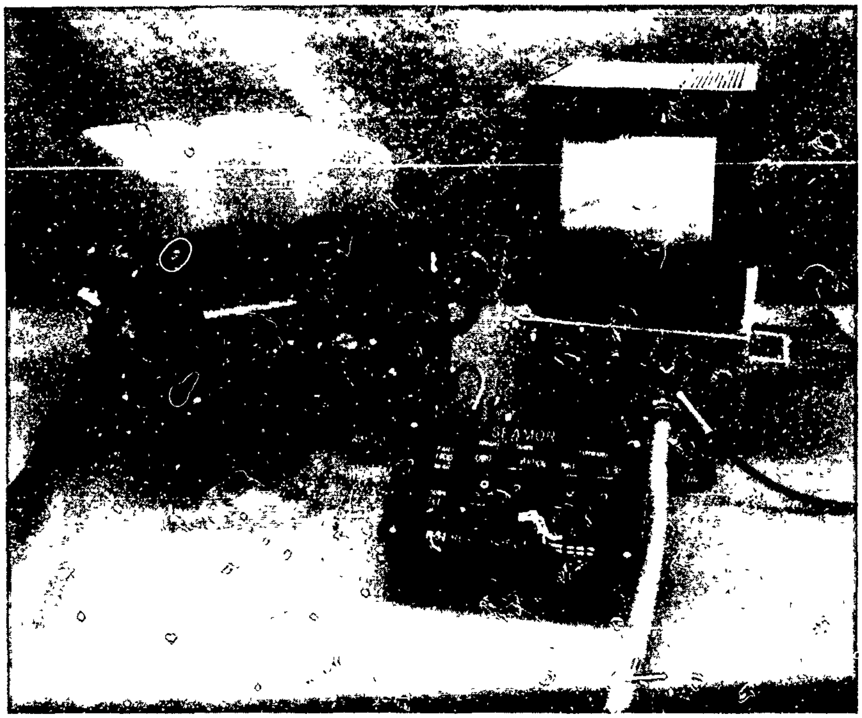
2.0 USV SYSTEM DESIGN

2.1 DEMONSTRATION AND EVALUATION OF COMMERCIAL ROVs

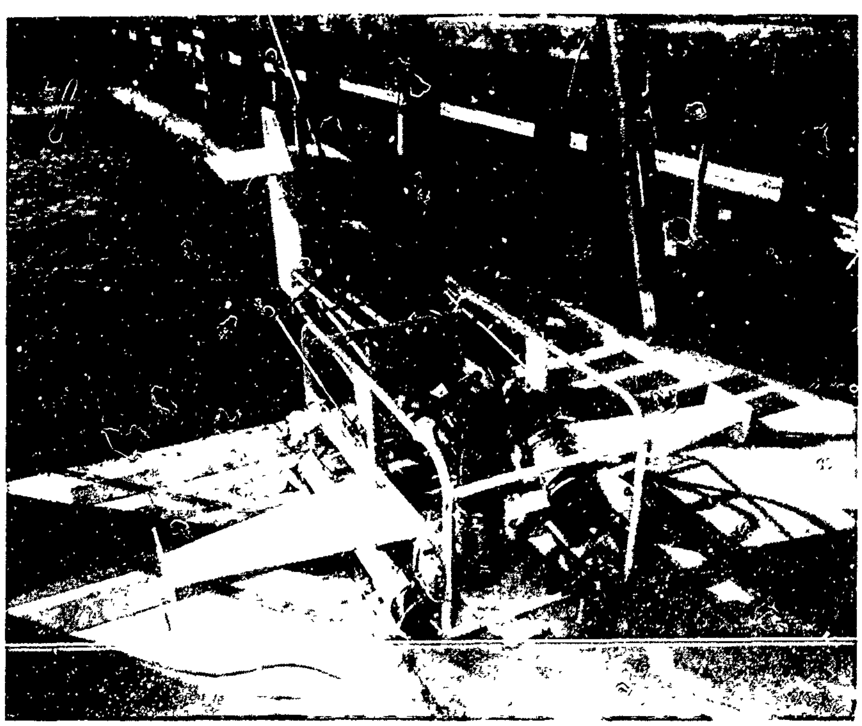
A series of demonstration tests were held in San Diego in January–February 1990 to evaluate the capabilities of various commercially available ROVs. The results of these tests were documented (Nobunaga, 1990), and the results are summarized in table 1. Five companies participated: RSI Research with SEAMOR, Sachse Engineering Associates with SEA SEARCH MK II, Perry Technologies with SPRINT 101, Benthos with SUPER SeaROVER, and Deep Ocean Engineering with PHANTOM SS4 (figure 3). Each system was evaluated on four major areas: physical characteristics, human factors, vehicle performance, and sensor performance. Operational sequences were performed using actual diver targets, demonstrating target acquisition, interception, and assessment. Of the systems tested, the SUPER SeaROVER and the PHANTOM SS4 were deemed most suitable to fulfill the USV mission.

Table 1. Demonstrated vehicle systems.

	RSI Research SEAMOR	S.E.A. Sea Search MK II	Perry SPRINT 101	Benthos SUPER SeaROVER	Deep Ocean Engineering PHANTOM SS4
Vehicle Size (l×w×h) (in)	16 × 11 × 12	68 × 24 × 28	26 × 26 × 43	53 × 25 × 22	65 × 34 × 16
Vehicle Weight (lbs)	24	162	254	177	267
Thrust (lbs)		Towed System			
Forward	2	N/A	55	91	105
Reverse	1	N/A	20	53	45
Vertical	<1	N/A	30	8	16
Lateral	<1	N/A	25	5	N/A
Average Speed (knots)	0.8	N/A	1.4	2.1	2.7
Camera Type	Color CCD	B&W Low Light	Color CCD SIT, 35 mm	Color CCD	B&W Low Light
Sonar Type	None	Side scan Sector scan	Sector scan	Sector scan	Pulse scan



