RECOVERY OPERATIONS UTILIZING A REMOTELY CONTROLLED VEHICLE/WORK SYSTEM

Norman B. Estabrook
Robert L. Wernli
Robert T. Hoffman

NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152

ABSTRACT

As part of the Navy's extended salvage depth capability R&D Program, a conceptualized Deep Ocean Recovery System (DORS) was simulated by the integration of an unmanned salvage Pontoon Implacement Vehicle (PIV) with a previously developed Work Systems Package (WSP). The integrated system was exercised over a six-week period at San Clemente Island, CA, and successfully performed rigging, attachment, and lift efforts on various recovery targets, culminating with the successful attachment and lift of an F-4 aircraft.

A wide variety of novel devices were utilized in the recovery system, including a microprocessor controlled lift module. Results of these tests will be applied to determine the capabilities and specifications of future recovery systems. This paper will present an overview of the testing and results.

INTRODUCTION

Increasing exploration and exploitation of the seafloor for raw materials, food, and defense have resulted in the proliferation of special-purpose ships and underwater vehicles. It is inevitable that accidents will occur resulting in loss of equipment in deep-ocean depths. For reasons of national value, intelligence, or science, there is a continuing need for salvage and recovery operations.

During Fiscal Year 1979, a multi-laboratory working group was formed to examine alternative techniques for recovery in the deep ocean. The group was comprised of representatives from the Naval Ocean Systems Center (NOSC), the Civil Engineering Laboratory (CEL), the Naval Coastal Systems Center (NCSC), Battelle Memorial Institute (BMI), and the Office of the Supervisor of Salvage. Under the Deep Ocean Technology Program (DOT) managed by the Naval Sea Systems Command (NAVSEA 05R2), the project has as its ultimate aim the specification, fabrication, and documentation of representative equipment, systems and techniques which will form a technology base for the recovery of objects up to 5 tons from depths to 20,000 feet.

Technology developed through the Navy's Deep Ocean Technology (DOT) Program, the Large Object Salvage System (LOSS) Program and the Extended Salvage Depth Capability (ESDC) Program would be directly integrated to help form this technology base.

Through extensive tradeoff studies, an early concept of such a recovery system was established. However, the research indicated key areas where additional information would be required, involving at-sea simulation of the conceptual system.

It was determined that two systems currently existing could, when combined, closely meet the requirements for work capability, size, and thrust inherent in that concept. These are the Work Systems Package (WSP) and the Pontoon Implacement Vehicle (PIV). Although mating the two systems would provide only a shallow operational capability, many key questions could be answered.

The Work Systems Package (Figure 1) was chosen as a representative system to demonstrate work capabilities required for deep water recovery and work operations. The WSP was developed and fabricated under the Navy's Deep Ocean Technology Program and is designed to provide a versatile work capability to depths of 20,000 feet. The WSP is a group of manipulator arms and tools integrated into a modular package that will provide a heavy-duty work capability when mounted as a unit on unmanned cable-controlled submersible vehicles, as well as on manned vehicles. In addition, it can be positioned and controlled by divers or operated independently from a surface support ship for operations at shallow depths without the need for a submersible. The system was designed to accomplish a complete work task on the ocean floor without the necessity of resurfacing for tool interchange. Basic components of the work package include two simple outer manipulator arms, without elbow functions, that act as "grabbers" or restraining/holding arms to steady the vehicle or to hold small work pieces. A centrally located seven-function manipulator arm can select, interchange, and operate a variety of

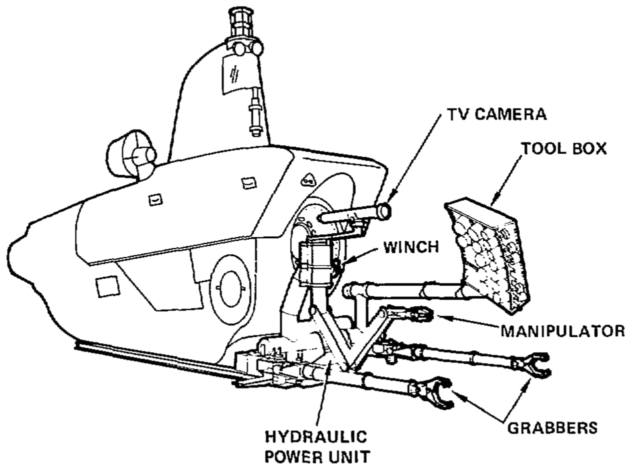

Figure 1. WSP on Alvin.

hydraulically-powered, explosively actuated, or electrically-actuated tools. Included in the storage box are tools to perform cable cutting, synthetic line cutting, nut torquing, jacking, prying, wire brushing, sawing, grinding, drilling, chipping, and stud driving. An electrically driven hydraulic pump unit supplies the power to a majority of the tools. Electric power is supplied from a self-contained battery package. Control of all operations and functions is provided through a multiplexed telemetry circuit from the vehicle. Pressure insensitive electronic circuits and pressure compensated hydraulic components allow all systems to operate at full ambient pressure.

The Pontoon Implacement Vehicle (Figure 2) was chosen as the mounting platform for the WSP. The PIV was developed as a part of the Large Object Salvage System (LOSS) at the Naval Coastal Systems Center, (NCSC) Panama City, FL. The PIV is a cable-controlled, highly-maneuverable, and precisely controlled vehicle. The PIV is powered through a system of five variable-speed thrusters, providing three-dimensional motion. A variable ballast system, carrying a load of sea water up to 2,000 pounds, can be used in conjunction with thrusters to provide the lifting force. A television camera and light source are mounted on each of two pan and tilt units to assist in flying and positioning of the vehicle for salvage or recovery operations.

This paper summarizes the devices used and the results obtained during the at-sea testing of the WSP/PIV system. A description of the test objects, attachments, rigging and lift methods, and overall scenarios is provided.

