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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

FULL-SCALE POWERING TRIALS OF THE STABLE SEMISUBMERGED PLATFORM, SSP KAIMALINO

by

Richard J. Stenson

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SHIP PERFORMANCE DEPARTMENT

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a speed of 19.08 knots at an average shaft horsepower of 2936 (2189 kw), an average shaft RPM of 307.8, and an average propeller pitch of 90 inches (229 cm), while operating at 75 percent of design propeller shaft torque. Powering data obtained during rough water trials revealed an increase in powering of 5 to 6 percent over the power required in smooth water in order to maintain a speed of 17 knots in a high State 3 sea. The speed and powering data are compared to data obtained on an 11-foot (3.35 m) model, and are found to be in excellent agreement.

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ABSTRACT

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ADMINISTRATIVE INFORMATION

These trials were authorized by Naval Material Command (03) Memorandum of 21 December 1972. Work was performed under David W. Taylor Naval Ship Research and Development Center Work Unit Number 1-1170-026. The Center's Technical Manager for the SWATH Project Office was originally Mr. S. Hawkins and during the trials was Mr. G. Elmer. The Center's Trial Director was Mr. R. Stenson. The Naval Undersea Center (NUC) Program Manager for administrative control of the SSP was Mr. D. Hightower. The NUC Project Engineer while operating in the Chesapeake Bay was Mr. W. Mazzone, and the Skipper was Mr. H. Lynch. While operating in Hawaii, the Project Engineer was Mr. T. Hughes and the Skipper was Mr. W. Steele.

INTRODUCTION

The Stable Semisubmerged Platform (SSP) KAIMALINO was designed and built to serve as a work platform for the Naval Undersea Center (NUC), San Diego, California for use at their Hawaii Laboratory. Design of the SSP was started at NUC in March of 1970, and construction began at the U.S. Coast Guard Shipyard, Curtis Bay, Maryland in June of 1972.

Because of its configuration as a Small Waterplane Area Twin Hull (SWATH) Ship, the SWATH Project Office, established at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) in 1972, was tasked to conduct the full-scale trials. The SSP was to be manned and operated by civilian personnel under the administrative control of the Naval Undersea Center, San Diego with eventual administrative control and operation being turned over to the NUC Hawaii Laboratory upon completion of trials.

KAIMALINO was launched on 7 March 1973, and construction was completed in October 1973. The initial shakedown of the vessel was conducted on 24-25 October 1973, 19 November 1973, and 23 January 1974, while operating out of the Coast Guard Shipyard in the northern part of the Chesapeake Bay. On 12 February 1974 KAIMALINO transited to the DTNSRDC Laboratory, Annapolis, Maryland, which was to serve as home port for calm water trials. While at this site, the SSP conducted mapping trials on 19-20 February 1974, single engine speed and powering trials on 21 February 1974, and transient response trials on 25 February 1974. On 27 February 1974, while attempting to conduct additional trials, the vessel suffered a failure in the starboard chain drive system, and a consequent engine casualty. The vessel returned to the yard for repairs on 1 March 1974. On 4 March 1974 a series of vibration runs were conducted while running on the port engine in an attempt to determine possible causes of the chain-drive failure. Extensive modifications and repairs to the chain-drive system were undertaken along with the replacement of the starboard engine during the period 5 March through August 1974.

On 9 September 1974 a post repair trial shakedown was scheduled, however, an engine casualty and resulting fire on the port side caused cancellation of these tests. The ship was again repaired, the port engine replaced, and on 28 January 1975 the SSP was trans-shipped to Oahu, Hawaii. From mid February 1975 to mid May 1975 the SSP was outfitted with an auxiliary diesel propulsion system and made ready for trials at the Dillingham Shipyard Honolulu, Hawaii. On 28 May 1975 the SSP transited from Honolulu to Kaneohe Bay, the site of the Naval Undersea Center, Hawaii Laboratory.

Trials commenced at the Kaneohe Bay location on 14 July 1975, continued through 23 July 1975, and included turning trials and speed and powering runs using electronic tracking, structural seakeeping trials, vibration trials, and transient response trials. On 28 July 1975 the SSP transited back to Honolulu to operate out of the Pearl Harbor Naval Shipyard in order to utilize the measured mile course at Barbers Point, Oahu. During the transit, seakeeping runs were conducted in the Molokai Channel while operating in consort with the USS TAWAKONI, a 1640 ton (1660 metric tons) ATF.

Speed and powering trials were conducted on the measured mile on 30 July 1975, seakeeping trials were conducted on 31 July 1975, and additional transient response trials were conducted on 1 August 1975, completing the full-scale trials effort. On 4 August 1975, the KAIMALINO was drydocked at Dillingham Shipyard for upkeep and removal of trial instrumentation. A summary of the total number of trial runs conducted on the SSP is presented in Table 1.

TABLE 1

SUMMARY OF TRIAL RUNS

DATE	TYPE OF RUN	LOCATION	NO. OF RUNS
01/22/74	Photographic Trials	Curtis Bay, MD	9
02/19/74	NUC Mapping Trials	Annapolis, MD	6
02/20/74	NUC Mapping Trials	Annapolis, MD	24
02/21/74	Speed & Powering, One Engine	Annapolis, MD	10
02/25/74	Transient Response Trials	Annapolis, MD	17
04/04/74	Vibrations Trials	Curtis Bay, MD	22
		1974 SUBTOTAL	88
07/16/75	Structures Trials	Kaneohe, HA (Ocean)	5
07/16/75	Speed & Powering Trials	Kaneohe, HA (Ocean)	3
07/16/75	Turning Circles	Kaneohe, HA (Ocean)	2
07/16/75	Optical Tracking	Kaneohe, HA (Ocean)	2
07/18/75	Speed & Powering Trials	Kaneohe, HA (Ocean)	12
07/18/75	Turning Circles	Kaneohe, HA (Ocean)	4
07/22/75	Vibrations Trials	Kaneohe, HA (Ocean)	2
07/22/75	Speed & Powering Trials	Kaneohe, HA (Ocean)	2
07/22/75	Seakeeping Trials	Kaneohe, HA (Ocean)	3
07/23/75	Transient Response (Includes Movies from Shore)	Kaneohe, HA (Bay)	43
07/28/75	Vibrations Trials	Transit Kaneohe to Pearl Harbor	3
07/28/75	Helo Photos	Transit Kaneohe to Pearl Harbor	4
07/28/75	Seakeeping Trials	Transit Kaneohe to Pearl Harbor	3
07/30/75	Speed & Powering Trials	Barbers Point, HA	17
07/31/75	Seakeeping Trials	Koko Head, HA	10
07/31/75	Structures Trials	Koko Head, HA	1
08/01/75	Transient Response	Barbers Point, HA	34
		1975 SUBTOTAL	150
		GRAND TOTAL	238

DESCRIPTION OF TEST VEHICLE

The SSP is a two strut per hull version of a Small Waterplane Area Twin Hull ship. The principal ship and propeller characteristics are listed in Table 2, while Figure 1 shows dimensional details of the SSP. The vessel consists of two submerged, parallel torpedo-shaped hulls, which support a cross-structure above water by means of four vertical surface-piercing struts. Two controllable canard fins located near the hull bows, and a full-span stabilizing fin with two controllable flaps located near the hull sterns, are shown in Figure 2. The vessel is equipped with two controllable, reversible pitch (CRP) propellers, and twin rudders, one of each also appearing in Figure 2.

The six control surfaces are hydraulically operated from the pilot house. The two rudders operate together, while each canard and flap can be operated independently. The CRP propellers are also operated from the pilot house, however, pitch change is accomplished by mechanical means rather than by hydraulic means.

Propulsion is provided by two General Electric GE-T64 gas turbines, located in the cross structure, which drive the CRP propellers through a four tier chain-drive system. These engines are rated at 2100 shaft horsepower (1566 KW) each. In addition, the auxiliary diesel propulsion system can also drive the propellers through the chain-drive system. The auxiliary propulsion system is used when getting underway and while maneuvering, and enables the gas turbines to be put on the line with the vessel underway. A more detailed description of the SSP characteristics and design features can be found in Reference 1.*

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[1] Lang, T. G., J. D. Hightower, and A. T. Strickland, "Design and Development of the 190-Ton Stable Semisubmerged Platform (SSP)," Journal of Engineering for Industry, Trans., ASME, November 1974 pages 1105-1111

TABLE 2

PRINCIPAL SHIP AND PROPELLER CHARACTERISTICS

SHIP DIMENSIONS

Overall Length	88.33 feet	26.92 meters
Maximum Beam	49.66 feet	15.14 meters
Displacement, salt water	190 long tons	193 metric tons
Design Draft	15.25 feet	4.65 meters
Overall Height	31.75 feet	9.68 meters
Deck Width	45.00 feet	13.72 meters
Lower Hull Diameter	6.50 feet	1.98 meters
Height, Design Waterline to Deck	14.50 feet	4.42 meters
Deck Well	23.0 feet x 12.5 feet	7.01 meters x 3.81 meters
Distance between Lower Hull Centerlines	40.00 feet	12.19 meters

PROPELLER CHARACTERISTICS

Wilkinson Controllable Pitch Propellers	2	2
Diameter	78 inches	1.981 meters
Pitch Diameter Ratio	Variable	Variable
Number of Blades, each	4	4
Direction of Rotation	Right Hand	Right Hand

