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Research and Development Report

Automated Underwater Hull Maintenance Vehicle

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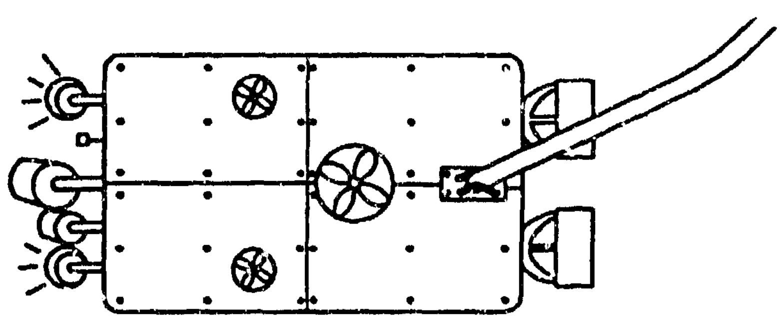

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The maintenance and repair of the underwater hulls of Navy ships is expensive and labor intensive. While the introduction of effective epoxy anticorrosive paints and improved ablative antifouling paints have contributed to lengthening the time between drydocking, needed repair work is often not discovered until the ship is in drydock. In addition, the U.S. Navy has implemented cuprous oxide containing ablative antifouling paints to replace the standard antifouling paint (F121) in the fleet. While the ablative antifouling paints are performing better than the F121, some fouling of these paints has been reported. The process of underwater hull cleaning therefore has the potential to discharge unacceptable amounts of copper toxicant into Navy harbors.

An underwater vehicle designed to perform a multitude of hull husbandry tasks

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is under development at the Annapolis Detachment of the Carderock Division, Naval Surface Warfare Center. This vehicle, which has its roots in remotely operated vehicle technology, would have the capability to self-navigate around the hull while recording data on hull systems, such as paint thickness, hull plate thickness, and cathodic protection potentials. These data would allow planners to determine how much ablative AF paint needs to be applied at the next docking to track the average hull thickness and to monitor the health of the impressed current cathodic protection system. This will reduce maintenance costs in drydock. In addition, the vehicle would have the capability to detect the presence of significant marine fouling, which increases hydrodynamic drag and fuel consumption. Thus, only the fouled areas of the hull, usually less than 20 percent of the area, would be cleaned, thereby significantly reducing the amount of copper discharged from underwater hull cleaning, which now cleans the entire hull.

The system would maintain a database of the ship hull condition that could be used to plan upcoming drydock work and reduce costs from anticipated repairs. Robotic drydock machines for paint application and repair could then be used to further reduce costs and improve quality.

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ABSTRACT

The maintenance and repair of the underwater hulls of Navy ships is expensive and labor intensive. While the introduction of effective epoxy anticorrosive paints and improved ablative antifouling paints have contributed to lengthening the time between dyrdocking, needed repair work is often not discovered until the ship is in drydock. In addition, the U.S. Navy has implemented cuprous oxide containing ablative antifouling paints to replace the standard antifouling paint (F121) in the fleet. While the ablative antifouling paints are performing better than the F121, some fouling of these paints has been reported. The process of underwater hull cleaning therefore has the potential to discharge unacceptable amounts of copper toxicant into Navy harbors.

An underwater vehicle designed to perform a multitude of hull husbandry tasks is under development at the Annapolis Detachment of the Carderock Division, Naval Surface Warfare Center. This vehicle, which has its roots in remotely operated vehicle technology, would have the capability to self-navigate around the hull while recording data on hull systems, such as paint thickness, hull plate thickness, and cathodic protection potentials. These data would allow planners to determine how much ablative AF paint needs to be applied at the next docking to track the average hull thickness and to monitor the health of the impressed current cathodic protection system. This will reduce maintenance costs in drydock. In addition, the vehicle would have the capability to detect the presence of significant marine fouling, which increases hydrodynamic drag and fuel consumption. Thus, only the fouled areas of the hull, usually less than 20 percent of the area, would be cleaned, thereby significantly reducing the amount of copper discharged from underwater hull cleaning, which now cleans the entire hull.

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ADMINISTRATIVE INFORMATION

This investigation was sponsored by the INNOVATION CENTER of the Carderock Division, Naval Surface Warfare Center. The work was conducted at the Annapolis Detachment under Work Unit No. 5-1200-163-49 and was performed by a joint team from the Propulsion and Auxiliary Systems Department and the Ship Materials Engineering Department. The results of this investigation also were presented to the 9th Inter-Naval Corrosion Conference at the Naval Postgraduate School, Monterey, CA, in April 1992.

INTRODUCTION

The underwater hulls of Navy ships have several systems that are subject to the harsh marine environment. These systems on surface ships include the anticorrosive (AC) and antifouling (AF) paint systems, rudders, propellers and propeller shaft struts, the impressed current cathodic protection (ICCP) system, sacrificial anodes for corrosion protection, seachests for intake and discharge of cooling water, and sonar domes. All of these systems can suffer deterioration due to corrosion and marine fouling. The planning and execution of maintenance for these systems is difficult and expensive. Most Navy surface ships typically have docking intervals of 5 to 7 years. Periodic diver inspections are conducted to assess marine fouling on the hull; however, diver inspections cannot always discern deterioration of the many components on the hull. Thus, often significant, additional repairs beyond what has been planned are discovered. Unplanned repair work is always expensive to conduct, due to interruptions in work already planned and additional costs likely to be imposed by the shipyard for the unplanned work. It is therefore advantageous to collect as much data as possible regarding the hull condition prior to docking.

The standard antifouling (AF) paint used by the U.S. Navy for many years has been formula 121 (F121), a 70-percent by weight cuprous oxide vinyl rosin material. Formula 121 has exhibited a variable service life of 7 to 30 months; see Fig. 1.

The U.S. Navy spends about $500M per year on propulsive fuel for ships. About $75 to $100M is used in overcoming the added hydrodynamic drag due to marine fouling on hulls. In an attempt to reduce this fouling penalty, underwater hull cleaning of F121 was introduced into the Navy in 1978. This process has resulted in a cost savings of about 20percent, or $15 to $20M of the annual fuel penalty. In addition, the Navy has pursued more effective AF paints. A class of materials known as ablative AF paints developed by the paint industry has had wide acceptance in the commercial shipping trade. There have been several evolutions of AF paint technology during the last 15 years, and these materials have been subjected to research and testing by the Navy.

This work has resulted in the U.S. Navy approving fleetwide implementation of ablative AF paints containing cuprous oxide as the antifouling toxicant.

The "copper ablative paints", which were first applied for ship testing in 1984, have now been implemented by the Navy and are used on over 190 ships and submarines in the U.S. fleet of 499 ships[2]. It has been observed that the copper ablative paints are performing better than the F121. Figure 2 shows the age distribution of the population of copper ablative painted ships. About 25 percent of these ships have fouled enough to require underwater cleaning. Figure 3 shows the age distribution of copper ablative painted ships that have fouled and had an underwater cleaning. While the underwater cleanings on the copper ablative painted ships have been successful in removing fouling and reducing the propulsive fuel penalty, the ablative paints are softer than the F121, which may cause the cleaning operation to remove from 1 to 2 mils of AF paint. This does not affect the long-term performance of these paints, since they are typically applied about 15 mils thick. The paint debris discharged during the cleaning, however, may contain significant amounts of cuprous oxide that would then enter the harbor. The underwater cleaning of ablative AF paints is now being investigated by the Navy to quanitify the copper release, but it is possible that regulatory agencies would question the cuprous oxide discharged during this operation.

AN AUTOMATED UNDERWATER HULL VEHICLE CONCEPT

The challenge of monitoring the condition of the underwater hull systems during service combined with the desire to reduce the potential discharge of copper compounds into Navy harbors has resulted in the development of a concept for a tethered automated hull husbandry vehicle (AHHV). This vehicle would be designed to perform a variety of hull inspection chores in addition to performing hull cleaning operations that reduce the discharge of copper compounds. The AHHV would perform similar to a remotely operated vehicle (ROV), which is commonly used for a variety of underwater inspection and work tasks. The various functions of the AHHV are shown in Fig. 4. The AHHV would have an acoustic nagivation system to give its location and heading relative to the hull. This system coupled with a computer and software would guide the vehicle in traversing the hull in a systematic fashion for fouling removal and hull inspection. The nagivation/control system is now available and has been adapted for use on a modified ROV to be used for acoustic measurements.

