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TECHNICAL MEMORANDUM

title: DEVELOPMENT, TEST AND EVALUATION OF HYDRAULICALLY-DRIVEN MARINE OUTBOARD PROPULSION UNITS

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INTRODUCTION

The Civil Engineering Laboratory (CEL) was tasked by the Naval Facilities Engineering Command to develop a hydraulically-driven marine outboard propulsion system as a possible replacement for existing outboard type propulsion units which utilize mechanical drive trains. This document reports progress to date.

BACKGROUND

Naval Amphibious Construction Battalions have used propeller-type outboard propulsion units since World War II to move Navy Lighter (NL) pontoon craft such as lighters, barges, and floating cranes in harbors, and for warping tugs in amphibious operations. This type of unit, as illustrated in references 1 and 2, consists of a deck-mounted frame with an engine, plus a tail section extending downward over the stern of the craft about six feet below the deck. A power train, from the engine to a propeller at the lower end of the tail section, passes through two right-angle drives which require expensive, high precision gears. A misalignment of the gears, causing damage requiring extensive repairs, may result from either the propeller or tail section striking a submerged object or the sea bottom.

The propeller must be elevated to a position above the plane of the barge bottom to avoid its striking the sea bottom during operation in the surf or other shallow water. This is accomplished, in existing units, by rotating the tail section outward about its upper end, thus tilting the propeller until its axis is about 45 degrees above the horizontal. In this position, however, it is inefficient and steering control is seriously affected.

Inboard (reference 3) and water jet propulsion (reference 4) systems have been investigated as solutions to the problems described because they can be designed with little or no protrusion below the hull and without exposed propellers to foul lines and cables. These propulsion systems are not without problems, however. As stated in the reference documents, these problems include reduced efficiency at the slow speeds of warping tug operations and reduced thrust-to-horsepower ratios.

Another approach by which the expensive and vulnerable gears could be eliminated is to utilize a hydraulic motor to drive the propeller directly. Power could then be transmitted through flexible hydraulic hoses that would be unaffected by propeller or tail section impacts. Furthermore, a hydraulic unit that is unencumbered by a gear train offers more structural flexibility. The propeller elevation mechanism could be designed so that the propeller axis would remain horizontal and retain essentially the same thrust and steering characteristics as when in its lower position. The purpose of the work reported herein was to investigate such a system.

ACCOMPLISHMENTS TO DATE

By Contract N62399-71-C-0010, CEL obtained the design and fabrication of a hydraulically-driven system (Figure 1) from Western Gear Corporation, Heavy Machinery Division, Everett, Washington. Most of the planned testing has been completed.

DISCUSSION

Description of the Hydraulic Propulsion System

Two propulsion units and a separate, common remote operator's console make up the complete system, as illustrated in Figure 1.

The separate remote station permits one operator to control the two propulsion units either individually or simultaneously. Instruments and controls at the remote station console are connected to the propulsion units by electrical, hydraulic, and flexible drive cable means. The console may be located as much as 25 feet (7.6 meters) away from the power assemblies and at a ten-foot (three-meter) elevation above the deck of the craft.

Each propulsion unit is a complete, self-contained 28,000 pound (12,700 kg) package that may be mounted on an NL barge and used to propel, steer, and stop the barge. Each unit includes a complete diesel-engine-driven, hydraulic-power package and a separate outboard drive assembly. Power is transmitted hydraulically through detachable lines which connect the power package and the outboard drive assembly. A complete operator's unit-control console is mounted on each power package.

A Detroit Diesel, 8V71, 250 hp (186 kw) engine equipped with a scavenger blower (not supercharged) is used in each power package. The engine is designed to be operated at a constant 2,000 ± 50 rpm at no load. The main pump in the power package is a variable displacement unit designed to displace up to 150 gallons per minute (9.5×10^{-3} m3/5) at 3,000 rpm. The engine and pump, together with all associated hydraulic components and the unit operator console, are mounted above the hydraulic oil reservoir and the diesel fuel tanks.

