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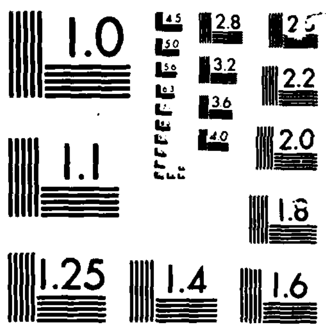

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REPORT OF BOLLARD PULL TESTS

FOR THE BARGE "SEACON"

G&A REPORT NO. 78-026-003

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prepared by

PAUL R. VAN MATER, JR.

for

NAVAL FACILITIES ENGINEERING COMMAND
CHESAPEAKE DIVISION (FPO-1)

under

CONTRACT N62477-78-C-0346

6 MARCH 1980

OCEAN ENGINEERING
AND CONSTRUCTION PROJECT OFFICE
CHESAPEAKE DIVISION
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An experiment was conducted on the Naval Facilities Engineering Command's ocean construction barge "SEACON" to measure the bollard pull generated by the barge's propulsive system in both the ahead direction and the athwartships direction. The experiment was conducted in Fort Lauderdale, Florida on (Con't)

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1 November 1979. This report documents the result of the experiment, and concludes that the barge develops approximately 15,250 poounds of bollard pull in the ahead direction, approximately 10,000 pounds in the athwartships direction, and, further, that the propulsion engines are developing close to their rated power when operating in the ahead mode. However, when thrusting laterally the reduced thrust noted is reflected in lower engine power output. Recommendations include a suggested modification to the stern lines to improve propulsive performance.

SUMMARY

An experiment was conducted on the Naval Facilities Engineering Command's ocean construction barge "SEACON" to measure the bollard pull generated by the barge's propulsive system in both the ahead direction and the athwartships direction. The experiment was conducted in Fort Lauderdale, Florida on 1 November 1979. This report documents the result of the experiment, and concludes that the barge develops approximately 15,250 pounds of bollard pull in the ahead direction, approximately 10,000 pounds in the athwartships direction, and, further, that the propulsion engines are developing close to their rated power when operating in the ahead mode. However, when thrusting laterally the reduced thrust noted is reflected in lower engine power output. Recommendations include a suggested modification to the stern lines to improve propulsive performance.

1.0 BACKGROUND

The SEACON is currently propelled by one type 14G Voith-Schneider propulsor unit located forward and two similar type units located aft. Each unit is driven by a Detroit Diesel Allison Model 12V-71 diesel engine. With this system the ship has had difficulty making an adequate speed and has had further difficulties bringing her head into wind in strong breezes, maintaining position, and translating cross-wind. As part of a study to evaluate proposed modifications to the propulsion system to alleviate these conditions, bollard pull experiments were conducted on the barge in Fort Lauderdale, Florida, to measure the present bollard pull capacity of the barge in both ahead and athwartships modes. In addition to this information, it was also desired to determine whether the engines are delivering their rated horsepower.

A Plan of Action for the tests was prepared by G&A and forwarded to NAVFAC in Reference 1.

2.0 DESCRIPTION OF EXPERIMENTS

The experiments were conducted on 1 November 1979 at Pier 1 in the Turning Basin, Port Everglades, Fort Lauderdale, Florida. Figure 1 shows the location. This was during a period during which the SEACON was berthed at Tracor Shipyard undergoing several equipment additions and modifications. Support for the experiment was provided by Tracor in supplying dynamometers to measure the line tensions and support personnel to assist in the test. Tracor also installed engine pyrometers in each bank of all three engines to register exhaust gas temperatures.