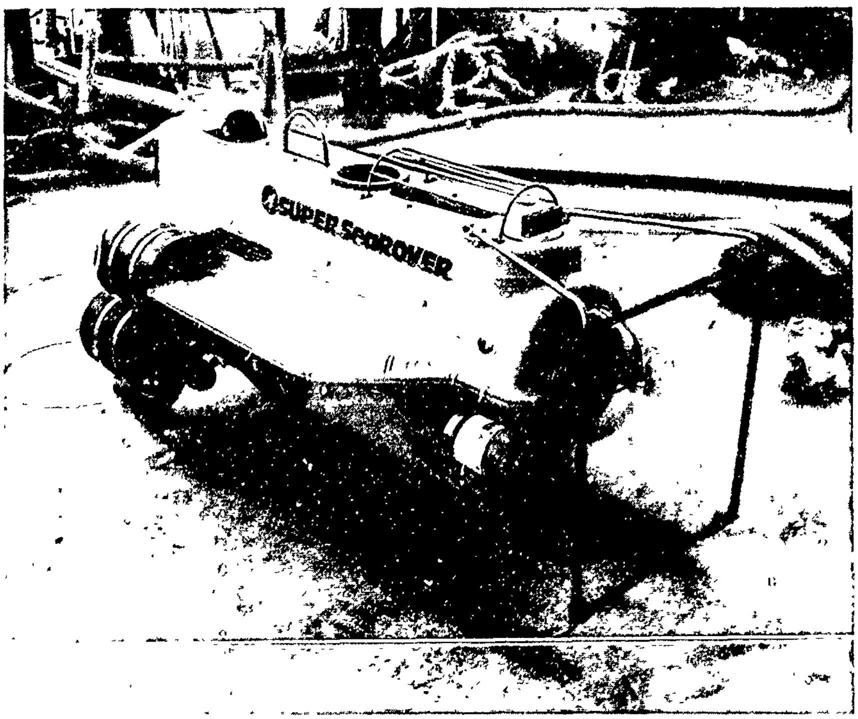
SEAMOR System



SEA SEARCH Mk-II System

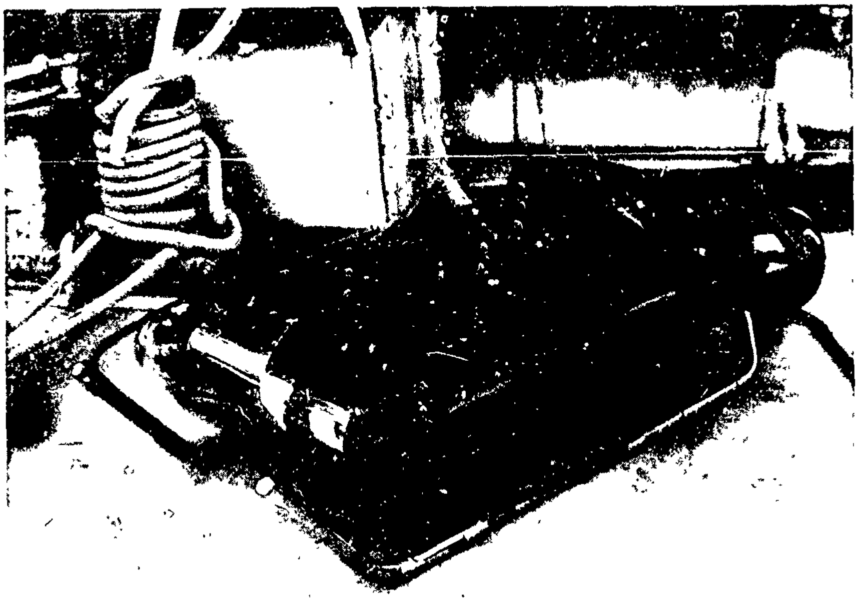
Figure 3. Demonstrated commercial vehicles.

SPRINT 101 System



SUPER SeaROVER System

Figure 3. Demonstrated commercial vehicles (continued).



PHANTOM SS4 Vehicle

Figure 3. Demonstrated commercial vehicles (continued).

2.1.1 Benthos SUPER SeaROVER

The Benthos SUPER SeaROVER is a compact system designed for multiple uses. It consists of a slightly buoyant vehicle, tether, modular vehicle-control console, power supply, joystick controller, sonar processor, sonar display, and navigation system. Two navigation systems and two sonar systems were available for evaluation with the system. The initial setup had the vehicle outfitted with a Mesotech 971 sonar and ORE Trackpoint II navigation system. An alternative configuration was also demonstrated using the UDI AS360 MS5 sonar and the SHARPS navigation system. The vehicle control console, power supply, Mesotech sonar processor, and displays were housed in similar shipping containers. The system is powered by 220-V, single-phase, ac. Control signals are sent from the control console to the vehicle. The vehicle contains the motor-control circuits within the pressure hull.

The SUPER SeaROVER is a multioperator system. It was shipped in several, man-portable, shipping containers and had to be deployed with a winch. The system can be controlled by a single operator, but for optimal performance, requires both a vehicle operator and a sonar-data analyst.

2.1.2 Deep Ocean Engineering Phantom

Phantom SS4 is a compact system that can be modified to meet user requirements. The system consists of a slightly buoyant vehicle, tether, vehicle control console, power transformer, joystick controller, sonar processor, and sonar display. Vehicle weight in this configuration is 267 pounds. The step-up transformer converts the 110 Vac to 220. The system is hard wired from the vehicle to the control console and from the joystick controller to the control console. All vehicle processing is done within the control console.

The Smiths Hi-Scan 600 (Cooke, 1988) sonar system demonstrated on the Phantom vehicle was very impressive. Since it is a scan-within-a-pulse sonar, the sonar image is updated rapidly, up to 8 times/second; thus, the operator does not have to wait for the sweep to be completed to get an updated image. The sonar clearly detected the target 80 meters away and tracked the target to within 5 meters from the vehicle. To reduce system weight and size, the mechanical pan mechanism was removed from the sonar, restricting sonar monitoring to a 30-degree sector. So, to pan the sonar unit, the vehicle was rotated.

Phantom is a multioperator system and was shipped in several, man-portable, shipping containers. The vehicle was deployed and retrieved by two people without a winch. However, a winch is highly recommended. For optimal system performance, one operator is needed to control the vehicle and one operator to interpret the sonar data.

2.1.3 Conclusion

The USV demonstration tests exhibited a full range of remotely operated vehicle systems. Each system demonstrated was evaluated relative to the USV system requirements for physical characteristics, performance parameters, operational performance, sensor performance, and human factors. Both the SUPER SeaROVER and Phantom SS4 performed well within the desired USV operating ranges. The Smiths Hi-Scan 600 sonar was considered by far the best choice for the USV system. Its high scan rate (8 times/second), clear display, and ease of use under the required dynamic operating conditions make it the clear choice for the USV application.

2.2 USV SYSTEM SPECIFICATION AND DESCRIPTION

Based on the mission requirements and available systems, a specification was developed for the USV proof-of-concept system. The system procured was the Benthos SUPER SeaROVER vehicle with the Smiths Hi-Scan 600 sonar as shown in figure 4.

