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By Nate Sinclair

Technical Report

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PORTABLE HYDRAULIC POWER SOURCE

ABSTRACT The Naval Civil Engineering Laboratory (NCEL) has developed a Portable Hydraulic Power Source (PHPS) designed to enable the Naval Construction Divers to operate oil hydraulic tools in an Arctic environment. The PHPS is a three-piece assembly developed to be lightweight, mobile, and capable of powering hydraulic tools through a 250-foot hose. It can be handled manually by four personnel, transported in a small aircraft, and operated from a 22-foot inflatable boat. The PHPS can start at -40°F and supply 8 gpm of hydraulic fluid at 2,000 psi. This report describes the system, the approach used in developing the system, and the results of performance and reliability testing.

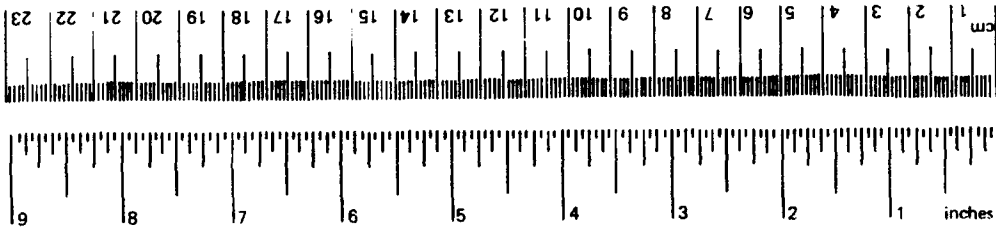
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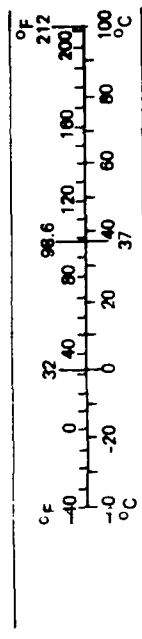
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures				Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
in	inches	2.5	centimeters	mm	millimeters	0.04	inches
ft	feet	30	centimeters	cm	centimeters	0.4	inches
yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	1.1	yards
						0.6	miles
in ²	square inches	6.5	square centimeters	cm ²	square centimeters	0.16	square inches
ft ²	square feet	0.09	square meters	m ²	square meters	1.2	square yards
yd ²	square yards	0.8	square meters	km ²	square kilometers	0.4	square miles
mi ²	square miles	2.6	square kilometers	ha	hectares (10,000 m ²)	2.5	acres
	acres	0.4	hectares				
oz	ounces	28	grams	g	grams	0.035	ounces
lb	pounds	0.45	kilograms	kg	kilograms	2.2	pounds
	short tons (2,000 lb)	0.9	tonnes	t	tonnes (1,000 kg)	1.1	short tons
tsp	teaspoons	5	milliliters	ml	milliliters	0.03	fluid ounces
Tbsp	tablespoons	15	milliliters	l	liters	2.1	pints
fl oz	fluid ounces	30	milliliters	l	liters	1.06	quarts
c	cups	0.24	liters	l	liters	0.26	gallons
pt	pints	0.47	liters	m ³	cubic meters	35	cubic feet
qt	quarts	0.95	liters	m ³	cubic meters	1.3	cubic yards
gal	gallons	3.8	liters				
ft ³	cubic feet	0.03	cubic meters	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature
yd ³	cubic yards	0.76	cubic meters				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature				



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10.286.



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CONTENTS

	Page
INTRODUCTION	1
BACKGROUND	1
SYSTEM DESIGN	3
SYSTEM DESCRIPTION	6
TESTING	8
EVALUATION	13
Reliability	16
Logistic Supportability	17
DISCUSSION	18
RECOMMENDATIONS	20
BIBLIOGRAPHY.....	20
 APPENDIXES	
A - Advanced Development Model Testing	A-1
B - Schematics: Hydraulic and Electric	B-1
C - Operating Procedures	C-1

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INTRODUCTION

The Underwater Construction Teams (UCTs) need a hydraulic power unit for operations in Arctic environments (-40°F). This unit must be simple, rugged, and mobile.

The Naval Civil Engineering Laboratory (NCEL) was tasked by the Naval Facilities Engineering Command (NAVFAC) to design, fabricate, test, and evaluate a Portable Hydraulic Power Source (PHPS). This hydraulic power unit must be capable of powering any of the oil hydraulic tools used by the UCTs in extremely cold environments. The unit must be man portable, and transportable in a Twin Otter aircraft.

This hydraulic power source was developed at NCEL as a mobile, self-contained assembly capable of operating in Arctic climates. It provides up to 8 gpm of flow at 2,000 psi to power hydraulic tools through 250 feet of hose. This system was designed as a modularized assembly to accommodate ease of handling and to fit into small aircraft.

This report describes the overall development of the PHPS. The testing and evaluation described in this report pertains to the Engineering Development Model (EDM). The testing performed on the Advanced Development Model (ADM) can be found in Appendix A of this report. The development of the PHPS consisted of designing and testing prototype units. The results from these efforts were then used to develop an Operation and Maintenance (O&M) Manual and a Purchase Description package, complete with a level 3 drawing package of the final production unit.

BACKGROUND

The Underwater Construction Teams presently have three oil hydraulic power sources available to power their tools. These units have the following characteristics:

<u>Model No.</u>	<u>Weight (lb)</u>	<u>Maximum Flow (gpm)</u>	<u>Maximum Pressure (psi)</u>
MOD 2	1,000	15	2,000
MOD 3	420	7	1,500
MOD 7	250	10	2,000

The Naval Sea Systems Command (NAVSEA) MOD 2 has sufficient power to drive any two UCT hydraulic tools, but is too heavy to be man portable. The NAVSEA MOD 3 is portable, but not powerful enough to drive the UCT rock drill. The NAVSEA MOD 7 is sufficiently portable and

powerful, but it is a modified outboard motor and can only be operated from the transom of a boat. None of these hydraulic power units can operate in an Arctic environment.

A Portable Hydraulic Power Source Advanced Development Model (ADM) was designed by Eastport International in accordance with UCT requirements, as stated in the Test and Evaluation Master Plan (TEMP). One unit was delivered to NCEL in December 1988. The test and evaluation of this power source included laboratory testing and field testing. The laboratory tests of the ADM were conducted at NCEL. Field tests were conducted at Priest Lake, Idaho; in the Arctic north of Greenland; and in the Bering Sea off the Alaskan coast. Testing of the ADM was accomplished for evaluation of performance and human factors. The improvements made were based on the results of the testing and evaluation, and discussions with the UCT users (refer to Appendix A for details on testing and evaluation of the ADM unit).

Based on results of ADM testing, the following improvements were incorporated into EDM:

1. Modified the quick-disconnect couplings to eliminate their tendency to vibrate loose during operation.
2. Eliminated the gear pump option in favor of the variable displacement piston pump.
3. Reduced the diameter of the return hose between the reel and power source from 1-1/4 inch to 1 inch.
4. Improved the mating of the upper and lower unit by reducing the difficulty in connecting the two short, stiff hoses.
5. Evaluated ways to improve the cold start capability.
6. Replaced the factory key and push-button engine switches with toggle switches rated for service and cold temperature.
7. Eliminated the screwdown mating latch in favor of quick-release pins.
8. Prepared a more detailed operating instruction plaque showing correct startup, operation, and shutdown procedures.
9. Included a heat-resistant, flexible duct hose with the unit and modified the engine tailpipe to accommodate the larger hose diameter.
10. Provided a means to access the compression release lever in a convenient way.
11. Investigated the possibility of a fuel line which would act as a bypass option to the fuel pump.

12. Identified alternate construction to reduce the weight of the hose reel.
13. Provided the unit with lifting points and tiedown points.
14. Sealed all reservoirs to allow the power source to be filled with fluids during transportation.
15. Ensured that the oil pressure gauge is protected from falling objects, etc.
16. Located the flow valve on the downstream side of the pressure relief valve.
17. Removed all sharp edges from the power unit and hose reel.
18. Added a fuel pump to the spare parts list.

Two Portable Hydraulic Power Source EDMs were fabricated, and delivered to NCEL in January 1990.

SYSTEM DESIGN

The Portable Hydraulic Power Source is required to meet the thresholds specified in the "Arctic Tools and Techniques Test and Evaluation Master Plan (TEMP)." Table 1 describes the TEMP requirements.

The PHPS must be capable of powering any one of the UCT hydraulic tools. The unit is required to operate in Arctic conditions. The size and weight of power source unit is constrained so that all of its components will fit inside a small aircraft, and be readily moved by four personnel.

To ensure that the PHPS will be capable of driving any one of the UCT hydraulic tools, the hydraulic power output of the power source was matched to the hydraulic requirements of the Stanley Tool HD-20 rockdrill. The HD-20 rockdrill is the UCT's most demanding hydraulic tool. Manufacturer's recommendations, and experience in the field, indicate the need for a hydraulic fluid flow of 8 gpm at 2,000 psi to properly power this rockdrill. Nine different diesel engines were researched for incorporation into the hydraulic power source. Table 2 lists these various diesel engines and their characteristics. It was determined that the Lombardini diesel engine best meets the system requirements. This engine provides the required horsepower, is lightweight, and has relatively low noise output. The Lombardini is also equipped with compression release levers to allow easier cranking when cold.

Table 1. TEMP Requirements

Parameter	Requirement
Power Source Performance	Operate at least one tool
Operating Temperature (°F)	-40 to 60
Storage Temperature (°F)	-60 to 150
Operating Wind Speed	15 knots
Maximum Size (must fit into Twin Otter)	yes
Maximum Single Component Weight (lb)	400
MTBF (hr) (Mean Time Between Failure)	67
MTTR (hr) (Mean Time To Repair)	2
Minimum Reliability (for 7-hour mission)	0.90
Minimum Availability	0.90
Maximum Maintenance (hr)	
Daily	2
End-of-Project	16
Annually	8
Useful Life (yr)	7

Table 2. Engine Comparison Chart

System	Engine Supplier ^a	Model Number	Horsepower at Max. rpm	rpm at 14.6 Horsepower	Engine Weight (lb)	Horsepower Per Pound	Noise Level ^b	Comments
UCT II	Hatz	E780	9.5/3,000	Imposs.	195	0.049	82 dB	Only 1,000 psi at 6.0 gpm as tested June 16, 1988.
1	Slanzi	DVA1030	20/3,000	1,500	265	0.075	86 dB	Previous cold weather experience down to -40°F.
2	Slanzi	DVA1030S	20/3,000	1,900	295	0.068	80 dB	Silenced version has plastic components that may not survive the cold.
3	Slanzi	DVA1200S	22/3,000	1,700	305	0.072	80 dB	Silenced version has plastic components that may not survive the cold.
4	Ruggerini	TRD2-655-1	14.8/3,600	3,600	138	0.107	86 dB	Running at high rpm a concern. Marginal configuration.
5	Ruggerini	TRD2-955-1S	17.1/3,600	2,400	220	0.084	80 dB	Added power to run slower and stronger.
6	Lombardini	12LD4352/B1	18.0/3,600	2,400	225	0.086	80 dB	Sufficient power over a range of speed.
7	Deutz	F2L-208F	19.4/3,000	2,200	250	0.078	80 dB	Glow plug provision must be adapted. One supplier indicated difficulties with this engine.
8	Hatz	2630	18.8/3,600	2,200	205	0.092	86 dB	No compression release, bad for weak battery starting. Rope start pulley must be added.

^aAll engines were selected to be capable of supplying 2,000 psi at 8.0 gpm at the diver tool using a pump efficiency of 0.80 and a pump outlet pressure of 2,500 psi.

^bNoise level is taken at maximum engine rpm with no load.

The design of this power source emphasizes the ability to withstand storage at -60°F , and to operate at -40°F . The wires, hoses, and fittings on the unit are all specified to withstand temperatures down to -60°F . Electric preheaters are installed in the unit for startup and operation at temperatures down to -40°F . These are powered by an external source of 120-VAC electricity. Two hydraulic fluids, both manufactured by Aerospace Lubricants Incorporated, provide the desired viscosity at ambient temperatures between -40 and 60°F . The hydraulic tools require fluid with a kinematic viscosity range of 20 to 80 centistokes. Tribolube L-6 is suitable for use between -40 and 32°F ambient air temperature (fluid temperature of 0 to 60°F). Tribolube L-1 is used for ambient temperatures above 32°F (fluid temperature of 60 to 135°F) (see Figure 1 for the viscosity versus temperature chart for these two fluids). Arctic Diesel Fuel (DFA) or JP-5 fuel is required to run the diesel engine under Arctic conditions. These fuels contain little wax or water, thus preventing them from solidifying at -40°F . For this same reason, synthetic motor oil is needed for the engine.

For ease of handling, the PHPS is designed as three individual components. These components are transported separately, and then joined together to form the power source. This configuration was selected to meet the size and weight constraints which allow the system to be handled by personnel, and enable it to fit inside small aircraft.