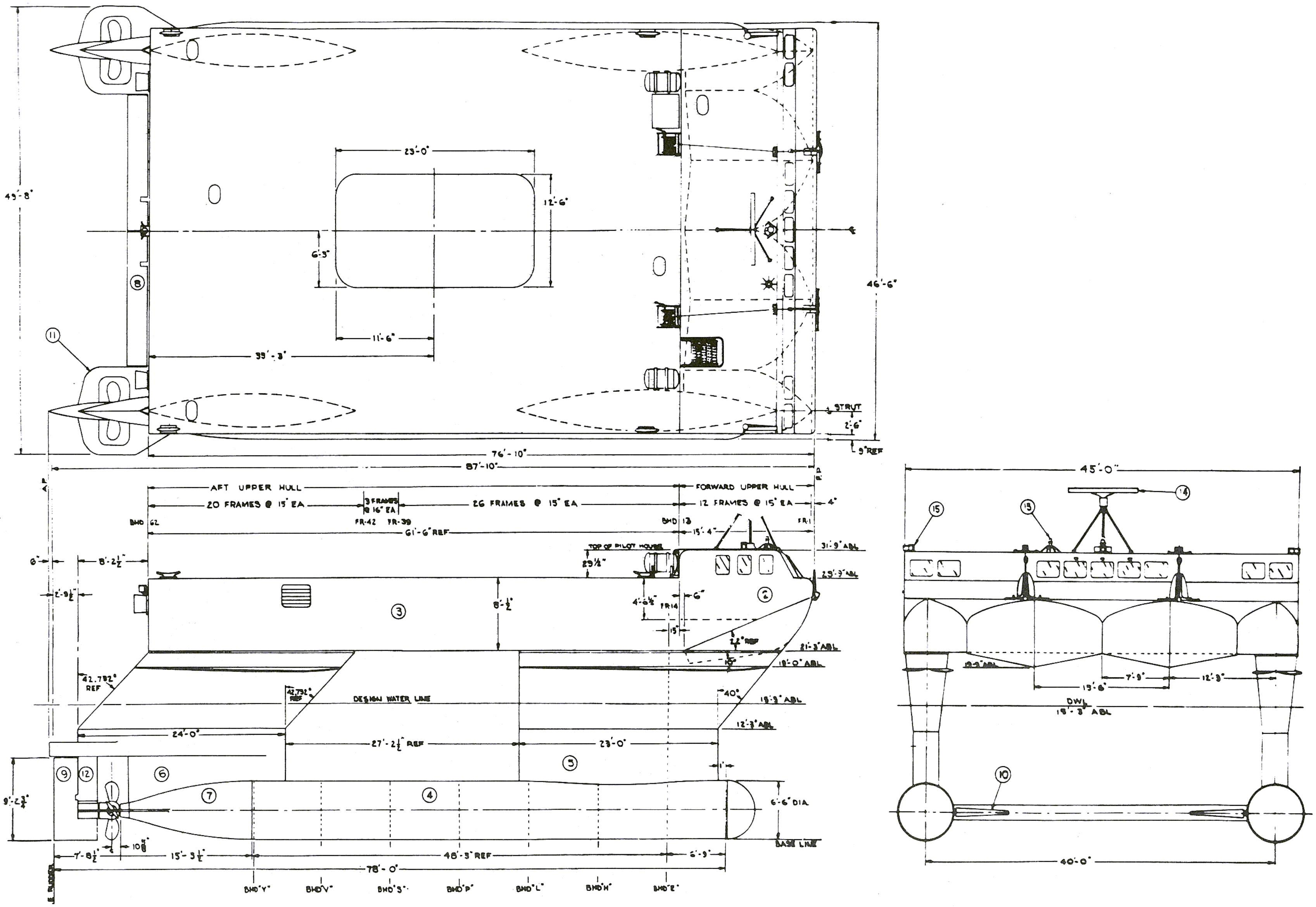
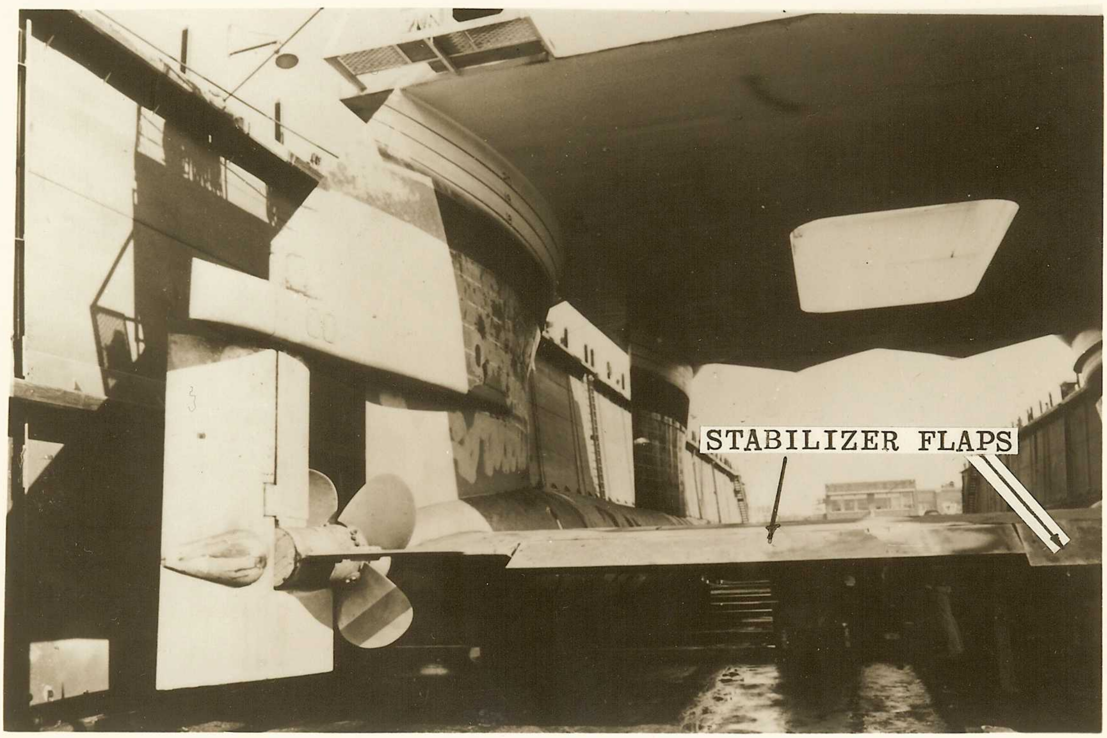


Figure 1 - SSP KAIMALINO, Dimensions

BOW VIEW, CANARDS



STERN VIEW, STABILIZER

Figure 2 - SSP KAIMALINO in Drydock

TRIALS PREPARATION

SHIPBOARD INSTRUMENTATION

Four separate areas of instrumentation were provided for the trials; Structures, Seakeeping, Vibrations, and Powering, including electronic tracking. Figure 3 shows the compartment layout of the SSP with the respective locations of the recording equipment for these instrumentation areas. Communications were established between these different locations, and the pilot house (control) for coordination of runs and data collection. Figure 4 is a composite view of three different instrumentation recording consoles (Seakeeping, Structures, and Vibrations). Details of these areas of instrumentation will be reported separately. This report addresses the Powering and Tracking instrumentation in detail.

The Powering and Tracking instrumentation is shown in Figure 5 and is depicted as a block diagram in Figure 6. Referring to Figure 6, propeller shaft RPM was measured by an electromagnetic pickup in proximity to a magnetic toothed wheel mounted on the propeller shaft. This magnetic signal was converted to a D.C. signal which was recorded by a digital printer through a scanner. A linear variable differential transformer (LVDT) mounted in a clamp on torsionmeter on a specially installed propeller stub shaft was used for measuring propeller shaft torque. A carrier amplifier system excited the LVDT and demodulated the output signal from the LVDT to a D.C. signal. This D.C. signal was recorded by a digital printer through a scanner. The parameters of rudder angle, flap angle, canard angle, and propeller pitch were obtained by tying into the ship's system. The signals obtained from the ship's system were conditioned by an amplifier box, and recorded on a digital recorder through a scanner. Ships speed was determined by an electro magnetic speed log mounted midway on the outboard side