BACKGROUND

The Work Systems Package (WSP) was mated with the Pontoon Implacement Vehicle (PIV) (Figure 3) and transferred to San Clemente Island (SCI) for testing on 17 July 1979. SCI had been chosen as the test site because of the clarity and depth of the water and the protection provided by the NOTS

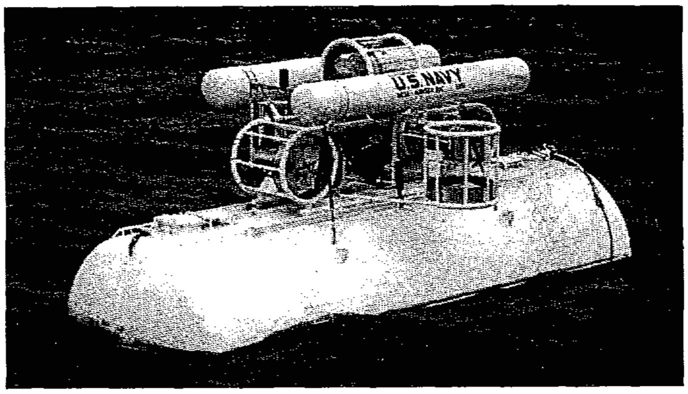

Figure 2. Pontoon Implacement Vehicle

Pier area. Operations were conducted off the YD197, a NOSC crane barge. This provided WSP personnel with adequate deck space and support facilities along with a crane capable of launching and recovering the approximately 28,000 pound vehicle. The vehicle was released from the YD197 crane by divers once it was in the water.

The purpose of the test was to investigate or develop applicable recovery techniques to be used in conjunction with a remotely controlled vehicle/ work system; the WSP/PIV. Results from the testing will be used in the formulation of a technology base which will provide the Navy with the capability to develop future systems to perform deep ocean recovery operations.

An operational depth of 65-95 feet was chosen. Although the lighting and cable dynamics for the system at this depth were not the same as they would be in a 20,000 foot system, most of the important exercises were realistically duplicated. Additionally, through the use of scuba divers, both observation and photographic documentation could be maximized, while the system performed the complex rigging and recovery operations. Besides the still and motion picture coverage provided by the divers (Figure 4), the WSP/PIV cameras were connected to a video tape system for backup documentation, and a test log was kept which detailed each step of the operation and all problems encountered (reference (1)).

The WSP/PIV was operated during the six week testing period by two of three team members chosen for this task. The WSP and PIV control consoles were installed side-by-side in the control van to allow close communications between the operators. The WSP functions and TV cameras were controlled by the WSP operator while giving direction to the PIV pilot during in-water flight. Once the desired dive area was reached by the vehicle, it was thrust to the bottom and positioned for the test sequence of the day. The vehicle, which is slightly buoyant, was then held on the bottom using its vertical thrusters. The WSP/PIV operators were then able to decide the required course of action and begin the task.

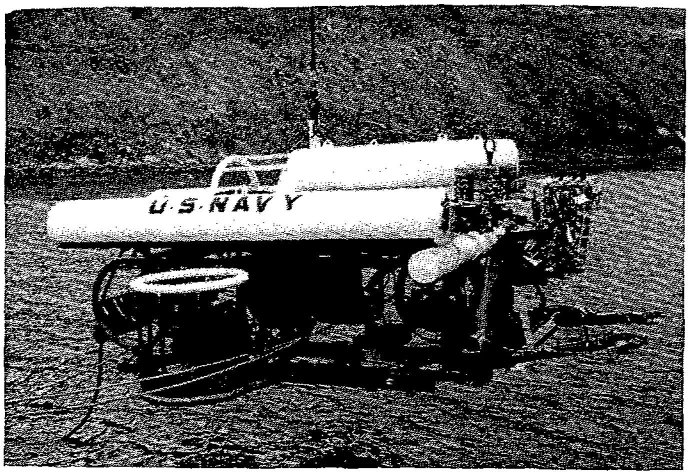

Figure 3. Work System Package mated with Pontoon Implacement Vehicle.

TEST OBJECTS

Tradeoff studies were conducted during FY79 to determine the most appropriate method of rigging and lifting objects from the ocean bottom for the WSP/PIV. For testing purposes, test objects were chosen to reflect the general characteristics of classes of objects which might require recovery. The generic objects chosen were:

a. Flat Plate - Approximately 8 feet x 8 feet, 1/2 inch thick steel. This provided a heavy, thick, large drag object capable of accepting simple attachments.

b. Large Appendaged Object - A larger, heavier object that would allow use of both simple or complex methods of attaching/rigging both on or off the bottom was desired. The "old WSP test fixture" was used for this object. It is approximately a 5 foot x 5 foot x 7 foot open steel cube weighing approximately 2,400 pounds.

c. Jet Engine

d. Wing section

e. Aircraft - F4 and E1B

The aircraft components provided structures with thin skins upon which multiple methods of lift could be attempted. They also are large, high drag objects with considerable entrained water. These objects were placed off SCI near the kelp line prior to the operations. The devices and methods used to recover them are discussed in the following sections.

RECOVERY SCENARIOS

Studies were conducted to determine the most effective scenarios for attachment, rigging, and recovery of objects using an unmanned tethered vehicle. It was assumed that the object had been located, marked, and photographed and that the recovery team knew, as accurately as possible, the condition of the object to aid in the choice of attachments. Several different techniques were utilized for the recovery exercises, depending upon the generic class of the target. It should