The drive unit thrusters are 39-inch (0.99-meter) diameter, 34-inch (0.86-meter) constant pitch propellers with Kort nozzles. Each thruster can be rotated continuously through 360 degrees (2π radians) about its vertical support column. Each propeller may be driven either clockwise or counterclockwise by a hydraulic motor, mounted at the propeller axis, acting through a planetary gear system.

Auxiliary hydraulic systems provide means for:

1. Steering. Rotating the thrusters to the right or to the left provides the primary steering means. Steering may also be accomplished by varying thrust output of one unit relative to the other.

2. Raising the thruster assembly. The thruster with its vertical support column can be raised in either of two modes:

    a. Raised along an inclined plane while maintaining vertical orientation, so that the Kort nozzle is lifted above the bottom plane and outward from the stern of the craft. The propeller axis remains in the horizontal plane.

    b. Raised by pivoting about a horizontal axis rearward and upward through a 90-degree (1.57-radian) arc to a horizontal orientation.

High pressure hydraulic accumulators are continually charged to provide emergency means for raising the thruster assembly in either of two modes when, for whatever reason, the power plant is not providing the pressurized fluid required.

Automatic safety systems are provided to protect the system against damage. These function to:

1. Cause the thruster/vertical column assembly to be raised from deep to shallow water operations position upon sensing a vertical component contact with the seafloor.

2. Permit the thruster/vertical column assembly to freely pivot aft and upward through an arc when the craft is underway ahead, upon sensing a horizontal component contact with an object or the seafloor, and thereby ride up and over the obstruction.

A hand cranking means is provided to permit the thruster to be rotated 360 degrees (2π radians) about the vertical column axis when the powered hydraulic system is not functioning.

Design Objectives and Features

Each propulsion unit was designed to produce at least 6,000 pounds (26,700 newtons) of static thrust. The two units working together were to produce 10,500 pounds (46,700 newtons) of static thrust and 4,000 pounds (17,800 newtons) of thrust during forward movement at seven knots. Design thrust when backing down with propellers in deep water position was to be not less than 70 percent of maximum forward thrust (with the propeller rotated 180 (π radians) degrees about the vertical column). With the rotational direction of the propeller and hydraulic motor reversed, the required thrust was desired to be not less than 30 percent of maximum forward thrust.

Rate of rotation of the thruster assembly about the vertical column was to be not less than 10 rpm.

The thrusters were required to be raised from deep water position to shallow water position in less than 20 seconds, against full propeller thrust, without noticeably retarding engine speed. They were also to be returned to full down position while continuing underway.

Requirements included provisions permitting optional separation of the power package assembly from the outboard drive assembly by a distance of up to 20 feet (6.1 meters) without degrading performance. Only hydraulic lines would join the assemblies thus separated.

Criteria also included the requirement that the design permit easy accessibility for maintenance and repair in the field.

To meet noise pollution standards, the noise level at the engine operator's station was specified to be not over 90 decibels (dba) measured on the A scale of an ASA sound level meter.

A pressure-sensitive hydraulic reaction system was required as a means to provide for automatic raising of the propeller from deep water to shallow water position within three seconds upon striking a submerged object or the sea bottom.

A pressure-spike-actuated hydraulic bypass means was required to permit the vertical column/propeller assembly to pivot freely in an upward arc upon collision with an underwater object and to remain in whatever position it assumed in riding over the object, until returned to operating position by the operator.

Test Program

The test program was divided into two sections:

1. Contractor's functional tests to demonstrate that the propulsion system and all components were operational and that they functioned properly.

2. Government acceptance tests to functionally check the system after it was mounted aboard a suitable barge; to determine specific performance factors by subjecting the system to static pull tests; to functionally test the system at full throttle while underway; to evaluate beach retraction capability; and to subject the system to random cruising maneuvers for the remaining portion of 100 hours total cumulative testing. The random cruising was required to include 3 six-hour uninterrupted periods to determine whether the units could operate continuously without overheating and to uncover any evidence of malfunction.