The barge was scheduled to get underway at 0800, proceed to the test area less than a mile away, rig for the tests and commence testing at 0900. Unfortunately a delay in delivery of the line dynamometers delayed commencement of the tests until 1245 which in turn required curtailing the test plan. The tests conducted were

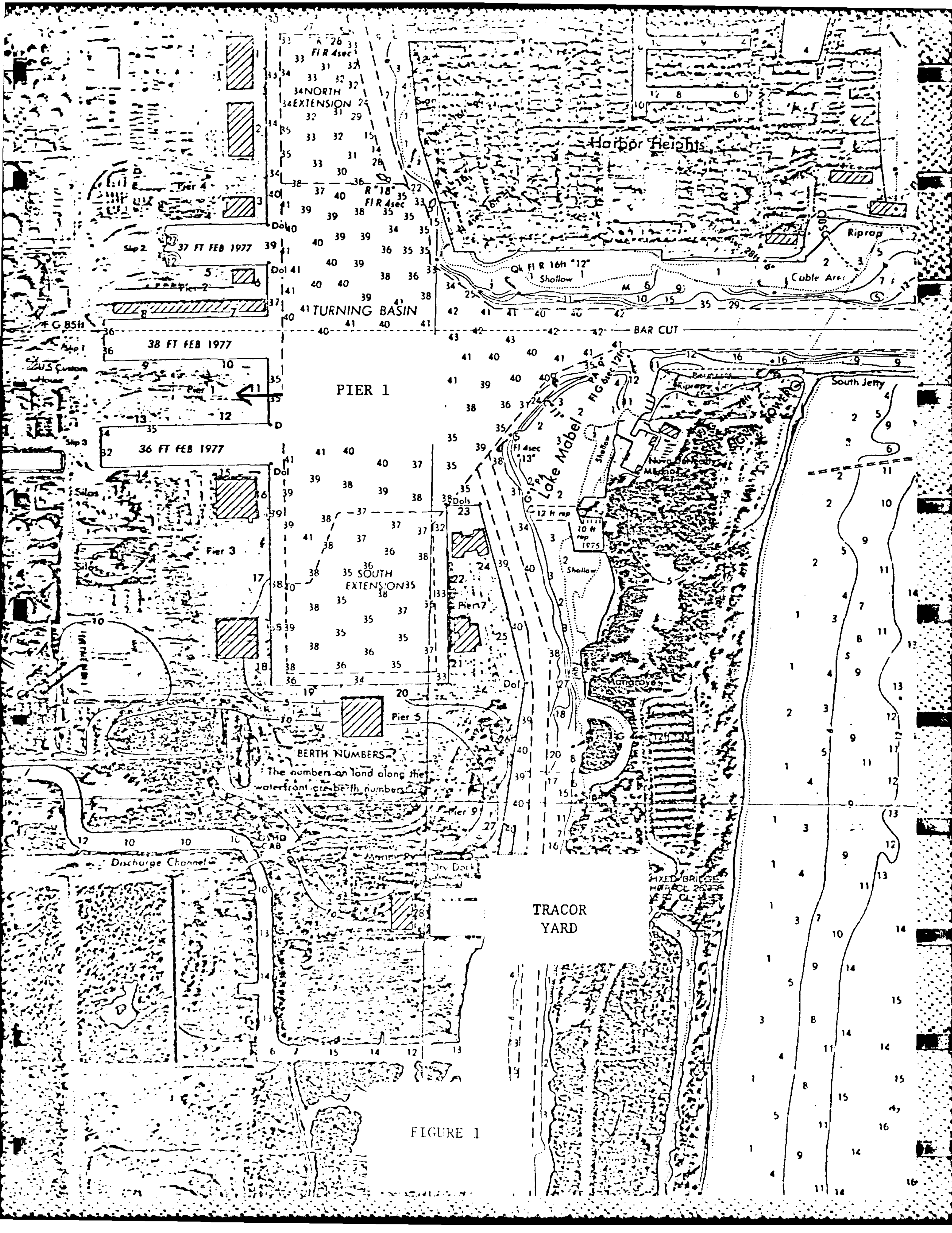

Harbor Heights
NORTH EXTENSION
TURNING BASIN
BAR CUT
PIER 1
SOUTH EXTENSION
TRACOR YARD
37 FT FEB 1977
38 FT FEB 1977
36 FT FEB 1977
Pier 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 7
Pier 9
Slip 1
Slip 2
Slip 3
Silos
Lake Mabel
South Jetty
Riprap
Cable Area
Shallow
Mangroves
Dry Dock
Discharge Channel
BERTH NUMBERS
The numbers on land along the waterfront are berth numbers

FIGURE 1

confined to the athwartships bollard pull tests, the ahead bollard pull tests, and some free running observations.