FOULING DETECTION AND REMOVAL

The capability to detect and clean marine fouling from ship hulls would be a critical function of the AHHV. Optical and acoustic methods of image analysis for fouling detection are therefore being investigated. Optical methods have been evaluated for their capability to determine the height of fouling above a baseline surface, while high-frequency, high-resolution acoustic imaging systems for diver use are being studied for the AHHV. The image analysis system would detect and determine the density of the fouling, and activate a cleaning tool for fouling removal.

Methods being evaluated for fouling removal efficiency and copper discharge include:

1. Rotary Brush Cleaning
2. High Pressure Waterjet Cleaning
3. Acoustic Cleaning

Rotary brushes have been used to remove fouling for over 15 years when used on a variety of underwater cleaning machines. These brushes are effective, but would discharge cuprous oxide when used to clean ablative AF paints due to the softness of the paint. In addition, they would also release cuprous oxide into the water, if used on the AHHV. The total amount of cuprous oxide discharged would be much less, since only areas covered with calcareous fouling would be cleaned and not the entire hull.

High pressure waterjets have been used for a variety of cleaning tasks in the ship maintenance area. Development work is underway on a high-pressure waterjet paint removal method.[3] Underwater, this method has been used to clean fouling from propellers and seachests.

Recent work with waterjets has demonstrated the capability to improve efficiency and reduce water consumption with multiple nozzles on a rotating head. While fouling removal with waterjets has been demonstrated, the amount of cuprous oxide that would be released is a function of pressure, nozzle size, and translation rate.

Work also is ongoing on the use of acoustic arrays to remove fouling from oil production platforms[4]. The method uses a focused array of multiple transducers to concentrate acoustic energy and remove fouling. This system is being investigated for the AHHV because it is lightweight and has the potential for minimal disruption of the ablative AF paint with reduced cuprous oxide discharge. Figure 5 shows the AHHV cleaning marine fouling as it moves along a hull. The contour lines indicate the presence of varying thicknesses of fouling.

HULL MAINTENANCE SENSORS

Several sensors would be incorporated into the AHHV to provide information on underwater hull systems:

1. Paint Thickness
2. Hull Electropotential
3. Hull Plate Thickness

These sensors would be deployed periodically as the vehicle transits the hull, and the data would be transmitted through the umbilical to the topside computer.

The paint thickness sensor provides data to determine the amount of AF paint that has ablated off the hull during service. This, when compared with baseline paint thickness data taken at undocking, would allow maintenance planners to determine if additional AF paint should be applied to the ship at upcoming dockings, and how much to apply. Figure 6 is a histogram of the underwater hull paint system on an aircraft carrier. There are two populations of data, one at application and another taken at a drydocking 20 months later. A small decrease in total paint thickness is noted. Similar data would be generated by the AHHV.

The impressed current cathodic protection (ICCP) system, installed on most Navy ships, is designed to protect the underwater hull from corrosion. The ICCP system, which consists of several anodes mounted on the hull regulated by a reference cell, reacts to changes in the electropotential of the hull by putting electrical current into the water through the anodes until the reference cell detects an acceptable potential, usually minus 850 millivolts. The system generally works well. Anodes do fail, however, and these failures are difficult to detect. Also, the stern areas of ships (including the rudders and shaft struts) are known to corrode despite the ICCP system. The actual distribution of the electrical field in these areas is not well understood. A reference cell mounted on the AHHV would be able to read hull potential while transiting the hull and thereby aid in determining proper anode functioning as well as the static electrical field distribution over the entire hull. An example graphic representation of data using actual data taken by the acoustic ROV of acoustic emissions from a ship hull is shown in Fig. 7. In a similar manner, both the ICCP potential and paint thickness can be displayed in this fashion and compared with past data to determine changes in the systems. Hull plate thickness also can be taken with an underwater sensor to detect thin areas of the hull that may need maintenance in an upcoming drydock period.

VEHICLE CONFIGURATION

Figure 8 is an artists' rendering of the acoustic cleaning concept showing the various components of the AHHV, including sensors, thrusters, and cameras. Figures 9 and 10 show the brush and waterjet cleaning configurations. A block diagram of the various systems coupled to the topside support electronics, which provide programmed navigation control, data analysis, and video of the hull, is shown in Fig. 11.

The vehicle is designed to have both free swimming and hull crawling capability. This would enable the AHHV to move around the hull for positioning and to monitor ICCP fields, and still be able to roll over the hull with wheels to conduct the fouling removal and hull inspection functions. The navigation/control system would be programmed with the hull shape to enable the vehicle to move to any positions desired. A topside computer would control the movement and the deployment of various sensors while fouling is being detected and removed. Consideration is also being given to composite construction of the AHHV (Fig. 12) to reduce maintenance in the marine environment and to keep weight down.

A typical vehicle deployment sequence involves setting up of an equipment van on the job site and lowering the AHHV into the water; see Fig. 13. The vehicle would free swim to the hull, then rotate and attach to the hull and commence the cleaning and inspection operations. A complete record of the areas cleaned and of the data generated by the various sensors would be maintained and be available to assist maintenance planners in anticipating work necessary in upcoming drydock availabilities. This would decrease maintenance costs during ship overhauls, and reduce the time in dock. Ultimately, the automated transfer of underwater hull system data generated by the AHHV to robotic paint removal and application systems which would be used in drydock is envisioned. These systems now under development would be used to reduce drydock costs, improve the quality of paint maintenance, and reduce hazardous waste generation in drydock. As shown in Fig. 14, data taken in drydock (such as paint thickness) could be transferred to the AHHV computers and thus provide a continuity of maintenance records over the ship operating cycles, thereby reducing costs and improving efficiency.

ACKNOWLEDGMENTS

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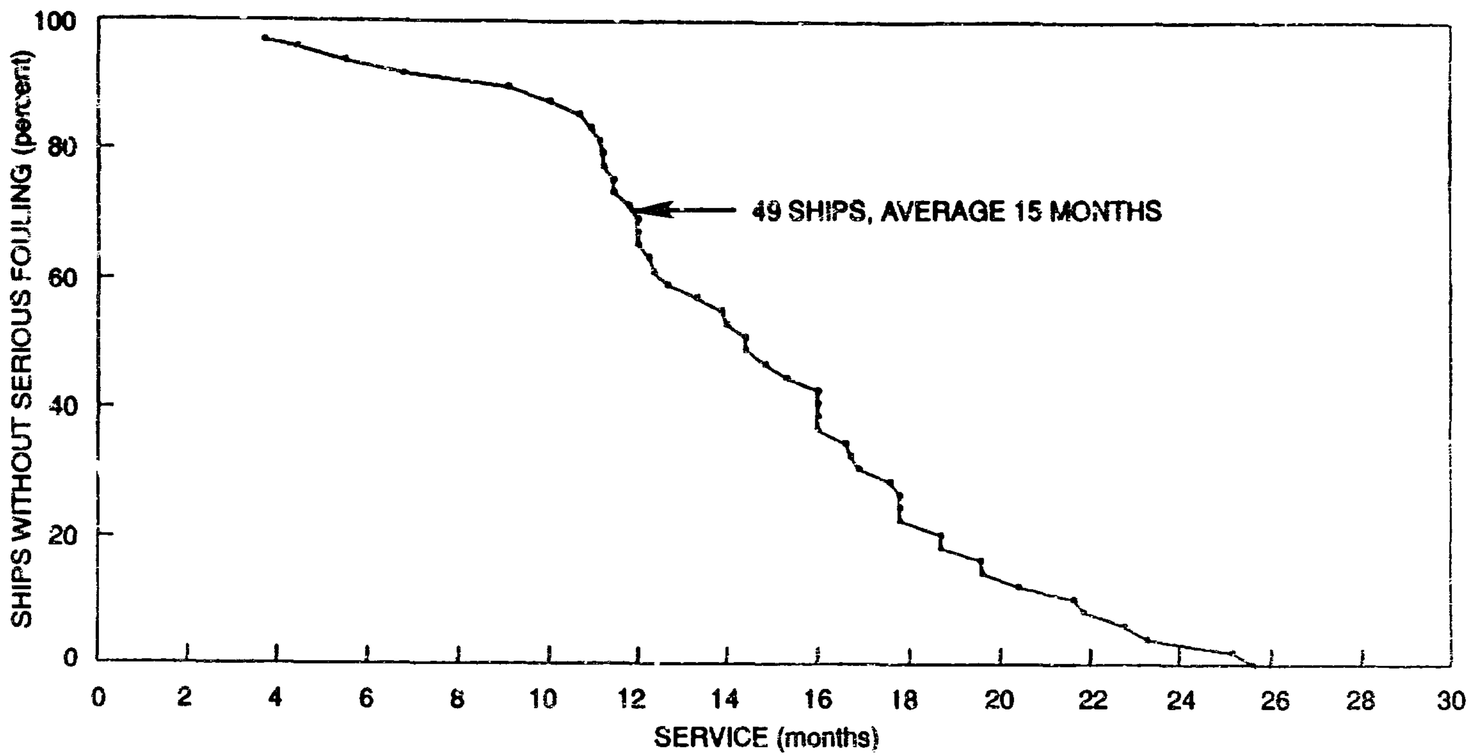

Fig. 1. Performance of Navy F121 antifouling paint.