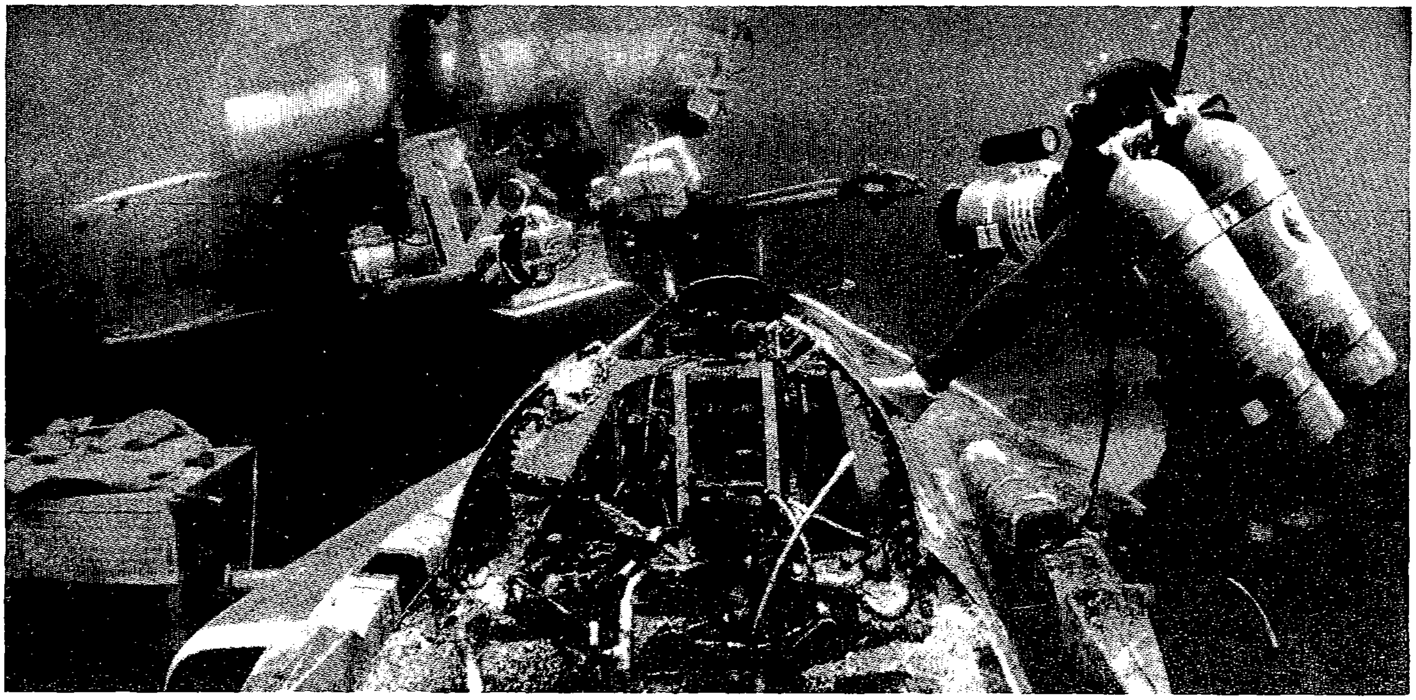

Figure 4. WSP/PIV with divers taking photographic coverage of lift module (bottom left) being rigged to the aircraft (center) prior to recovery.

be emphasized that in the recoveries it was assumed that the system being used can take down tools and devices but in most cases will not have the capability to grab and recover the object in one operation. The primary tests will be discussed along with the devices used to perform the recoveries.

High Density Objects

The recovery of high density objects (i.e., steel structures) which do not have appendages or other points for attachment, may require the installation of several attachment points to prepare them for lift. Once the target is located, the installation of the attachment points can begin.

The first and most simple target was the flat steel plate. The WSP has the capability to drill holes through steel plate. Therefore, an attachment, the toggle bolt padeye, was developed to utilize this capability and the dexterity of the manipulator.

The primary advantages of the toggle bolt padeye (Figure 5) include easy installation, small size, and high lifting strength with a small through hole requirement. The prototype has been tested to 4,700 pounds with a through hole of 3/4 inch diameter. This is achieved primarily through the unique eccentric configuration of the unit. A relatively large load bearing area is available through the grip plug configuration. The toggle bolt is easily installed by the WSP manipulator into a predrilled hole and locked by turning it 180 degrees. The entire assembly then rotates as a unit and the bearing surface is preserved for all orientations of the eye.

During the testing at SCI, installation of two padeyes into the steel plate was straightforward. Since the drilling capability of the WSP had been proven during previous testing (reference (2)), the toggles were installed into predrilled holes. The primary concern during installation was with viewing the toggles to determine their installation status. A problem with any system occurs when the manipulator is working in front of the cameras; i.e., it will usually block all or part of the view. This can cause both alignment and insertion difficulties. The dual camera capability of the WSP helped offset this inadequacy. Also, contrast of system components against the target is required. A steel toggle near a hole in a steel plate in slightly turbid water becomes close to invisible. The zoom lens installed on the WSP aided significantly in this area although there were focus problems during full "magnification." A means must be provided to help highlight the drilled holes and/or the toggle being inserted. One last point is the insertion status. A means was needed to tell the operator when the toggle was in and locked, other than pulling on it or letting go to find out. This can often result in a lost attachment or unnecessary repetition of the task.

Lifting of the plate would require the rigging of all attachments to a single point for lift. Following this, the vehicle can attach to the plate and recover it using the thrusters, 2,000 pound variable ballast, or by attaching auxiliary lift devices. Such techniques will be discussed during other scenarios. Actual recovery of the plate was not attempted since the methods to be utilized had been demonstrated on the steel test cube which will be discussed next.