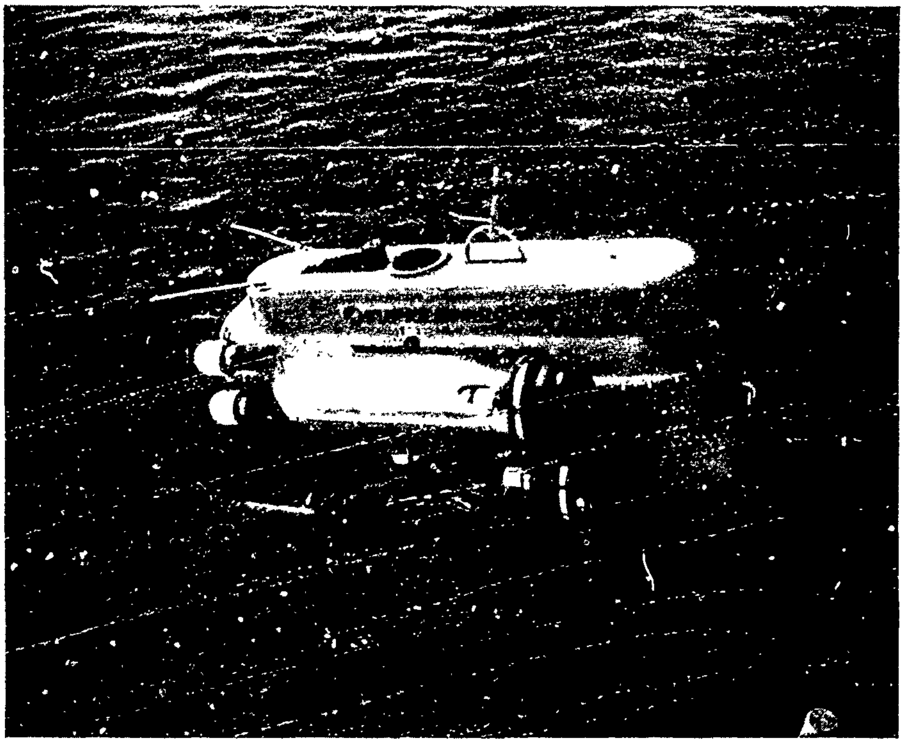


Figure 4. Photo of USV vehicle.

2.2.1 System Components

The USV system consisted of a Benthos SUPER SeaROVER vehicle, 1100 feet of 0.7-inch-diameter tether cable, a control console, a hand controller, a power-conditioning console, two monitors, and an 8-kW generator (figure 5). System consoles and monitors may be operated directly from their respective shipping cases where they are shock mounted in 19-inch racks. The system is designed to be easily transported and operated off a variety of platforms.

2.2.2 Performance Parameters

The specification for the USV required a vehicle capable of reacquiring and intercepting a swimmer or scuba-diver target. Vehicle speed was a major criteria; but thrust, stability, and maneuverability were also essential to meet these mission requirements. Desired parameters included

Depth: 150 feet minimum (1000 feet standard)

Range: 300–feet horizontal standoff minimum

Speed: 3 knots with 500 feet of tether deployed
1-knot headway in a 2-knot current

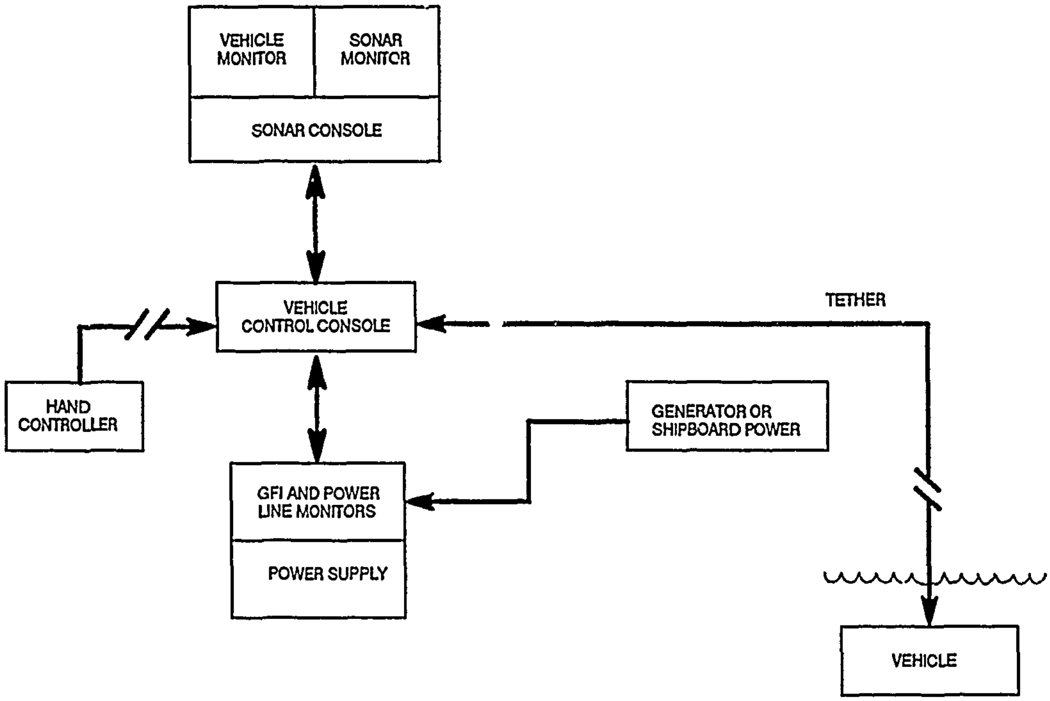


Figure 5. USV system block diagram.

2.2.3 Physical Size

As the operational system is to be used on a small 30-foot patrol boat, the system must be small and compact. Desired physical requirements included

Vehicle dimensions: No greater than 36 × 36 × 72 inches

Vehicle weight: No more than 250 pounds

Cable length: 500 feet, minimum

2.2.4 Sensor Performance

A wide-angle video camera and adjustable lighting provide the assessment and identification capability required by the USV and other missions. A Smiths Hi-Scan 600 sonar permits the reacquisition of a known target with a 30-degree swath width and a range of 40+ meters for a diver-like target. While the narrow swath and short range limit the detection capabilities of this sonar, its fast (8 times/second) update rate allow continuous tracking of a moving target. Figure 6 shows a typical sonar image.

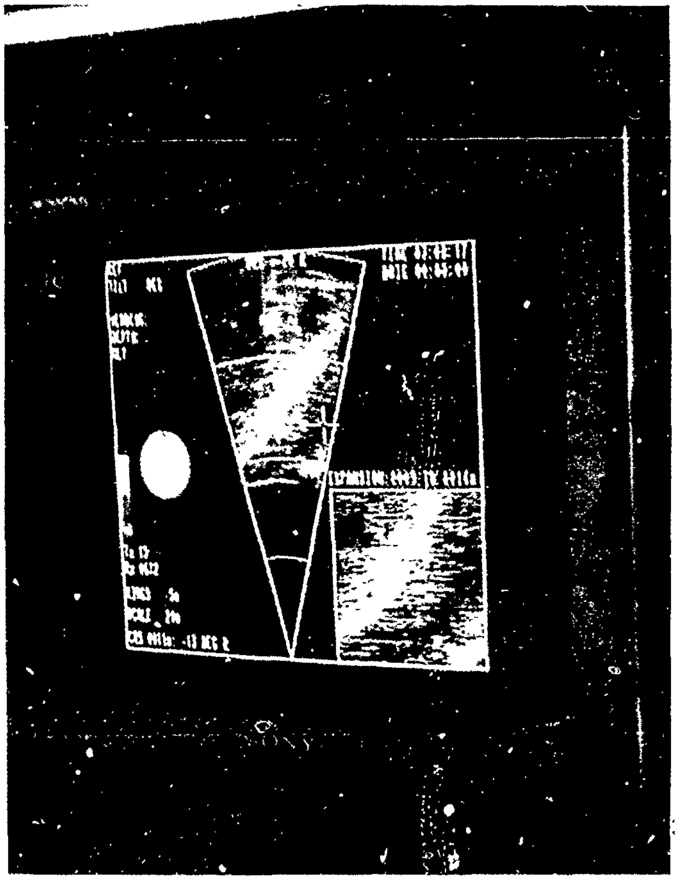


Figure 6. Photo of Smiths Hi-Scan 600
sonar display of barge hull.