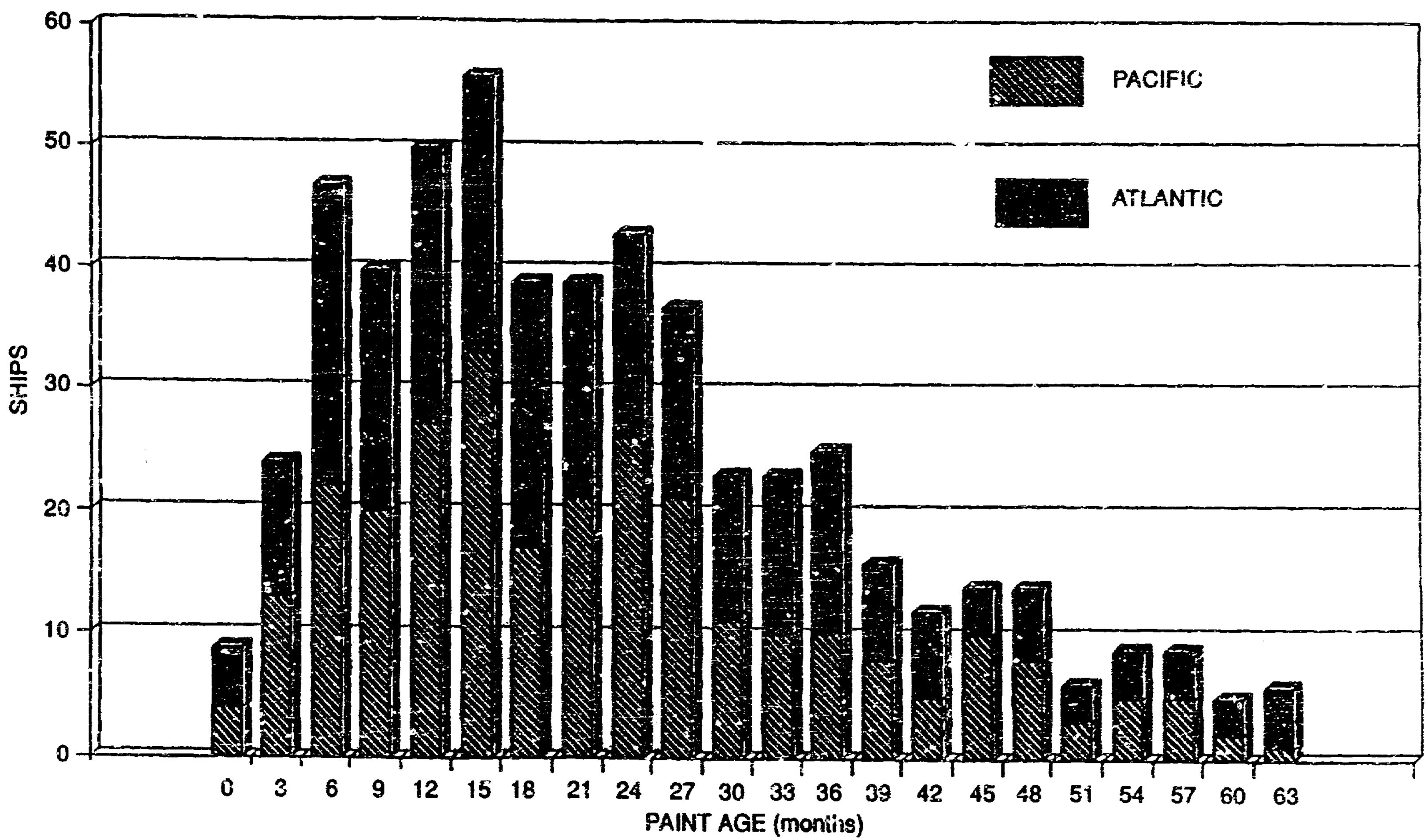

Fig. 2. Age distribution of ships painted with copper ablated antifouling paint.

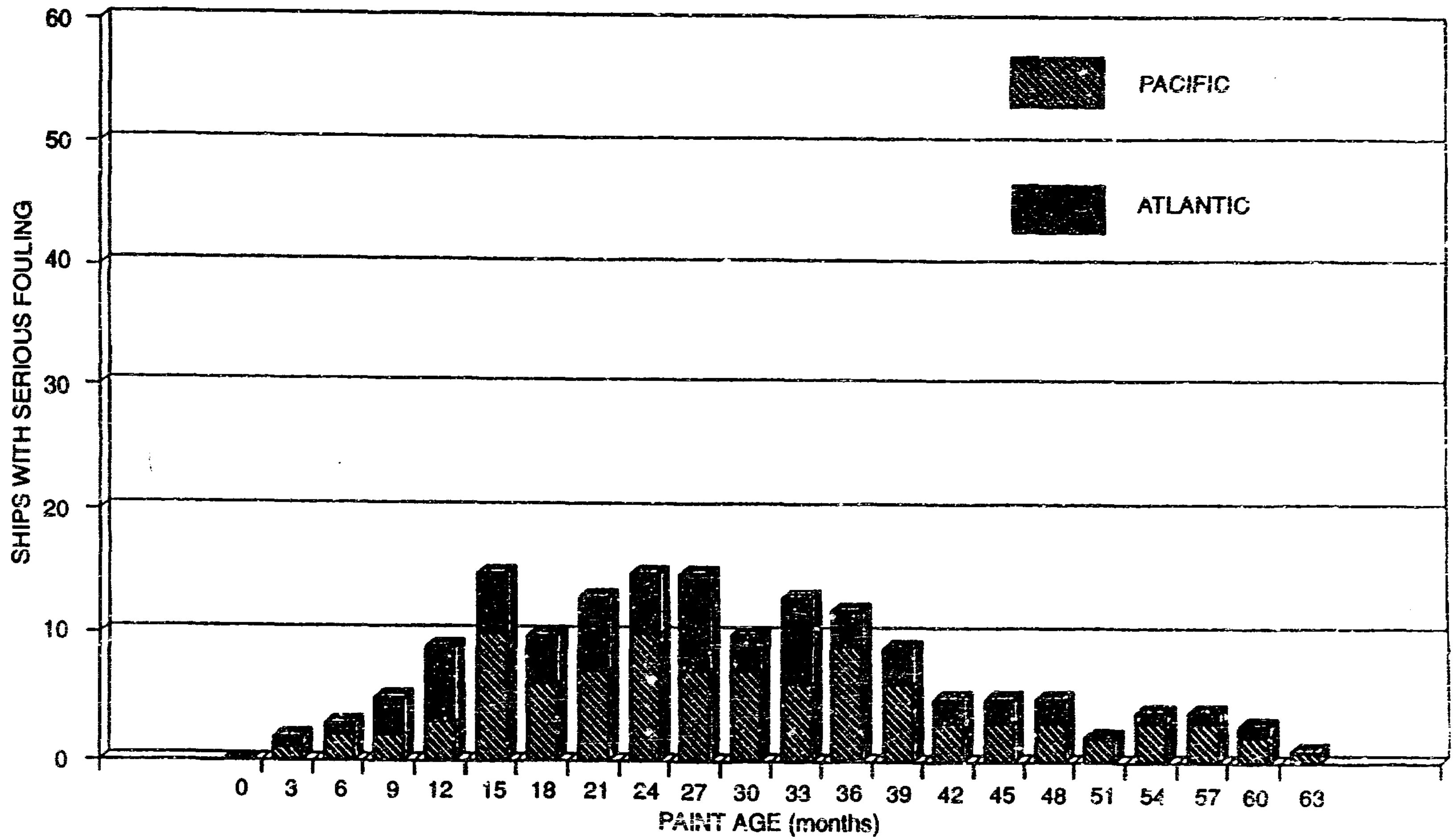

Fig. 3 Age distribution of copper ablated painted ships.