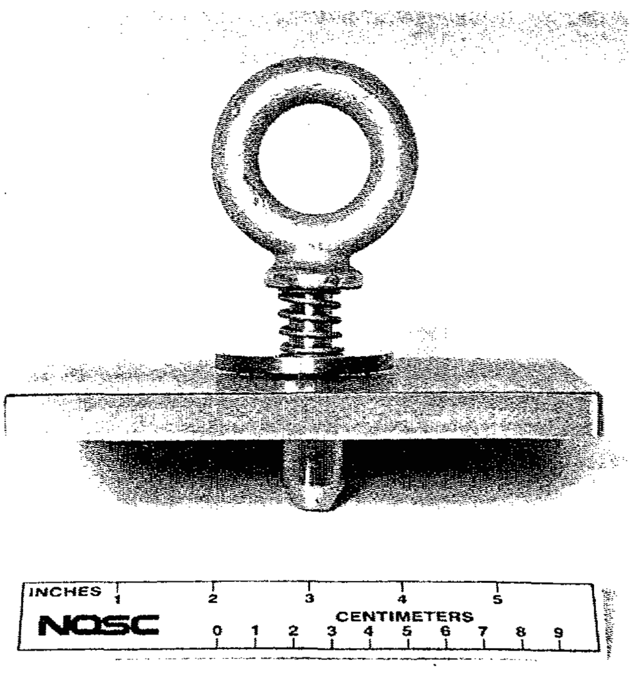

Figure 5. Toggle Bolt padeye.

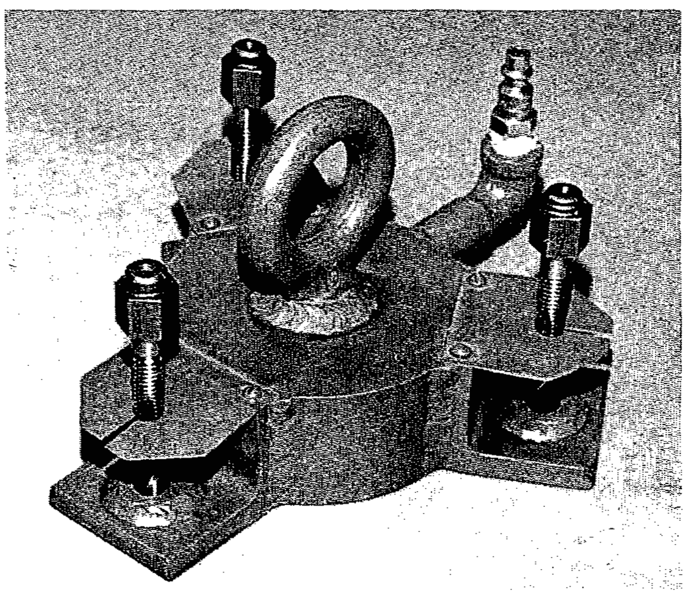

Figure 6. Drill-Tap-Bolt padeye.

The 2,400 pound steel test cube provided a target on which several of the recovery techniques could be used. It also provided one with considerable entrained water. The vertical smooth sides provided an optimum location to demonstrate the Drill-Tap-Bolt (DTB) Padeye (Figure 6). It was developed to provide an adequate attachment capability for systems with limited manipulative capability. It is a triangular unit with integral Padeye, 3 drill-tap-bolts and a suction cup. A vehicle with a single manipulator can install such a device. After attaching the suction line, the manipulator can place the DTB padeye against the target, and, after applying suction, leave it in place without support by the arm. This frees the manipulator to obtain the impact wrench with which the drill-tap-bolts are driven into the object. Upon completion, the suction line is removed and placed on the next DTB padeye. It is removed from the holder and the process is repeated until all attachments have been installed. This is much simpler than having one arm hold the padeye in place while another drills, taps, and inserts three bolts. Also, improved operator control over problems such as the breaking of taps during installation or removal, holding of the padeye during bolt insertion and alignment/installation of the attachment bolt(s) is provided by the integrated design of the DTB padeye. Thus, the DTB unit will provide a time-effective method of installing a padeye regardless of the dexterity of the system.

Unfortunately, the use of this device was limited to the laboratory, due to the failure of the vehicle suction pump. Instead of installing the 4 DTB padeyes, the shackles which had been installed as a backup would be utilized for the remainder of the scenario. To complete preparation for the recovery these four points would require rigging to a single, central lift point.

The single lift point was a requirement placed on all recovery operations because the primary lift method, other than vehicle capabilities, would be a single lift module with a 10,000 pound lift capability, the maximum weight addressed during these exercises. However, for the test cube, the combined capabilities of the 2,000 pound variable ballast and the approximately 1,600 pounds of vertical thrust would be used to recover the 2,400 pound object. Therefore, one area of concern remained -- how do you rig a 4 point lift to a single point while only using the vehicle? This led to the development of the Rigging Module.

The Rigging Module (RM) (Figure 7), was developed to provide a single point lift capability during a multi-attachment operation. It also provided a means to automatically equalize the load distribution on the lifting lines caused by errors during installation or by objects with unbalanced weight distribution.

The RM consists of buoyancy pods encased in a steel frame equipped with a garland ring at the top as an attachment point for the lift line. Four attachment arms extend from the underside of