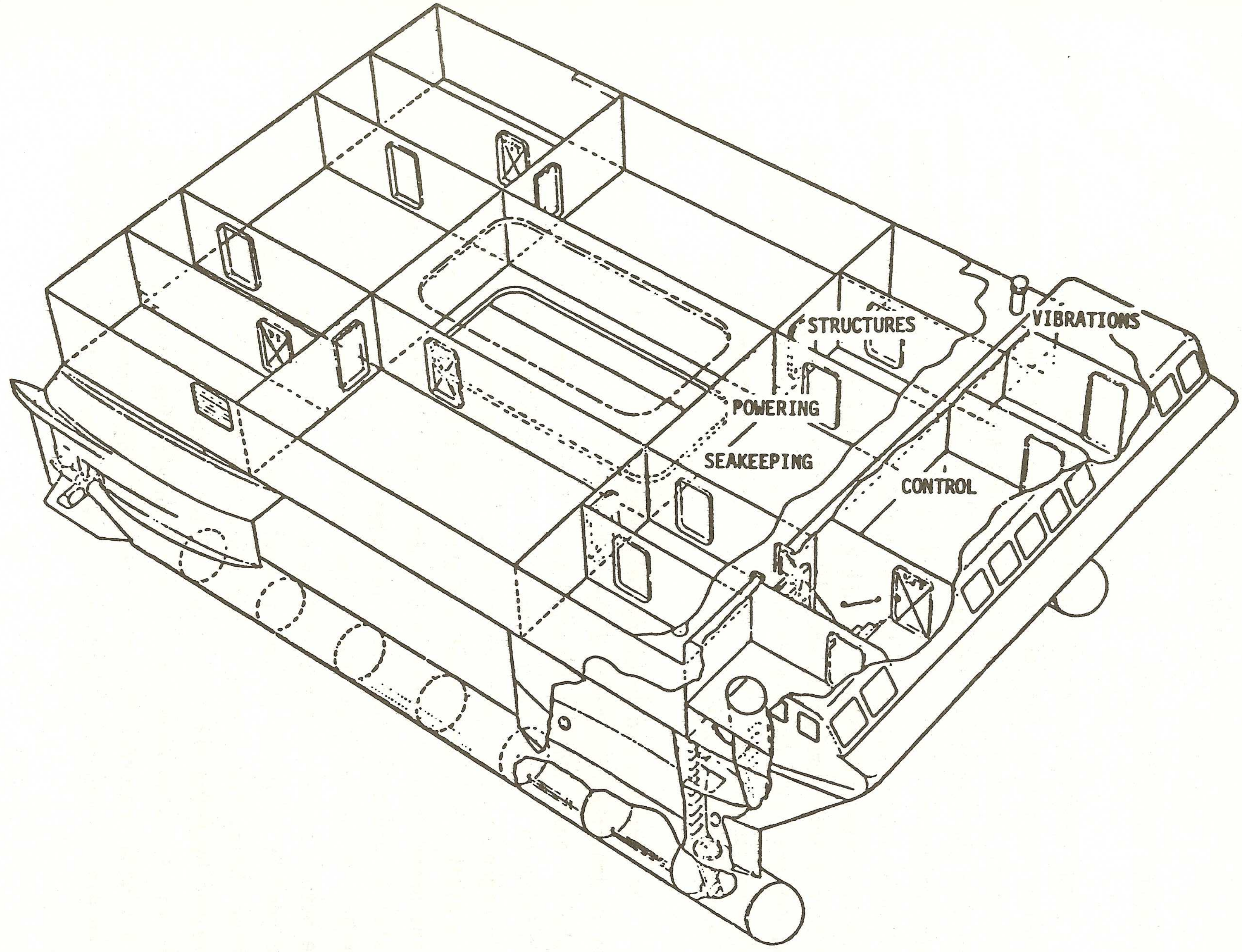
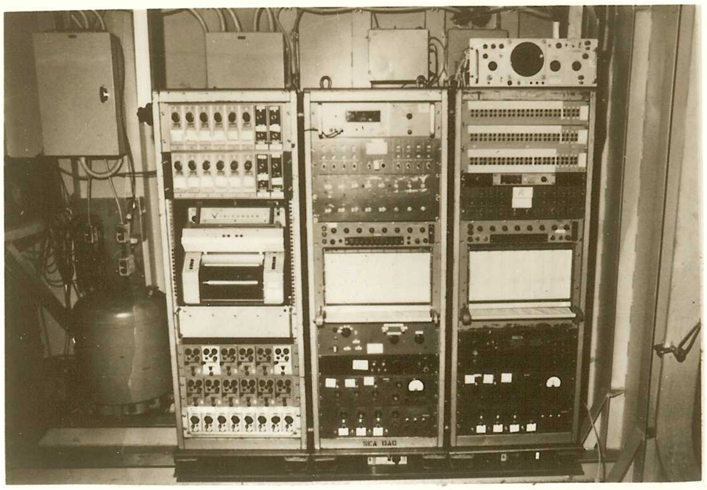
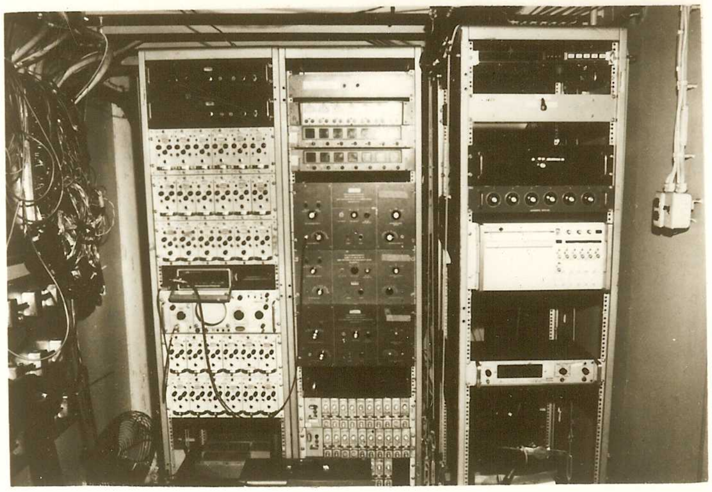


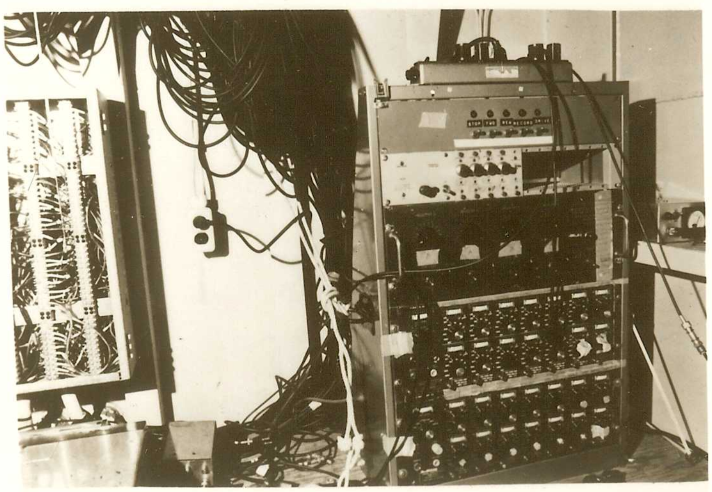
Figure 3 - SSP KAIMALINO Compartment Layout, Instrumentation Locations