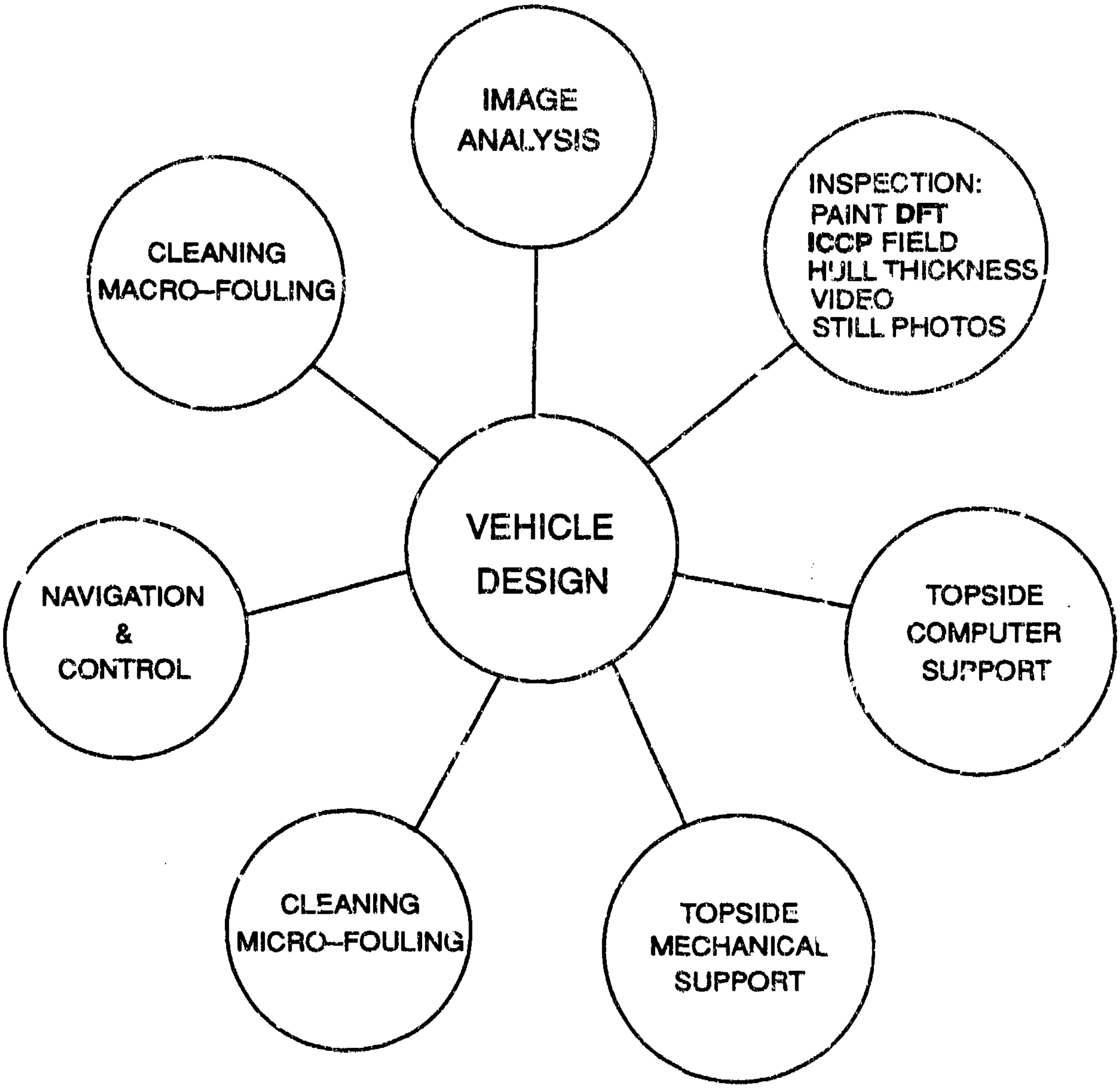

Fig. 4. Automated hull husbandry vehicle systems.

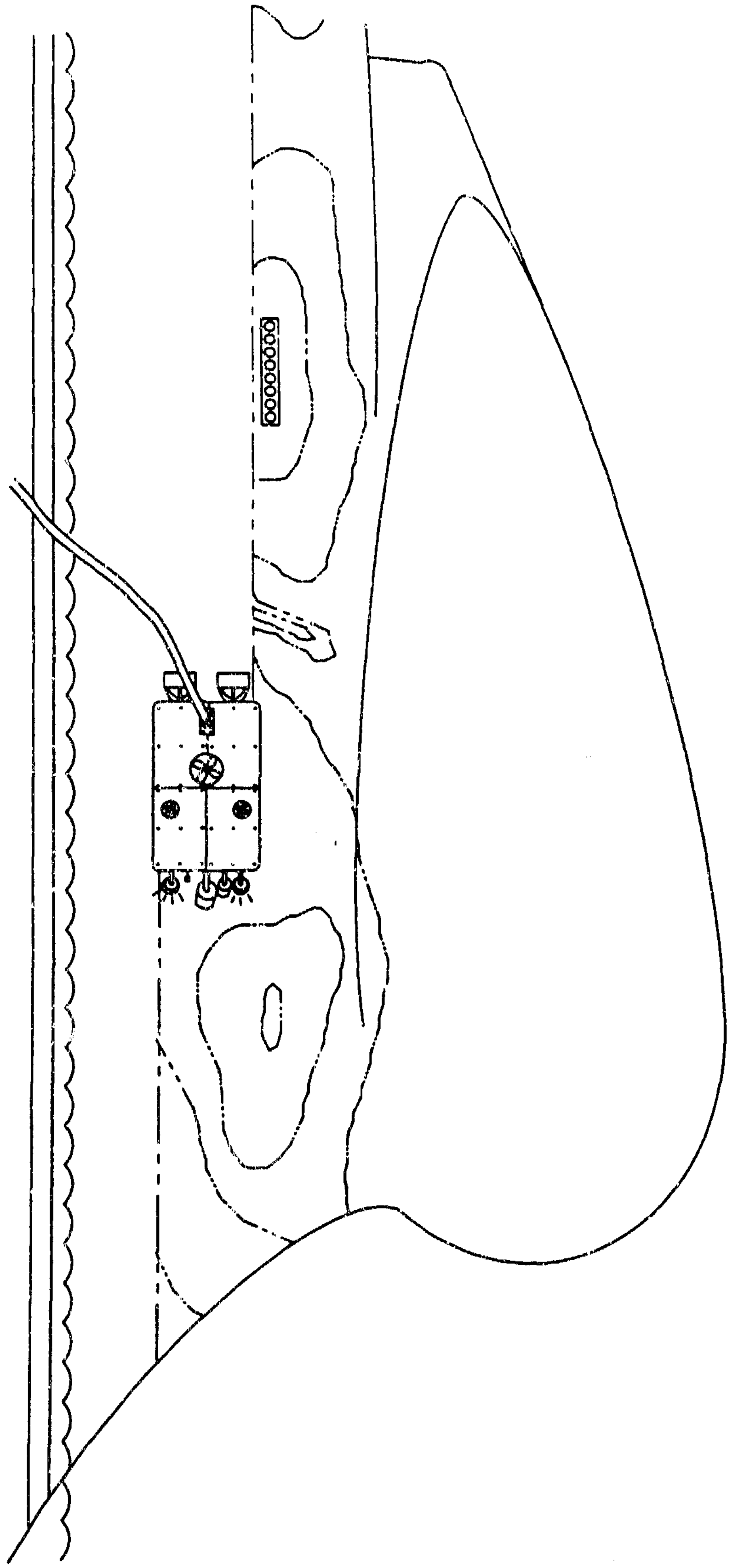

Fig. 5. AHHV cleaning marine fouling as it moves along a hull.