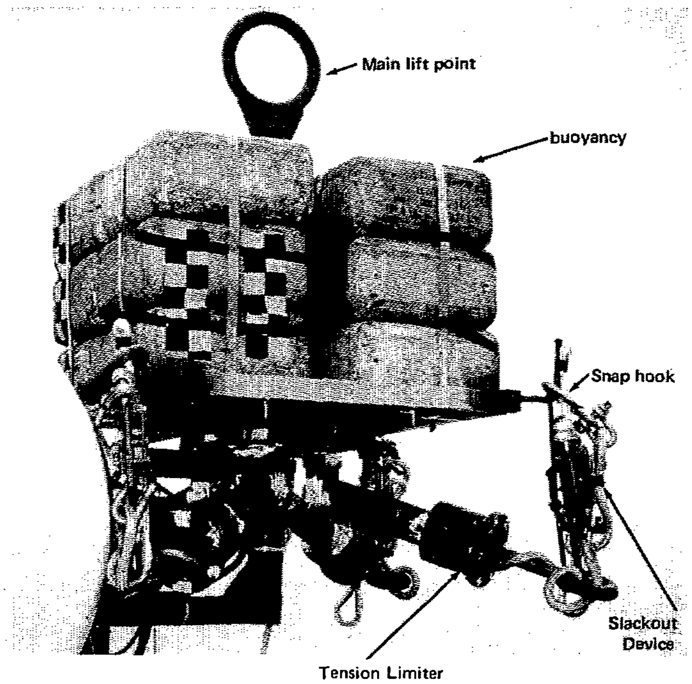

Figure 7. Rigging Module

the frame and are equipped with load attachment lines and hooks. Each rigging line consists of a snap hook and a "slackout device." Once connected to the attachment point, the line can be pulled through the "cam cleats" of the slackout device to remove the excess rigging line. During operation, the RM is first attached to a point centrally located within the attachment points and then deployed. The buoyant RM is then hauled down by the vehicle to a point closer to the rigging location using a "slackout device" in the deployment line. The vehicle can now acquire one of the rigging lines to connect. After all rigging lines are attached, final adjustments are provided automatically by each arm which includes a tension limiter assembly (Figure 8) that adjusts to equalize distribution of the load on all four arms during the lift. The tension limiter resistance force can be preset by the placement of a locking pin in one of four hole positions in each arm. Each hole position represents a different predetermined resistive force that the attachment line must exceed before it begins to slip. The line is easily held back in the tension limiter by pinching it between the end of the bolt shaft and the smooth passage hole in the spring loaded casing. Due to the mechanical advantage of the line wrapped around the eyebolt, considerable force can be restrained while pinching the line lightly so as not to damage it. As the lift is begun, the attachment arm on the heavy side of the recovery object will reach its predetermined load limit and begin to pay out line. Depending on the weight distribution of the object, three of the four tension limiter assemblies may have to slip to distribute the weight of the load on all four arms equally. This prevents the "domino effect" of one attachment point becoming overloaded and tearing out, followed by the next one, etc. At

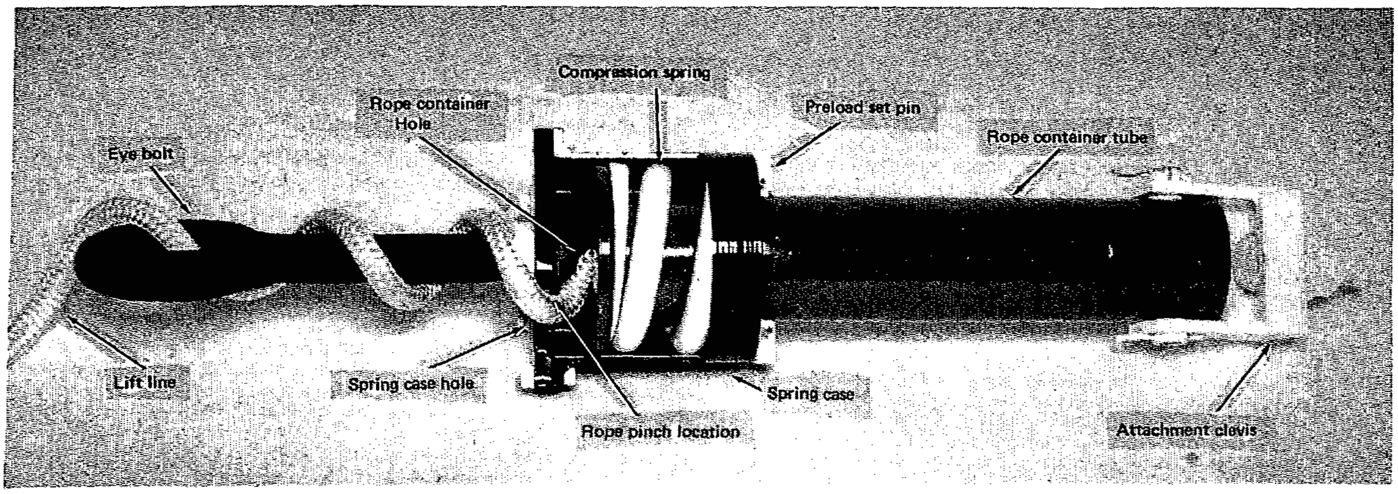

Figure 8. Attachment Arm/Tension Limiter Assembly. (Sectioned view)

this point, the object is ready for attachment of the lifting device.

The deployment of the RM was easily performed by the WSP/PIV as it maneuvered midwater to attach, release, and haul down the unit to the prescribed position. The difficulty arose during the remaining midwater operations of rigging each attachment line to the required lift point. Unlike the initial grasping of the haul down line, grasping the small plates attached to the snap hooks proved difficult. Once again, the contrast of the components was not adequate to quickly distinguish them, and during midwater operations there is not much time to ponder the situation. However, the greatest difficulty came from the midwater control of the vehicle by the pilot while the work system operator attempted to grasp the hook. This is primarily due to the lack of translational sensitivity of the vehicle, caused partly by the size and reaction of the thrusters but primarily due to the inertia of the 28,000 pound vehicle. Even this can be overcome, however, through operator training. As the operation progressed, the pilot and work system operator became more capable with the system and their own interaction. The first rigging line attachment took over 1/2 hour while the second took only a few minutes. Additional difficulty was placed on the task by using the system too conservatively. Being early in the six-week program, the grabbers were not used for their primary purpose, station keeping assistance. Fear of damage from impact with the target or by being overstressed during vehicle maneuvering caused the operator to be overly cautious. This highlights three areas of concern: (1) operators should be highly trained and aware of the actual limitations of their system, (2) grabbers should be designed to function in an unfavorable environment, both through strong design and also by utilizing built-in impact and overload protection, and (3) design of attachment devices to be utilized by grabbers in various situations (i.e., suction cups, explosively attached restraining points) should be developed and available or integrated into the system.

One control aspect of the system which soon became an operational necessity was the automatic altitude control. Without this the pilot would have been pressed to hold the 3-dimensional orientation required for the work system operator to perform accurate manipulative operations. If additional automatic heading or position controls were available, the midwater tasks would have been much easier.