2.2.5 Human Factors

Human factors such as ease of use, launch and recovery considerations, and maintainability were considered very important due to the projected operational use of the system. Desired characteristics included

Launch and Recovery: Two people on a small boat should be able to launch and recover the vehicle.

Operation: Only one person should be required to operate and control the vehicle. The displays and controls should be clear and easy to operate.

Transportation: The system (vehicle, console, cables, and related equipment) must be easily transportable.

Maintainability: The system must be rugged and easy to maintain.

3.0 USV TEST AND EVALUATION

3.1 ACCEPTANCE TESTS

Upon receipt of the USV system, a series of acceptance tests were performed to determine if the critical points of the specification were met. These tests concentrated on the general physical and performance characteristics of the system.

3.1.1 Physical Characteristics

The physical characteristics of the USV system were measured to ensure that they fell within the specification. All areas were acceptable as summarized in table 2.

Table 2. USV system characteristics.

Component	Weight (pounds)	Closed-Case (1×w×h) (in)
Vehicle	197	53 × 26 × 26
Control Console	120	33 × 27 × 28
Power Console	187	33 × 27 × 28
Video Monitor	100	33 × 27 × 24
Sonar Monitor	100	33 × 27 × 24
Tether (1100 ft)	216	Spool: 36 dia × 19
Generator	250	30 × 22 × 26

3.1.2 Performance

As with the physical characteristics, the basic performance parameters were measured and compared to the system specification. Forward speed and thrust, determined to be the most critical areas, were better than required, due to a new thruster design on the SeaROVER vehicle. (See table 3.) However, also due to the new thruster design, reverse thrust was greatly diminished from the version shown in the vehicle demonstrations (refer to paragraph 2.1). This was not considered a critical flaw in the system in light of the other results.

The sensor system onboard contained the required video and sonar capabilities. The Smiths Hi-Scan 600 performed well, yielding the fast, high-resolution images required. The video image, however, was compromised due to the use of a twisted-shielded pair in the tether for signal telemetry. A new tether containing coaxial cables for both the sonar and video was delivered in November 1991.

Table 3. USV system performance.

	Measured	Specification
Speed (knots)		
Forward	3.1	>3.0
Reverse	1.3	>1.0
Vertical	0.5	>1.0
Lateral	0.5	>1.0
Thrust (pounds)		
Forward	110	>90
Reverse	25	>45
Vertical	8	>10
Lateral	8	>5

3.2 MISSION PERFORMANCE TESTS

Once the system was accepted, tests were run to determine the general operating parameters of the system. Of particular interest for the USV mission was that the vehicle system could be used to reacquire, track, and intercept the target (figure 7). All tests, unless otherwise noted, were performed off the Kaneohe Marine Corps Air Station fuel pier in 6–7 meters of water.

3.2.1 Detection

The first series of tests run were to determine the target-acquisition characteristics of the USV system. Specific factors measured were target depth, type, and orientation. The best methods of operating the system were determined to optimize the target-acquisition range.

Under actual operational conditions, the position of the target in the water column will not be known. Therefore, the first test was to determine the optimal operating depth of the vehicle for the full range of target depths. Figure 8 shows the detection ranges for varying vehicle depths on different target depths. The maximum range achieved was 42 meters for a midwater target detected by a midwater vehicle. The limitation on the near ranges was due to the target falling outside the cone of the sonar beam. Based on these results, the best operating position for the USV was in the midwater position to achieve the maximum detection range for the full range of targets. In particularly deep water, this recommendation should be modified so that the vehicle is operating in the midrange of where the target is expected (i.e., the surface to 100 feet).

Figure 7. Photo of video showing vehicle operation with the target.

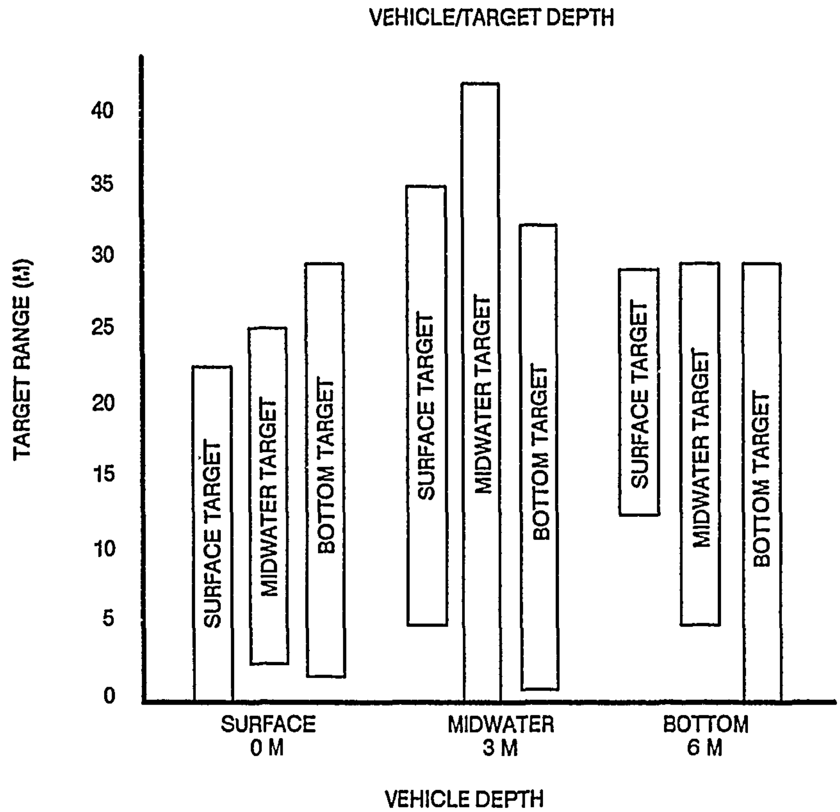


Figure 8. Vehicle/target depth chart.