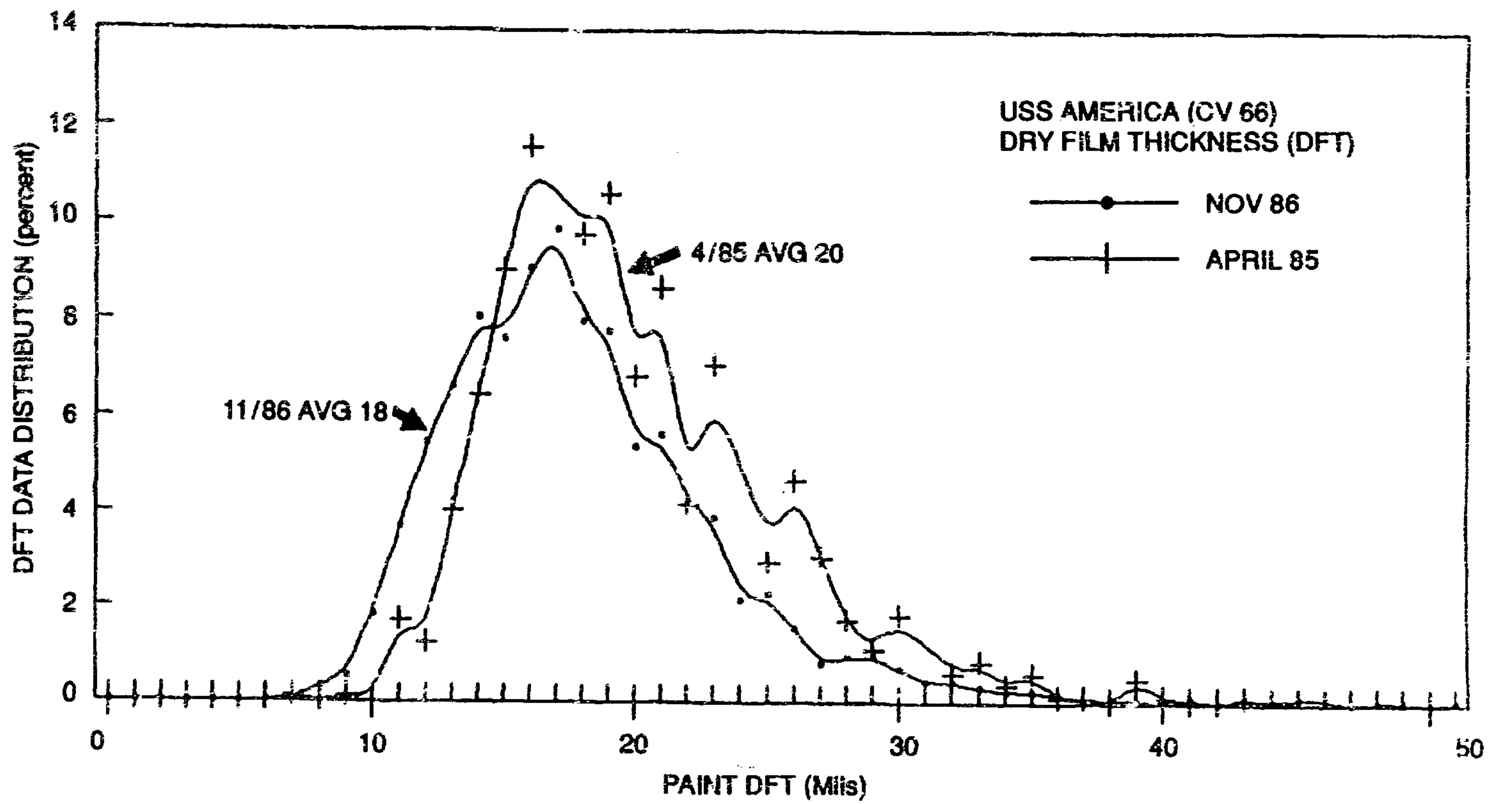

Fig. 6. Underwater paint thickness distributions on an aircraft carrier hull.

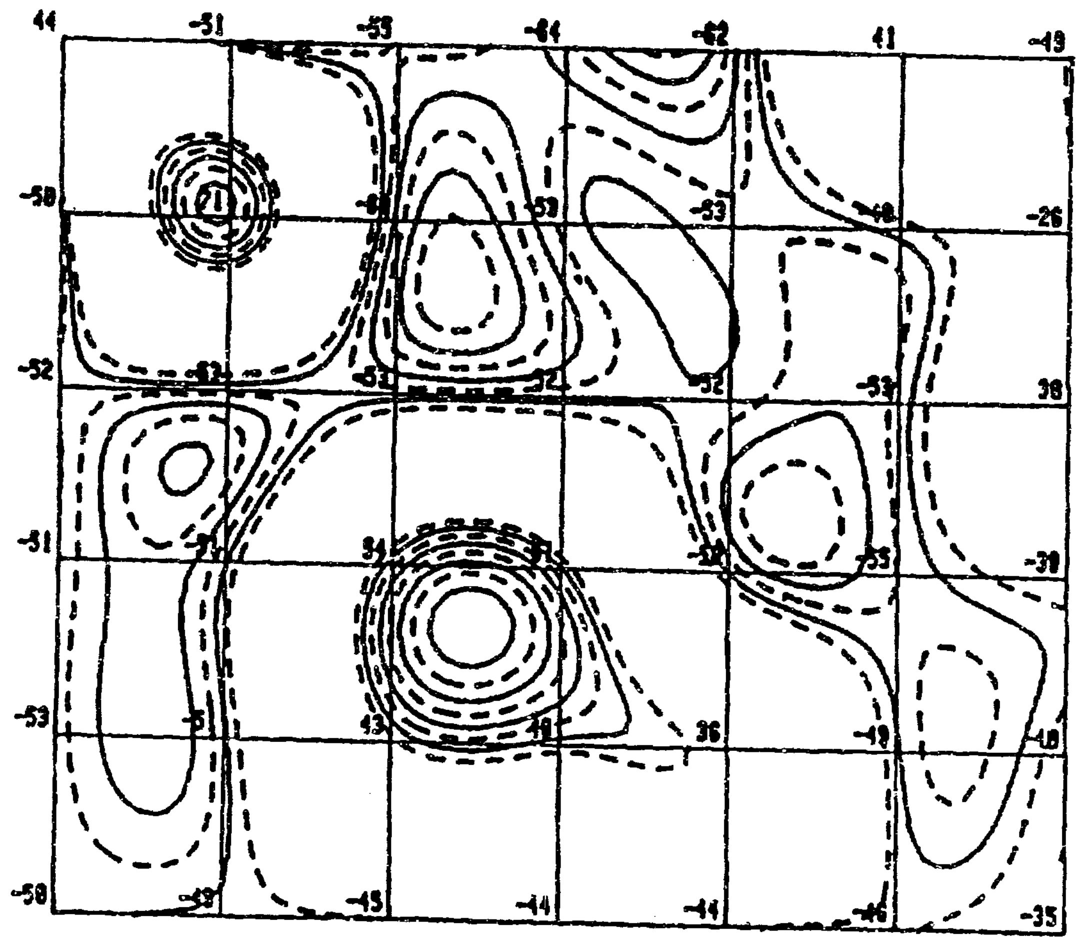

Fig. 7. Graphic representation of ROV-generated data from a ships hull.