SYSTEM DESCRIPTION

The Portable Hydraulic Power Source is a modularized assembly consisting of three basic components: (1) a lower engine/pump module, (2) an upper reservoir module, and (3) a hose reel. These power unit modules are designed to be quick and easy to set up in the field.

The engine/pump module is enclosed in an aluminum frame that is 36 inches long by 23 inches wide by 28 inches high. This module weighs 325 pounds and is configured with four lifting handles, as well as four lifting/tiedown provisions. The prime mover and the hydraulic pump are housed in this lower module. The prime mover is an 18-horsepower, two-cylinder, Lombardini diesel engine. Two glow plugs are mounted in the engine inlet air manifold, one over each cylinder, that provide greater preheating of the inlet air. The engine is started electrically by means of a 12-volt battery integral to the system. The hydraulic pump is a variable displacement, axial piston pump. The variable displacement characteristic of the pump allows the engine to be started with no hydraulic load.

The reservoir module frame measures 35 inches long by 20 inches wide by 16 inches high. This upper module consists mainly of a 5-gallon hydraulic oil reservoir and a battery box. This module weighs 145 pounds with the battery and hydraulic fluid. The battery used is a marine/RV gel-cell battery with a 700 cold cranking amps rating. The gel-cell construction provides high recovery capability from deep discharge, as well as a leakproof feature that allows the battery to be shipped without special considerations.

**VISCOSITY VS. TEMP. FOR TRIBOLUBE L-6 AND L-1
(DEGREES F. VS. CENTISTOKES)**

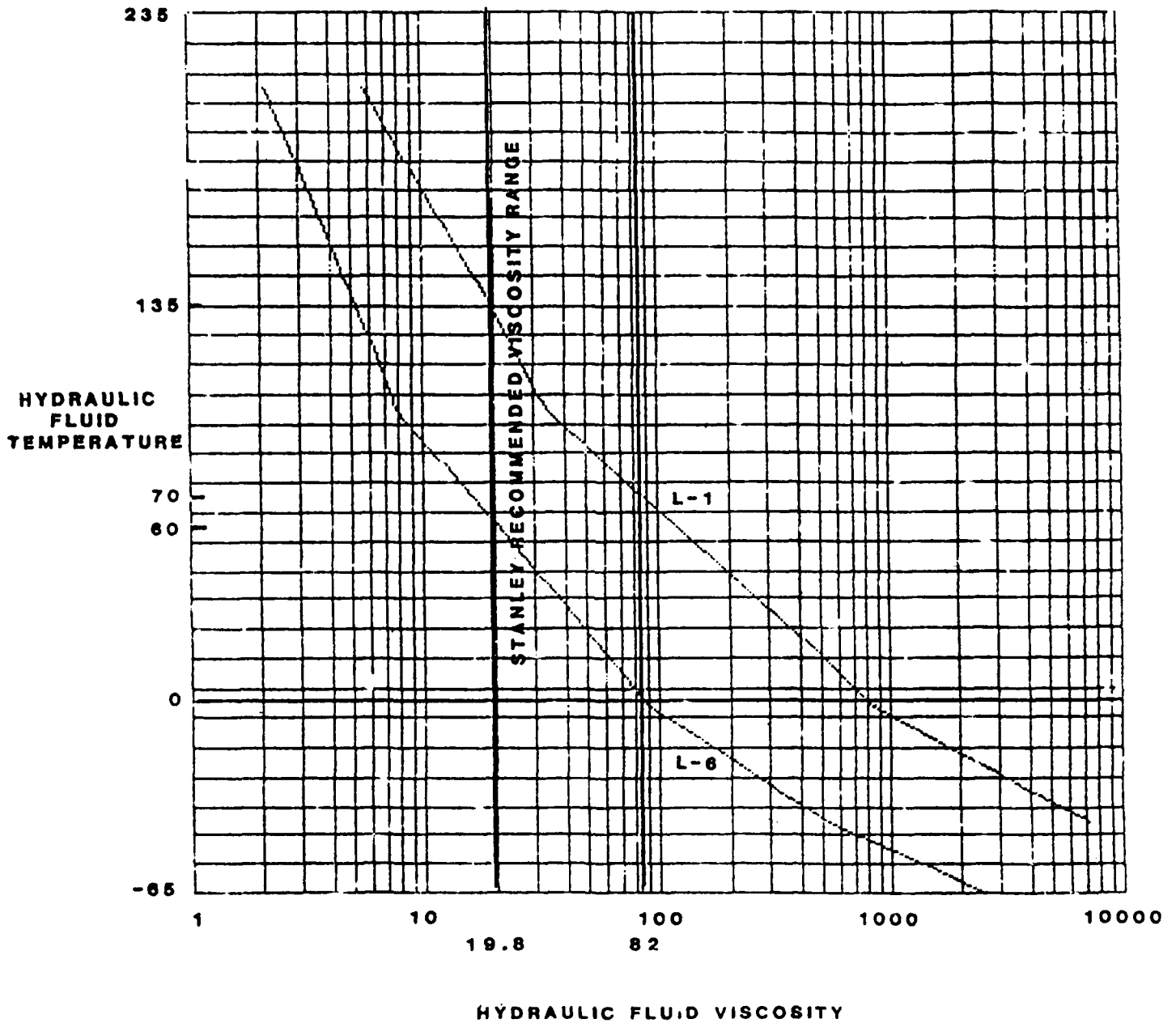


Figure 1. Hydraulic fluid viscosity versus temperature.

The portable hose reel measures 33 inches long by 33 inches wide by 34 inches high. It holds 250 feet of 3/4-inch tandem hose and weighs 365 pounds with the hose filled with oil. A single length of tandem hose delivers the oil to the tool and returns it to the power unit.

System preheaters are incorporated for operation in extremely low temperatures. These preheaters are located in the engine oil sump, the hydraulic fluid reservoir, and in the battery enclosure. These are powered by an external source of 120-VAC electricity. Appendix B shows the system electrical schematic, including the 120-VAC system preheater circuit and the 12-VDC engine circuit. Figures 2 through 5 show the various features of the Portable Hydraulic Power Source.

TESTING

Two EDM power sources were subjected to performance testing in the NCEL cold chamber facility. Both units were then subjected to development testing and user testing in an Eastern Arctic field operation. One of the EDM power sources, Unit No. 1, was also subjected to endurance testing at NCEL in order to complete the reliability testing that began in the Arctic.

Both Portable Hydraulic Power Source EDMs were tested in the NCEL cold chamber facilities to evaluate system performance at extreme temperatures. This testing was accomplished in February 1990.

The modular components of both units were separated and placed in the cold chamber at -55°F for 16 hours. Both units were assembled without difficulty. To make the hydraulic connection between the upper and lower modules, the upper module was tilted in order to reduce the angle required for bending the two hoses into position.

The power sources were subsequently cold-soaked overnight at -40°F. Preheat was applied to one unit for 30 minutes. At this point, three attempts were made to start the engine. The glow plugs were applied for 30 seconds the first try, 60 seconds the second try, and 90 seconds the third try. Attempts to start the unit at this point were abandoned when its battery began to run down. This unit was then preheated for an additional 30 minutes. After this, the glow plugs were applied for 30 seconds, the engine started, sputtered for about 15 seconds, then quit. This continued for six attempts. The engine was finally started by turning the engine on while holding the glow plug on and priming the engine fuel pump. After 2 minutes of running, the pump was adjusted to full flow. The power source was then run at 8 gpm and 2,000 psi. At this point, the unit was performing well, so the testing was stopped.

After cold-soaking for 60 hours at -40°F, the second unit started with 1 hour of preheat time. The engine initially ran very rough and cycled up and down at a slow speed. The glow plugs were kept on until the engine started to run normally (20 seconds). The unit was run for 10 minutes at pressures up to 2,000 psi. This cold chamber testing demonstrated that both Portable Hydraulic Power Source EDM units have the capability to startup and operate in an Arctic climate.

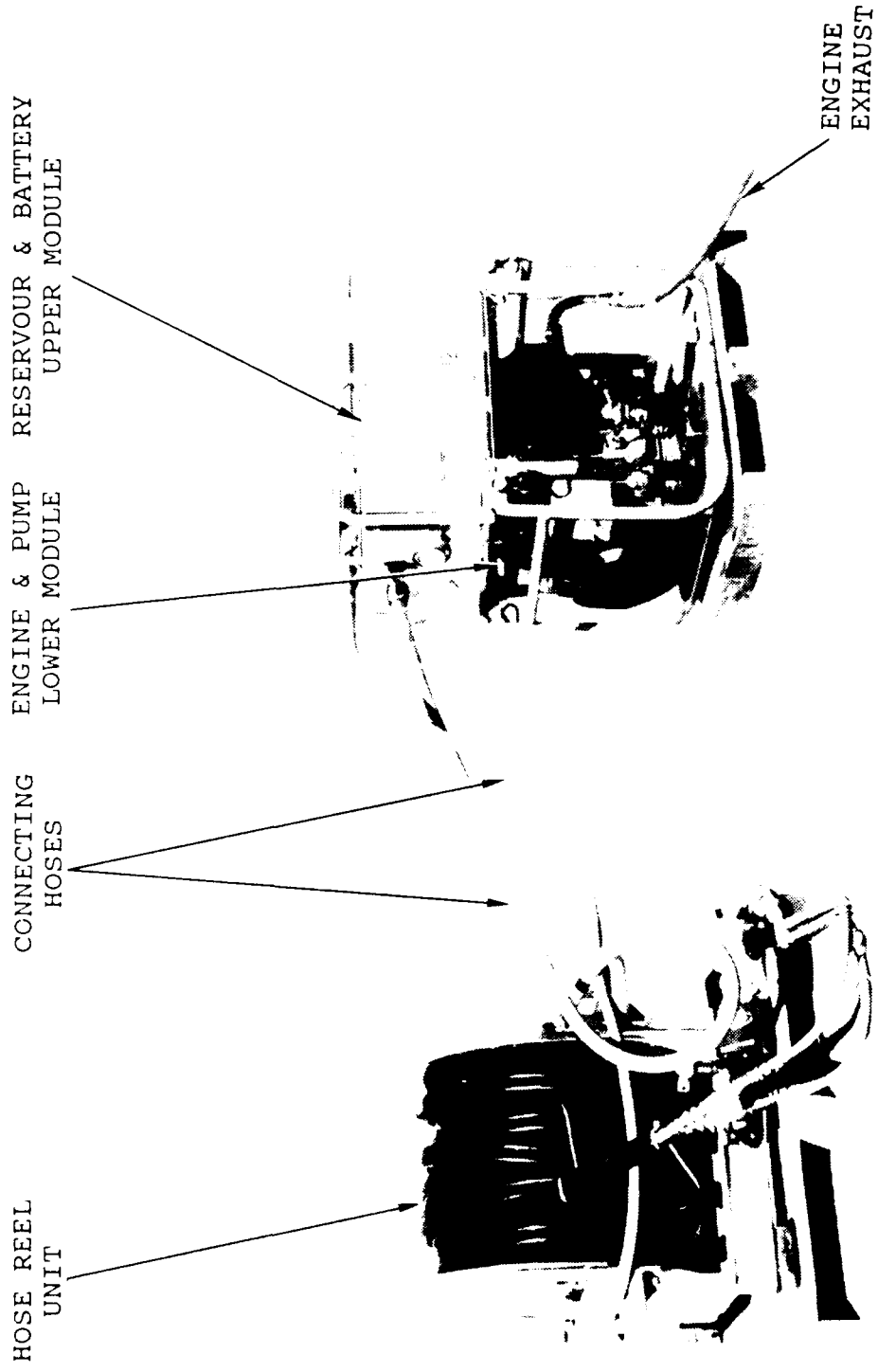


Figure 2. Portable hydraulic power source.