SEAKEEPING

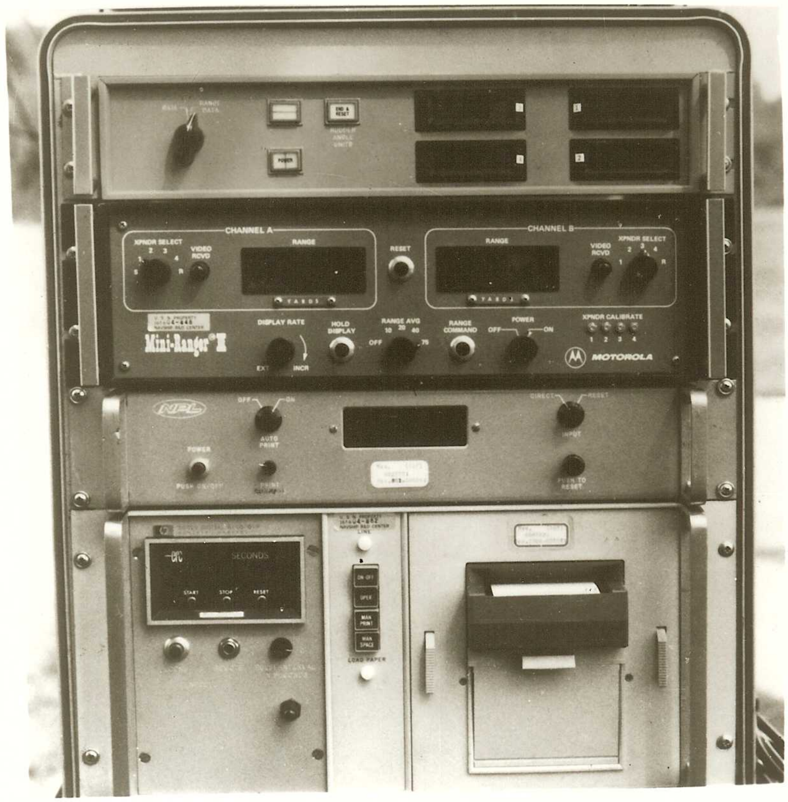


STRUCTURES



VIBRATIONS

Figure 4 - Instrumentation Recording Consoles



TRACKING SYSTEM

POWERING

Figure 5 - Powering and Tracking Instrumentation

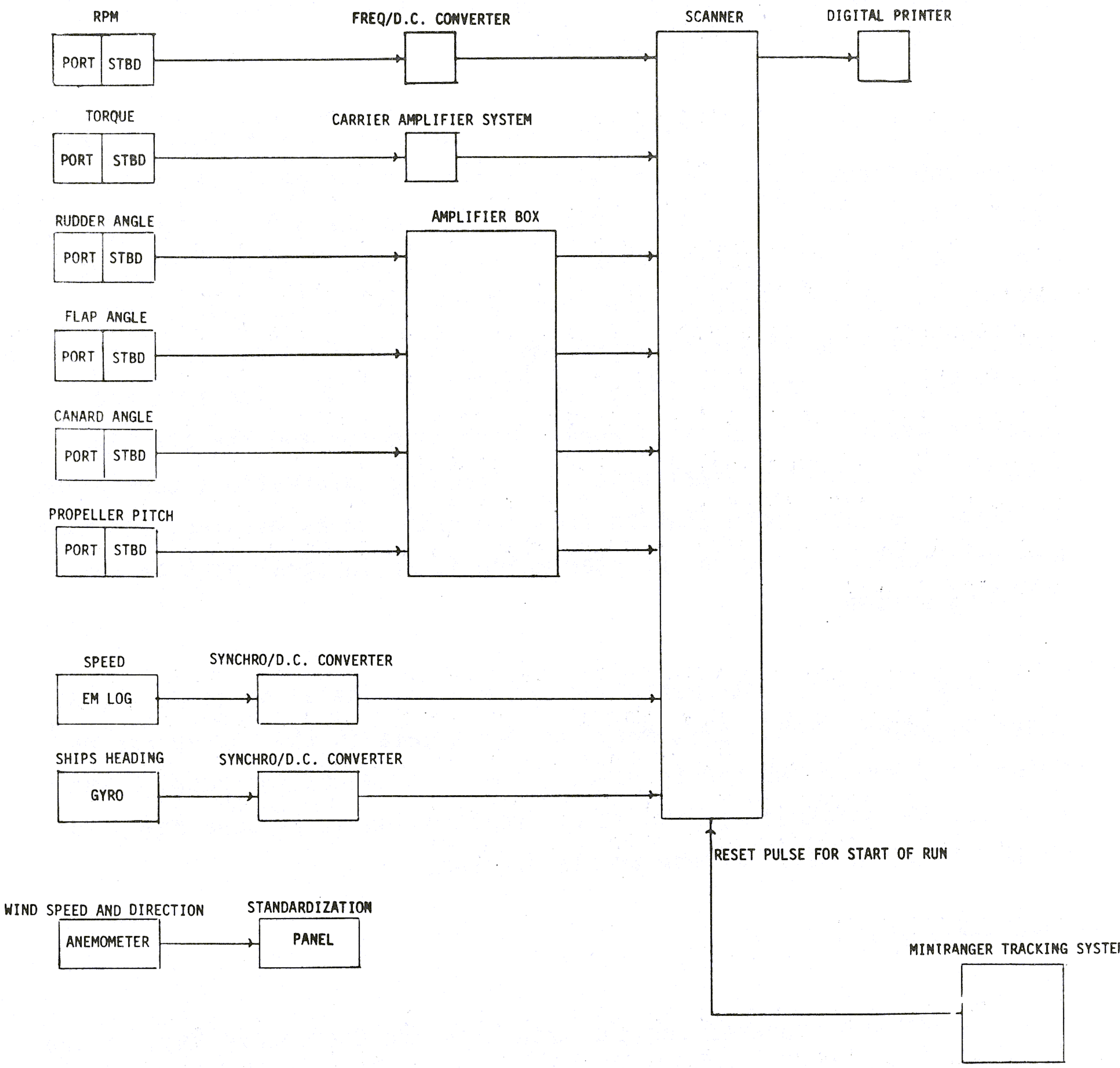


Figure 6 - Powering Instrumentation Block Diagram

of the forward starboard strut, approximately one foot above the lower hull. Both the EM log and ship's heading obtained from the ship's gyro compass were 60 cycle synchro signals which were converted to give proportional D.C. signals. These D.C. signals were fed through the scanner to the digital recorder.

Wind speed and direction were obtained with an anemometer mounted on the bow above the pilot house, with the signals being fed to a standardization panel. Electronic tracking of the SSP was accomplished with a Motorola Miniranger Tracking System, consisting of a receiver/transmitter unit mounted on the ship; aft of the pilot house, two transponders located ashore approximately one mile apart, and a tracking system console located in the pilot house. A reset pulse from the tracking system went to the scanner which synchronized the starting time of the scanner-digital printer. Tracking information, consisting of ranges to each shore station from the ship, ships heading, and time were recorded by a digital printer which is an integral part of the tracking system.

This complete instrumentation package was installed at the Coast Guard Shipyard, Curtis Bay, Maryland for trials in the Chesapeake Bay. Prior to shipping the SSP to Hawaii, the instrumentation package was removed, for safekeeping, and it was reinstalled at Kaneohe Bay prior to the Hawaii portion of the trials program.

SHIP PREPARATION

The SSP was prepared for the trials in the Chesapeake Bay, at the Coast Guard Shipyard. This preparation included drydockings to clean and paint the underwater portion of the hull, a propeller pitch survey, and an inclining experiment. The propeller pitch survey was conducted on 9 August 1973 during which time the propeller hub was scribed at the full ahead position, 100 inches (254 cm) of pitch, the zero position, and the full astern position, 50 inches (127 cm) of pitch. An aluminum template was also constructed which would enable propeller pitch to be determined by divers with the craft in the water.

The inclining experiment was conducted on 4 February 1975 by a Naval Ship Engineering Center representative with assistance from DTNSRDC personnel and the ship's crew. The Metacentric height (GM) of the craft was found to be 6.95 feet (2.12 m), at a displacement of 184.5 tons (187.5 metric tons).

For the Hawaii portion of the trials, it was determined from the initial powering trials that the hull was badly fouled, the tip of the port canard was missing, and a fairing on the port side propeller guard was missing. A commercial diving company was hired to wire brush clean the underwater portion of the hull. The propeller guard fairing was replaced, and a number of protective zincs were removed in way of the propeller. The port canard was not repaired, however, it is not felt that this irregularity adds significantly to the drag of the SSP. In addition, for this portion of the trials, the starboard propeller was found to be locked in the ahead position. Using the aforementioned template, divers determined the pitch to be 90 inches (229 cm), and when full pitch was applied to the port propeller, a reading of 90 inches (229 cm) was also recorded by the divers. All trials in Hawaii had to be conducted with this nominal 90 inches (229 cm) of pitch. It is not known whether some other pitch setting might be more efficient.

A second inclining experiment was conducted on 1 August 1975 at Pearl Harbor, and the Metacentric height was determined to be 5.52 feet (1.68 m), at a displacement of 193.75 tons (196.83 metric tons). It should be noted that this experiment was conducted with the instrumentation onboard in their respective locations, and a total of 13 people onboard. This corresponds to the as-tested condition of the SSP. The results of this test are included as Appendix A.

TRIALS PROCEDURE AND CONDUCT, CHESAPEAKE BAY

It should be noted that the SSP was designed to operate with the control surfaces in the automatic mode. The trials presented in this report only cover the condition wherein the control surfaces are preset on the approach, so as to give level flight and trim, and are left fixed for the duration of the run.

PHOTOGRAPHIC TRIALS

The first trials conducted on the SSP were a series of photographic runs on 22 January 1974 in the upper Chesapeake Bay. A total of nine runs were conducted running alongside of a 41-foot (12.50 m) Coast Guard boat which was used as the photographic platform. Five runs were made in the straight ahead mode, at nominal speeds of 9, 11, 16, 21, and 25 knots as determined by the uncalibrated ship's, impeller-type, speed log. These runs were typically of five minutes duration during which time motion pictures were obtained from the Coast Guard boat, including closeups showing flow visualization at the struts. Four runs were conducted at a nominal approach speed of 11 knots, using the starboard engine only. These included a port turn using full rudder, a run during which the canards were cycled full up to full down throughout the run causing the craft to impact the water, a run wherein the vessel was rolled port and starboard by cycling the port and starboard flaps, and a similar roll run cycling the port and starboard canards. These runs were all documented by motion pictures from the chase boat, and are available as Naval Undersea Center Film SSP(DA-LHA-74-10).

MAPPING TRIALS

The second series of trials conducted were the mapping trials, consisting of thirty runs conducted in the Chesapeake Bay while operating out of DTNSRDC Annapolis, Maryland on 19-20 February 1974. The trial conditions for these runs are summarized in Table 3. The purpose of these trials was to map the operating parameters of the craft, RPM, propeller pitch, canard angle, flap angle, and ship speed, and to determine the optimum conditions for conducting ensuing trials.

The procedure for conducting these runs was to steady up on a predetermined course at a nominal approach speed, and propeller pitch setting, with the canards and flaps adjusted to give level trim. Two minutes of data were then collected. A matrix of these runs was conducted at nominal approach speeds of 10, 15, 20, and 25 knots, with nominal propeller pitch settings of 70 inches (178 cm), 80 inches (203 cm), and 90 inches (229 cm) of pitch, using both engines. In addition, a series of single engine runs using the starboard engine were conducted at a nominal approach speed of 9 knots at pitch settings of 50 inches (127 cm), 60 inches (152 cm), 70 inches (178 cm), and 90 inches (229 cm) of pitch. A final series of runs using the port engine were conducted at a pitch setting of 90 inches (229 cm) at nominal approach speeds of 6, 7, 8, 9, and 10 knots.

The data collected during these runs is not included in this report, as the main purpose of this preliminary series of trials was to determine the operating conditions of the vessel. The results gave an indication of the relationship between propeller pitch, propeller RPM, and ship's speed, as well as the canard and flap angle settings required to maintain level flight at various ship's speeds. This information was a prerequisite for conducting the remaining trials.

TABLE 3

SUMMARY OF TRIAL CONDITIONS

DATE	LOCATION	WATER TEMPERATURE (DEGS F)	WATER TEMPERATURE (DEGS C)	WATER SPECIFIC GRAVITY	AVERAGE TRUE WIND DIRECTION (DEGS)	AVERAGE TRUE WIND VELOCITY (KNOTS)	SEA STATE	DISPLACEMENT (TONS S.W.)	DISPLACEMENT (METRIC TONS)	MEAN DRAFT (FEET)	MEAN DRAFT (METERS)
01/22/74	Curtis Bay, MD	--	--	--	--	--	--	--	--	--	--
02/19/74	Annapolis, MD	--	--	--	--	18	1→2	186.4	189.4	15.15	4.62
02/20/74	Annapolis, MD	--	--	--	--	--	2	193.4	196.5	15.50	4.72
02/21/74	Annapolis, MD	42.0	5.6	1.0083	182	5	0	187.4	190.4	15.30	4.66
02/25/74	Annapolis, MD	--	--	--	--	15	1	196.2	199.3	16.58	5.05
04/04/74	Curtis Bay, MD	--	--	--	--	--	1	--	--	--	--
07/16/75	Kaneohe, HA (Ocean)	77.0	25.0	1.0253	069	16	1	193.5	196.6	15.69	4.78
07/18/75	Kaneohe, HA (Ocean)	76.5	24.7	1.0253	062	15	1	193.0	196.1	15.62	4.76
07/22/75	Kaneohe, HA (Ocean)	77.5	25.3	1.0253	083	19	1→2	191.4	194.5	15.38	4.69
07/23/75	Kaneohe, HA (Bay)	81.0	27.2	1.0248	084	10	0→1	191.7	194.8	15.42	4.70
07/28/75	Molokai Channel, HA	77.0	25.0	1.0248	070	18	2	193.3	196.4	15.67	4.78
07/30/75	Barbers Point, HA	78.0	25.6	1.0243	078	14	1	193.1	196.2	15.64	4.77
07/31/75	Koko Head, HA	77.5	25.3	1.0253	058	24	3	195.0	198.1	15.92	4.85
08/01/75	Barbers Point, HA	77.5	25.3	1.0253	--	--	1→2	193.7	196.8	15.73	4.79

SPEED AND POWERING TRIALS, ONE ENGINE

The trial conditions for the single engine speed and powering trials are presented in Table 3. These trials were conducted at the measured mile course at Kent Island, Chesapeake Bay on 21 February 1974. A total of ten runs were conducted, one with the port engine driving and the other nine with the starboard engine driving. These runs were conducted with the ship traversing a course parallel to the measured mile in sufficient depth of water, 75 to 100 feet (22.9 m, 30.5 m), to preclude shallow water effects. The ship was steadied up on the approach at the predetermined propeller pitch, and RPM, with the canard and flaps positioned to give level flight. As the first set of range markers was passed, data taking began, and continued until the second set of markers was passed signifying end of run. The ship then reversed course and made a run on the opposite heading using the same settings of propeller pitch, RPM, canards, and flaps. A third pass on the original ship's heading completed a sequence, or three pass spot.