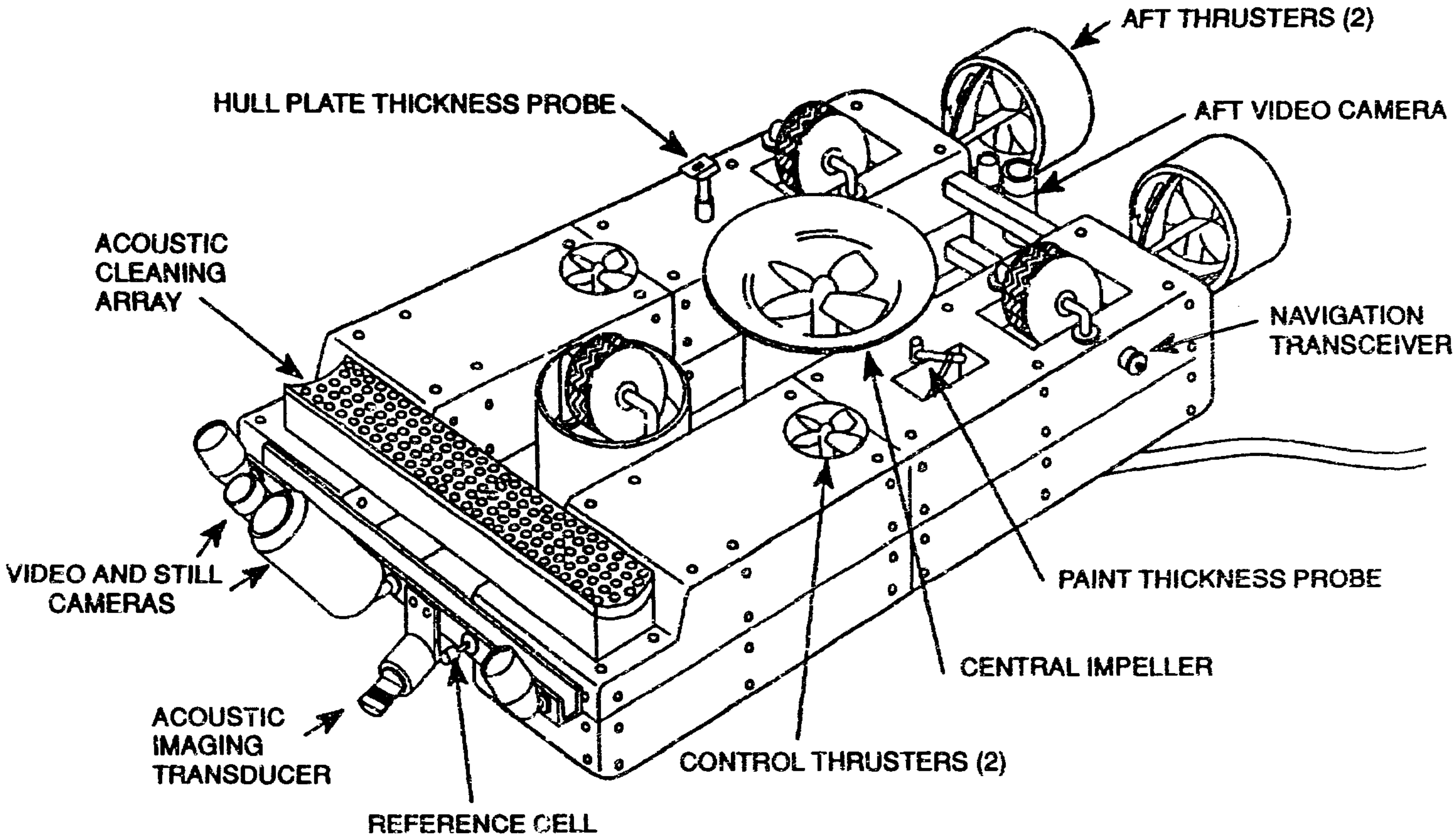

Fig. 8. Acoustic cleaner configuration of the AHHV.

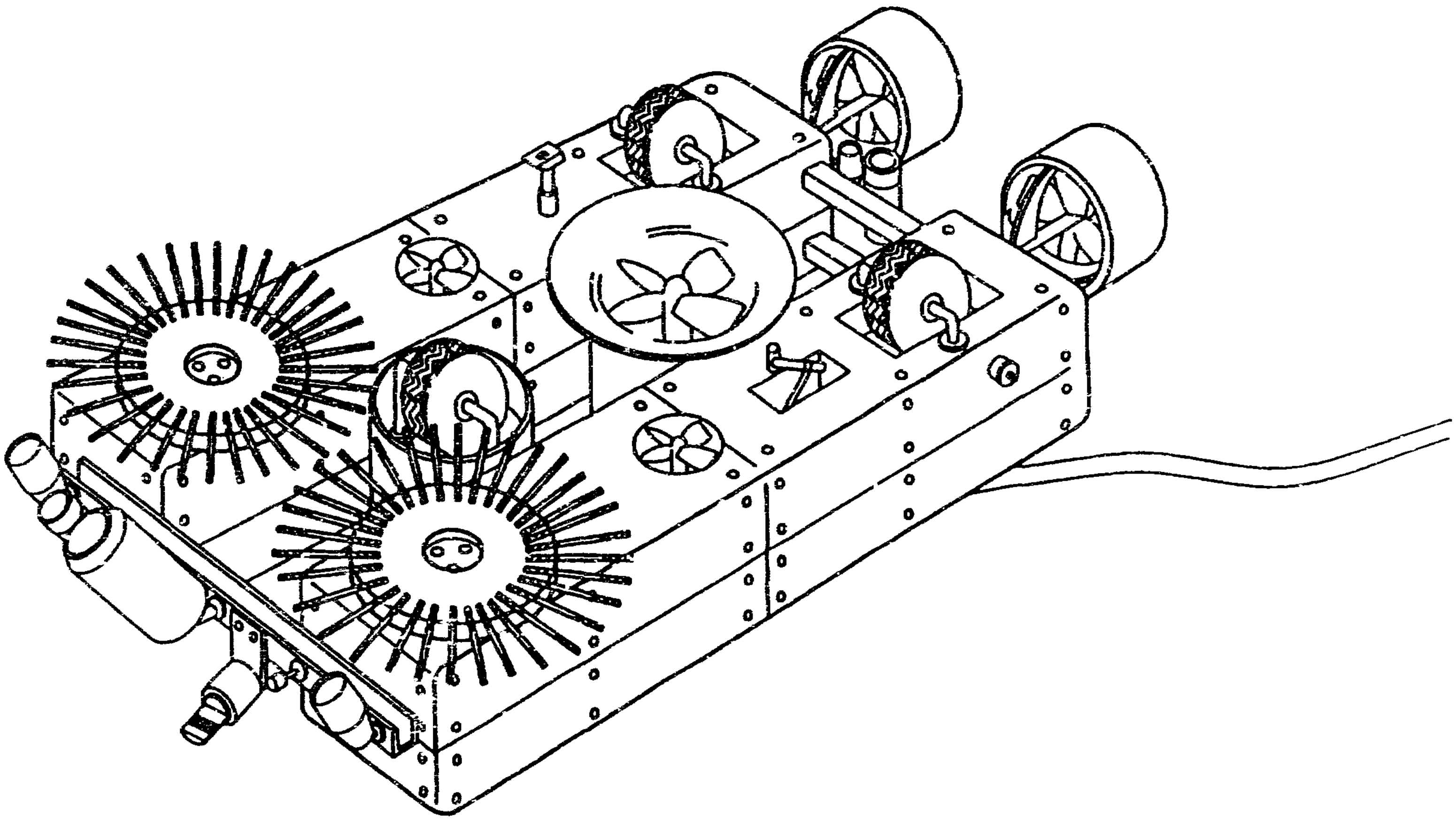

Fig. 9. Brush cleaner configuration of the AHHV.