Test Results

Contractor's Functional Tests. Contractor's functional tests were performed at Everett, Washington during mid-winter. The system was mounted on a framework constructed ashore. Engine coolant heat exchanger raw water was provided from domestic sources. Under these conditions, it was demonstrated that a preliminary warm up period was required to adequately thin the hydraulic oil to permit proper functioning of the system. Since the propellers were rotated in air only, it was not possible to adjust the main pump control linkage to determine required system pressure and related propeller rpm to provide the design value thrust. All circuits of the system were exercised, and each required function was demonstrated satisfactorily.

Government Acceptance Tests. For the government acceptance tests at Port Hueneme, California, the system was mounted on a 3 x 14 NL pontoon barge.

Functional tests at dockside demonstrated that all operator-controlled functions were executed in accordance with design, and responses were within acceptable limits of design criteria.

Bollard pulls were conducted to measure static thrust of each unit and of the two units working together as a system. The results were as follows:

1. In forward direction:
    a. With thrusters in deep water operating position:
        (1) Single unit - 6,200 pound (27,600 newton) thrust
        (2) Both units together - 11,500 pound (51,200 newton) thrust

   b. With thrusters fully retracted into shallow water operating position:

      (1) Single unit - 6,000 pound (26,700 newton) thrust

      (2) Both units together - 10,200 pound (45,400 newton) thrust

2. Backing down with thrusters rotated 180 degrees (π radians):

   a. With thrusters in deep water operating position:

      (1) Single unit - 4,100 pound (18,200 newton) thrust

      (2) Both units together - 8,700 pound (38,700 newton) thrust

   b. With thrusters fully retracted into shallow water operating position. No measurable thrust. Water flow pattern and cavitation resulted in foaming water. This may be due to recirculation caused by hull shape and proximity. Thrust increases as the thrusters are lowered toward the deep water position.

3. Backing down by reversing propeller rotation only:

   a. With thrusters in deep water operating position:

      (1) Single unit - 3,000 pound (13,300 newton) thrust

      (2) Both units together - 5,400 pound (24,000 newton) thrust

   b. Not tested with thrusters fully retracted into shallow water operating position.

Tests at full power were conducted, with results as follows:

1. The vertical column (steering control) will rotate continuously at 10.5 rpm.

2. Thrusters will raise to shallow water position in 30 seconds.

3. The reaction system functioned properly when the barge was driven over a sandbar.

4. The system will stop the barge within its own length from full speed, when the thrusters are rotated 180 degrees (π radians) about the vertical column.

5. The system will stop the barge within one and a half barge lengths when the propeller rotation is reversed.

Three retractions were made from consecutive beachings at full speed. No assistance was required and total elasped time of the approaches, beachings, and retractions was less than one-half hour. Beach slope was approximately 1 to 50 (about the trim of the barge). Figures 2 through 4 show the barge during an unassisted retraction. It is apparent from these tests that there is some thrust when backing down with the thrusters in the shallow water position and rotated 180 degrees, even though the bollard tests indicated no measurable thrust under those conditions.

Both at dockside and while underway, the engine noise level exceeded the specified 90 dba limit at most locations on the barge (readings were 103 - 108 dba at the local control stations on the units, 91 - 101 dba at the remote control station, 111 - 118 dba between the engines, and 78 - 90 dba at the bow edge of the barge).

In addition to the problem of excessive noise, several other minor problems were observed during the tests. These are noted in the Appendix, categorized according to whether only minor modification of the existing system would correct the problem, or whether significant redesign would be necessary.

Table 1 shows a comparison of the thrust and fuel consumption characteristics of the hydraulically-driven system with those of two mechanically-driven systems and a first-generation experimental water jet system.

Test Status

Testing was completed to the point at which the system was accepted by the government and the performance potential had been confirmed. Shortly thereafter, immediately following installation of longer hydraulic lines to simulate a 20-foot (6.1-meter) separation of the power unit from the thruster assembly, the hydraulic system in one of the units failed. Testing was discontinued at that time because the estimated cost to repair the failure exceeded the funds available.

CONCLUSIONS AND RECOMMENDATIONS

Work to date has shown the concept of the hydraulically-driven outboard propulsion system to be a viable one. The problems cited in the Appendix are not uncommon in development of a new concept, and they are of the kinds which can be readily solved by additional development effort.