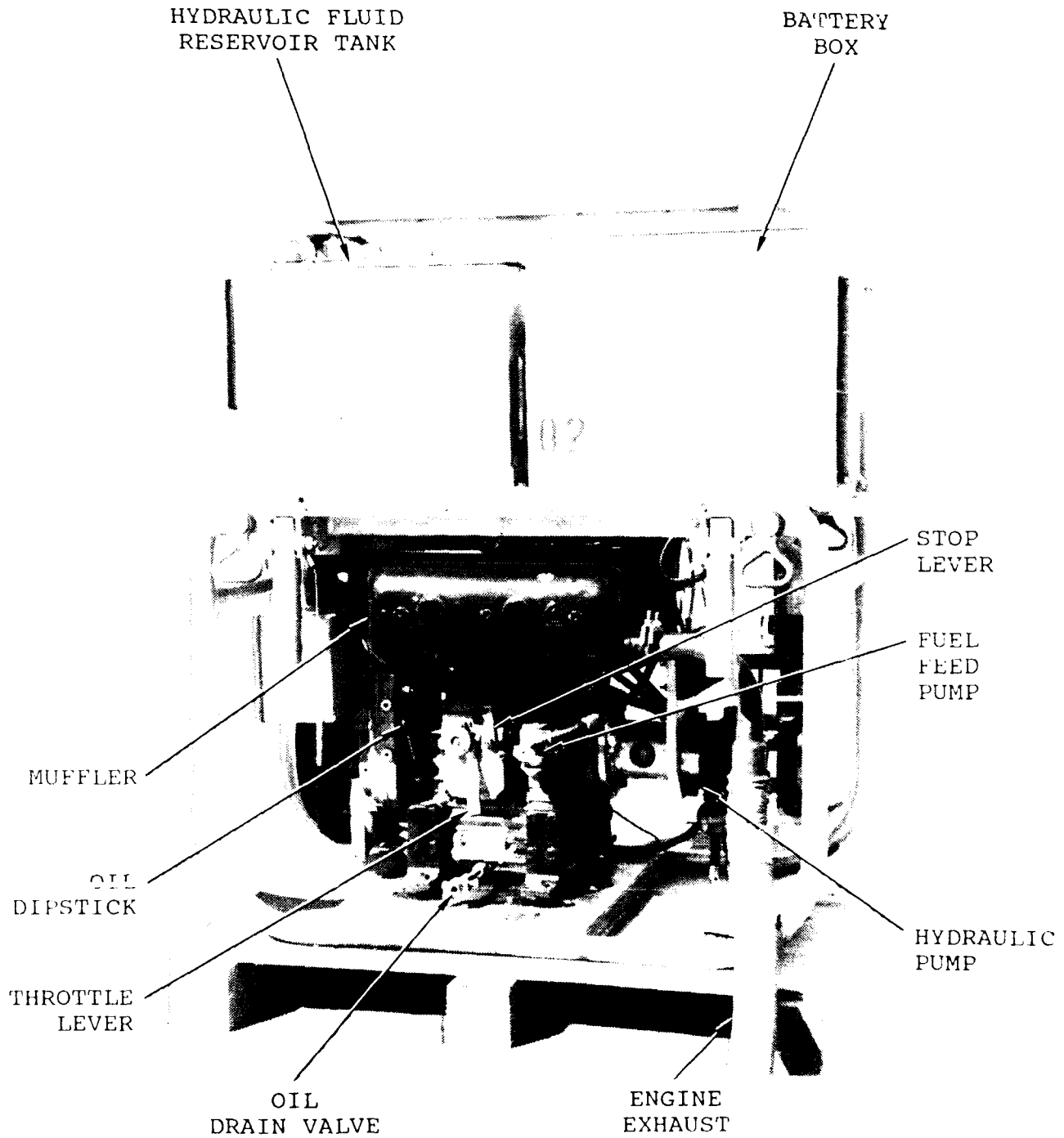


Figure 3. Upper reservoir module mounted on lower engine/pump module, front view.

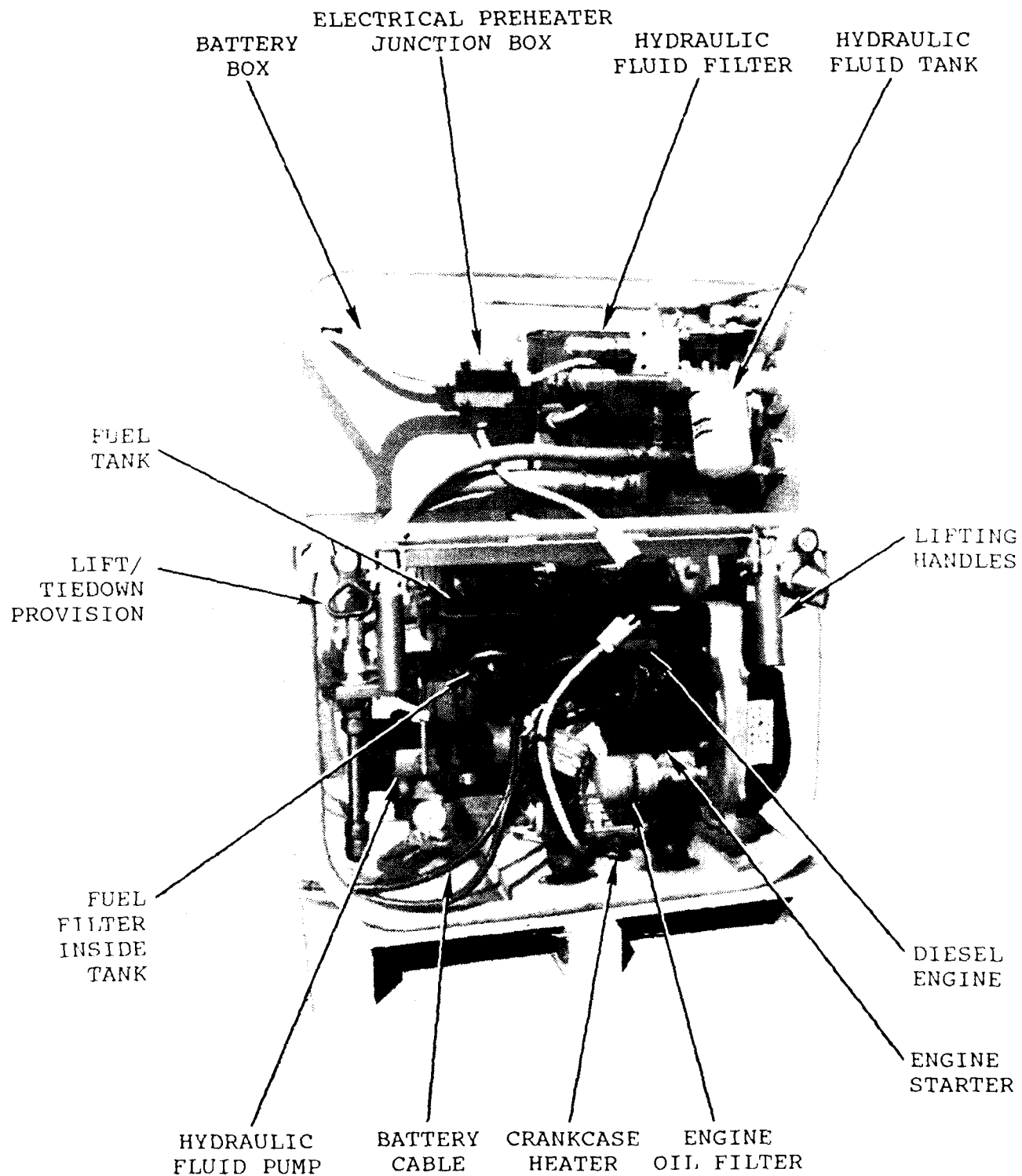


Figure 4. Upper reservoir module mounted on lower engine/pump module, rear view.

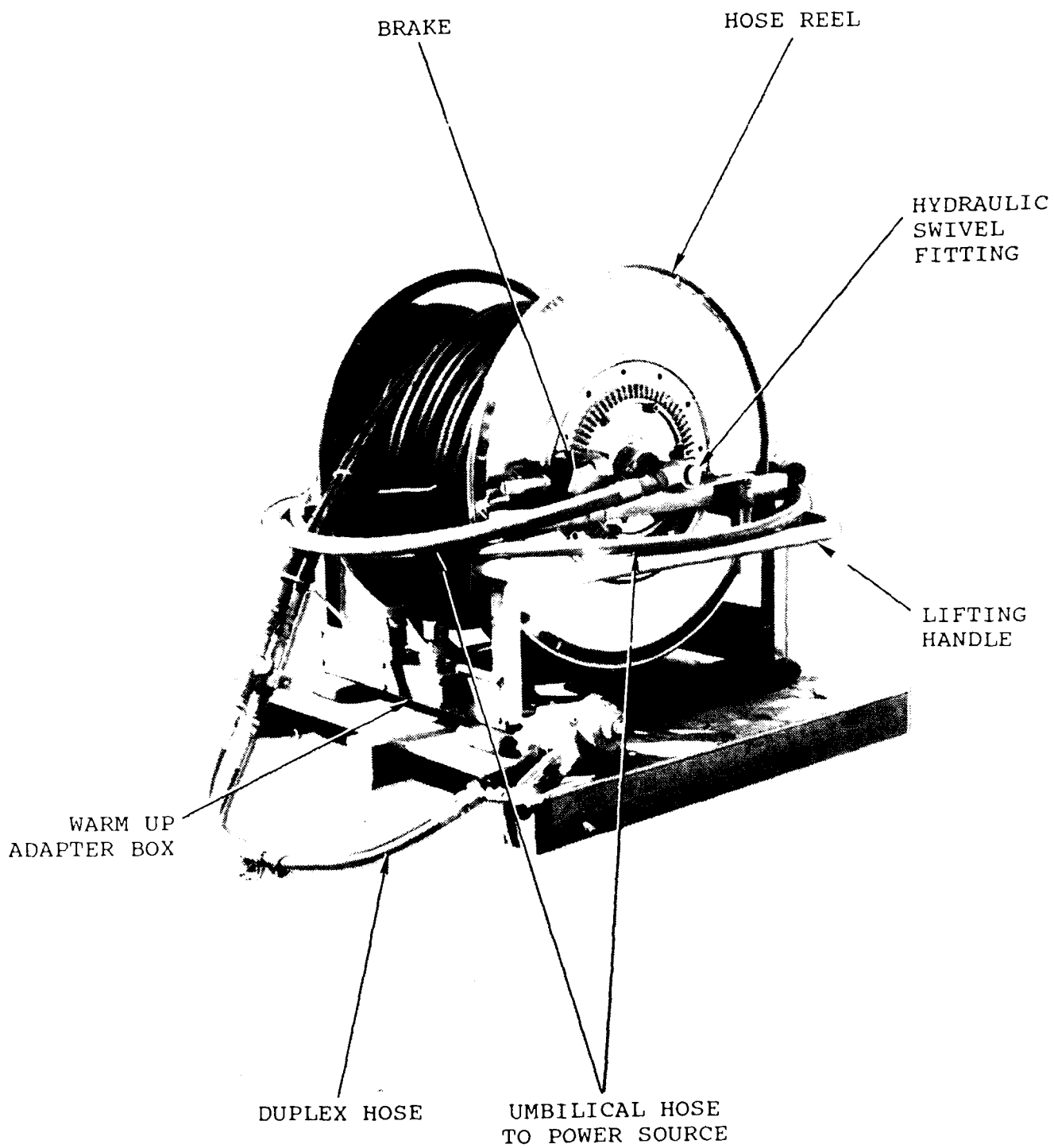


Figure 5. Hose reel assembly.

Both PHPSs were shipped to a field operation in the Eastern Arctic in March 1990 for development testing and user testing. They operated for 2 weeks in temperatures down to -25°F . Unit No. 1 was subjected to endurance testing in order to obtain reliability data. It was tested for 7 days. The unit was preheated for 1 hour before each start. Startups were accomplished with no problem. The power source was typically operated for 4 hours in the morning and 4 hours in the afternoon. The unit ran at 6 to 8 gpm with pressure averaging 800 psi. EDM Unit No. 1 accumulated 45 hours of run time with no failures.

Unit No. 2 was used for operational testing with hydraulic tools. During the 8 days that Unit No. 2 was operated, three problems were observed. First, the fitting below a high-pressure quick-disconnect (Q/D) failed. This was due to the Q/D not having been secured, and vibrating loose. The fitting took 45 minutes to repair. Second, at one point the battery was not energizing the engine starter sufficiently. It was discovered that the battery cable connectors between the upper and lower module had become severely corroded. These were then cleaned and reconnected, which fixed the problem. Third, this unit was observed to blow oil out of the exhaust. Evidently, this was caused by insufficient break-in of the engine. Synthetic oil works so well, valves will take longer to seat properly when synthetic motor oil is used to break the engine in. EDM Unit No. 2 ran for 24 hours without any failures after the repairs were made.

Both EDM units started whenever required, and provided the necessary hydraulic power. Comments were made by the UCTs that the top and bottom modules were still somewhat difficult to connect at these extreme temperatures, and that the system needs a greater fuel storage capacity.

Upon return to NCEL, the Portable Hydraulic Power Source EDM Unit No. 1 was subjected to further long-term operation. EDM Unit No. 1 was fabricated from system components taken from the ADM unit, and used to demonstrate overall system reliability of the PHPS. This reliability testing consisted of accumulating operating hours on the power source by running it for 6 hours a day. The unit was started and stopped twice a day. The power source was fueled from an outside jerry can throughout the course of this testing. This power source was run at 2,000 psi and 6 gpm. The duplex hose was submerged in the NCEL dive tank to keep the system temperature down. The hydraulic oil temperature remained at 110°F during testing. The Portable Hydraulic Power Source EDM Unit No. 1 was operated at NCEL for 58 hours with no failures.