During these runs, propeller pitch, propeller shaft RPM, propeller shaft torque, canard angles, flap angles, rudder angles, ship's heading, time over the mile, and relative wind speed and direction were recorded. It was later determined that the manufacturer provided propeller shaft torsionmeters, which were an integral part of the propulsion chain-drive system, were malfunctioning during these runs. They were eventually replaced by a section of stub shafting manufactured by DTNSRDC which was used to mount a DTNSRDC provided torsionmeter. As a result, however, for the single engine runs, there was no torque or horsepower data available.

TRANSIENT RESPONSE TRIALS

The transient response trials in the Chesapeake Bay consisted of a total of 17 runs conducted on 25 February 1974 in the vicinity of

Kent Island. These runs were conducted at a nominal speed of 14 knots with 90 inches (229 cm) of pitch on both propellers. The first run conducted was a verification of the control settings required for level flight at the required speed and propeller pitch. It was determined that +7 degrees canard (trailing edge down), and -12 degrees flaps (trailing edge up), would suffice, and this was considered the zero condition for the remainder of the transient response runs. The remaining 16 runs consisted of steadying the craft up at the required zero or approach condition and then varying the control surfaces about the zero condition, and recording the crafts response to these changes. Details of these trials will be reported separately.

VIBRATIONS TRIALS

A series of vibration runs were conducted on 4 April 1974 in the upper Chesapeake Bay. The main purpose of these runs was to try and determine the cause of the previously mentioned chain-drive failure by measuring the vibration levels at various points in the propulsion system. A total of 22 runs were conducted while running on the port engine at two pitch settings, 47 inches (119 cm) and 80 inches (203 cm). Twenty of these runs were straight ahead at various RPM settings and were typically of 5 minutes duration. The other 2 runs consisted of right and left turns using 30 degrees rudder. During all of these runs, vibration levels were recorded and the chain-drive system was monitored using television cameras. The results of these trials are not included herein but were reported separately by the DTNSRDC Vibrations Division.

TRIALS PROCEDURE AND CONDUCT, OAHU, HAWAII

VIBRATIONS TRIALS

DTNSRDC was requested to conduct additional vibration trials by NUC after the modifications had been made to the propulsion system. The purpose of these trials was to determine the acceptability of the torsional vibration levels, by measuring mean and alternating torsional strain at two locations on the port propulsion shafting. These trials consisted of two runs on 22 July 1975, while operating out of Kaneohe Bay, and three runs on 28 July 1975 while in the vicinity of the Molokai Channel. The trial conditions for these days are listed in Table 3.

The procedure for 4 of these runs was to accelerate the craft by increasing the port RPM in 10 RPM increments from approximately 200 RPM to the maximum obtainable at various pitch settings; 50 inches (127 cm), 60 inches (152 cm), 70 inches (178 cm) and 90 inches (229 cm). The starboard shaft during these runs was held at 90 inches (229 cm) of pitch and approximately 240 RPM. The final run consisted of port and starboard turns of 360 degrees, using 10, 20, and 30 degrees right and left rudders, with full pitch on the two propellers, at approximately 250 RPM. Vibrations data recorded during these runs will be reported separately from this report.

STRUCTURES TRIALS

The structures trials consisted of six runs, five conducted on 16 July 1975 while operating out of Kaneohe Bay, and one conducted on 31 July 1975 in the ocean off of Koko Head Crater. Trial conditions are listed in Table 3. The first five runs were conducted while operating on diesel propulsion. The approach conditions were the minimum speed to maintain heading, while using the rudders, with the canards and flaps positioned to give level flight. The predominant seaway was kept on the port side. Runs were typically 15 minutes in duration, and consisted of a beam sea run, a bow quartering sea, a head sea, a stern quartering sea, and a repeat beam sea run. Structural data were recorded throughout these runs while powering data were recorded for the middle 5 minutes only. Sea conditions were recorded with the use of a wave rider buoy provided by the Seakeeping Group, and launched in the vicinity of the trials area. The same procedures were used for the run conducted on 31 July. This was a beam sea run on the port side with the craft operating on gas turbines for propulsion. The port engine was at its ground idle speed, while the starboard engine was off the line. Details of these structures trials will be reported separately.

SEAKEEPING TRIALS

The seakeeping trials consisted of a total of 16 runs, three conducted on 22 July 1975 while operating out of Kaneohe Bay, three conducted on 28 July 1975 in the Molokai Channel while enroute to Pearl Harbor, and ten more runs conducted on 31 July 1975 in the waters off of Koko Head Crater. In addition to these runs, four runs were also conducted on 28 July 1975 while running alongside the USS TAWAKONI, a 1640 ton (1666 metric ton) ATF. Trial conditions for these runs are presented in Table 3. Motion pictures of the two craft were obtained by helicopter showing the relative motions in the existing seaway.

The procedure for conducting these runs was similar to that for the structures trials. The wave rider buoy was launched in the vicinity of the trials area for all of these runs to record sea conditions. All runs were conducted with gas turbine propulsion. The runs on 22 July 1975 were conducted at a nominal approach speed of 8 knots, and consisted of a following sea run, a head sea run, and a port beam sea run. These runs were typically 10 minutes in duration with motions and powering data recorded throughout. The runs on 28 July were typically 15 minutes long at a nominal approach speed of 10 knots and consisted of a bow sea run, a port stern quartering run, and a starboard beam run. The runs on 31 July consisted of two 10 knot runs, and 8 runs at a nominal 18 knots and were typically 15 minutes long. The 10-knot runs were a following and starboard bow quartering run, while the 18-knot runs were 2 following sea runs, a head sea run, 2 stern quartering runs, a port bow quartering run, a port beam run, and a starboard beam run. Motion data were recorded throughout these runs, while powering data was collected during the middle portion of the run. Details of these trials will be reported separately. An analysis of the powering data collected during a portion of these runs is presented in a later section of this report.

TRANSIENT RESPONSE TRIALS

The transient response trials consisted of 43 runs conducted in Kaneohe Bay, Hawaii on 23 July 1975, and 34 runs conducted in the ocean near Barbers Point, Hawaii on 1 August 1975. Trial conditions are listed in Table 3. The nominal speed for the runs conducted in Kaneohe Bay was 14 knots, while both 14- and 18-knot runs were conducted at Barbers Point. The run procedure was to steady up on approach conditions so as to maintain level flight, and then commence the run by deflecting the scheduled control surface a predetermined amount. The crafts response to the scheduled deflection was recorded. During the trials in Kaneohe Bay, motion pictures of the craft were taken from ashore. Details of these trials will be reported separately.

SPEED AND POWERING TRIALS

The speed and powering trials were conducted on 18-22 July 1975 while operating out of Kaneohe Bay, and on 30 July 1975 at Barbers Point. The trials on 18 July consisted of 12 runs and were accomplished using the electronics tracking system. The 22 July trials consisted of 2 runs in the open ocean, and the 30 July trials consisted of 17 runs on the measured mile course at Barbers Point. Trial conditions for these runs are listed in Table 3.

For the trials using electronic tracking, the procedure was to steady up on an approach course parallel to the electronic transponders located on shore. Once steady state conditions were obtained, a standby signal was given, 30 seconds later the execute command was given, and 2 minutes later the run was ended. During the 2-minute run, propeller shaft RPM, propeller shaft torque, propeller pitch, canard angles, flap angles, rudder angles, ship's heading, and ship's speed by log were recorded every 10 seconds. In addition, ship's speed and heading were obtained by electronic tracking, and relative wind speed and direction were obtained with an anemometer. Three pass spots were run, and the data averaged using mean of means in order to eliminate current effects.

The 2 runs conducted on 22 July in the open ocean were a repeat of run conditions conducted using electronic tracking. Two opposite direction runs were conducted for 2 minutes duration with the data collected every 10 seconds. The purpose of these runs was to ascertain whether a hull cleaning had helped improve the performance of the craft. As a result of these runs, additional cleaning and repair efforts were undertaken as previously mentioned, and further speed and powering trials were conducted at Barbers Point.

The procedure for the runs conducted at Barbers Point was similar to that for the electronic tracking runs with the exception that the actual run time would vary based on the approach speed. The run was started and stopped as the ship passed the measured mile markers on either end of the trial course. Data were collected every 10 seconds as in the previously described runs. In addition, the ship's electromagnetic speed log was calibrated during these runs.

TURNING TRIALS

The turning trials consisted of 2 runs conducted on 16 July 1975, and 4 runs conducted on 18 July 1975 while operating out of Kaneohe Bay. Trial conditions are presented in Table 3. These runs were accomplished using electronic tracking. The procedure was to steady the craft up at a predetermined approach speed on a course parallel to the electronic transponders. The control surfaces were set so as to give level flight and trim. The craft was tracked electronically for 90 seconds on this approach course at which time the execute command was given, and the rudder was deflected as scheduled. The rudder angle was held at this position, and the ship was electronically tracked until a turn of 540 degrees was completed which signified end of run. During these runs, approach speed, speed in the turn, and ship's heading and position were determined by electronic tracking. Rudder angle, propeller pitch, canard angles, flap angles, and propeller RPM were sampled every 10 seconds throughout the run.