As indicated in Table 1, the thrust obtained per unit power input is equal to or greater than is being obtained with existing mechanically driven units and considerably greater than that of the first generation inboard water jet. Specific fuel consumption is considerably less than that for the other systems.

The primary concerns of operating personnel who observed the system appeared to center about its size and weight, and the apparent complexity of the outdrive assembly. The power unit appears to be large, since the engine and pump are mounted on top of the fuel tank and hydraulic fluid reservoir. The size would be reduced considerably by locating the fuel tank, and possibly the reservoir, inside the hull. A much greater reduction could be accomplished by also placing the entire power package inside the hull, as is done with the water jet, and leaving only the outdrive thruster assembly mounted on the deck.

There are a number of alternatives available for reducing the weight and complexity. An extreme would be to redesign the thruster assembly so that it is always operated in the equivalent of the "up" position of the present system. Table 1 indicates this is not an unreasonable approach for detailed consideration, since the resulting system would have thrust and fuel consumption performance essentially equal to or better than all the other types of systems listed. This approach should also lead to a substantial reduction in cost.

PLANS FOR FUTURE WORK

As noted earlier in this report, testing of the system was discontinued because a hydraulic system in one of the units failed, and the estimated cost of repair exceeded the funds available. At about that time, the Laboratory entered into a contract (reference 5) for development of a second generation water jet propulsion system for powered causeways deployable by LST side carry. Since the resulting water jet propulsion system may be suitable also for other applications, such as side-loaded warping tugs, the Laboratory was instructed to preserve and store the hydraulically-driven system pending testing and evaluation of the new water jet system. Consequently, the hydraulically-driven system has been preserved and stored, and no further work on its development is scheduled in the immediate future.

REFERENCES

1. Civil Engineering Laboratory. Technical Report R-266: Evaluation of Murray and Tregurtha Mod. 9D-200 Propulsion Unit, by A. L. Scott, Port Hueneme, California, Sep 1963.

2. Civil Engineering Laboratory. Technical Note N-312: Evaluation of Prototype Chrysler Outboard Propulsion Units, by W. B. Mitchell and A. L. Scott, Port Hueneme, California, Sep 1957.

3. Civil Engineering Laboratory. Technical Note N-307: Test of Murray and Tregurtha Prototype Inboard Propulsion Units, by W. B. Mitchell and A. L. Scott, Port Hueneme, California, Jul 1957.

4. Civil Engineering Laboratory. Technical Report R-724: Evaluation of a Water Jet Propulsion System for Warping Tug and Similar Naval Applications, by A. L. Scott, Port Hueneme, California, Apr 1971.

5. Contract N00123-76-C-0036 with Food Machinery Corporation under CEL work unit Y41X6-001-01-001b.

Table 1. Comparison of Thrust and Fuel Consumption Characteristics With Those of Other Systems

Item	Outboard Mechanical Drive				Inboard Water Jet (1st generation)	Outboard Hydraulic Drive	
	9D200		L295				
	Down	Up	Down	Up		Down	Up
English Units:							
Lb static thrust/hp							
Forward	23.6	18.6	19.9	13.6	15.2	23.0	20.4
Astern	13.6	10.7	(11.5) (b)	(7.8) (b)	12.2	17.4	See Note (a)
Lb weight/lb static thrust							
Forward	2.45	3.11	3.00	3.98	3.48	4.87	5.49
Astern	4.25	5.40	(5.20) (b)	(6.91) (b)	4.33	6.44	See Note (a)
Gal fuel consumed/hr/lb static thrust							
Forward	0.0040	0.0051	0.0034	0.0050	0.0037	0.0029	0.0033
Astern	0.0069	0.0088	(0.0059) (b)	(0.0087) (b)	0.0047	0.0039	See Note (a)
SI Units:							
Newton static thrust/watt							
Forward	0.141	0.111	0.119	0.081	0.091	0.137	0.122
Astern	0.081	0.064	(0.069) (b)	(0.047) (b)	0.073	0.104	See Note (a)
Kg/newton static thrust							
Forward	0.250	0.317	0.306	0.406	0.355	0.497	0.560
Astern	0.434	0.551	(0.531) (b)	(0.705) (b)	0.442	0.657	See Note (a)
M^3 fuel consumed/sec/newton static thrust							
Forward	0.95×10^{-9}	1.2×10^{-9}	0.80×10^{-9}	1.2×10^{-9}	0.88×10^{-9}	0.69×10^{-9}	0.78×10^{-9}
Astern	1.60×10^{-9}	2.1×10^{-9}	(1.4×10^{-9}) (b)	(2.1×10^{-9}) (b)	1.10×10^{-9}	0.92×10^{-9}	See Note (a)