Table 3 summarizes the malfunctions encountered during all the reliability testing performed on the Portable Hydraulic Power Source ADM and EDM Unit No. 1.

Testing on the PHPS was completed in August 1990. The operating procedures developed during testing are shown in Appendix C.

EVALUATION

Both Portable Hydraulic Power Source EDM units met the requirement for starting at -40°F . This required 1 hour of preheat time. These power sources also met the performance requirement (8 gpm at 2,000 psi) when operating in the cold chamber.

Table 3. Malfunctions Observed During Reliability Testing on Unit No. 1

Hours on Unit	Malfunction	Cause	Remedy
<u>Eastern Arctic, 1989</u>			
0	Begin testing		
27	Engine would not start at -20°F	Frozen fuel	Use DFA or JP-5 fuel
27	Starter switch would delay 5 to 8 seconds at -20°F	Switch not rated for extremely low temperatures	Rewire switch using components rated for extremely low temperatures
35	Overflow of hydraulic fluid	Pump inlet Q/D had backed off	Modify Q/D connectors
40	Engine quit, fuel spitting from fuel pump	Ice blockage in fuel filter, and breather/separator hose	Develop preventative maintenance procedures
44	Engine quit	Broken diaphragm retainer in fuel pump	Supply spare fuel pump
44	End testing		
<u>Western Arctic, 1989</u>			
44	Begin testing		
49	Engine stalled (flow meter stuck at 6 gpm)	Pump outlet Q/D had backed off	Modify Q/D connectors
51	End testing		
<u>Eastern Arctic, 1990</u>			
51	Begin testing		
80	Pump washplate fell off	Both retaining screws vibrated loose	Reinsert and retighten screws
81	Pump washplate fell off	Both retaining screws vibrated loose	Reinsert and retighten screws
94	End testing		

continued

Table 3. Continued

Hours on Unit	Malfunction	Cause	Remedy
<u>NCEL, 1990</u>			
94	Begin testing		
117	Engine sump leaks slightly	Fitting for heater element leaked and could not be re-tightened from outside	Replace any missing oil
147	Pump limit screw fell out	Screw vibrated loose	Reinsert and retighten screw
151	Pump suction collar came loose	Retaining screws vibrated loose	Reinsert and retighten screws
154	End testing		

The deficiencies encountered during testing can be solved with relatively minor changes to the unit design and its operating procedures. One comment from the operators in the field was that the frequent refueling requirement of the power source (approximately every 2 hours) was a major inconvenience. The capability to be fueled from an external jerry can will be incorporated into the design to enable the PHPS to operate for up to 8 hours without refueling. Comments were also made that there is still some difficulty in connecting the upper module to the lower module out in the field. The hose connections between the upper and lower module will be further modified to ease the difficulty associated with manipulating hoses stiffened from the Arctic conditions. The hardware that vibrated loose was not properly secured. This will be corrected with the addition of simple locking devices to the design. Also, the battery cable design will be simplified into a more rugged configuration.

The following modifications have been made to the PHPS design for incorporation into the final production units:

1. Provide capability to fuel the APS from an external jerry can.
2. Improve hose connectibility between upper and lower modules. Use a lower pressure, more flexible hose for pump inlet. Lengthen pump inlet hose by moving its connection on the reservoir. Add extra techniques on hose connection to the O&M manual.

3. Replace battery cable terminals with more rugged wing-nut types.
4. Eliminate the connectors on the battery cable (use a single length of electrical cable).
5. Mark flow meter to be read from both sides so the operator can see the flow rate while adjusting the pump.
6. Label the warmup adaptor box on the hose reel.
7. Label the Q/D locking wing-nuts disconnect directions on the lower module connection plate.
8. Secure the retaining screws on the pump assembly to prevent their vibrating loose.
9. Add the following instructions to the O&M manual:
 - a. Provide methods for easy connection of hoses between the upper and lower modules.
 - b. Give recommendation for engine break-in.
 - c. Check (and clean) electrical connectors periodically.
 - d. Keep glow plugs on during startup.
 - e. Secure Q/D wings together to prevent vibrating loose.
 - f. Provide operating temperature range of the hydraulic fluid.

These modifications will eliminate the shortcomings of the Portable Hydraulic Power Source system identified during testing of the EDM unit.

Both EDM units performed well in a field operation in the Eastern Arctic. The Underwater Construction Team personnel were pleased with the overall performance of the power sources, especially the ease of startup in Arctic conditions.

Reliability

A generally accepted definition of reliability is: the probability that an item will perform its mission without failures for a specified period of time. The reliability definition for the Portable Hydraulic Power Source has been derived from this general definition. Reliability is expressed mathematically as follows:

$$R = e^{-t}$$

where: R = reliability (expressed as a decimal)
 e = base of the natural log system (2.718)
 t = mission time in hours
 = failure rate per million hours, or 1/MTBF

by substitution:

$$R = e^{-t/MTBF} \quad \text{or} \quad MTBF = -t/\ln R$$

For a reliability of 0.90, the PHPS needs a Mean Time Between Failure (MTBF) of 67 hours. This is for a mission time of 7 hours specified in the TEMP. The MTBF of 67 hours derived above represents an estimate of true system reliability. A confidence level is then applied as a measure of the approximation of the estimated MTBF to the true value. Confidence levels are based on a Chi Square distribution. The PHPS must run for 154 hours without failure to achieve a confidence level of 90 percent.

Failure is defined as any malfunction that the operator cannot remedy by adjustment, repair, or replacement action within the Mean Time To Repair (MTTR) using only controls, tools, or spare parts incorporated in or carried with the system.

Unit No. 1, which was built from the original components used on the ADM version, demonstrated system reliability by operating for the required 154 hours with no failures. Given the definition of failure shown above, none of the malfunctions that occurred throughout the testing on this unit are considered failures. Thus, the PHPS has demonstrated a reliability of 0.90 with a confidence level of 90 percent.

Inherent availability is expressed as a decimal and is calculated mathematically as follows:

$$A = MTBF/(MTBF+MTTR)$$

Given an MTBF of 67 hours and an MTTR of 2 hours, the inherent availability is 0.97.

Logistic Supportability

The Portable Hydraulic Power Source is designed to be compatible with the UCT's operation and maintenance capabilities. Each unit will be delivered to the user with an operation and maintenance kit, including replacement parts and regular maintenance parts. No special tools are required to perform any of the maintenance outlined in the Operation and Maintenance Manual.

All spare parts will be transportable in a permanent storage case. The spare parts list is as follows:

Engine air filter.....	2 each
Engine oil filter.....	2 each
Fuel filter.....	2 each
Hydraulic fluid filter.....	2 each
Hydraulic oil, Tribolube L6 or L1..... (oil selection is dependent on temperature)	5 gallons

Arctic diesel fuel (DFA) or JP-5 fuel.....	as required
Engine oil, synthetic.....	6 quarts
Engine glow plug.....	2 each
Engine fuel pump.....	1 each
Quick disconnect.....	2 sets

The spare parts list is configured to provide the consumables for two routine maintenance cycles. Engine glow plugs are an important part of startup procedures in the Arctic, and are also considered consumables. The engine fuel pump is included due to the malfunction of a fuel pump early on in the testing.

All training required to operate, maintain, troubleshoot, and repair the PHPS is covered in the Operation and Maintenance Manual.

There are no special requirements for transporting the PHPS other than the usual fuel shipping procedures. The battery is a gel-cell type that does not require any special shipping procedures.

A Technical Data Package has been developed for the Portable Hydraulic Power Source. This package consists of an Operation and Maintenance (O&M) Manual, a Purchase Description (PD), and a level 3 drawing package. These provide all the information necessary to own and operate the PHPS.

DISCUSSION

The Portable Hydraulic Power Source has been developed for use by the Underwater Construction Teams for operations in Arctic climates. Testing has established that the PHPS meets the requirements called out in the TEMP. Table 4 compares the TEMP requirements to the actual PHPS performance characteristics.

The power source (ADM version and EDM version) has been successfully operated in three field operations. In March 1989, it was operated in the Eastern Arctic at temperatures of -30°F. An operation with UCT-2 in the Western Arctic during August 1989 demonstrated the additional capability of the PHPS to be operated from a 22-foot inflatable boat. In March 1990, two PHPSs were operated in the Eastern Arctic at temperatures down to -25°F.

The Portable Hydraulic Power Source has proved its capability of providing the flow and pressure required to operate any of the UCT's hydraulic tools. It has also shown that it is readily transportable so that it can be taken anywhere the UCTs require, and can function in any cold weather environment that the UCTs will operate.

Table 4. TEMP Requirements Versus As-Built Characteristics

Parameter	TEMP Requirement	As-Built Characteristics
Power Source Performance	Operate at least one tool	Operates the worst-case tool (rockdrill)
Operating Temperature (°F)	-40 to 60	-40 to 80
Storage Temperature (°F)	-60 to 150	-60 to ^a
Operating Wind Speed	15 knots	20 knots
Maximum Size (must fit into Twin Otter)	yes	yes
Maximum Single Component Weight (lb)	400	365
MTBF (hr) (Mean Time Between Failure)	67	67
MTTR (hr) (Mean Time To Repair)	2	2
Minimum Reliability (for 7-hour mission)	0.90	0.90
Minimum Availability	0.90	0.97
Maximum Maintenance (hr)		
Daily	2	0.5
End-of-Project	16	8
Annually	8	8
Useful Life (yr)	7	^b

^aNot tested.

^bInsufficient testing for high level of confidence.

RECOMMENDATIONS

Hydraulic power sources conforming to the specifications and drawings produced under this development effort should be purchased to support the work performed by the U.S. Navy Underwater Construction Teams in Arctic areas.

In addition, hydraulic fluids with higher operating temperatures should be identified which will extend the operating environment of this power source to include warm climates. This will enable the Portable Hydraulic Power Source to meet the hydraulic power requirements for the UCTs in any environment.

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Appendix A

ADVANCED DEVELOPMENT MODEL TESTING

ACCEPTANCE TEST

The objective of the advanced development model testing was to verify the correctness and completeness of the initial Operations and Maintenance (O&M) Manual, evaluate the human factor considerations, and ensure that the Portable Hydraulic Power Source (PHPS) met the contract requirements for size, weight, power output, and Arctic compatibility.

The Portable Hydraulic Power Source ADM was delivered in December 1988. It was set up and operated by the NCEL project engineer. The PHPS met the contract specifications. However, this initial inspection revealed a number of minor design/fabrication deficiencies.

The following list details the observations and evaluations made from the initial inspection of the advanced development model:

1. The two quick-release pins for securing the modules are functional and easy to operate.
2. The single spin-latch for securing the modules is easy to secure but sometimes difficult to release; its position interferes with mating the RETURN hose quick-disconnect (Q/D).
3. The PRESSURE hose Q/D at the power supply panel is too close to the framework, securing the coupling is difficult.
4. Two personnel are sufficient for lifting reservoir tank module on top of engine/pump module, as required in the specifications.
5. The PRESSURE hose Q/D at the pump is difficult to align.
6. The note, "Care should be taken to ensure that all Q/Ds are fully made up to indicator line," should be added into O&M manual.
7. The laynards on the Q/D protective caps are very inconvenient.
8. Instructions should be added to the O&M manual for battery and heater connections.
9. Refueling is easy with either a one-piece or two-piece configuration.

10. The fuel cap needs a lanyard.
11. The fuel bleed screw requires a wrench to open.
12. The compression release lever is hard to reach.
13. The oil pressure gauge is positioned on top of the unit, which makes it vulnerable to damage.
14. The flow meter is located before the pressure relief valve, thus measuring flow coming out of the pump as opposed to flow going to the tool.
15. The flow meter cannot be seen from the throttle operator position, making it difficult to set the engine speed.

The Portable Hydraulic Power Source ADM was set up and run in accordance with its Operating & Maintenance Instructions. The unit was then shutdown, and a dummy load was put on the system. The PHPS was started and then operated at a flow of 8 gpm and pressure of 2,000 psi.

The system performed as required without any major problems.

PERFORMANCE TESTS

The individual tests conducted in this evaluation are shown below. The Portable Hydraulic Power Source ADM performance was satisfactory and no safety problems were discovered.

Rockdrilling Tests

The objective of these tests was to compare the relative drilling speed of the PHPS to the MOD 3 power source. At this time, the UCTs have to use the underpowered MOD 3 for operations requiring a readily portable power unit. Three separate rockdrilling tests were performed, all using a Stanley HD-20 rockdrill. These tests were accomplished by drilling holes into rock, alternating between the two power sources. The drilling time and the hole depth were noted for each drilling test.

Test I was conducted at NCEL with the project engineer operating the rockdrill. Test II was conducted out in the field (Priest Lake, Idaho), with the project engineer operating the rockdrill. Test III was conducted out in the field using the same rock as Test II, but with a UCT member operating the rockdrill. The drilling rate of each individual tool system varied depending on the rock hardness and the rockdrill operator.