In addition to these electronic tracking runs, two optical tracking runs were attempted on 16 July 1975 using the NUC Optical Range at Kaneohe Bay. The purpose of these runs was to verify an alternative method of tracking the vessel if required. The data for these runs are not presented in this report.

PRESENTATION AND DISCUSSION OF RESULTS

SPEED AND POWERING TRIALS

The speed and powering trial results are tabulated in Tables 4, 5, and 6, and depicted graphically in Figures 7 and 8. Table 4 presents the speed and RPM data for the single engine runs in the Chesapeake Bay. As previously mentioned, there are no torque data available for these runs. Three pass spot averages (mean of means) are presented for two series of runs at 8.55 and 6.69 knots, while a two spot average is presented for the 5-knot runs. Two single pass runs, at 9.48 knots and 8.36 knots, are also presented. It can be observed that the trailing shaft will turn as high as 104 RPM even with zero pitch in this mode of operation. The trailing shaft RPM appear to be independent of ship's speed above 6.34 knots. Port and starboard single engine operation appear to give similar results. The maximum speed obtained in this mode of operation was a 9.48-knot run on the port engine at 268 RPM and 89 inches (226 cm) of pitch.

Table 5 and Figure 7 present the speed and powering data from the measured mile runs at Barbers Point. Figure 7 is a plot of propeller shaft RPM and power developed versus ship's speed in knots. The points plotted are the average of three pass spots with the exception of the 7-knot run which is a two pass spot average. As can be seen in Table 5, a top speed of 19.08 knots was achieved at an average RPM of 307.8 and a total shaft horsepower of 2936 (2189 kw). These conditions correspond to 70 percent of rated power and slightly over 75 percent of rated propeller shaft torque. These limiting conditions were imposed due to the physical dimensions of the section of stub shafting installed in order to measure shaft torque. Extrapolation of the power curve in Figure 7 to the rated horsepower of 4200 SHP (3132 KW) results in a ship's speed of approximately 23 knots.

TABLE 4

SPEED AND RPM DATA, ONE ENGINE

RUN NUMBER	PORT RPM	PORT CANARD* ANGLE (DEG)	PORT FLAP* ANGLE (DEG)	PORT PROPELLER PITCH (IN)	PORT PROPELLER PITCH (CM)	STARBOARD RPM	STARBOARD CANARD* ANGLE (DEG)	STARBOARD FLAP* ANGLE (DEG)	STARBOARD PROPELLER PITCH (IN)	STARBOARD PROPELLER PITCH (CM)	SHIPS SPEED (KNOTS)
1160 N	268	+ 2.9	+ 0.4	89	226	91	+ 5.5	+ 4.0	0	0	9.48
1161 S	97	+10.2	- 7.6	0	0	226	+12.7	- 0.8	86	218	8.34
1170 N	85	+10.3	- 8.3	0	0	226	+12.6	0	86	218	8.72
1180 S	96	+10.3	- 8.3	0	0	227	+12.7	0	88	224	8.43
						226					8.55
1190 N	90	+10.2	- 9.9	0	0	154	+12.5	- 1.3	86	218	7.00
1200 S	96	+10.3	- 9.9	0	0	153	+12.8	- 1.3	87	221	6.34
1210 N	104	+10.2	-10.0	0	0	153	+12.8	- 1.3	87	221	7.08
						153					6.69
1162 S	94	+ 7.0	-10.4	0	0	237	+10.0	- 0.8	86	218	8.36
1220 N	68	+10.2	-10.4	0	0	100	+14.5	- 0.8	87	221	5.60
1230 S	60	+10.4	-10.4	0	0	99	+14.6	- 0.8	87	221	4.40
						100					5.00

*+ Trailing Edge Down
 - Trailing Edge Up

N METERS	TOTAL POWER SHP	TOTAL POWER KW	SPEED (KNOTS)	CANARD* ANGLE (DEGREES) PORT	CANARD* ANGLE (DEGREES) STBD	FLAP* ANGLE (DEGREES) PORT	FLAP* ANGLE (DEGREES) STBD
0980	1847	1378	15.05	+2.7	+4.1	-1.2	-1.6
1390	1876	1399	15.94	+2.7	+4.1	-1.2	-1.6
0910	1851	1381	15.21	+2.8	+4.1	-1.2	-1.6
1170	1862	1389	15.54	+2.8	+4.1	-1.2	-1.6
				+3.5		-1.4	
6110	1392	1038	10.41	+2.7	+4.0	+1.1	+0.8
6580	1391	1038	9.39	+2.7	+4.0	+1.1	+0.8
6680	1395	1040	10.51	+2.7	+4.0	+1.1	+0.8
6490	1392	1038	9.93	+2.7	+4.0	+1.1	+0.8
				+3.4		+1.0	
6300	1474	1099	12.97	+3.7	+4.2	-4.4	-5.6
5920	1466	1093	14.09	+3.7	+4.2	-4.4	-5.6
4640	1397	1042	12.70	+3.7	+4.3	-4.3	-5.2
5700	1451	1082	13.46	+3.7	+4.3	-4.3	-5.2
				+4.0		-5.0	
7350	2909	2170	19.59	+5.0	+5.6	+6.8	+6.1
7910	2929	2184	18.58	+5.0	+5.6	+6.9	+6.4
8550	2977	2220	19.57	+5.0	+5.6	+7.7	+7.4
8930	2936	2190	19.08	+5.0	+5.6	+7.1	+6.6
				+5.3		+6.8	
2170	207	154	6.52	+5.1	+5.7	+1.7	+0.6
2200	210	157	7.43	+5.1	+5.7	+1.7	+0.6
2180	208	156	6.98	+5.1	+5.7	+1.7	+0.6
				+5.4		+1.2	
2500	2571	1918	17.49	+5.0	+5.7	+4.5	+3.4
3790	2638	1969	18.34	+5.0	+5.7	+4.5	+3.4
3690	2661	1985	17.72	+5.0	+5.7	+4.9	+3.4
3440	2627	1960	17.97	+5.0	+5.7	+4.6	+3.4
				+5.4		+4.0	

RQUE ON METERS	TOTAL POWER SHP	TOTAL POWER KW	SPEED (KNOTS)	CANARD* ANGLE (DEGREES) PORT	CANARD* ANGLE (DEGREES) STBD	FLAP* ANGLE (DEGREES) PORT	FLAP* ANGLE (DEGREES) STBD
7354	96	72	5.25	+9.6	+10.7	-4.7	-5.0
7228	97	73	6.04	+9.4	+10.5	-4.9	-5.3
7786	102	76	5.30	+9.5	+10.6	-4.8	-5.2
7399	98	74	5.66	+10.0		-5.0	
3600	519	387	8.17	+9.0	+ 9.3	-3.5	-5.0
3870	521	389	7.60	+9.2	+ 9.4	-3.4	-4.6
3560	517	385	8.18	+9.0	+ 9.3	-3.5	-4.9
3720	520	388	7.89	+9.2		-4.1	
2370	1775	1329	14.15	+6.9	+ 8.9	-6.7	-8.4
2830	1798	1341	13.71	+7.0	+ 9.0	-6.2	-7.4
3760	1832	1366	14.43	+7.1	+ 9.0	-6.2	-7.2
2950	1801	1344	14.00	+8.0		-7.0	
7930	1413	1054	9.50	+7.2	+ 8.5	+3.7	+3.4
8030	1417	1057	10.13	+7.1	+ 8.6	+3.7	+3.4
8220	1418	1057	9.50	+7.1	+ 8.6	+3.7	+3.4
8050	1416	1056	9.82	+7.8		+3.6	
7810	1536	1145	13.69	+8.2	+ 8.7	-1.9	-2.8
7860	1496	1116	12.94	+6.9	+ 7.7	-2.5	-4.8
7840	1516	1130	13.32	+7.9		-3.0	
0020	1508	1135	10.18	+7.0	+ 7.7	-2.5	-4.7
				+7.4		-3.6	
0890	1771	1321	14.39	+6.2	+ 8.2	-2.6	-3.0
1140	1776	1324	13.73	+6.6	+ 6.6	-1.5	-3.6
1020	1774	1322	14.06	+6.9		-2.6	