NOTES: (a) Bollard pull test effort with units thrusting 180° (π radians) astern failed to register any reading on towline dynomometer. However, beaching tests indicated that thrust strong enough to unbeach the 3 x 14 NL pontoon barge did occur. Planned bollard pull tests during which the thrusters were to be positioned at various angles with respect to the longitudinal dimension of the barge were not carried out, as noted in the text.

(b) Estimated.

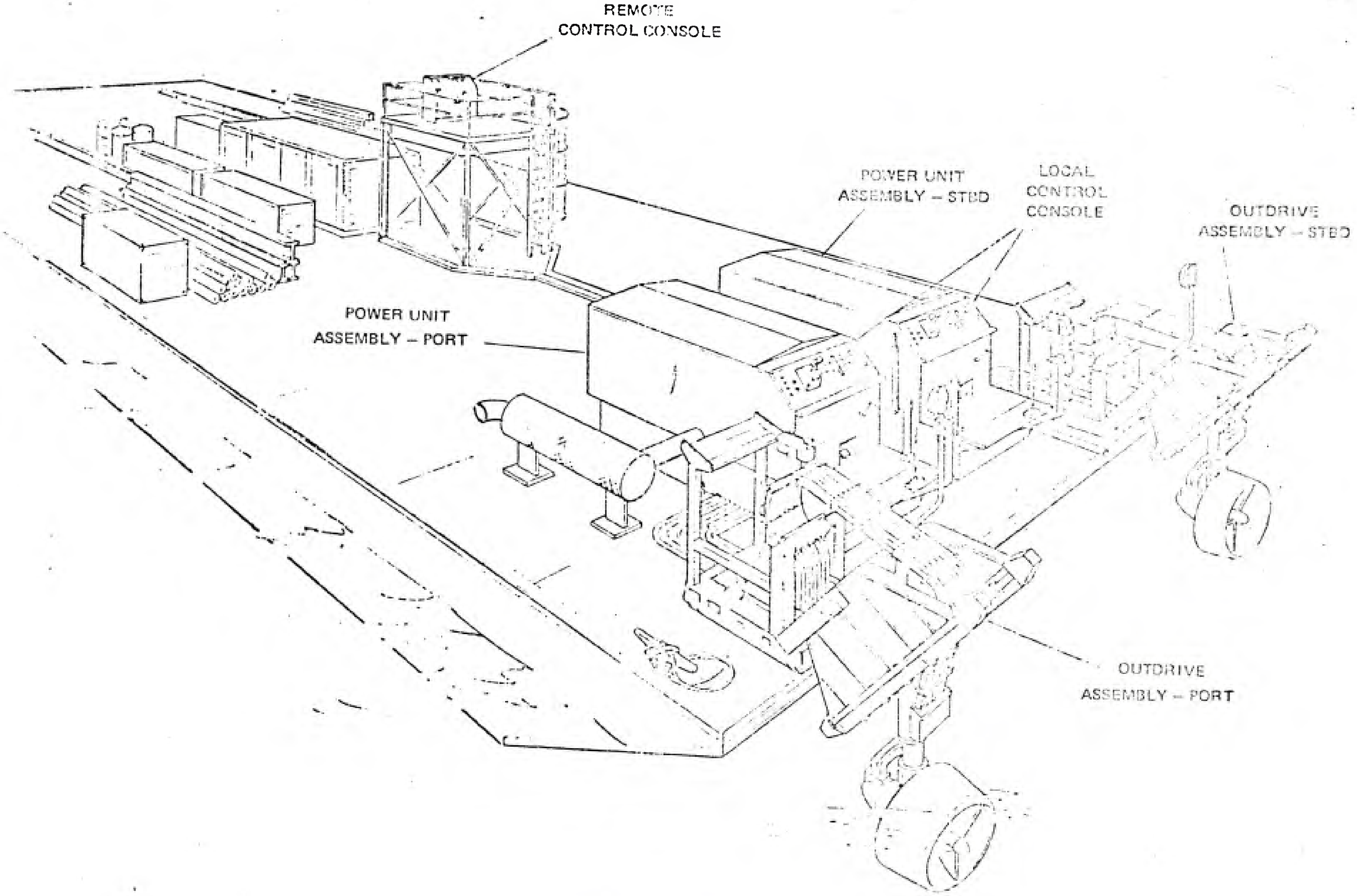

Figure 1. Hydraulically-driven Outboard Propulsion System

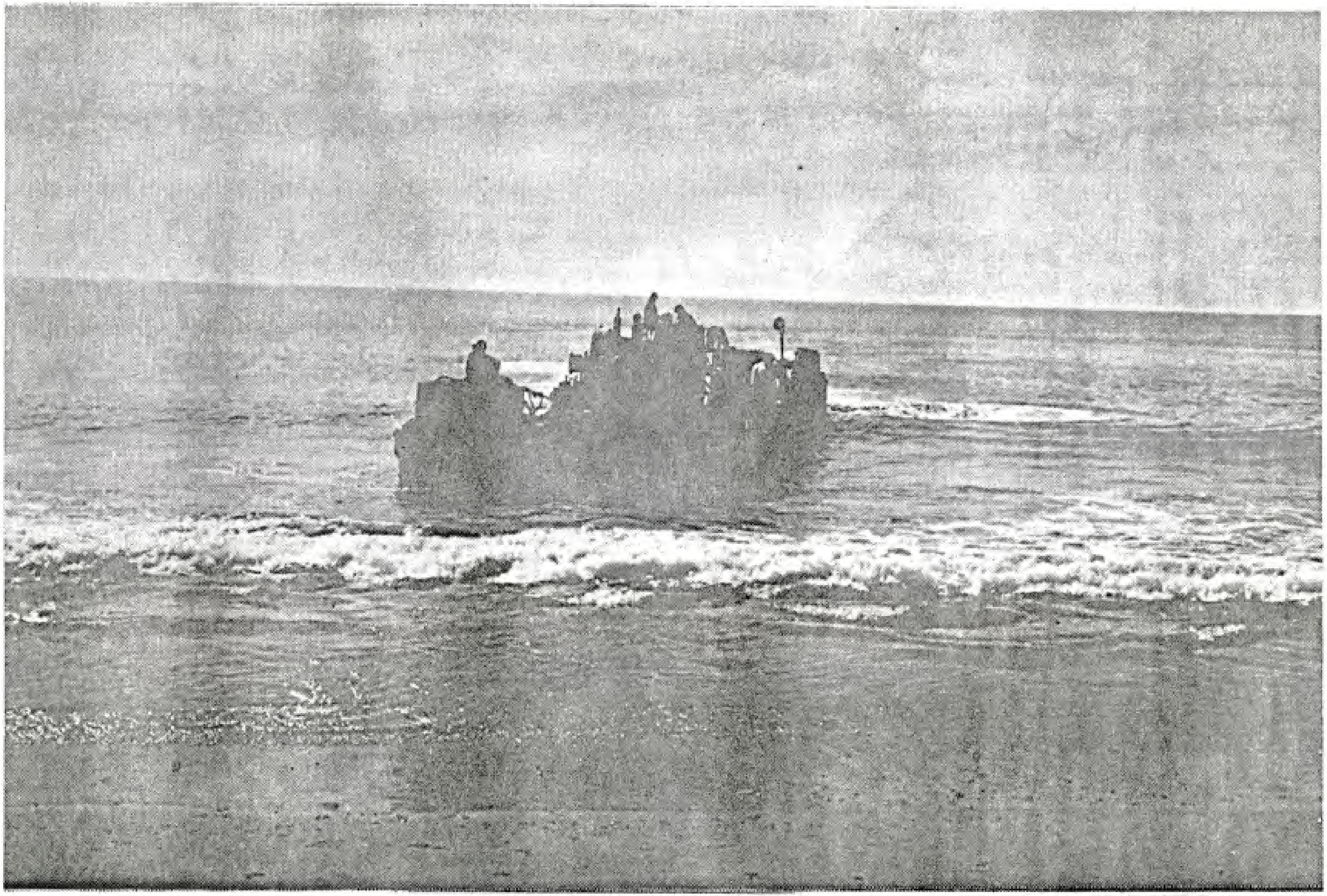

Figure 2. Barge being driven onto the beach at full power by the hydraulically-driven propulsion system.