Tension in the forward line was read on a Dillon mechanical dynamometer, 100,000 pound capacity, resolution 250 pounds, rigged from a bridle on the dock and read on the dock. Tension in the after line was read on a Dillon hydraulic type dynamometer with the hydraulic sending unit rigged from a bridle on deck and the receiver gage located nearby on deck. The aft dynamometer had a range of 25,000 pounds and a resolution of 250 pounds. The following data was recorded on each run:

line tensions
wind speed and direction
engine RPM
engine water jacket temperature
exhaust gas temperature
indicated thrust percentages
time

A summary of the run identifications, times and experimental data is given in Appendix A. In the first test series with the barge lying alongside Pier 1, two lines were rigged from the barge to "dead men" on the dock. Both forward and after lines were located approximately at the locations of the forward and after V-S units. The barge then moved out from the dock about 250 feet took a tension on the lines and adjusted position so that the ship was parallel to the dock and the lines were perpendicular to the ship and dock. By the time the tests were ready to begin the morning breeze has freshened to 16 mph and waves were being generated in the Turning Basin which were estimated at 1-ft. in height and 50 feet in length. Wind and waves were from 110° Relative, just slightly abaft the beam.

An interesting observation was made under these conditions. In order to move slowly off the pier against these relatively mild wind and wave conditions, the SEACON had to use an indicated 80% lateral thrust, a revealing indicator of its lack of lateral thrusting capacity. During this time data was collected and designated Runs 2-6 although line tension was still slack. Slack was taken out of the lines and readings made of the tension in both forward and aft lines using the dynamometers. Runs 7-12 were made at indicated percentage thrusts of 80,85,90,95 and 100 percent. The barge was then brought back to the dock and rerigged for the ahead tests. The hydraulic dynamometer was rerigged between a bridle on deck and a single line tending aft to a dead man on the dock. The barge was headed directly into the wind. Runs 13 to 18 were taken with all propulsors thrusting and at indicated thrust levels of 17,40,60,80 and 100 percent. The line parted on Run 19, was rerigged and Run 20 taken. Runs 21 through 24 were taken in the ahead mode with only the forward propulsor thrusting. Runs 25 through 27 were taken with only the aft two propulsors thrusting. Finally, during the return trip to the Tracor yard engine conditions at an indicated 100% thrust were recorded as Runs 28 to 31.

3.0 RESULTS

3.1 BOLLARD PULL MEASUREMENTS

The presence of wind and wave forces on the SEACON was a noticeable affect for which correction was required, since some of the thrust generated by the propulsors was used to overcome these forces. There are several simplistic drag coefficient-type formulations for ship wind resistance; however, the most accurate formulations are a family of regression equations based on wind tunnel tests of ship above-water forms presented by Isherwood in Reference 2. These equations were programmed on a RD-11 computer for this application with results summarized in Table I and Figure 2. Note that wind speeds are given in knots in Table I and miles per hour in Figure 2. For the wind speeds of 16 to 18 mph which prevailed during the athwartships bollard