Based on the tests at the KMCAS fuel pier and the Coast Guard harbor defense exercise (paragraph 3.3), it was determined that the type and orientation of the targets did not noticeably affect detection capability. In the fuel pier tests, both a dummy wetsuit and live divers using open-circuit scuba were used, with no apparent difference in target strength. Similarly, the Navy SEALS in the harbor defense exercise provided very clear targets despite the use of closed-circuit scuba. This level of performance indicated that the USV would be an effective detection tool for any expected targets in an operational environment.

3.2.2 Tracking and Interception

The second series of tests run were to determine the performance of the system in tracking different target behaviors such as speed and path. During formal testing (Appendix A), 15 runs of targets following varying speeds and paths were made. The vehicle intercepted the target 11 times, a 73-percent success rate overall.

Target speed did not appear to affect the ability of the vehicle to acquire the target. Divers were towed on a known course and bearing at speeds of 0.5 and 1 knot; no difficulty was encountered in acquiring, tracking, and intercepting them. As the vehicle top speed was measured at 3.1 knots, an unassisted diver probably could not outswim the vehicle.

The target divers were given a variety of paths to swim, including straight compass courses, doglegs, varying depths, near bottom, erratic patterns, and full-on evasive maneuvers. At any time, the target course was unknown to the vehicle operator. Two major problems were found: one, the narrow sonar beam made following erratic path changes difficult, particularly at close range; and two, overshooting a target was very easy, particularly if the target was above the vehicle operating depth. Since the sonar does not give target-depth information, once the vehicle closes in, a target may be directly above or below the vehicle, thus out of the sonar cone. If a target was below the vehicle, bubbles often would be detected, indicating the location and nature of the target. However, if the vehicle was below the target, it was easy to pass, losing the track.

Overall, the system performed well, aptly demonstrating its capabilities to acquire, track, and intercept diver targets. Note that these tests were all performed with vehicle and sonar operators with less than 10 hours of operational time, indicating the usefulness of the system even in relatively untrained hands.

3.3 PROOF-OF-CONCEPT DEMONSTRATION

In addition to the tests just described, the capabilities of the USV system were demonstrated during the Coast Guard MDZ/PIDR OPS 91 harbor defense exercise on 10–11 August 1991. The vehicle system was used to augment the in-water security at the MARISCO facility at Barber's Point Harbor. The vehicle was operated from a platform off the northwest end of the dry dock, so that the approach to the dry dock could be scanned with the sonar. Figure 9 shows the system arrangement and its deployment out of a standard van.

The system was deployed and in the water at approximately 2345 on 10 August. In-water visibility was poor (approximately 1 foot), but excellent sonar images were received from the jetty and the base of the dry dock. The vehicle was placed in an outward-looking position, roughly 50 feet from the deployment platform at the designated 0001 starting time.

Once in position, the operator demonstrated the vehicle's capability to yaw and scan a wider area than the 30-degree sonar beam. At approximately 0025 hours, a sonar contact was made at a range of 25 meters. The vehicle was driven to intercept the target, using the sonar to maintain contact with it. At a range of approximately 3 meters, sonar contact was lost. The vehicle lights were then turned on to illuminate the target from below. At this point, the target reappeared on the sonar and was again tracked to within 2-3 meters. Lights were again turned on, and the target was located on the surface by security personnel. While no visual contact was made with the vehicle camera, the action of the sonar contacts clearly showed that the targets were of interest; thus providing the required assessment function.

Figure 9. Photo of operational setup.

The vehicle then resumed a scanning pattern, searching for any additional targets. At 0045 hours, the operators were informed that the diver portion of the exercise was complete, and the vehicle was then recovered.

Upon debriefing, the divers stated that they were aware of the presence of the vehicle, but they were unable to determine its direction. They said they knew they had been located and that their mission had been compromised, since the vehicle followed them around and shined its lights on them. At that point, the divers came to the surface and conceded defeat.

The USV vehicle system was successfully used to detect, track, intercept, and illuminate two diver targets before they reached their objective. This was accomplished in an actual security setting, at night, against aware and evasive targets.

4.0 USV SYSTEM RECOMMENDATIONS

4.1 VEHICLE

4.1.1 Configuration

The SUPER SeaROVER vehicle was compact and efficient in carrying the sensors required by the USV system. However, the configuration of the vehicle made it particularly awkward to service and troubleshoot the system. The protective hard hat required removal to access the interior bottle, interconnections, and the tether connection. Gaining this access required removing 34 screws or tie wraps. Additionally, the hardhat had to be replaced to lift or deploy the system to maintain its structural integrity. For a Fleet operational system, a vehicle with simpler access to the major subsystems would be highly desirable.

4.1.2 Performance

For most USV tasks, the vehicle system performed satisfactorily. However, the decreased thrust in the reverse and vertical directions sometimes led to sluggish system response. While not critical to the USV mission, improved response in these areas would be useful.

4.1.3 Response

Generally, the response of the vehicle was excellent, perhaps even excessive. Given a yaw command, the vehicle could turn very rapidly, faster than the response of the compass. This often resulted in overshooting the target and in difficulty maintaining a desired heading. Similarly, external effects, such as current and tether pull, could greatly affect the vehicle heading. A faster compass response would enable the operator to fully exploit the vehicle's capabilities.

4.2 SENSORS

4.2.1 Sonar

The high update rate of the Smiths Hi-Scan 600 sonar was invaluable for tracking moving targets while based on a moving platform. The sonar's high resolution enabled the determination of diver-like targets and their subsequent tracking and interception. However, the narrow field of view (30 degrees horizontally and 10 degrees vertically) can make it difficult to initially acquire a target or to follow one that is rapidly changing course. Adding a mechanically scanned sonar, capable of covering a 180–360 degree area, would enable the system to perform this acquisition role more efficiently. The target could be detected initially by the mechanical sonar, which would give the operator the proper bearing to direct the vehicle. Once the vehicle is pointed in the correct direction, the Hi-Scan 600 sonar may be used for tracking and interception. Similarly, if the target is overshot, the slower, but wider field-of-view sonar can be used to determine the proper bearing for a return.

One of the additional difficulties found with the sonar was its lack of target-depth information. Currently, no sonars are commercially available that would provide three-dimensional information of this type. However, sonars are in development such as the Daisy and the Acoustic Lens (Fletcher, 1991) that would address this requirement.

Another possibility to expand the effective swath width and depth capability of the Smiths Hi-Scan 600 sonar would be to mount the sonar head on a pan and tilt device. This could be run similarly to the video pan and tilt with the degree of pan and tilt indicated on the sonar display. Spring loading the control stick to the center of the pan position would ensure a forward view unless otherwise directed. Ideally, the pan and tilt information could be integrated with the vehicle heading and depth to give the operator direct information on how to steer the vehicle to intercept the target.

4.2.2 Video

Duuring all testing, because of insufficient coaxial cable in the vehicle tether, the video display had poor quality. When a "jumper" coaxial cable was temporarily installed, the video quality was adequate for operational use. The deficient tether was replaced in November 1991.