Figure 3. Beached barge

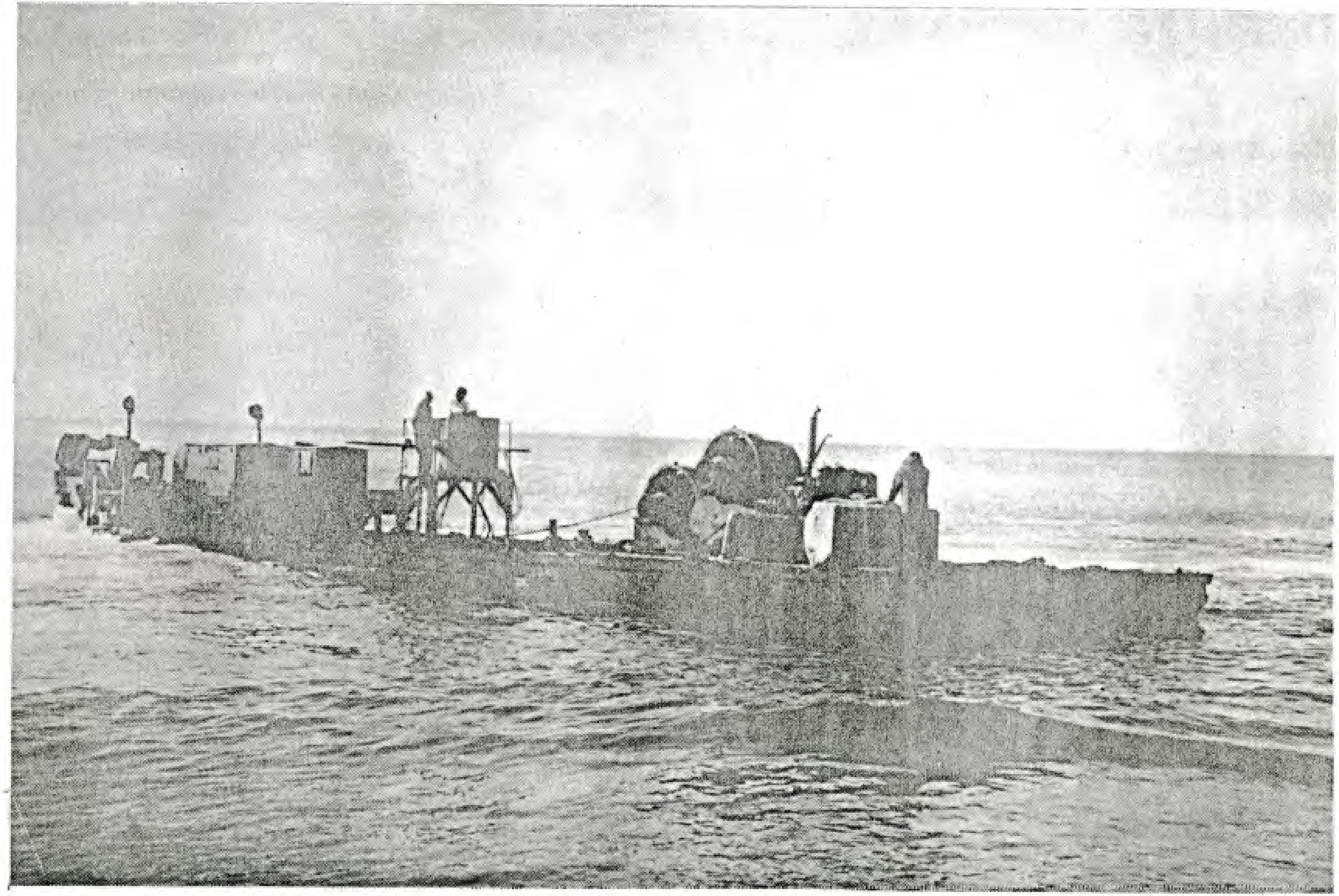

Figure 4. Hydraulically-driven propulsion system retracting the barge from the beach.

APPENDIX

Summary of Minor Problems

The purpose of this summary is to record problems which were observed during testing and which should be considered and corrected as part of any future development.

Problems which can be corrected by minor modification of the existing system are as follows:

1. Following the tests described in this report, examination of the Kort nozzles and other parts (such as hose fittings) which are normally submerged during barge operation revealed that significant electrolytic corrosion had occurred. The damaged areas were repaired, but adequate cathodic protection should be added to reduce such damage to a practicable minimum.

2. The main system hydraulic pump can overload the engine if the main system pressure is not securely set at an acceptable maximum (approximately 2,600 psig (18 megapascals) for the test system). Vibration during operation can cause the pump swash plate throttle linkage setting to change, thus causing overloading of the engine and raising engine exhaust temperature above the acceptable maximum 725°F (658°K) for continuous operation. Linkage design should be altered to ensure against changes in linkage settings. Also, remote engine exhaust temperature gauges should be provided at the operators' control stations so that the temperature can be continously monitored.

3. The forward and reverse throttle controls provided with the system presented problems while underway. These problems were as follows:

a. The type of control lever furnished provides a means to lock the spring loaded throttle linkage at any desired position. The throttle lever handle is screwed down against the housing to lock it in position, and it is unscrewed to release it. Vibration during operations causes the handles to screw down unintentionally into locked position. When this occurred at either the remote control station or at the local control station while the operator was at the other station, the operator lost throttle control briefly until the cause could be corrected. Some other type of control should be provided which will ensure firm operator control at all times.