The results of this comparison testing between the two power sources are shown in Table A-1.

The test results shown in Table A-1 indicate that the HD-20 rockdrill performs an average of 70 percent better when powered with the Portable Hydraulic Power Source versus the MOD 3 power source.

Table A-1. Comparison Rockdrilling Data

Test No.	Power Unit	Depth (in.)	Time (min)	Rate (in./min)	Drill Bit (in.)
I	APS	15.0	4:08	3.63	1
	MOD 3	15.0	6:56	2.16	1
II	APS	5.0	2:16	2.20	1
	APS	15.0	6:56	2.16	1
	MOD 3	4.0	2:54	1.38	1
	MOD 3	15.0	9:38	1.56	1
	APS	11.0	2:06	5.24	3/4
	APS	15.0	3:08	4.79	3/4
	MOD 3	8.0	1:58	4.06	3/4
III	APS	13.3	4:00	3.33	1
	APS	12.0	4:00	3.00	1
	MOD 3	6.5	4:00	1.60	1
	MOD 3	7.5	4:00	1.87	1
	APS	12.5	2:15	5.56	7/8
	APS	13.0	2:00	6.50	7/8
	MOD 3	12.5	5:00	2.50	7/8
	MOD 3	12.0	4:00	3.00	7/8

Noise Level Tests

The purpose of these tests was to measure the acoustic output of the Portable Hydraulic Power Source. The noise level was measured with a Genrad Model 1988 sound pressure level meter at a distance of 3 feet from each side of the unit. Test I was performed at NCEL, with the PHPS running at 8 gpm and 1,900 psi. Test II was performed in the field, with the unit running at 8 gpm and 2,000 psi.

The following data show the results of this acoustic monitoring:

Noise Direction	Test I		Test II	
	dB	dBA	dB	dBA
Exhaust side	100.3	93.2	99.0	97.0
Opposite side	98.6	93.3		
Front tank side	101.9	94.9	100.0	96.1
Pump side	98.9	94.2	101.0	98.6

The safe allowable exposure limit called out by the Occupational Safety and Health Administration (OSHA) is 36 minutes for a noise level of 99 dBA. Therefore, hearing protection should be worn when working within 3 feet of the operating PHPS for more than 36 minutes.

Fuel Consumption Test

This test was conducted in order to determine the length of time that the PHPS could operate without refueling. The unit was run at 8 gpm and 2,000 psi, with an ambient air temperature of 60°F. The engine consumed 1.16 gallons of fuel while operating for 2.5 hours. This fuel consumption rate of 0.8 gallon/hour gives the PHPS an operating range of 2.5 hours.

Pump Tests

The Portable Hydraulic Power Source ADM was equipped with two pump options: the fixed displacement gear pump and the variable displacement axial piston pump. The purpose of this testing was to determine which pump would be most suitable for Arctic service. Pump output tests were conducted using both the gear pump and the piston pump option, with no load on the system. The following data were recorded during these tests:

Flow (gpm)	Gear Pump Engine Speed (rpm)	Piston Pump Engine Speed (rpm)
3.0		988
3.5	1335	
4.0	1570	1634
5.0	1933	1912
6.0	2212	2318
7.0	2600	2694
8.0	3144	3082
9.2	3573	

The results shown above indicate that both the gear pump and the piston pump, when adjusted to maximum displacement, had virtually the same flow characteristics. The gear pump option was used for the first 6 hours of operation during the PHPS testing. The piston pump option was used for the remainder of the testing, which was 46 hours of operation time. Both hydraulic pumps performed well.

The piston pump was chosen to be installed on the Portable Hydraulic Power Source EDM. Its main advantage over the gear pump is the piston pump's capability of adjustable flow. This is important for being able to start the engine without pumping any hydraulic fluid.

Hydraulic Fluid Temperature Versus Backpressure Test

The system backpressure, which is a function of viscosity, should be held below 150 psi to insure proper operation of the HD-20 rockdrill. The system was tested to determine the relationship between hydraulic fluid temperature and system backpressure, at standard operating pressures and flows.

To perform this test, the Portable Hydraulic Power Source provided the rockdrill with 8 gpm of Tribolube L-6 at a pressure of 2,000 psi, via the 250-foot, 3/4-inch tandem hose. This field test was performed on land (Priest Lake, Idaho). With an ambient air temperature of 22°F and the hose spooled on its reel, it was necessary to shut the PHPS off after about 45 minutes to prevent the hydraulic oil from overheating. The following data show fluid temperature measured at the reservoir tank and the backpressure measured at the tool outlet:

Fluid Temperature (°F)	Backpressure (psi)
28	170
31	150
38	120
56	100
70	70
89	50
103	40
118	30

As indicated above, a system backpressure of 150 psi corresponds to a hydraulic fluid temperature of 31°F at 8 gpm. This fluid temperature falls in the middle of the viscosity range recommended by Stanley Tools, for L-6 hydraulic fluid (see Figure 1 in the main text).

Cold Chamber Tests

The objective of these tests was to establish minimum starting conditions for the Portable Hydraulic Power Source when exposed to extremely low temperatures. Testing was accomplished by operating the PHPS inside the cold chamber facility at NCEL. This chamber is not equipped for testing the PHPS much beyond startup due to the chamber's inability to maintain the low temperatures with the diesel engine running, and the restricted air supply. A duct hose was installed to vent the engine exhaust out of the cold chamber. The following paragraphs are an account of the testing performed in the cold chamber.

The PHPS was cold-soaked overnight at -10°F. The engine started easily at this temperature, with the system heaters disconnected (the system heaters were used on all subsequent cold chamber testing). The PHPS took 2 to 3 minutes to stabilize in order to support a load of 7 gpm at 500 psi.

The PHPS was then soaked overnight at -20°F. The power source started within a minute, but would not remain running. Upon inspection, it was discovered that the fuel was frozen (slushy). This diesel fuel was removed and replaced with JP-5 fuel.

To improve the cold temperature starting capability, an additional glow plug was added to the manifold at the entrance to the No. 2 cylinder. This modified manifold is virtually the same as the dual glow plug manifold marketed by the engine manufacturer, Lombardini, for this engine.

When operated at temperatures below 0°F, the start switch on the PHPS had a tendency to delay about 7 seconds before the contacts would close. To correct this, the starter circuit was rewired with a momentary toggle switch installed in lieu of the key switch. Toggle switches are easy to actuate in a cold weather environment. The marine grade electric cable used for powering the heaters became brittle and failed in the cold temperatures. These cables were replaced with electrical cables better suited for cold weather operation.

Upon completion of these modifications, the Portable Hydraulic Power Source was soaked for 6 hours at -10°F. The PHPS started within a minute. After another minute, the hydraulic system was set to 7 gpm at 500 psi, with no problems.

The PHPS was soaked overnight at -20°F. It was started and operational within 3 to 4 minutes. The PHPS supported a load of 7 gpm at 500 psi with no problems.

The PHPS was then soaked at -40°F for 6 hours. The engine started, but was erratic and would not continue to run. Due to time constraints, efforts for starting the PHPS in the cold chamber at -40°F were discontinued.

The following startup procedure was developed from this cold chamber testing for operating the power source at extremely low temperatures:

1. Keep system preheaters on for 2 hours before operation of the unit.
2. Keep gas tank full (JP-5), especially at end of day.
3. Adjust piston pump to zero flow.
4. Open compression release.
5. Crank engine five times with start switch.
6. Close compression release.
7. Set throttle at idle.
8. Hold glow plugs on during startup and until engine runs without them.
9. Crank engine with start switch.

This starting procedure worked well, making the Portable Hydraulic Power Source operational within 3 to 4 minutes. However, -20°F was the lowest ambient temperature at which the Portable Hydraulic Power Source ADM was started and operated effectively during the cold chamber testing.

DEVELOPMENT TEST I

The objective of these tests was to determine the effect of the Arctic conditions on the system performance and human interface of the Portable Hydraulic Power Source ADM. The testing was performed from April 4 to April 10, 1989, north of Greenland on the Arctic sea ice. The ambient temperature ranged between -25 and -30°F.

NCEL engineers and an Eastport International representative performed the testing of the PHPS during the Arctic East operation. The 6 days of testing consisted of setup, shakedown, and repair; hydraulic tool usage; and performance testing. The following paragraphs are an account of the testing performed during this period.

The Portable Hydraulic Power Source was transported to the site in an LC130H aircraft. The loading/unloading and moving of the PHPS components was done manually. Upon arrival, engine oil was visible on the engine module and pooled in the bottom of the frame. This was due to the unit having been tipped over during offloading. The module was cleaned and more oil was added to the engine.

Before attempting to install the reservoir module on top of the engine module, the two connection hoses had to be pushed in from the end of the frame and down to protrude from the bottom of the frame. This was virtually impossible to accomplish with two men, as the hoses were extremely stiff at the -30°F ambient temperature. Therefore, the reservoir module was placed in a shelter (approximately 60°F) for 1/2 hour. It was then returned to the test site, and the two modules were connected without incident. The two hoses that connect the PHPS to the hose reel were also stiff, but there was little problem in connecting them due to their greater length.

An attempt was made to start the PHPS without preheating (the hydraulic oil reservoir temperature was -25°F). The engine sputtered for about 30 seconds with the glow plugs held on until the battery was drained of energy. The internal heater system was then plugged into a generator for 1/2 hour. An attempt was then made to start the PHPS, with a hydraulic fluid reservoir temperature of 40°F. It would repeatedly catch and die, until the battery was drained of energy. The heating system was connected for another 1/2 hour, until the reservoir temperature came up to 80°F. This time the engine started, but it cycled up and down. It took an hour before the PHPS began to run normally. The engine was later stopped to add fuel. It was easily restarted with no glow plugs required.

The next day, an unsuccessful attempt was made to start the PHPS without preheating, at an ambient air temperature of -30°F. The internal heaters were then connected for 1 hour and the engine almost started. The engine started after 3 hours of preheating. After running for an hour, the maximum possible pressure reached was 1,750 psi for 8 gpm.

A simulated load was then applied to the PHPS. With a reservoir temperature of 130°F, the system pressure went to 2,100 psi and the backpressure to 50 psi.

The PHPS was shut down when it began leaking hydraulic fluid from the reservoir. Upon inspection, it was discovered that the quick-disconnect on the 1-1/4-inch hose connecting the reservoir to the pump inlet had backed off, causing the system to overflow.

The following day, the PHPS was restarted. The heaters were run for 1 hour. The glow plugs were held for 20 seconds and the engine was started, while holding the glow plugs for an additional 20 seconds. After warming up the unit, the pole saw, chain saw, and the sump pump were all given test runs. All the tools worked at 8 gpm and 1,000 psi.

The Portable Hydraulic Power Source was started the next day using the same startup procedure. It was used to power the hydraulic auger. Due to erratic behavior, the engine was inspected and found to have ice in the fuel filter and in the intake manifold separator/breather hose. The ice in the fuel filter most likely occurred due to water in the fuel. The ice in the separator/breather hose was probably due to condensation from the warm engine air being in contact with the cold outside air. The filter was replaced and the separator/breather hose was cleaned out. The unit was then started using the typical procedure.

The following day, the engine would not start, apparently from fuel starvation. The fuel pump was removed and disassembled and found to have a broken diaphragm retainer (the manufacturer has said that this is a rare occurrence). This being the final day, testing of the power source was concluded for the trip.

The Portable Hydraulic Power Source ADM accumulated approximately 18 hours of run time during this operation. The bulk of the test time consisted of operating the PHPS at reduced performance while looking for problems associated with operating in the Arctic climate.

USER TEST I

The objective of these tests was to better determine the operational effectiveness and suitability of the Portable Hydraulic Power Source. This was accomplished by allowing the UCTs to use the Portable Hydraulic Power Source ADM during an operation, with little outside support.

The tests were performed from July 17 to July 24, 1989, off the western coast of Alaska. An NCEL engineer was present to observe the use of the PHPS, and to give any guidance required.

The PHPS performed well during the 6.75 hours of operation in temperatures of 40 to 44°F. Twenty-eight holes, 5 inches deep, were drilled to install 1/2-inch-diameter rock bolts. The amount of time it took to drill each hole ranged from 30 to 120 seconds. The PHPS was also used to operate a capstan.

The Portable Hydraulic Power Source was operated from a 22-foot inflatable boat in sea states from 0 to 3. The PHPS (both modules attached together) was moved around onboard ship by four people. It was loaded into the inflatable boat using a shipboard crane. Handling the PHPS by crane was hindered due to the lack of proper attachment points for the lifting slings. Also, the PHPS was lacking the proper tiedown points to be readily secured in an inflatable boat. The center of gravity of the PHPS is low, posing no stability problems in the inflatable boat. Weight of the PHPS was not a problem for handling or use in the inflatable boat.

The users, UCT-2 personnel, initially were not familiar with the Portable Hydraulic Power Source. It became apparent that there was a need for easy access to detailed operating instructions. A more comprehensive instruction plaque was recommended to ensure that anyone unfamiliar with the PHPS could understand and operate it in a timely manner.