In the harbor environment, we found that video was ineffective until the target was near, generally within the 1-meter water visibility. No improvement of video cameras or telemetry can produce a picture at a range beyond that of water visibility. However, some of the current work in laser scanner imaging (Coles, 1988) shows promise for application to the USV mission area.

4.2.3 Navigation

Because of budgetary constraints, no vehicle positioning system was installed on the USV system. An ORE Trackpoint II system was used with the vehicle during the initial operator training, vividly illustrating the need for knowing where the vehicle is relative to the host platform. With an integrated navigation system, the vehicle position could be shown relative to the target as well. This could provide a basis for system integration with the WSS system (paragraph 4.3.3).

During the harbor defense exercise, the target location was described relative to the vehicle itself, in terms of range and bearing. From an operational point of view, being able to show the target position in real-world coordinates, such as a grid system, would be very desirable. This can be accomplished by additional work with the vehicle tracking system, where all points of interest can be shown on a single map-like display containing the desired coordinate system.

4.3 OPERATIONAL CONSIDERATIONS

4.3.1 Launch and Recovery

To perform an actual security scenario, the vehicle must be rapidly deployed and recovered. While the scope of the 1989–1991 USV effort did not encompass this requirement, it must be considered in the development of a Fleet deployable system. Figure 10 shows some options for system launch and recovery that would be suitable for a rapidly deployable operational system.

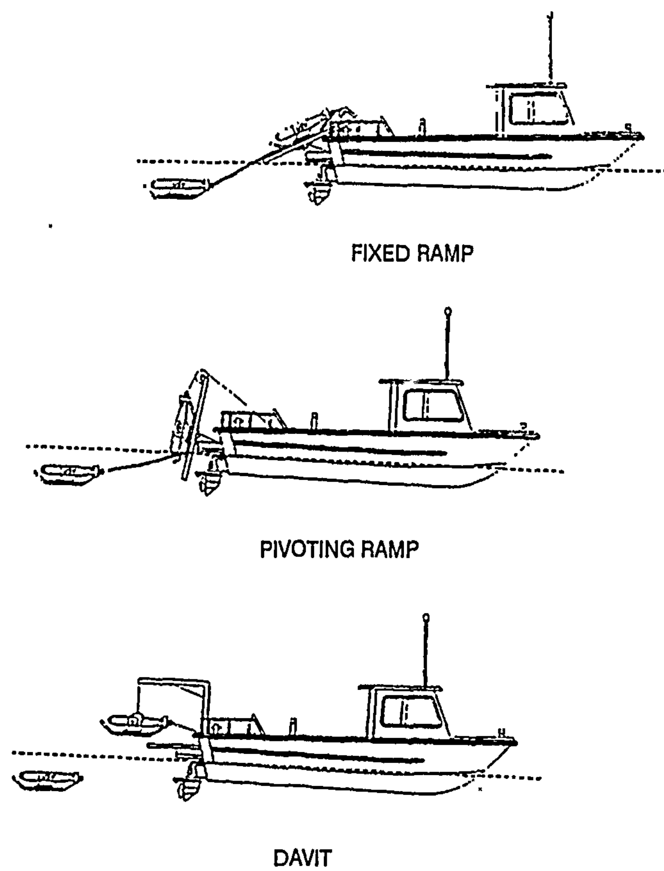


Figure 10. Proposed deployment options.

4.3.2 Operator Station/Sensor Integration

For operational use, a single operator must be capable of operating the USV system independently, controlling both the vehicle and the sonar. To do this efficiently, the video and sonar information should be available on a single monitor screen. This could be done with a window technique providing a major display with a small window of the alternate-sensor information. Since video has limited use until one closes in on the target, the sonar would be the primary image with the option to switch to video. An additional useful feature would be an auto-alert on the sonar system, providing the operator with an audible signal when a target is initially detected.

4.3.3 Integration with the Waterside Security System

Since the USV system is intended to work in conjunction with the Waterside Security System (WSS), a number of issues must be addressed prior to a Fleet deployable system. Of major importance is the issue of information exchange: how does the WSS operator provide target information to the USV operator and vice versa? Of major importance is determining the level of information available from each system and how it may be used most effectively. Also of concern is the issue of sensor compatibility: to what degree does the operation of the USV system affect the WSS sensors? Without addressing these issues, the USV system will not be an effective tool for underwater security.

5.0 CONCLUSIONS

5.1 USV FEASIBILITY

A ROV has been used effectively as a tool for underwater security. The USV system has been used to detect, track, intercept, and illuminate diver targets before they reached their objective. This was accomplished in actual security settings, including at night, against aware and evasive targets.

5.2 SYSTEM CONFIGURATION

The current USV system effectively demonstrated the concept of using a vehicle for assessing underwater targets. In addition to the current system, a fleet-deployable system would require additional sensors and a navigation system. In an operational environment, the following issues also require consideration: launch and recovery, operator display, and integration with other security systems such as WSS. With these additions, the USV would be an effective security asset.

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APPENDIX A

USV PROOF-OF-CONCEPT TEST PLAN AND RESULTS

A.1 INTRODUCTION

A.1.1 OBJECTIVE

The objective of this series of tests is to demonstrate the feasibility of using a commercially available remotely operated vehicle (ROV) for assessing previously detected underwater contacts.

A.1.2 APPROACH

A series of tests are planned to demonstrate the capabilities of a ROV for reacquiring and intercepting a target. Initially, the vehicle system will be checked out in the test pool at the contractor's facility, where the operators may gain experience in a very controlled environment. Once confidence in the vehicle operation has been acquired, full-scale operational tests will be held at the fuel pier, the location of the Waterside Security System (WSS) testbed. Vehicle operation will be demonstrated in an area known for its security-related characteristics. Upon completion of the USV system tests, demonstrations will be held at other available locations to demonstrate USV capabilities to Fleet representatives.

A.1.3 BACKGROUND

A series of vehicle demonstrations were held in San Diego in January–February 1990 to determine the most suitable ROV to use in the USV program. A system specification was drawn up based on the Phantom SS4 and Super SeaROVER vehicles and the Smiths Hi-Scan 600 sonar. The contract was awarded to Benthos, Inc., on 1 February 1991 for a Super SeaROVER vehicle with the Smiths sonar. The vehicle delivery date shifted from 1 April 1991 to 8 July 1991. This will be the system used for the USV proof-of-concept demonstration.

A.1.4 SCOPE

Due to time and funding constraints, the USV demonstration tests will be limited to a basic proof-of-concept demonstration. Given the range and bearing of a target, the operator will aim for sonar contact with the vehicle. Once sonar contact is made, the vehicle will be driven to intercept the target until a visual assessment can be made. The relevant tests will be held in a pier-side environment.

A.2 LOCATION AND SCHEDULE

A.2.1 LOCATIONS

Tests were planned between June and September 1991 at sites that include the Benthos facility in North Falmouth, MA, and the KMCAS fuel pier. Each test series was to demonstrate an additional facet of the USV capabilities.