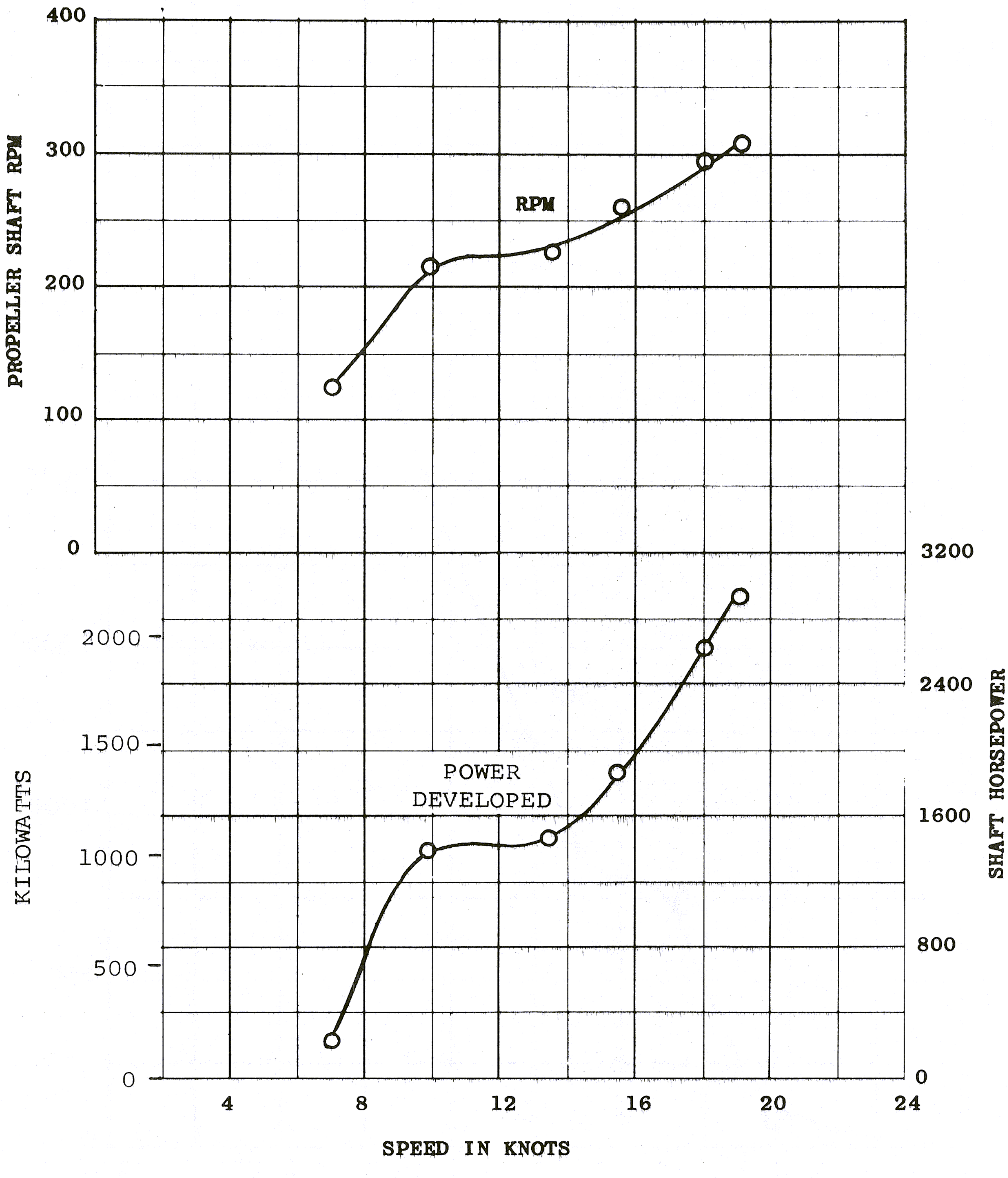


Figure 7 - Results of Speed and Powering Trials, Two Engines

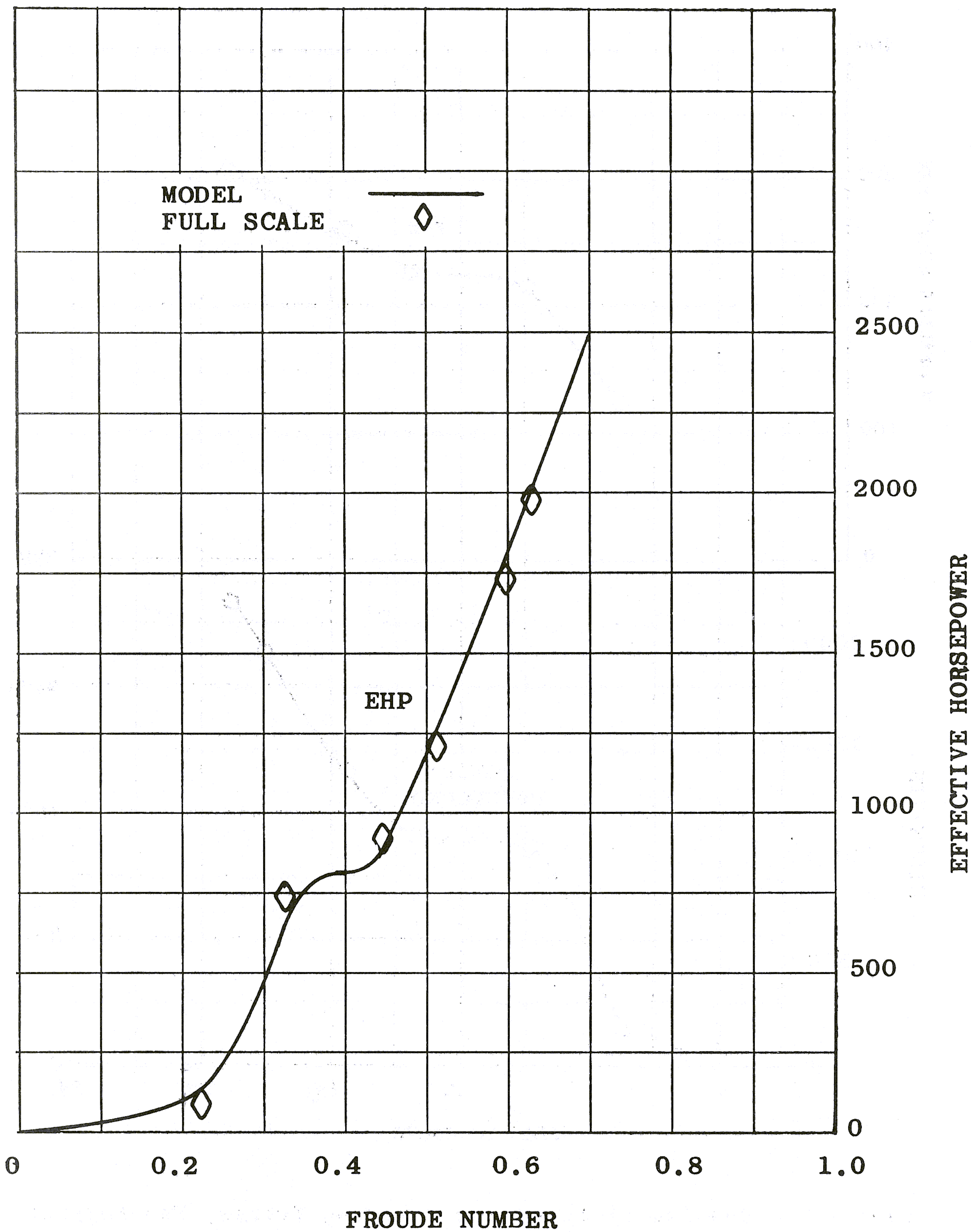


Figure 8 - Comparison of Full Scale and Model Results

Also apparent in Figure 7 is the wave drag peak occurring at approximately 10 knots. An increase of only 50 horsepower (37 kw) in this region increases the speed some three and a half knots to 13.46 knots.

Figure 8 is a plot of effective horsepower versus Froude number, defined as

$$F_n = V/\sqrt{gL}$$

where V = speed in feet per second, g = gravitational constant, ft/sec^2, and L = length in feet for an 11-foot (3.35 m) model of the SSP tested at DTNSRDC in 1972. The curve shown is plotted from model data for the design displacement of 190 tons salt water (193 metric tons). The model data presented was arrived at by using separate scaling techniques for the various shapes of the SSP components, and a correlation allowance, $\Delta C_f = 0$, due to the small linear ratio between model and full-scale.

Superimposed on this curve is the full-scale data from Figure 7, which has been nondimensionalized to Froude number using a length of 80 feet (24.38 m). The shaft horsepower data were converted to effective horsepower by using a curve of propulsion coefficient versus Froude number for design displacement developed from the model tests. As can be seen in Figure 8, the full-scale data agree excellently with the model prediction.

Table 6 presents the speed and powering data obtained while operating out of Kaneohe Bay utilizing the electronic tracking system. As previously mentioned, the ship's hull was considerably fouled and a section of fairing in way of the propeller was missing during these runs. As a result, it took considerably more power to obtain a given speed than expected. An attempt to clean the hull was made by the ship's crew and repeat Runs 1250 W and 1260 E in Table 6 indicate a slight improvement when compared to Runs 1070 through 1090. Based on these results, the commercial hull cleaning was undertaken, along with replacement of the fairing and removal of some protective zincs in way of the propeller. This fouled hull data are not depicted graphically, as it is not considered to be representative of the ship's performance capabilities.

TURNING TRIALS

Table 7 presents the turning circle data, while Figure 9 shows the measurements used to describe a turning circle maneuver. The data presented were obtained by electronically tracking the ship's position throughout a run and constructing a circle as shown in Figure 9. These data are corrected for drift due to wind and current. The data presented in Table 7 indicate that the craft turns slightly better with left rudder than with right rudder as evidenced by a smaller tactical diameter. The tactical diameter is also observed to increase with increasing speed and/or decreasing rudder angle as would be expected. Tactical diameters are on the order of 10 to 12 ship lengths. Finally the speed in the turn is found to decrease approximately one knot at an approach speed of 5.6 knots, and as much as 5.5 knots at an approach speed of 14.5 knots.