The quick-disconnect fitting between the reservoir and the variable displacement pump (pressure line at pump) vibrated loose during operation, stalling the engine. The flow indicator froze at this time reading 6 gpm. The connection was easily remade. However, the flow meter remained stuck for the remainder of the operation. Upon later inspection, the flow indicator sleeve was found to be wedged onto the aluminum sleeve. Apparently, high pressure in the flow meter caused the aluminum tube to expand, thus binding the sliding sleeve. When the pump pressure line is not connected to the upper module (i.e., the quick-disconnect comes loose), there is no pressure relief in the system. Also, the bolts securing the battery box vibrated loose during the user tests.

It was noted that the quick-disconnects should be compatible with UCT equipment. Also, for warmer weather operation, the hydraulic oil should be changed to one suited for warmer temperatures.

The Portable Hydraulic Power Source was well received by Underwater Construction Team personnel. This unit showed that it can accommodate operations from a small inflatable boat in addition to extreme cold weather operations.

SUMMARY OF TESTS

Although the Portable Hydraulic Power Source was required by the TEMP to operate at ambient temperatures of -40°F , -30°F was the lowest temperature at which the Advanced Development Model (ADM) operated. This was due to time constraints during cold chamber testing, and a warmer ambient temperature (-30°F) during field testing.

The highest pressure output recorded for the ADM in Arctic conditions, for a flow of 8 gpm, was 1,750 psi. This is sufficient for operating the UCT's hydraulic tools.

The ADM hose reel assembly exceeded the TEMP weight restriction by 25 pounds.

A high confidence level for meeting the system reliability requirements was not demonstrated due to the limited running time of the Portable Hydraulic Power Source ADM.

Table A-2 summarizes the malfunctions encountered during testing of the Portable Hydraulic Power Source ADM.

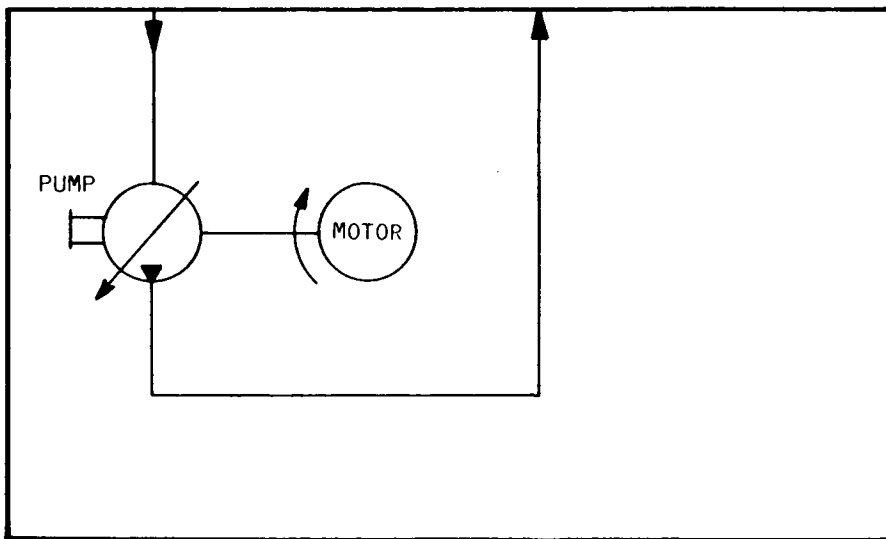
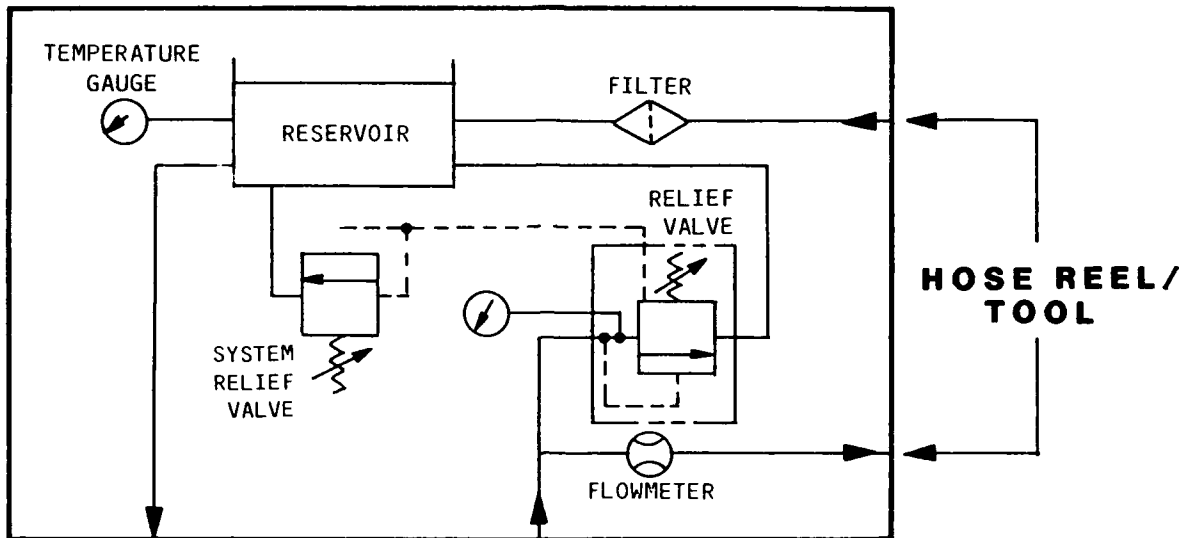
Table A-2. ADM Malfunctions

Hours on Unit	Malfunction	Cause	Remedy
27	Engine would not start at -20°F	Frozen fuel	Use DFA or JP-5 fuel
27	Starter switch would delay 5 to 8 seconds at -20°F	Switch not rated for extremely low temp	Rewire switch using components rated for extremely low temp
35	Overflow of hydraulic fluid	Pump inlet Q/D had backed off	Modify Q/D connectors
40	Engine quit, fuel spitting from fuel pump	Ice blockage in fuel filter, and breather/separator hose	Develop preventative maintenance procedures
44	Engine quit	Broken diaphragm retainer in fuel pump	Supply spare fuel pump
49	Engine stalled (flow meter stuck at 6 gpm)	Pump outlet Q/D had backed off	Modify Q/D connectors
51	End of testing		

Appendix B
SCHEMATICS: HYDRAULIC AND ELECTRIC

HYDRAULIC SYSTEM SCHEMATIC

RESERVOIR UNIT



PUMP/MOTOR UNIT

Figure B-1. Hydraulic system schematic.

12-VOLT CIRCUIT

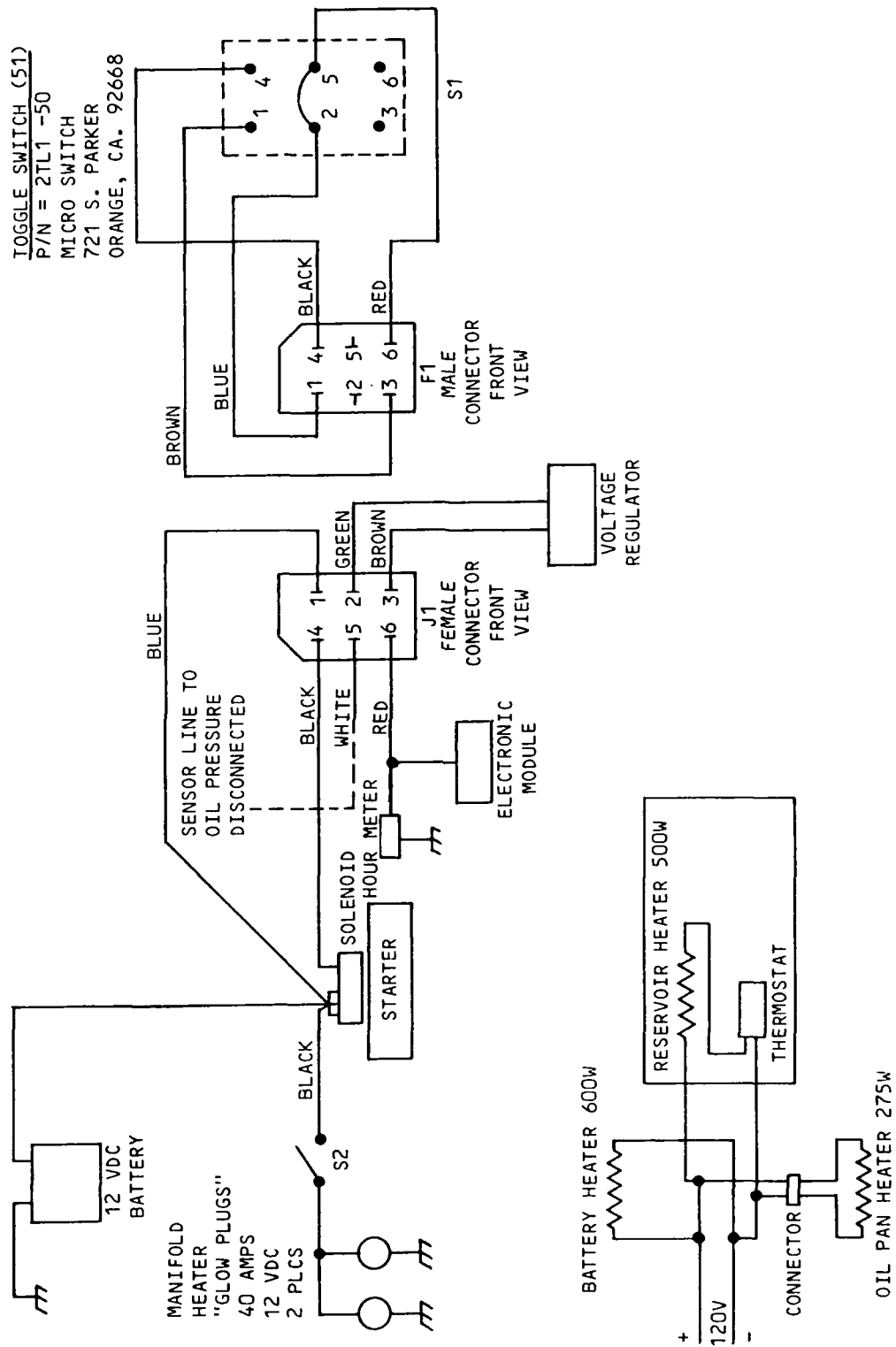


Figure B-2. Electrical circuit schematic.

Appendix C

OPERATING PROCEDURES

SETUP INSTRUCTIONS

- Place the engine/pump module on a level surface
- Place the reservoir module on top of the engine/pump module
- Attach the two hoses from the reservoir module to the engine/pump module

Note: These hoses will be extremely stiff in Arctic climates. Take care not to cross-thread the connections. Sliding the top module back or forth may allow for easier hose connection. (If all else fails, heating of the upper module in a warm environment may be necessary.)