Another deficient area was highlighted when reviewing the photographic documentation. During the midwater operations, the entire manipulative system would move towards the right as one arm and then another was used. This was due to the lack of a fixed reference point to help orient the component locations. As the vehicle hovered near the left side of the target, to allow the "right hand oriented" work system to operate, the manipulators would reach increasingly to the right until all stops were reached. A centrally located stationary TV camera, with a lens system capable of observing the entire manipulator suite at once, would provide a fixed point of reference, something that panning and tilting cameras lack.

After installation of the first two rigging lines, the vehicle was to be recovered and the operation concluded the following day. However, when leaving the target area, the vehicle ran into the test fixture knocking it onto its side. Therefore, divers were used to attach the final two lines to expedite the already tight schedule. The following day, the recovery was completed easily, with the lift line attachment performed by the vehicle in less than two minutes. Shortly thereafter, the variable ballast and thrust was used to lift the object to the surface. All RM components appeared to function properly, although the weight of the object was not excessive. Additional laboratory tests of the tension limiter assemblies are planned to aid in final design evaluation. The feasibility of using a remote system to attach to, rig, and recover high density objects was demonstrated.

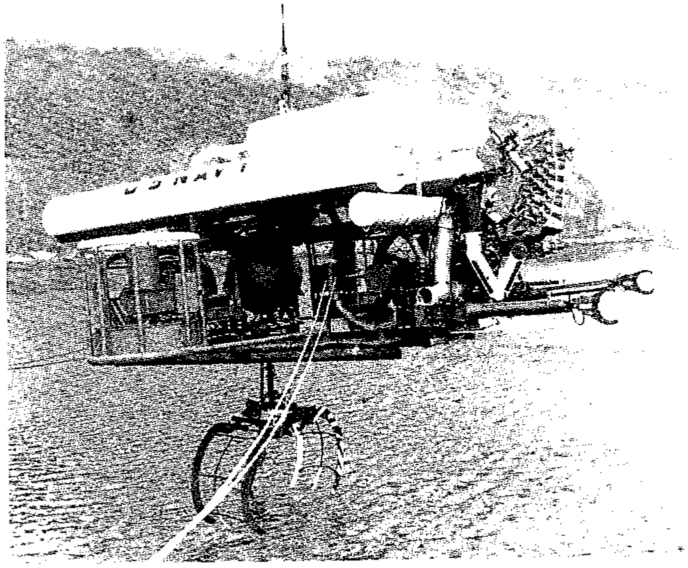

Figure 9. WSP/PIV launch with 5 foot wide claw assembly attached.

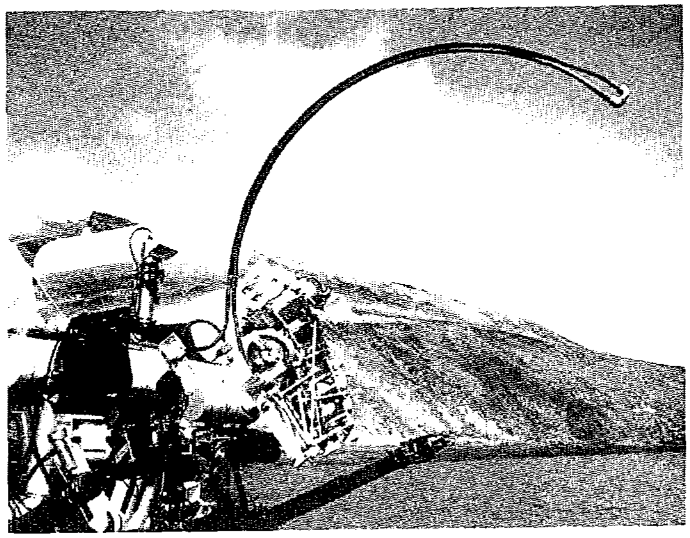

Figure 10. Lift sling emplacement device (15-3/4 foot long, 10 foot diameter semicircle.)

Aircraft Components

This class of objects considers that an aircraft has encountered a high velocity impact and is probably a "basket case". In this instance, most targets can be recovered directly with the grabbers and brought up with a basket or similar device. However, larger components such as jet engines may require recovery. For this case, a claw assembly was to be utilized.

The claw assembly (Figure 9) was attached to the underside of the vehicle during launch operations. The claw works thru an ice-tong effect. It is launched in the open position and, once around the target, is tripped by the vehicle manipulator, locking it on the target.

During the operation, the use of the automatic altitude capability of the PIV allowed slow and precise placement of the claw on a jet engine while being observed through TV cameras mounted below the vehicle. The operation was conducted without difficulty, thus supporting the use of such simple methods. The combined weight of the claw and engine was too high for recovery by the vehicle. Therefore, the recovery was performed by divers utilizing the 10,000 pound capacity lift module. The recovery was easily conducted, allowing the retrieval of the claw and engine while simultaneously providing a system checkout of the lift module, which will be explained in detail in the next section.

Intact Aircraft

The most complex recovery attempt was that of an F4 Phantom Jet, partially stripped but near 10,000 pounds in water. This scenario would include the installation and rigging of two slinging devices, transport and connection of the Lift Module (LM), and recovery utilizing the lift capability of the LM. No remotely controlled vehicle has ever performed such a recovery.

The first step required installation of the slinging devices fore and aft of the wing, connecting them to a central lift ring for a single point lift.

The lift sling emplacement device (Figure 10) provides a lift method for objects, such as aircraft fuselages, which do not readily lend themselves to the installation of hard attachment points. The most desirable method of rigging this type of object is through the use of rope, cable, or strap type lifting harness to provide a choke hold around it. Difficulty arises in this task when the object to be recovered is buried in mud or sand. The lift sling assembly was developed to alleviate this problem.