ROUGH WATER POWERING DATA

Table 8 presents the powering data collected during the rough water trials in a State 3 sea. The data were collected during the middle 5 minutes of a following sea run, a head sea run, and a beam sea run. Referring to the table, it can be observed that the ship's

TABLE 7

TURNING DATA

RUN NUMBER	APPROACH SPEED (KNOTS)	RUDDER ANGLE (DEGREES)	AVERAGE PROPELLER PITCH		AVERAGE* CANARD ANGLE (DEGREES)	AVERAGE* FLAP ANGLE (DEGREES)	ADVANCE		TRANSFER		TACTICAL DIAMETER		SPEED IN TURN (KNOTS)	AVERAGE APPROACH RPM
			(INCHES)	(CM)			(YARDS)	(M)	(YARDS)	(M)	(YARDS)	(M)		
2050	5.59	30 L	90	229	+10	- 5	150	137	160	146	287	262	4.73	94.8
2060	5.61	30 R	90	229	+10	- 5	163	149	175	160	312	285	4.83	95.8
2011	14.34	30 L	90	229	+ 6	- 7	178	163	162	148	310	283	10.02	244.4
2020	14.50	30 R	90	229	+ 7	- 6	175	160	169	155	323	295	9.01	246.6
2030	13.82	20 R	90	229	+ 7	-9	223	204	212	194	358	327	11.49	241.7

*+ Trailing Edge Down
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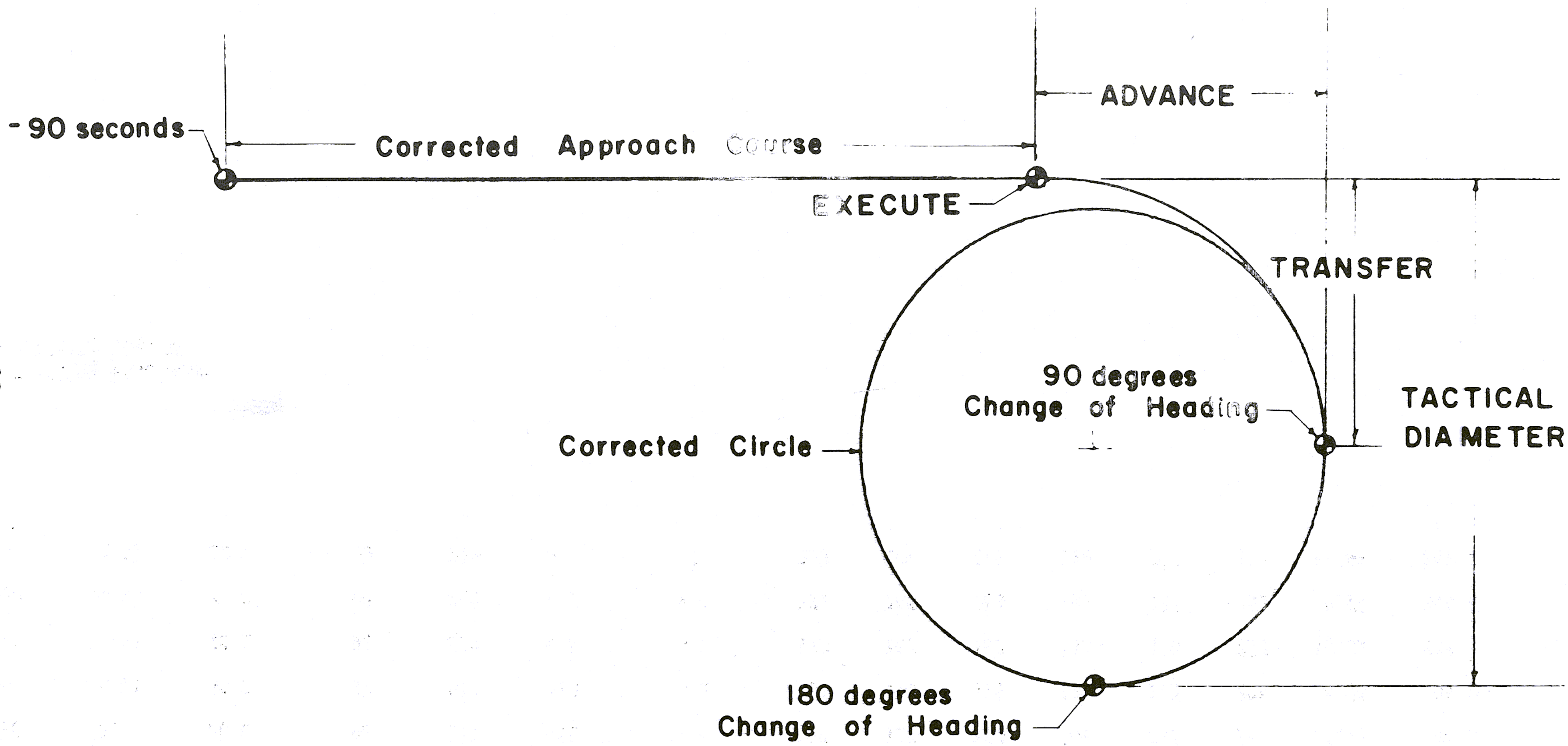

Diagram Showing Measurements Used to Describe a Turning Circle Maneuver

Figure 9 - Turning Circle Diagram

TABLE 8

ROUGH WATER POWERING DATA

AVG	SHP PORT	SHP STBD	SHP TOTAL	(KW) PORT	(KW) STBD	(KW) TOTAL	MAX SPEED IN RUN (LOG)	MIN SPEED IN RUN (LOG)	AVG SPEED FOR RUN (LOG)	CORRECTED SPEED FOR RUN*
281.6	1184	1105	2289	883	824	1707	20.20	13.61	15.77	16.40
287.9	1277	1174	2451	952	876	1828	16.93	15.89	16.41	17.10
295.8	1338	1250	2588	998	932	1930	18.18	16.02	16.94	17.75

PER CENT INCREASE IN POWERING DUE TO ROUGH WATER:

$$\% \text{ Increase} = \frac{2289 - 2120}{2120} = 7.97\%$$

$$\% \text{ Increase} = \frac{2451 - 2320}{2320} = 5.65\%$$

$$\% \text{ Increase} = \frac{2588 - 2520}{2520} = 2.70\%$$

$$\% \text{ Increase Two Spot Average} = \frac{2370 - 2220}{2220} = 6.76\%$$

$$\% \text{ Increase Three Spot Average} = \frac{2443 - 2320}{2320} = 5.30\%$$

*Corrected speed is obtained from speed log calibration over measured mile in calm water.

speed fluctuates as much as 6.6 knots in a following sea, approximately 1 knot in a head sea, and approximately 2.1 knots in a beam sea.

The average speed for each run was determined by averaging all the 10-second samples, and a correction to this speed was applied as determined by the speed log calibration at Barbers Point. The smooth water horsepower for this corrected speed was then obtained from Figure 7. The percent increase in powering (rough water over smooth water) was then determined by comparing this figure with the average horsepower as measured during the run. A two spot average of the head and following sea runs was obtained, and the smooth water power for this speed was compared to the actual recorded power. This revealed a 6.76 percent increase in power. Averaging all three runs and comparing them to the smooth water data indicate a powering increase of 5.3 percent.

CONCLUSIONS AND RECOMMENDATIONS

The SSP KAIMALINO has successfully completed a comprehensive full-scale trial program consisting of some 238 trial runs conducted over a 20 month period. It was found that the SSP could obtain a speed of 19.08 knots at an average shaft horsepower of 2936 (2189 kw), an average RPM of 207.8, and an average propeller pitch of 90 inches (229 cm), while operating at 75 percent of design propeller shaft torque. Full-scale data were found to be in excellent agreement with model data. It was determined that the SSP performed equally well with port or starboard single engine operation, and a speed of 9.48 knots was obtained at 268 RPM and 89 inches (229 cm) of pitch. During single engine operation, the trailing shaft was found to turn at approximately 90 to 100 RPM at speeds above 6.3 knots with zero pitch on the propeller. The SSP was found to have a tactical diameter on the order of 10 to 12 ship lengths, and was observed to turn slightly better with left rudder than with right rudder.

Speed in the turn was observed to drop anywhere from 5.5 knots with an approach speed of 14.5 knots and 30 degrees rudder, to 2.4 knots with an approach speed of 13.8 knots and 20 degrees rudder. SSP requires approximately 5 to 6 percent more power in a State 3 sea than it does in smooth water to maintain a speed of approximately 17 knots. The trial data presented in this report are considered to be good, and representative of SSP KAIMALINO as tested.

It is recommended that the ship's electromagnetic speed log be adjusted to correspond to the calibration obtained at Barbers Point. It is also recommended that if no further powering trials are contemplated, the propeller stub shaft provided for torque readings should be replaced by shafting sufficient in size to allow the craft to operate at design conditions. It is felt that speeds in the order of 23 knots can then be obtained at the continuous rated power, 4200 SHP (3132 kw).

ACKNOWLEDGMENTS

The successful completion of the trials on SSP KAIMALINO could not have been accomplished without the cooperation of the many Naval Undersea Center personnel supporting and manning the vessel, and the personnel comprising the various DTNSRDC Trials teams.

APPENDIX A

SSP KAIMALINO AS TESTED - INCLINING EXPERIMENT, PEARL HARBOR

Weight for Inclining = 2620 lbs (1188 Kg) = 1.17 long tons = 1.19 metric tons

(13 People on Board = 2365 lbs, 1073 Kg)

	Position 1	Position 2	Position 3	Position 4
Weight Location	Centerline	19' Stbd (5.79 m)	20' 2" Port (6.15 m)	46' 3" Aft (14.10 m)
Degrees Pitch	0° 7' Bow Up	0° 7' Bow Up	--	1° 15' Bow Up
Degrees List	0°	1° 9' Stbd	1° 18' Port	0°

SEAWATER

Temp °F	Temp °C	Specific Gravity
77.5°	25.3°	1.026

Mean Draft = 15' 8.75" = 15.73 (4.79 m), Displacement from Curves $\Delta_{s.w.}$ =

193.75 tons (196.83 metric tons) @ 15.73 (4.79 m) draft, BM = 14.65' (4.47 m)

1° 9' = 1.15° Tan 1.15° = .020

1° 18 = 1.30° Tan 1.30° = .023

Position 2,

$$GM = \frac{w \cdot d}{W \tan\phi} = \frac{1.17 \cdot 19}{193.75 \cdot .02} = 5.74 \ (1.75 \text{ m})$$

Position 3,

$$GM = \frac{w \cdot d}{W \tan\phi} = \frac{1.17 \cdot 20.167}{193.75 \cdot .023} = 5.29 \ (1.61 \text{ m})$$

$$GM_{avg} = \frac{5.74 + 5.29}{2} = 5.52' \ (1.68 \text{ m})$$

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2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.