A.2.2 SCHEDULE

Task	Location	Time
Vehicle Checkout	Benthos	13–21 June
Training	Benthos	17–21 June
Vehicle Acceptance	NOSC HI	8–12 July
Vehicle/Target Depth and Target Speed	Fuel Pier	25 July
Target Type and Orientation	Fuel Pier	31 July
Target Path	Fuel Pier	1 August
Proof-of-Concept Sponsor Demonstration	Fuel Pier	27 August
Additional Demonstrations Coast Guard Exercise	MARISCO Facility	9–10 August

A.3 SUPPORT REQUIREMENTS

A.3.1 FACILITIES

The facilities desired at each site include the availability of 220 V, single-phase power, weather protection for the control consoles, and a crane or davit for handling the vehicle.

A.3.2 PERSONNEL

Barbara Fletcher—test director

Brian Nobunaga—vehicle operator

Roy Yumori—vehicle operator

Tom Bamburg—technician/vehicle operator

Military divers will be used as targets for the operational sections of the tests.

A.3.3 LOGISTICS

Arrangements will be made with KMCAS and SSP *Kaimalino* personnel to ensure that no conflict exists in the use of the fuel pier. Some SSP *Kaimalino* facilities may be used to support the testing.

A.3.4 EQUIPMENT

In addition to the basic vehicle system equipment, some means must be available for launching and recovering the vehicle. A small hoist would be appropriate or possibly existing cranes aboard the SSP *Kaimalino*. A calibrated winch, such as used for the USV demonstration tests, will be used for towing targets.

Equipment Checklist

Recovery hook

Calibrated winch

Sonar reflectors for vehicle reference markers

Dummy target (wetsuit with clump weight and float)

A.4 TEST SETUP

A.4.1 TEST AREAS

The fuel pier will provide the primary area for evaluating vehicle performance and operational characteristics. The objective is to demonstrate the capabilities of the USV system under the realistic operating conditions used by the WSS testbed system. The setup will include a test course for measuring vehicle speed and locating the target. Natural objects and structures will be used for demonstrating the operational performance in a natural environment.

Usually, the vehicle system will be staged off the SSP *Kaimalino*. The ship's facilities will provide power, protection, and the hoist.

A.4.2 ENVIRONMENTAL CONDITIONS

The fuel pier is being used to evaluate system operation under a convenient, yet accessible source of natural operating conditions. Conditions will be measured and monitored so that such effects as water visibility and obstacles may be considered for the performance evaluation.

A.4.3 SAFETY REQUIREMENTS

Standard safety precautions will be observed for using high-voltage equipment around water. Proper procedures will be used for handling overweight and bulky items. Divers will be warned to avoid the vehicle thrusters when active. The vehicle will be kept away from ship propellers, pontoons, pilings, and other areas where the tether could become tangled.

A.5 TEST PROCEDURES

The first series of tests (paragraphs A.5.1, A.5.2, and A.5.3) will be conducted to determine the target-acquisition characteristics of the USV system. Target depth, type, and orientation are the specific factors to be measured. The best methods for operating the system will be determined to optimize the target-acquisition range.

The second series of tests (paragraphs A.5.4 and A.5.5) will be conducted to determine system performance for different target behaviors such as speed and path.

A.5.1 VEHICLE/TARGET DEPTH

A.5.1.1 Objective

The test objective is to determine the optimal operating depth of the USV system and the corresponding sonar settings.

A.5.1.2 Procedure

1. Initiate and launch the USV.
2. Record system and environmental conditions in the USV System Operations Log.
3. Set the reference buoys at the designated "home base" for the vehicle.
4. Set the dummy height above the bottom by adjusting the clump weight. These tests will be run for three target positions:
    a. Water surface
    b. Midwater (approximately 3 meters deep)
    c. Bottom
5. Set the dummy with the pier as background so the target may be easily distinguished.
6. Get maximum vehicle range by reversing until the target is lost on the sonar. For each target position, a test will be run for three vehicle positions:
    a. Water Surface
    b. Midwater (approximately 3 meters deep)
    c. Bottom
7. Reacquire the target on sonar.
8. Record maximum range and sonar settings on chart 1.

A.5.1.3 Data—Chart 1, Vehicle Depth Versus Target Depth

DUMMY TARGET 7/25/91

TARGET / VEHICLE	SURFACE	MIDWATER	BOTTOM
SURFACE	Range 25M Range Scale 40M RX 07TZ TX 14	Range 25M Range Scale 40 RX 05TZ TX 12	Range 15 Range Scale 20 RX 14 TX 7 BUOY
MIDWATER 2-3M	Range 26 Range Scale 40 RX 08TZ TX 14 MIN 1.25 M	Range 42 Range Scale 80 RX 3TZ TX 16	Range 20 Range Scale 20 RX 14TZ TX 7 BODY MIN 4M
BOTTOM 6M	Range — Range Scale — RX — TX —	Range 28 Range Scale 40 RX 4TZ TX 16	Range — Range Scale — RX — TX —

A.5.1.4 Data Evaluation

Target range data points will be plotted as a function of vehicle depth. Trends will be determined for the best vehicle depth for general-purpose operation. Similarly, trends for sonar settings will be observed to determine the most useful settings.

A.5.2 TARGET TYPE

A.5.2.1 Objective

The test objective is to determine if a difference in target detectability exists between the dummy and a diver using open-circuit SCUBA.

A.5.2.2 Procedure

1. Initiate and launch the USV.
2. Record system and environmental conditions in the USV System Operations Log.
3. Set the reference buoys at the designated "home base" for the vehicle.
4. Set the diver height above the bottom. The diver is to be in a vertical position. These tests will be run for three target positions:

a. Water surface

b. Midwater (approximately 3 meters deep)

c. Bottom

5. Set the diver with the pier as background so the target may be easily distinguished.

6. Get maximum vehicle range by reversing until the target is lost on the sonar. For each target position, a test will be run for three vehicle positions:

   a. Water Surface

   b. Midwater (approximately 3 meters deep)

   c. Bottom

7. Reacquire the target on sonar.

8. Record maximum range and sonar settings on chart 2.

A.5.2.3 Data—Chart 2, Differences in Target Detectability

VERTICAL DIVER TARGET 8/1/91

VEHICLE \ TARGET	SURFACE	MIDWATER	BOTTOM
SURFACE	Range 23M Range Scale 40 RX 05T2 TX 16	Range 25M Range Scale 40 RX 05T2 TX 16 MIN 2M	Range 30M Range Scale 40 RX 07T2 TX 16 FLOAT?
MIDWATER 2-3M	Range 35M Range Scale 40 RX 05T2 TX 15 5-7 MIN	Range 37M Range Scale 80, 40 RX 05T2 TX 15	Range 32M Range Scale 40 RX 06T2 TX 16 MIN 1.25
BOTTOM 6M	Range 30M Range Scale 40 RX 05T2 TX 16 12 MIN	Range 30M Range Scale 40 RX 05T2 TX 16 5 MIN	Range 30M Range Scale 40 RX 06T2 TX 16

A.5.2.4 Data Evaluation

Plot target range data points as a function of vehicle depth. Combine with data from paragraph A.5.1.3.