It is constructed with sixteen feet of curved steel tubing which is shaped in a ten-foot diameter semicircle. It is mounted on the WSP toolbox and removed through the use of the starboard grabber. After the grabber positions the assembly, the manipulator can force the sling under the aircraft. The sling is guided by three rollers located in the mount held by the grabber. The slinging device is equipped with a jetting nozzle which helps clear a path for the sling during insertion through a sand or mud bottom. After complete insertion, a synthetic line, which is attached to the near side of the sling, is taken over the aircraft and passed through a loop in the other end of the sling. The snap hook on the synthetic line can then be attached to the main lift point, thus providing a "choke hold" on the target.

The dexterity provided by the grabbers and manipulator made handling the slinging device by the WSP relatively easy. One problem encountered was determining insertion direction of the sling under the aircraft so that it would come out in the desired location on the opposite side. Although overcome during these operations, a mounting base which would provide a more accurate directional capability would be desirable.

Once again, the problem of visibility arose; contrast of the hardware being used is definitely required. Installation of the device did not require much jetting because of the rocky bottom, but this capability had been demonstrated during the development phase. However, a less cooperative bottom would have provided needed data on remote jetting operations. The present method of installation onto the vehicle leaves the device in a vulnerable position; this would have to be redesigned for transit to a recovery site under less favorable conditions. Overall, the slinging device worked satisfactorily.

A key learning experience was not in installation of the sling but with rigging it. The first sling was installed but when the vehicle tried to maneuver over the aircraft to the other side with the rigging line in the manipulator hand, the sling was pulled out. A slip of the control by the pilot eliminated several hours of work. Therefore, the procedure was changed; in the future the vehicle would fly up and straight forward over the aircraft dropping the heavy snap hook on the other side as soon as possible. This eliminated any fancy maneuvering requirements; once again the most simple approach proved to work best. The second sling was installed and rigged without incident.

The next task was the transportation of the lift module to the recovery site. Once the LM is in the water, it is mated with by the vehicle and held in the grasp of the two WSP grabbers. It is then transported to the recovery site where it is placed on the bottom next to the target. At this point, it is attached to the main lift point and activated by the WSP. A description of the LM and its operation follows.

The Lift Module (LM) (Figure 11) was developed to demonstrate the feasibility of utilizing a fixed displacement lift bag with a self-contained gas source as a means of transporting an object from the ocean bottom to the surface. This method eliminates the unreasonably high power required to lift a 10,000 pound object using vehicle thrusters.

The Lift Module is a submersible system with the lifting force provided by a 150 cubic foot, air filled, fixed displacement KEVLAR lift bag. (In a 20,000 foot design, a hydrogen gas generator would be used.) Initially, the lift bag is filled with water by a hydraulically driven pump which is under WSP control, thus converting it into a "rigid pontoon." This constant bag volume is maintained by a relief valve which keeps the internal bag pressure at 5 to 10 psi over ambient pressure as air is released into the bag. The buoyancy can be varied by forcing ballast water or air into or out of the lift bag while still under WSP control. When the lift bag buoyancy becomes sufficient for recovery, ascent is controlled by a microprocessor unit aboard the Lift Module. Control over the ascent rate is required to ensure that (1) the dynamic load on the rigged system is maintained within 10 percent of the static load,

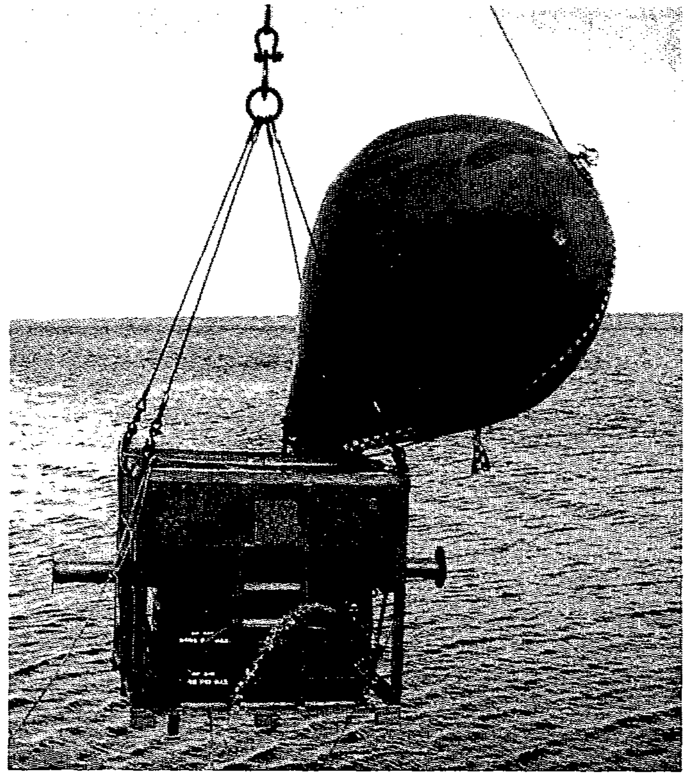

Figure 11. Lift Module being recovered after test.

and (2) the venting capacity of the relief valve is not exceeded. When the Lift Module/Object approaches the surface, the lift bag will break the surface leaving the module and object suspended beneath for recovery operations.

During the operation the LM was transported to the recovery site, rigged to the F4 and activated with relative ease. The difficulties encountered were (1) the long time to fill the system with air or water, which should be easily corrected, (2) the lack of real time feedback on the status of the filling procedures, and (3) the lack of adequate viewing of the LM when in the grasp of the vehicle. These problems, along with other minor developmental difficulties, can be easily corrected in the design of future systems. Due to the shallow test depths, the microprocessor control was not utilized; however, additional testing of programmed ascent profiles is anticipated during FY80. For the first time, an intact aircraft was rigged and transported to the surface entirely by a tethered vehicle and its support equipment (Figure 12).