- Secure the two modules together with the four mating pins
- Remove the red transport cap from the hydraulic oil fill hole and replace it with the breather cap
- Make all electrical connections
- Connect the hose reel pressure and return lines to the power unit
- Secure all hydraulic quick-disconnect fittings by lashing the Q/D wings together
- Attach the duct hose to the engine exhaust to direct the fumes away from the unit if personnel will be working next to the power source

PREOPERATION CHECKLIST

- Ensure that the breather cap, not the red transport cap, is screwed on the hydraulic oil reservoir fill hole
- Check engine fuel, oil, and reservoir oil
- Ensure that Arctic weather fuel is used when temperature is below 32°F

- Ensure that Tribolube L-6 hydraulic oil is used (for higher temperatures, use Tribolube L-1) when temperature is below 32°F
- Ensure that all hoses are fully made up
- Ensure that all electrical connections are made
- Plug unit into a 120-VAC electric power source and energize the preheaters for 1 hour before startup when temperature is below 32°F
- Connect hose ends to the warmup adapter located on the hose reel when temperature is below 32°F
- Set pump flow adjustment knob fully CCW - no flow
- Set pressure control valve adjustment fully CCW - no pressure
- Ensure that compression/decompression levers are in the compression position
- Allow heaters time to warm the engine (1 hour minimum at -40°F)

STARTING INSTRUCTIONS

- Hold glow plug switch on for 20 seconds
- Additional glow plug time and fuel priming may be required when temperature is below -20°F
- Adjust throttle fully CW - max throttle
- Push start switch to "start" position while holding glow plug switch on
- Allow heaters more time to warm the engine if the engine fails to start in an Arctic climate

RUNNING INSTRUCTIONS

- Adjust pump swashplate CW to obtain 8 gpm output after warmup
- Set pressure control valve adjustment to obtain 2,000 psi maximum system pressure

STOPPING INSTRUCTIONS

- Set pump flow adjustment knob fully CCW - no flow
 - Set throttle to idle engine for 5 minutes
 - Push stop lever
 - Push start switch to "off"
- (Warning: Never use decompression levers to stop engine)

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Library, Seattle, WA; Library, Philadelphia, PA
ARMY ENGRG DIV / ED-SY (Loyd), Huntsville, AL; HNDED-SY, Huntsville, AL
ARMY EWES / Library, Vicksburg, MS; WESCD (TW Richardson), Vicksburg, MS;
WESCD-P (Melby), Vicksburg, MS; WESCV-Z (Whalin), Vicksburg, MS;
WESCW-D, Vicksburg, MS
ARMY HHC / 7th ATC, Grafenwohr, GE, APO New York
ARMY MMRC / DRXMR-SM (Lenoe), Watertown, MA
ARMY TRANS SCH / ATSP-CDM (Civilla), Fort Eustis, VA
ARVID GRANT & ASSOC / Olympia, WA
BATTELLE / D. Frink, Columbus, OH
BATTELLE NEW ENGLAND MARINE RSCH LAB / Library, Duxbury, MA
BECHTEL CIVIL, INC / K. Mark, San Francisco, CA
BLAYLOCK WILLIS & ASSOC / T Spencer, San Diego, CA
BRANSTROM, L / Ann Arbor, MI
BULLOCK, TE / La Canada, CA
CALDWELL DIVING CO, INC / Toms River, NJ
CALIFORNIA / Nav & Ocean Dev (Armstrong), Sacramento, CA
CBC / Code 10, Davisville, RI; Code 155, Port Hueneme, CA; Code 430,
Gulfport, MS; Code 82, Port Hueneme, CA; PWO Code 400, Gulfport, MS;
CBU / Code 401, OIC, Great Lakes, IL; Code 405, OIC, San Diego, CA; Code
411, OIC, Norfolk, VA; Code 417, OIC, Oak Harbor, WA
CHAO, JC / Houston, TX
CHILDS ENGRG CORP / K.M. Childs, Jr., Medfield, MA

CITY OF AUSTIN / Gen Svcs Dept (Arnold), Austin, TX
CITY OF MONTEREY / Const Mgr (Reichmuth), Monterey, CA
CITY OF RIVERSIDE / Bldg Svcs Dept, Riverside, CA
CITY OF SACRAMENTO / Gen Svcs Dept, Sacramento, CA
CITY OF WINSTON-SALEM / RJ Rogers, PWD, Winston-Salem, NC
CLARK, T. / Redding, CA
CLARKSON COLL OF TECH / CE Dept, Potsdam, NY
CNO / DCNO, Logs, OP-424C, Washington, DC
COLORADO STATE UNIV / CE Dept (Criswell), Ft. Collins, CO
COM GEN FMF / LANT, SCE, Norfolk, VA
COMCBLANT / Code S3T, Norfolk, VA
COMDT COGUARD / G-ECV, Washington, DC
COMFLEACT / PWO, FPO Seattle; SCE, FPO Seattle
COMNAVACT / G.T. Clifford, London, UK, FPO New York; PWO, London, UK,
FPO New York
COMNAVAIR / Lant, Nuc Wpns Sec Offr, Norfolk, VA
COMNAVAIRSYSCOM / AIR-714, Washington, DC
COMNAVLOGPAC / Code 4318, Pearl Harbor, HI
COMNAVRESFOR / Code 08, New Orleans, LA; Code 823, New Orleans, LA
COMOCEANSYS / PAC, SCE, Pearl Harbor, HI
COMSUBPAC / SCE, Pearl Harbor, HI
CONSOER TOWNSEND & ASSOC / Schramm, Chicago, IL
CONSTRUCTION TECH LABS, INC / G. Corley, Skokie, IL
CORNELL UNIV / Civil & Environ Engrg, Ithaca, NY; Library, Ithaca, NY
CUE INC / M. Kocak, Mars, PA
CURTIS, C. / Ventura, CA
DAVY DRAVO / Wright, Pittsburg, PA
DE PALMA, J R. / Picayune, MS
DFSC / F, Alexandria, VA
DOBROWOLSKI, JA / Altadena, CA
DODDS / PAC, FAC, FPO Seattle
DTRCEN / Code 172, Bethesda, MD; Code 284, Annapolis, MD; Code 4111,
Bethesda, MD; Code 4120, Annapolis, MD; Code 42, Bethesda, MD
EASTPORT INTL, INC / JH Osborn, Mgr, Ventura, CA
EDWARD K NODA & ASSOC / Honolulu, HI
ENERCOMP / Amistadi, Brunswick, ME
EWI ENGINEERING ASSOCIATES / Jack Cox, Middleton, WI
FCTC / LANT, Code 182, Virginia Beach, VA; LANT, PWO, Virginia Beach, VA
FLORIDA ATLANTIC UNIV / Ocean Engrg Dept (Hart), Boca Raton, FL; Ocean
Engrg Dept (Martin), Boca Raton, FL; Ocean Engrg Dept (McAllister),
Boca Raton, FL
FLORIDA INST OF TECH / CE Dept (Kalajian), Melbourne, FL
FOWLER, J.W. / Virginia Beach, VA
GDM & ASSOC, INC. / Fairbanks, AK
GENERAL DYNAMICS / D-443 (Leone), Groton, CT
GEOTECHNICAL ENGRS, INC / Murdock, Winchester, MA
GOLDER ASSOC / Brumund, Atlanta, GA
GSA / Code Engrg Branch, PQB, Washington, DC
HALEY & ALDRICH, INC. / Chet Seydemir, Cambridge, MA
HAN-PADRON ASSOCIATES / Dennis Padron, New York, NY
HANDLEY, DM / Gulf Breeze, FL
HARDY, S.P. / San Ramon, CA
HAYNES & ASSOC / H. Haynes, PE, Oakland, CA

HAYNES, B / Lynden, WA
HENRICO CO. GEN SVCS / JW Warren, Richmond, VA
HERONEMUS, W.E. / Amherst, MA
HOPE ARCHTS & ENGRS / San Diego, CA
HQ AFLC / DEMM, Wright-Patterson AFB, OH
INST OF MARINE SCIENCES / Dir, Morehead City, NC; Library, Port Aransas, TX
INTL MARITIME, INC / D. Walsh, San Pedro, CA
KLIENER, PAUL / CE, Northbrook, IL
KTA-TATOR, INC / Pittsburg, PA
LAWRENCE LIVERMORE NATL LAB / Plant Engrg Lib (L-654), Livermore, CA
LAYTON & SELL, INC, P.S. / Redmond, WA
LEHIGH UNIV / Marine Geotech Lab, Bethlehem, PA
LEO A DALY CO / Honolulu, HI
LEVINE-FRICKE / Newport Beach, CA
LIN OFFSHORE ENGRG / P. Chow, San Francisco, CA
LONG BEACH PORT / Engrg Dir (Allen), Long Beach, CA; Engrg Dir (Lizzi),
Long Beach, CA
LOS ANGELES COUNTY / PW Dept (J. Vicelja), Harbor City, CA
MAG / 16, CO, MCAS, Tustin, CA
MAINE MARITIME ACADEMY / Library, Castine, ME
MARATHON OIL CO / Gamble, Houston, TX
MARBKS / Sec Offr, FPO San Francisco
MARCORBASE / Base Maint Dept, Camp Lejeune, NC; Code 4.01, Camp
Pendleton, CA; Code 405, Camp Lejeune, NC; Code 406, Camp Lejeune,
NC; Facilities Coordinator, Camp Pendleton, CA; Maint Offr, Camp
Pendleton, CA; PAC, PWO, FPO Seattle
MARCORDIST / 12, Code 4, San Francisco, CA
MARCORPS / FIRST FSSG, Engr Supp Offr, Camp Pendleton, CA
MARINE CONCRETE STRUCTURES, INC / W.A. Ingraham, Metairie, LA
MARITECH ENGRG / Donoghue, Austin, TX
MARITIME ADMIN / MMA, Library, Kings Point, NY
MC CLELLAND ENGRS, INC / Library, Houston, TX
MCA ENGINEERS / Shane, Camarillo, CA
MCAS / Code 1JE.50 (Isaacs), Santa Ana, CA; Code 6EDD, FPO Seattle; Code
LCU, Cherry Point, NC; Code LE, Cherry Point, NC; El Toro, Code
1JD, Santa Ana, CA; PWO, Kaneohe Bay, HI
MCLB / Code 506, Albany, GA
MCRDAC / AROICC, Quantico, VA
MERMEL, TW / Washington, DC
MICHIGAN TECH UNIV / CO Dept (Haas), Houghton, MI
MOBIL R&D Corp / Offshore Engrg Library, Dallas, TX
MOFFATT & NICHOL ENGRS / R. Palmer, Long Beach, CA
MT DAVISSON / CE, Savoy, IL
NAF / Dir, Engrg Div, PWD, FPO Seattle; PWO, FPO San Francisco; PWO,
FPO Seattle
NALF / OIC, San Diego, CA
NAS / Chase Fld, PWO, Beeville, TX; Code 072E, Willow Grove, PA; Code
163, Keflavik, Iceland, FPO New York; Code 18300, Kingsville, TX;
Code 18300, Lemoore, CA; Code 1833, Corpus Christi, TX; Code 18700,
Brunswick, ME; Code 421, San Diego, CA; Code 6234 (C. Arnold),
Point Mugu, CA; Code 70, Marietta, GA; Code 725, Marietta, GA; Code
8, Patuxent River, MD; Code 83, Patuxent River, MD; Dir, Engrg Div,
PWD, Keflavik, Iceland, FPO New York; Fac Mgmt Offc, Alameda, CA;

Lead CPO, PWD, Self Help Div, Beeville, TX; Memphis, PWO, Millington, TN; Miramar, PWO, San Diego, CA; Miramar, PWO, Code 183, San Diego, CA; Miramar, PWO, Code 187, San Diego, CA; NI, Code 183, San Diego, CA; P&E Supr, FPO Seattle; PW Engrg, Patuxent River, MD; PWD Maint Div, New Orleans, LA; PWO Code 6200, Point Mugu, CA; PWO, Cecil Field, FL; PWO, Corpus Christi, TX; PWO, Key West, FL; PWO, Meridian, MS; PWO, Moffett Field, CA; PWO, Willow Grove, PA; PWO, Sigonella, Italy, FPO New York; SCE, Barbers Point, HI; SCE, FPO San Francisco; SCE, Norfolk, VA; Whidbey Is, PW-2, Oak Harbor, WA; Whidbey Is, PWE, Oak Harbor, WA; Memphis, Code 18200, Millington, TN; Memphis, Dir, Engrg Div, Millington, TN

NAS ADAK / Code 114, FPO Seattle,
NAS NPWC / Code 102 (J. Aresto), San Diego, CA
NATL ACADEMY OF SCIENCES / BRB, (Smeallie), Washington, DC
NAVAIRDEVCCEN / Code 832, Warminster, PA
NAVAVIONICEN / Code D-701, Indianapolis, IN
NAVAVNDEPOT / Code 61000, Cherry Point, NC; Code 61000, Pensacola, FL; Code 640, Pensacola, FL; SCE, Norfolk, VA
NAVCAMS / MED, SCE, Naples, Italy, FPO New York; PWO, Norfolk, VA; SCE, Wahiawa, HI; WESTPAC, SCE, FPO San Francisco
NAVCOASTSYSCEN / Code 423, Panama City, FL; Code 715 (J. Mittleman), Panama City, FL; PWO (Code 740), Panama City, FL
NAVCOMMSTA / PWO, FPO San Francisco; PWO, Thurso, UK, FPO New York
NAVCONSTRACEN / Code B-1, Port Hueneme, CA; Code D2A, Port Hueneme, CA; Code S24, Gulfport, MS
NAVEODTECHCEN / Tech Library, Indian Head, MD
NAVFAC / Centerville Bch, PWO, Ferndale, CA; N62, Argentina, NF, FPO New York; PWO, Oak Harbor, WA
NAVFACENGCEN / Code 04A1D, Alexandria, VA; Code 04A3, Alexandria, VA; Code 04A3C, Alexandria, VA; Code 04B3, Alexandria, VA; Code 051A, Alexandria, VA; Code 1002B, Alexandria, VA; Code 163, Alexandria, VA; Code DS02, Alexandria, VA
NAVFACENGCEN / CHESDIV Code 112.1, Washington, DC; Code 407, Washington, DC
NAVFACENGCEN CONTRACTS / AROICC, Coleville, CA; AROICC, Quantico, VA; DROICC, FPO Seattle; DROICC, Lemoore, CA; North Bay, Code 1042.AA, Vallejo, CA; ROICC (Code 495), Portsmouth, VA; ROICC, Crane, IN; ROICC, Jacksonville, FL; ROICC, Philadelphia, PA; ROICC, Point Mugu, CA; ROICC, Santa Ana, CA; ROICC, Twentynine Palms, CA
NAVFACENGCEN LANTDIV / Code 403, Norfolk, VA
NAVFACENGCEN NORTHDIV / CO, Philadelphia, PA
NAVFACENGCEN NORTHDIV / Code 111, Philadelphia, PA; Code 202.2, Philadelphia, PA
NAVFACENGCEN PACDIV / Code 102, Pearl Harbor, HI; Code 2011, Pearl Harbor, HI
NAVFACENGCEN SOUTHDIV / Code 04A3, Charleston, SC; Code 0525, Charleston, SC; Code 1021F, Charleston, SC; Code 102B, Charleston, SC; Code 102H, Charleston, SC; Code 4023 (RDL), Charleston, SC; Code 4023, Charleston, SC; Code 405, Charleston, SC
NAVFACENGCEN WESTDIV / Code 09B, San Bruno, CA; Code 09P/20, San Bruno, CA; Code 102, San Bruno, CA; Code 403.2 (Kelly), San Bruno, CA; Code 406.2 (Smith), San Bruno, CA; Code 407, San Bruno, CA; PAC NW Br Offc, Code C/42, Silverdale, WA; ROICC, Silverdale, WA