A.5.3 TARGET ORIENTATION

A.5.3.1 Objective

The objective of this test is to determine the differences in target detectability for varying orientations of a diver such as a side view versus a front view.

A.5.3.2 Procedure

1. Initiate and launch the USV.
2. Record system and environmental conditions in the USV System Operations Log.
3. Set the reference buoys at the designated "home base" for the vehicle.
4. The diver is to be in the midwater, about 3 meters deep. Tests are to be run for two target positions:
   a. Horizontal, parallel to the pier (side view).
   b. Horizontal, perpendicular to the pier (front view).
5. Set the diver with the pier as background so the target may be easily distinguished.
6. Get maximum vehicle range by reversing until the target is lost on the sonar. For each target position, these tests are to be run for three vehicle positions:
   a. Water Surface
   b. Midwater (approximately 3 meters deep)
   c. Bottom
7. Reacquire the target on sonar.
8. Record the maximum range and sonar settings on chart 3.

A.5.3.3 Data—Chart 3, Target Detectability Versus Diver Orientations

DIVER TARGET 8/1/91

TARGET POSITION / VEHICLE	SIDE VIEW	FRONT VIEW	VERTICAL (FROM SECTION 5.2)
SURFACE	Range ____ Range Scale ____ RX ____ TX ____	Range ____ Range Scale ____ RX ____ TX ____	Range ____ Range Scale ____ RX ____ TX ____
MIDWATER 3M	Range 32M Range Scale 40M RX 05TZ TX 16	Range 32M Range Scale 40M RX 06TZ TX 16	Range 37M Range Scale 40 RX 05TZ TX 15
BOTTOM	Range ____ Range Scale ____ RX ____ TX ____	Range ____ Range Scale ____ RX ____ TX ____	Range ____ Range Scale ____ RX ____ TX ____

TARGET STRENGTH APPEARS EQUIVALENT

A.5.4 TARGET SPEED

A.5.4.1 Objective

The objective of this test is to determine the effect of the target's speed on the vehicle's tracking and interception ability.

A.5.4.2 Procedure

1. Initiate and launch the USV.
2. Record system and environmental conditions in the USV System Operations Log.
3. Set the reference buoys at the designated "home base" for the vehicle.
4. Set the diver height above the bottom. These tests are to be run for three target positions:
   a. Water surface
   b. Midwater (approximately 3 meters deep)
   c. Bottom

5. Attach the diver to the calibrated winch.

6. The diver swims out to maximum range (estimated at 100 meters).

7. Set the vehicle at the base point and desired water depth.

8. Pull the target in at varying speeds. (Straight path)

   a. 0.5 knot

   b. 1.0 knot

9. Record the time and range of target acquisition on chart 4.

10. Drive the vehicle out to intercept the target and obtain a visual assessment.

11. Record the time of target interception or loss. Estimate the range at the point of target loss.

A.5.4.3 Data—Chart 4, Target Speed Versus Vehicle Tracking/Interception Capability

R1: Range at which target is detected.
R2: Range at which target is intercepted or lost.
T1: Time at which target is detected.
T2: Time at which target is intercepted or lost.
Ttot: Total time of ROV/target interaction.

DIVER TARGET 8/1/91

TARGET SPEED / TARGET DEPTH	0.5 KNOTS	1.0 KNOTS
SURFACE	R1: 21 R2: 0 T1: 0:41 T2: 1:16 Ttot: 35 SEC FOUND	R1: 30 R2: 15 T1: 0 T2: 1:01 Ttot: — LOST
MIDWATER	R1: 32 R2: 0 T1: 0:16 T2: 0:49 Ttot: 0:33 FOUND	R1: 37 R2: 0 T1: 0 T2: 48 Ttot: 48 FOUND
BOTTOM	R1: 30 R2: 0 T1: 1:16 T2: 1:45 Ttot: :29 BUBBLES	R1: 35 R2: 0 T1: 0 T2: 48 Ttot: :48 BUBBLES

A.5.5 TARGET PATH

A.5.5.1 Objective

The objective of this test is to determine if the vehicle can be driven to intercept a target that is following a variety of paths toward an asset.

A.5.5.2 Procedure

1. Initiate and launch the USV.
2. Record system and environmental conditions in the USV System Operations Log.
3. Set the reference buoys at the designated "home base" for the vehicle.
4. The diver swims out to maximum range.
5. The divers swim the following patterns:
   - A. Straight compass course at surface
   - B. Straight compass course midwater (10 feet)
   - C. Straight compass course near bottom
   - D. Straight compass course at varying depths
   - E. Dogleg pattern, changing compass course once
   - F. Erratic pattern, changing compass course repeatedly
   - G. Creep along bottom, taking evasive maneuvers
   - H. Evade the vehicle any way possible
6. Record the time and range of target acquisition and loss on chart 5.

A.5.5.3 Data—Chart 5, Vehicle Target Path Versus Interception Capability

DIVER TARGETS 8/6/91

	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE
Description:	A	B	C	A
R1:	38	39	37	38
R2:	2.5	5	2	2.5
T1:	0	0	1:12	0
T2:	:53	51	1:42	:55
Ttot:	53	51	:30	:55
	LOST	FOUND	FOUND BUBBLES	FOUND

	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE
Description:	E	D	D	F
R1:	37	30	32	37
R2:	2	0	0	2.5
T1:	1:20	0	29	0
T2:	1:42	:22	1:03	:50
Ttot:	:22	:22	:34	:50
	FOUND	BUBBLES	BUBBLES	BUBBLES

Chart 5 (continued)

	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE
Description:	F	F	G	G
R1:	39	38	35	25
R2:	25	5	35	2
T1:	0	:44	:23	1:20
T2:	:57	2:40	1:50	1:41
Ttot:	:57	—	—	:21
	BUBBLES	DIVERS LOST/ OFF COURSE	LOST -PULLED OFF COURSE	FOUND BUBBLES

	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE	DIVER CHOICE
Description:	H	H	H	SONAR FREEZING
R1:	35	37	35	
R2:	3	0	0	
T1:	:30	20	:31	
T2:	1:30	1:12	1:16	
Ttot:	:60	:52	:45	
	LOST	FOUND BUBBLES -PASSED	FOUND BUBBLES	

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The results of the Underwater Security Vehicle (USV) program are given. The objective of this program was to evaluate the feasibility of using a remotely operated underwater vehicle system as an aid to underwater security. An Underwater Security Vehicle (USV) system was tested and its performance was evaluated in Coast Guard harbor defense exercises. These tests and exercises demonstrated that a remotely operated vehicle (ROV) can be used effectively for assessing and intercepting underwater threats in a security environment.

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