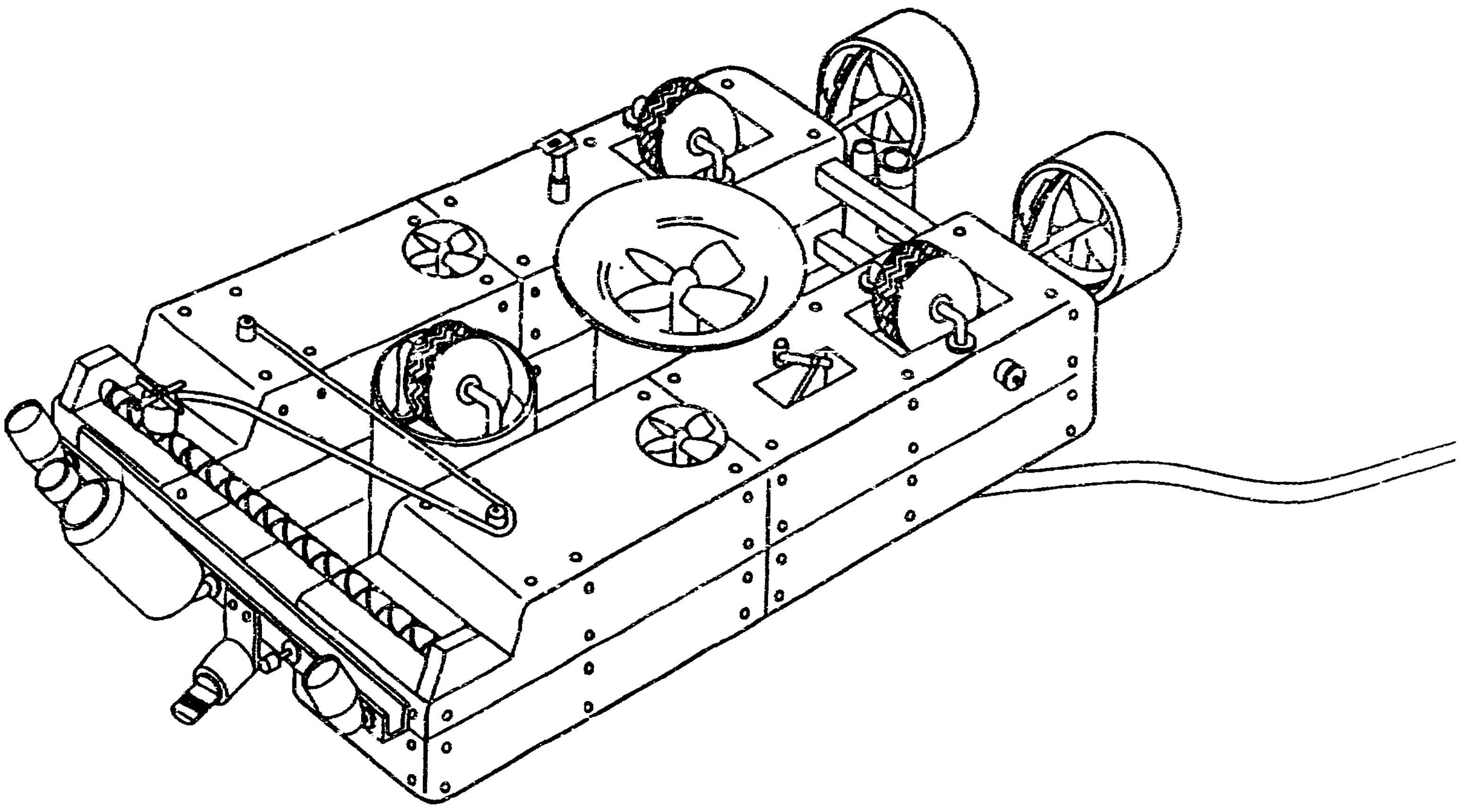

Fig. 10. Waterjet cleaner configuration of the AHHV.

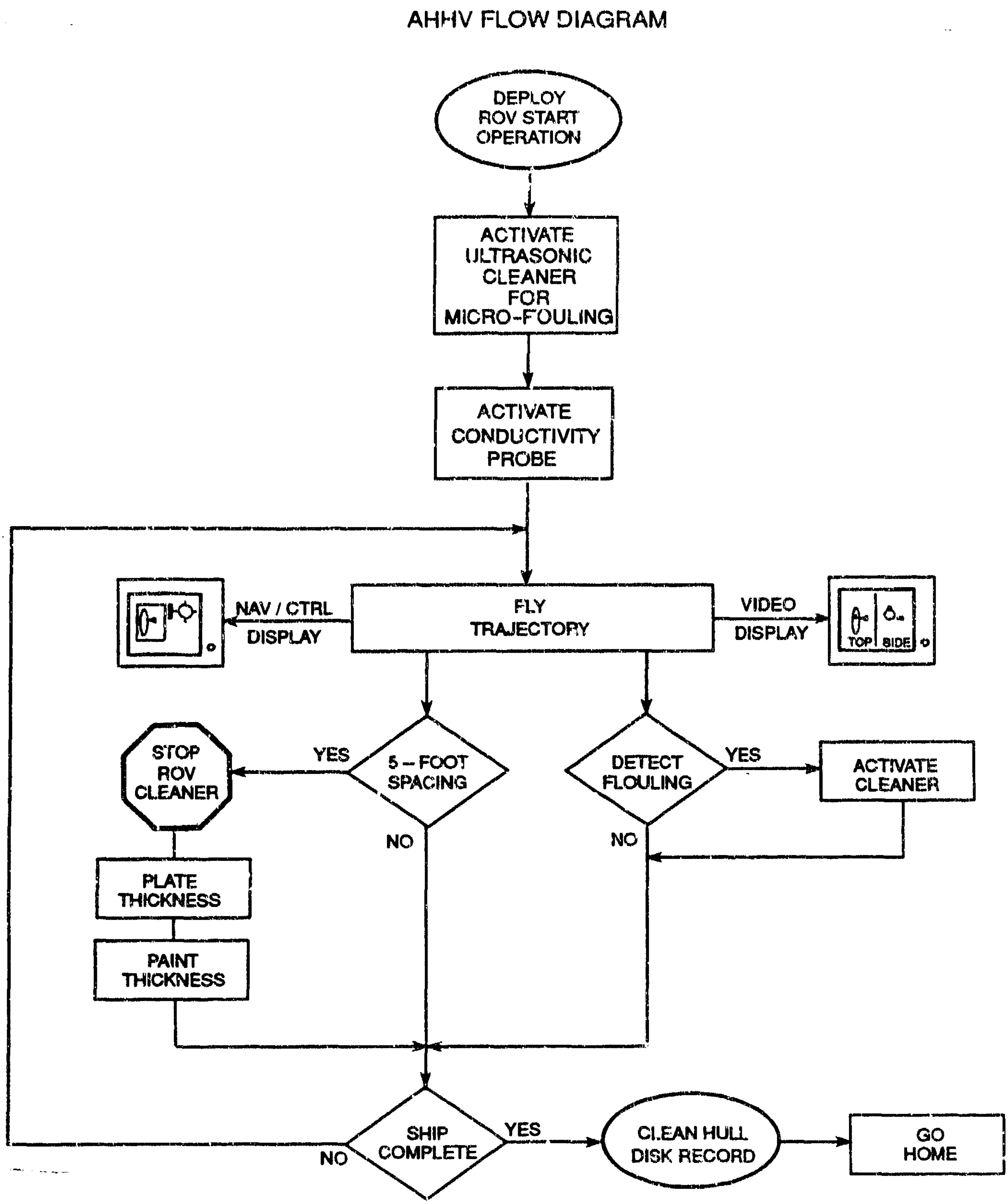

Fig. 11. AHHV System block diagram.

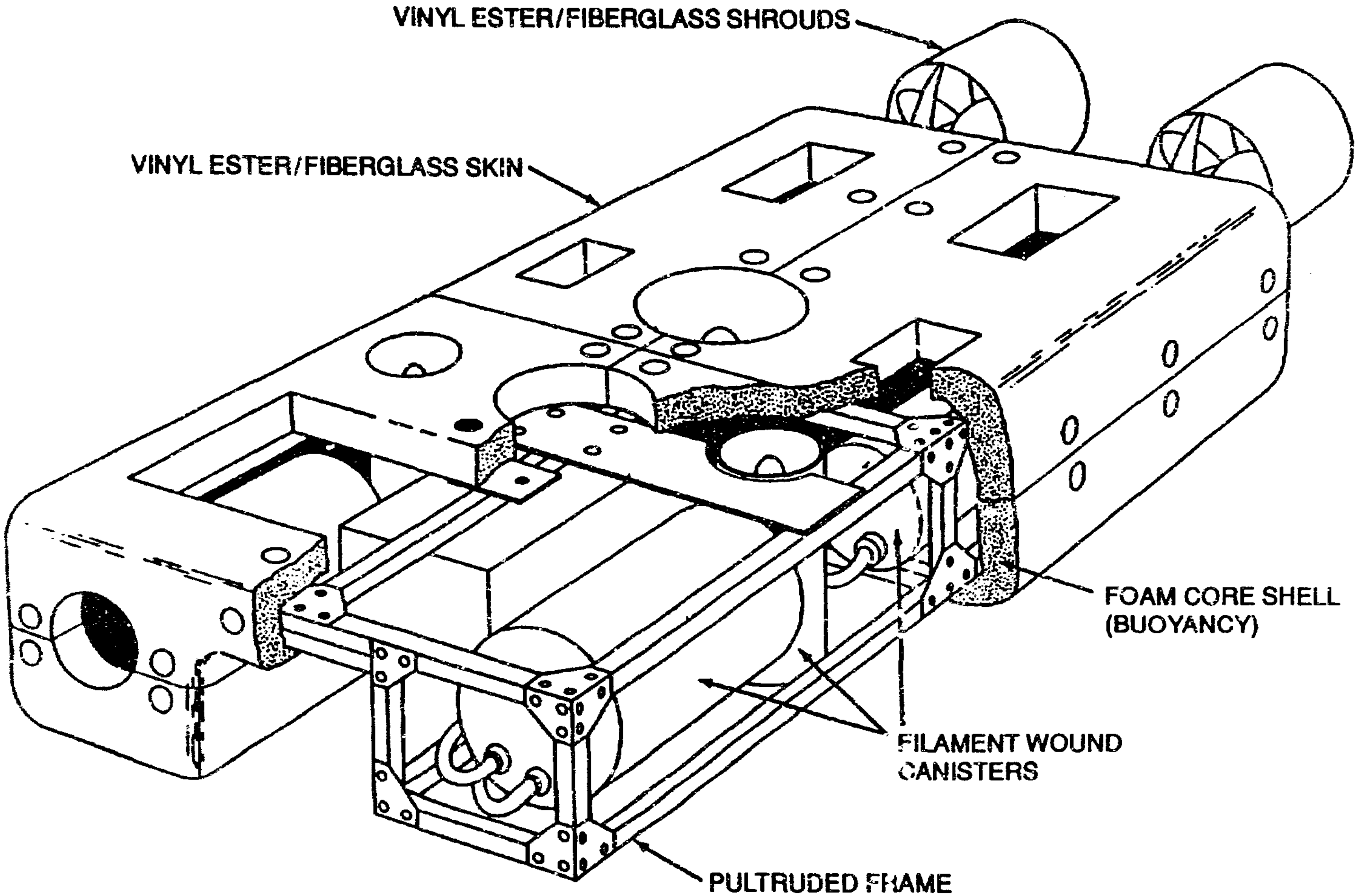

Fig. 12. Composite construction of the AHHV.