NAVHOSP / CO, Millington, TN; PWO, FPO Seattle; SCE, FPO San Francisco;
SCE, FPO Seattle
NAVMAG / SCE, FPO San Francisco
NAVOCEANCOMCEN / Code EES, FPO San Francisco
NAVOCEANO / Code 6200 (M Paige), NSTL, MS; Library, NSTL, MS
NAVOCFANSYSCEN / Code 9642B, San Diego, CA
NAVPETOFF / Sec Offr (Code 20), Alexandria, VA
NAVPGSCOL / Code 68WY (Wyland), Monterey, CA
NAVPHIBASE / PWO, Norfolk, VA; SCE, San Diego, CA
NAVPWC / Taylor, Pensacola, FL
NAVSCSCOL / PWO, Athens, GA
NAVSEA DET / NISMF Pearl Harbor, Director, Waipahu, HI
NAVSEASYSKOM / Code 05M3, Washington, DC
NAVSECGRU / Code G43, Washington, DC
NAVSECGRUACT / CO, FPO Miami; Code 31 PWO, FPO Miami; PWO (Code 40),
Edzell, Scotland, FPO New York; PWO, FPO Seattle
NAVSECSTA / Code 60, Washington, DC
NAVSHIPREFAC / SCE, FPO San Francisco; SCE, FPO Seattle
NAVSHIPYD / Carr Inlet Acoustic Range, Bremerton, WA; CO, Philadelphia,
PA; Code 134, Pearl Harbor, HI; Code 244.13, Long Beach, CA; Code
308.3, Pearl Harbor, HI; Code 382.3, Pearl Harbor, HI; Code 420,
Long Beach, CA; Code 441, Portsmouth, NH; Code 443, Bremerton, WA;
Code 450.4, Charleston, SC; Code 903, Long Beach, CA; Mare Is, Code
106.4, Vallejo, CA; Mare Is, Code 202.13, Vallejo, CA; Mare Is,
Code 280, Vallejo, CA; Mare Is, Code 401, Vallejo, CA; Mare Is,
Code 421, Vallejo, CA; Mare Is, Code 440, Vallejo, CA; Mare Is,
Code 457, Vallejo, CA; Mare Is, PWO, Vallejo, CA; Norfolk, Code
380, Portsmouth, VA; Norfolk, Code 440, Portsmouth, VA; Tech
Library, Portsmouth, NH
NAVSTA / CO, Brooklyn, NY; CO, Long Beach, CA; Code 423, Norfolk, VA;
Design Sec, Brooklyn, NY; Dir, Engr Div, PWD, Guantanamo Bay, Cuba,
FPO New York; Engr Div, PWD, FPO Miami; Engrg Dir, PWD, Rota,
Spain, FPO New York; PWO, Mayport, FL; PWO, Guantanamo Bay, Cuba,
FPO New York; PWO, Rota, Spain, FPO New York; Sec Offr, FPO San
Francisco; Util Engrg Offr, Rota, Spain, FPO New York
NAVSUPCEN / Code 700A.1, Norfolk, VA
NAVSUPPACT / PWO, Holy Loch, UK, FPO New York; PWO, Naples, Italy, FPO
New York
NAVSUPPFAC / Contract Assistant, FPO San Francisco
NAVSUPPO / Sec Offr, La Maddalena, Italy, FPO New York
NAVSUPSYSCOM / Code 0622, Washington, DC
NAVSWC / Code W41C1, Dahlgren, VA; Code W42 (GS Haga), Dahlgren, VA;
DET, White Oak Lab, PWO, Silver Spring, MD; PWO, Dahlgren, VA
NAVTECHTRACEN / SCE, Pensacola, FL
NAVTRASTA / PWO, Orlando, FL
NAVWPNCEN / Code 2634, China Lake, CA; Code 2637, China Lake, CA; PWO
(Code 266), China Lake, CA
NAVWPNSTA / Code 092, Concord, CA; Code 093, Yorktown, VA; PWO,
Yorktown, VA
NAVWPNSTA EARLE / Code 092, Colts Neck, NJ
NCR / 20, CO, Gulfport, MS; 20, Code R70, Gulfport, MS
NE OHIO REG SEWER DIST / Bldg Maint (Scherma), Cuyahoga Heights, OH
NEESA / Code 111C (Hickenbottom), Port Hueneme, CA; Code 111E3, Port
Hueneme, CA

NETPMSA / Tech Library, Pensacola, FL
NMCB / 3, Ops Offr, FPO San Francisco; 40, CO, FPO San Francisco; 74,
CO, FPO Miami
NOAA / Library, Rockville, MD
NORDA / Code 1121SP, NSTL, MO
NORTHDIV CONTRACTS OFFICE / ROICC, Colts Neck, NJ; ROICC, Portsmouth, NH
NPWC / Code 310, Pensacola, FL
NRL / Code 2511, Washington, DC; Code 2530.1, Washington, DC; Code 6123,
Washington, DC; Code 6127, Washington, DC
NSC / Code 43, Oakland, CA; Code 54.1, Norfolk, VA; Code 700, Norfolk,
VA; Code 700P/M (Fuel Dir), Richmond, CA; Code 703, Pearl Harbor,
HI; SCE, Charleston, SC; SCE, Norfolk, VA; SCE, Pearl Harbor, HI
NUHN & ASSOC / A.C. Nuhn, Wayzata, NM
NUSC DET / Code 2143 (Varley), New London, CT; Code 3322 (Brown), New
London, CT; Code 44 (Munn), New London, CT; Code TA131, New London,
CT; Library, Newport, RI
NWSTAT / ROICC, Colts Neck, NJ
OCNR / Code 1121 (EA Silva), Arlington, VA; Code 1234, Arlington, VA
OFFICE OF SEC OF DEFENSE / OASD (P&L)E, Washington, DC
OICC / Engr and Const Dept, APO New York
OREGON STATE UNIV / CE Dept (Hicks), Corvallis, OR; CE Dept (Yim),
Corvallis, OR
OREGON STATE UNIV / Oceanography Scol, Corvallis, OR
PACIFIC MARINE TECH / M. Wagner, Duvall, WA
PAULI, DC / Silver Spring, MD
PAYE-KOSANOWSKY, S / Pond Eddy, NY
PENNSYLVANIA STATE UNIV / Rsch Lab, State College, PA
PHILADELPHIA ELEC CO / E. D. Freas, West Chester, PA
PIKE, L / San Antonio, TX
PILE BUCK, INC / Smoot, Jupiter, FL
PMTC / Code 5041, Point Mugu, CA
PWC / ACE Office, Norfolk, VA; CO, Oakland, CA; Code 101, Great Lakes,
IL; Code 1011, Pearl Harbor, HI; Code 110, Oakland, CA; Code 123C,
San Diego, CA; Code 400, Oakland, CA; Code 400A.3, FPO San
Francisco; Code 412, San Diego, CA; Code 420, Oakland, CA; Code 421
(Kaya), Pearl Harbor, HI; Code 421 (Quin), San Diego, CA; Code 421
(Reynolds), San Diego, CA; Code 421, Norfolk, VA; Code 422, San
Diego, CA; Code 423, San Diego, CA; Code 430 (Kyi), Pearl Harbor,
HI; Code 50, Pensacola, FL; Code 500, San Diego, CA; Code 505A,
Oakland, CA; Code 590, San Diego, CA; Code 600, Great Lakes, IL;
Code 612, Pearl Harbor, HI; Code 612, Pearl Harbor, HI; Code 615,
FPO San Francisco; Code 700, Great Lakes, IL; Code 700, San Diego,
CA; Waid, San Diego, CA
SAN DIEGO STATE UNIV / CE Dept (Noorany), San Diego, CA
SEATECH CORP / Peroni, Miami, FL
SEATTLE PORT / Dave Van Vleet, Seattle, WA
SEATTLE UNIV / CE Dept (Schwaegler), Seattle, WA
SIMPSON, GUMPERTZ & HEGER, INC / Hill, Arlington, MA
SMELSER, D / Sevierville, TN
SOUTHWEST RESEARCH INSTITUTE / Thacker, San Antonio, TX
SOUTHWEST RSCH INST / M. Polcyn, San Antonio, TX
SPCC / Code 082, Mechanicsburg, PA; PWO, Mechanicsburg, PA
STATE UNIV OF NEW YORK / CE Dept, Buffalo, NY

SUBASE / Bangor, PWO (Code 8323), Bremerton, WA
SUPSHIP / Tech Library, Newport News, VA
TAMPA PORT AUTHORITY / Engrg Dept (Schrader), Tampa, FL
TECHNOLOGY UTILIZATION / K Willinger, Washington, DC
TEXAS A&M UNIV / CE Dept (Herbich), College Station, TX; CE Dept (Machemehl),
College Station, TX; Ocean Engr Proj, College Station, TX
TEXTRON, INC / Rsch Cen Library, Buffalo, NY
THE KLING-LINDQUIST, INC / Radwan, Philadelphia, PA
TREMCO, INC / M. Raymond, Cleveland, OH
TRW INC / Rodgers, Redondo Beach, CA
UCT TWO / CO, Port Hueneme, CA
UCT ONE / CO, Norfolk, VA
UNIV OF ALABAMA / Dir Fac Mgmt (Baker), Birmingham, AL
UNIV OF CALIFORNIA / CE Dept (Fourney), Los Angeles, CA; CE Dept
(Gerwick), Berkeley, CA; CE Dept (Polivka), Berkeley, CA; CE Dept
(Taylor), Davis, CA; Marine Rsr Inst (Spiess), LaJolla, CA
UNIV OF DELAWARE / Engrg Col (Dexter), Lewes, DE
UNIV OF HAWAII / Manoa, Library, Honolulu, HI
UNIV OF HAWAII / Ocean Engrg Dept (Ertekin), Honolulu, HI
UNIV OF ILLINOIS / Arch Scol (Kim), Champaign, IL; Metz Ref Rm, Urbana, IL
UNIV OF RHODE ISLAND / CE Dept, Kingston, RI; Dr. Veyera, Kingston, RI
UNIV OF TEXAS / CE Dept (Thompson), Austin, TX; Construction Industry
Inst, Austin, TX; ECJ 4.8 (Breen), Austin, TX; ECJ 5.402 (Tucker),
Austin, TX; MScol, Marine Biomed Inst, Talveston, TX
UNIV OF WASHINGTON / Applied Phys Lab (Sandwith), Seattle, WA; Applied
Phy Lab Library, Seattle, WA; CE Dept (Mattock), Seattle, WA
UNIV OF WISCONSIN / Great Lakes Studies Cen, Milwaukee, WI
US DEPT OF INTERIOR / BLM, Engrg Div (730), Washington, DC
USCINCPAC / Code J44, Camp HM Smith, HI
USCOASTGUARDACADEMY / Superintendent, New London, CT
USDA / For Svc, Reg Bridge Engr, Aloha, OR; Forest Prod Lab (Johnson),
Madison, WI
USNA / Ocean Engrg Dept, Annapolis, MD; PWO, Annapolis, MD
USNA / Sys Engrg, Annapolis, MD
VALLEY FORGE CORPORATE CENTER / Franklin Research Center, Norristown, PA
VAN ALLEN, B / Kingston, NY
VENTURA COUNTY / Deputy PW Dir, Ventura, CA; PWA (Brownie), Ventura, CA
VIATEUR DE CHAMPLAIN / Inst of Maritime Engrg, Matane, Quebec
VULCAN IRON WORKS, INC / DC Warrington, Cleveland, TN
WESCR-P / Hales, Vicksburg, MS
WINSTON CHEE / Gretna, LA
WISWELL, INC. / Wiswell, Southport, CT
WOODWARD-CLYDE CONSULTANTS / R. Cross, Oakland, CA; West Reg, Library,
Oakland, CA