TEST RESULTS

During the 30 days of testing at SCI, 14 dives were made with the vehicle which accumulated a total of 58 hours, 13 minutes of in-water time. Of the remaining 16 days, seven were required for routine maintenance or repair while nine were lost for various reasons (Figure 13). This time breakdown is typical of what can be expected when testing newly developed or integrated equipment/systems at sea for the first time. The

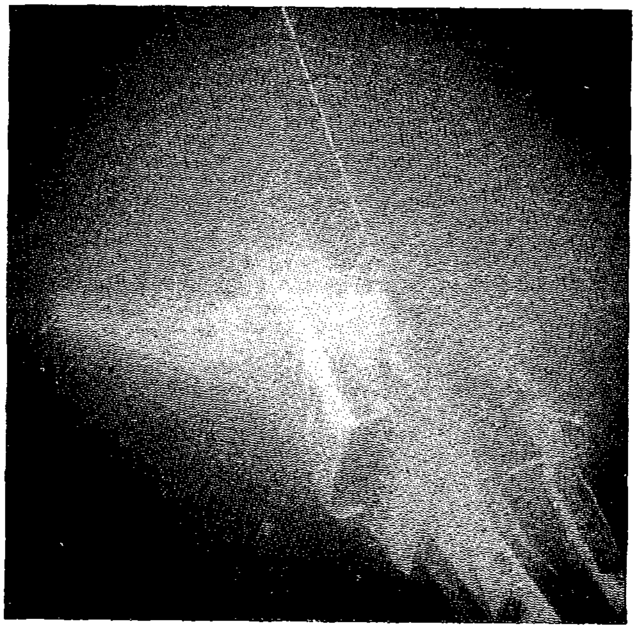

Figure 12. F-4 recovery

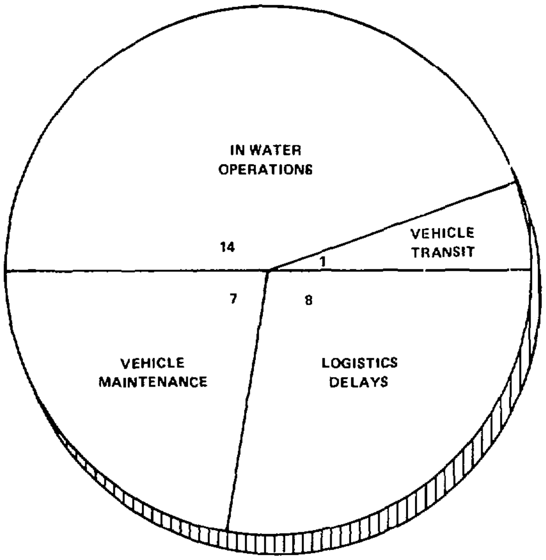

Figure 13. SCI testing time breakdown (days).

operating experience gained with the vehicle/work system and the substantial amount of photographic documentation acquired has greatly enhanced the success of this test series.

The basic approach to these tests was from an engineering standpoint. Given a recovery task, an engineering approach could be made to the task which would result in the development of simple and reliable techniques to ensure a successful recovery through the use of remote systems. Based on this approach, the following objects were successfully rigged for recovery and lifted to the ocean surface using the recovery techniques developed and explained in previous sections:

- Slinging and lift of an F4 aircraft.

- Claw attachment to and recovery of a jet engine.

- Rigging and recovery of a large steel object.

In addition, techniques were developed which successfully demonstrated the system's capability to perform the following:

- Rigging of objects (installation of lift lines, snaphooks, etc.)

- Performance of midwater maneuvering, docking, rigging, and recovery operations.

- Successful installation of lift slings on an intact aircraft.

- Object recovery using the vehicle variable ballast and thrust as the lift force.

- Remote implacement and deployment of a lift module which can be controlled by the work system or a microprocessor to generate a 10,000 pound lift force.

- Object recovery using the Lift Module while under diver control.

- Installation of "toggle bolt" lift points through heavy steel plate.

The ability to perform the previous tasks through the use of remote systems, while the operator is topside in a comfortable environment, validates their usefulness. By identifying classes of objects to be recovered, and designing recovery tecniques and devices for those classes of objects, a basic inventory of hardware can be established to provide a remote recovery capability. Although these tests were performed in shallow water where they could be properly documented, the successful completion of the work-related tasks of the system at depths to 20,000 feet would not be significantly different since they are basically depth independent. The primary depth dependent requirement would be the need to eliminate cable dynamic forces at the vehicle, which were not of a magnitude to hamper operations due to the shallow water at SCI. Also, operations were conducted under ambient lighting conditions. This entire test series was performed during the first at-sea operations of the WSP/PIV, using newly developed attachment devices and techniques by operators who were new to the systems operational idiosyncrasies. When considering these facts, the reality of what could be accomplished through the development of a technology base which would provide the path to an optimized deep ocean recovery system cannot be overlooked.

CONCLUSIONS

At this time, the Navy does not have a routine, cost effective method for recovering objects below diver depths. However, by establishing a proper technology base, methods can be developed which will provide a deep ocean recovery capability to 20,000 foot depths. The testing of the WSP/PIV was a demonstration of such technologies derived from previous programs, and new recovery techniques which were generated specifically for the San Clemente Island (SCI) operations. The ability to successfully develop such recovery techniques through an engineering approach was demonstrated during the SCI testing.

The tests demonstrated the capability of the remotely-controlled system to perform underwater work operations, remote installation and riggging of slings around an aircraft, and the ability to raise the aircraft to the surface using a gas operated lift module which had been transported to the work site by the vehicle/work system. New techniques for installation of lift points, attachment of snap hooks and rigging lines in a "fail safe" manner, and the successful recovery of a jet engine have expanded the Navy's recovery technology. It is through programs such as this, where recovery techniques are not merely concepted, but operationally tested, that the technology base for deep ocean recovery by remote systems will evolve.

REFERENCES

1. WERNLI, R.L., NOSC TR 553, Work Systems Package/Pontoon Implacement Vehicle Operational Testing at San Clemente Island, CA 1979.

2. WERNLI, R.L., Development of a Design Baseline for Remotely Controlled Underwater Work Systems, Naval Ocean Systems Center, San Diego, CA, paper presented at OCEANS '78.