b. The forward and reverse control linkage furnished with the system provides such a short stroke in either direction that fine control of speed is difficult. Linkage providing a longer stroke would permit more satisfactory intermediate speed settings.

4. The directional control levers at the remote station were installed with a shear pin. The pin securing the starboard unit control lever was sheared twice during manuevering. A larger diameter shear pin was installed to correct the problem on the prototype unit, and should be incorporated into the design.

Problems observed and which would require significant redesign for adequate correction are as follows:

1. Any air leakage into the raw-water coolant circuit will prevent adequate cooling of the engine. Because of the location within the assembly, such leaks could not be corrected without dismounting the complete power unit to permit access from its underside. The design should be modified to eliminate this difficulty.

2. Hydraulic fluid leaks occurred and recurred at a number of the hose flange fittings and rigid tubing fittings. Many of these were difficult to correct because of their location within the assembly and proximity to adjacent equipments. Off-the-shelf tools proved unsatisfactory for leak corrections largely because of lack of working room. Attempts to modify tools for that purpose did not yield satisfactory results. The design should be modified to minimize the probability that fittings will loosen during operation, and to provide adequate space in which to utilize tools to check and tighten the fittings. Special tools should be provided for any exceptions.

3. Multiple O-ring failures at the main system hydraulic hose manifold flange fittings indicate a need for further design effort in that area. The O-ring failures appeared to have resulted from repeated extrusions, possibly during cycling of the high pressure main system circuit through forward and reverse modes.

4. As mentioned earlier in this report, noise levels during operation generally exceeded the specification and the OSHA regulation (which both state a limit of 90 dba). Noise reduction should be included as an objective of any design modification effort.