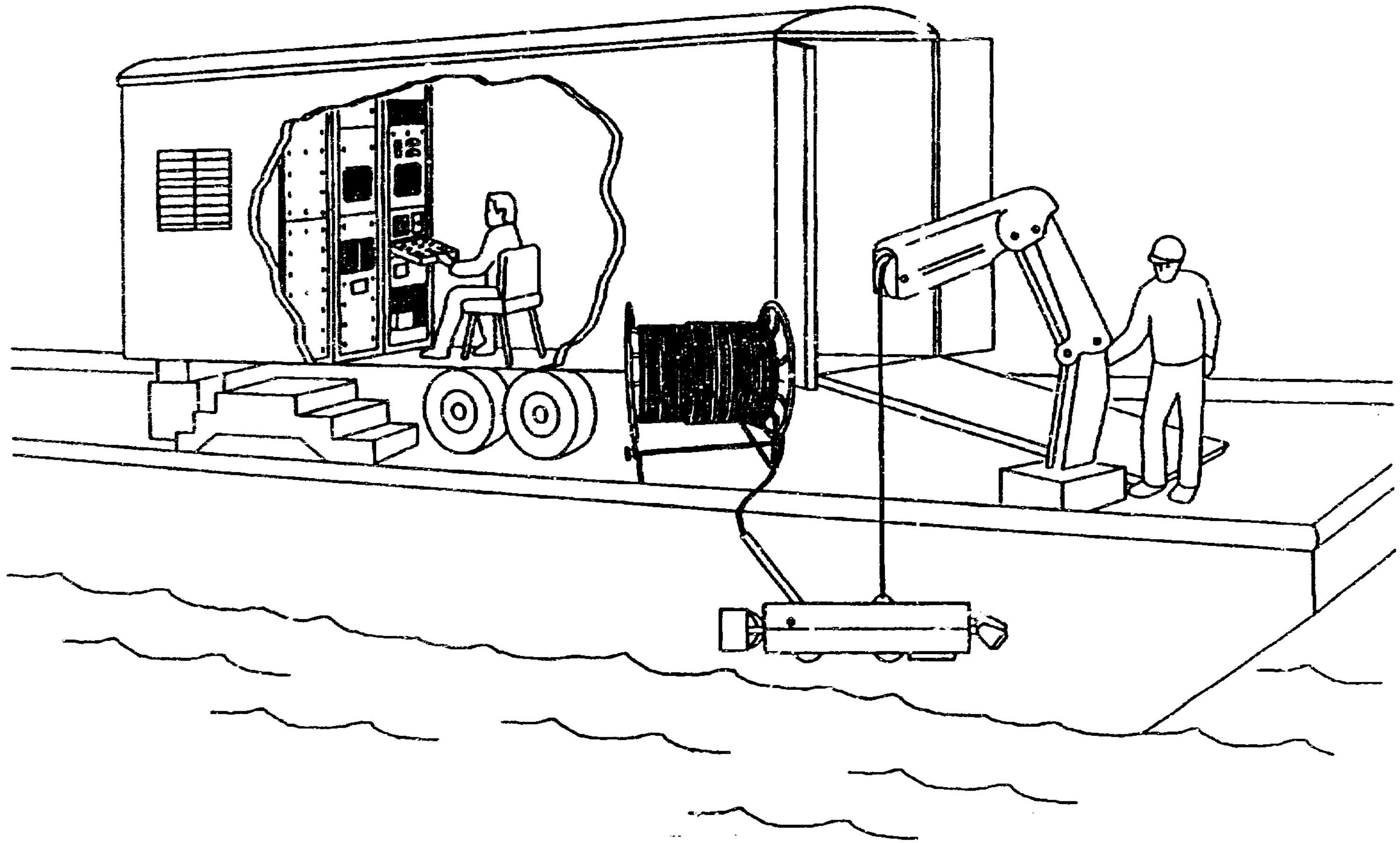

Fig. 13. Typical deployment of the AHHV.

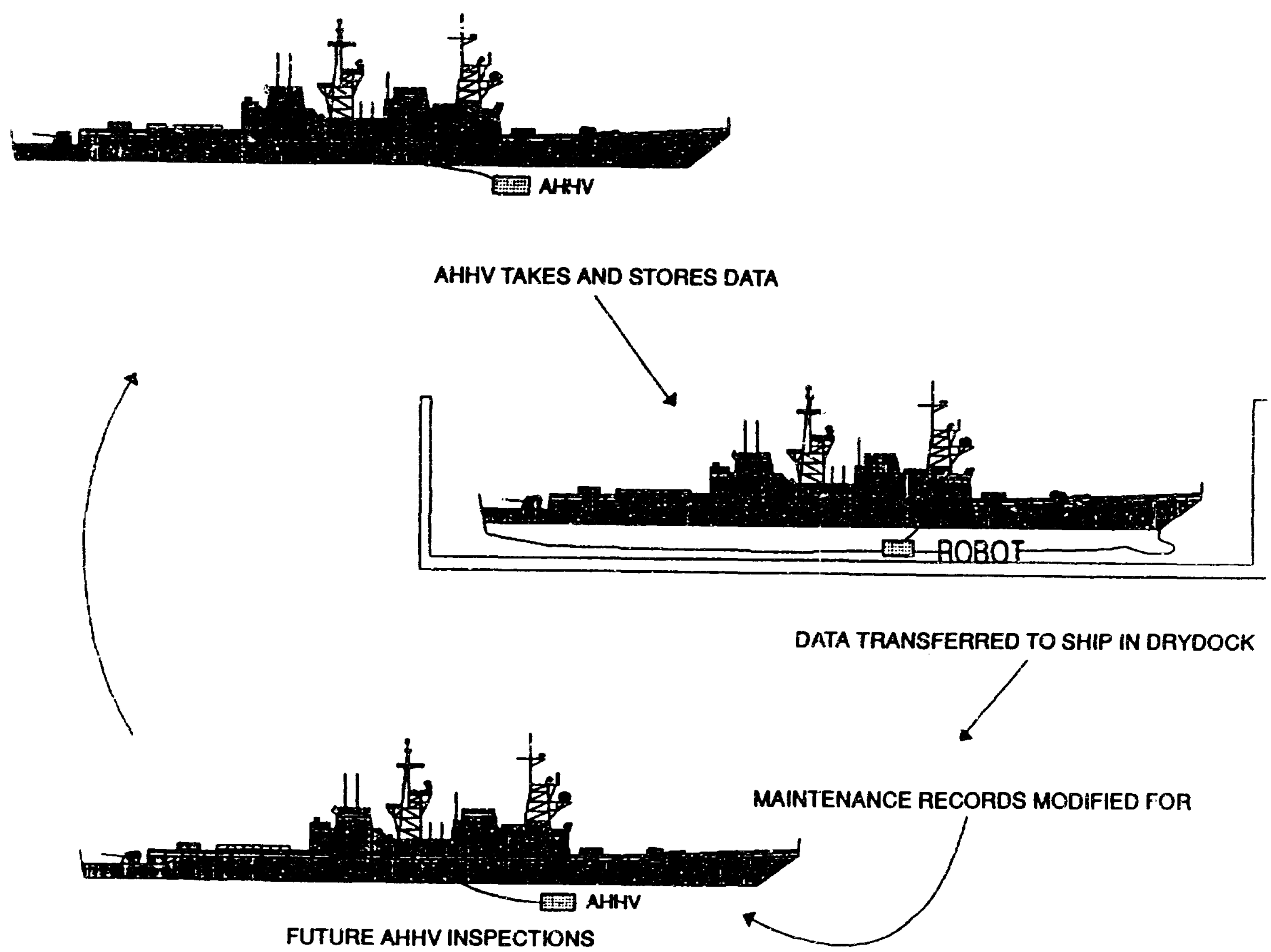

Fig. 14. Automated hull husbandry concept.

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