TABLE I

WIND FORCES ON SEACON

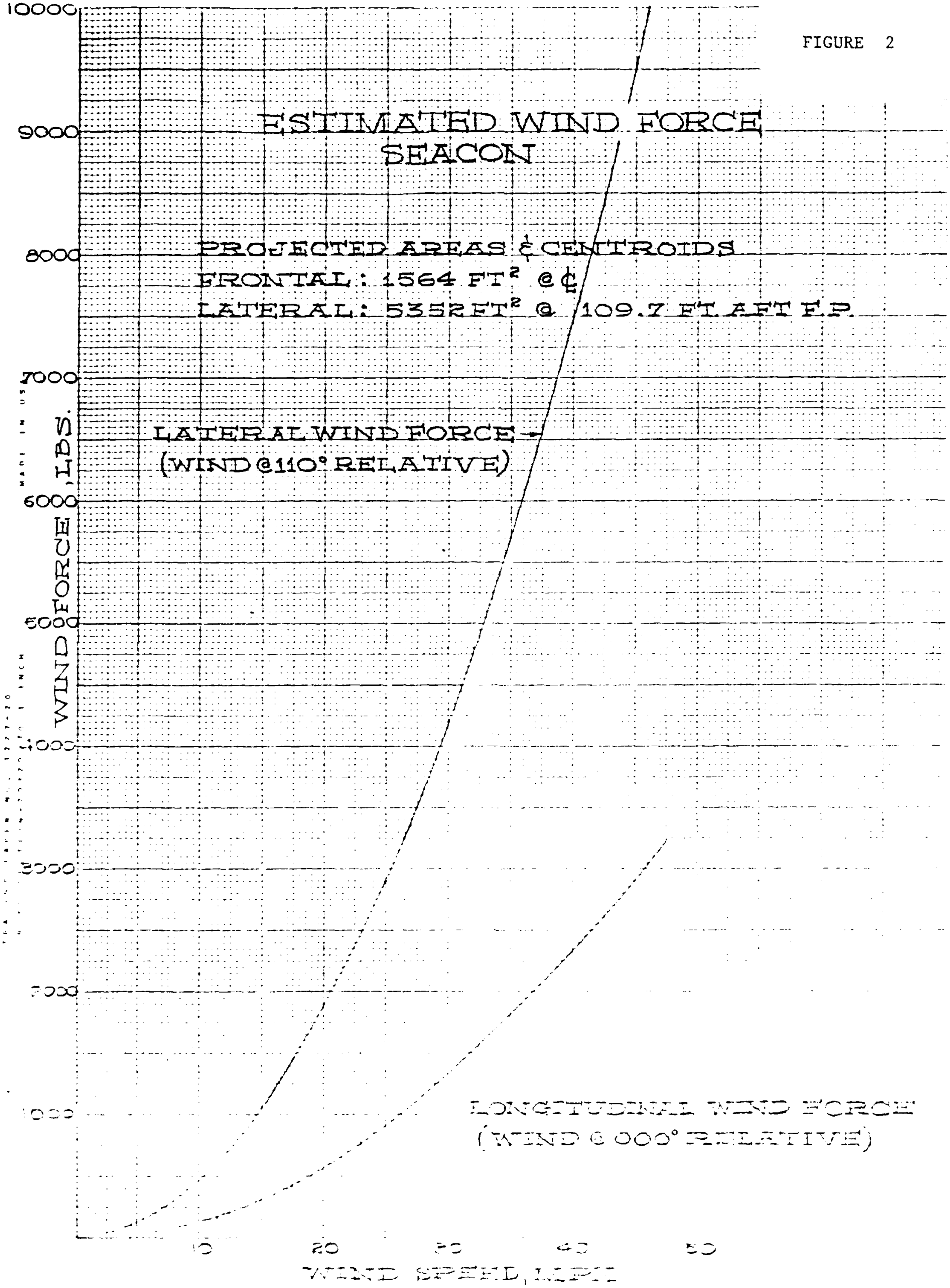
LONGITUDINAL COMPONENT OF WIND FORCE, F_x, LBS.

RELATIVE WIND / WIND SPEED KNOTS	HEAD WIND 180	150	120	BEAM WIND 90	60	30	FOLLOWING WIND 0
10	190	190	80	20	- 10	- 130	- 190
15	430	420	180	40	- 30	- 300	- 440
20	760	740	320	70	- 50	- 530	- 780
25	1190	1150	500	110	- 75	- 830	-1220
30	1710	1660	720	150	-110	-1190	-1750
35	2320	2260	980	210	-150	-1620	-2380
40	3030	2960	1280	270	-190	-2110	-3110

LATERAL COMPONENT OF WIND FORCE, F_y, LBS.

RELATIVE WIND / WIND SPEED KNOTS	HEAD WIND 180	150	120	BEAM WIND 90	60	30	FOLLOWING WIND 0
10	0	360	690	650	650	400	0
15	0	810	1550	1450	1470	910	0
20	0	1440	2760	2580	2610	1610	0
25	0	2250	4310	4040	4080	2520	0
30	0	3250	6200	5810	5880	3620	0
35	0	4420	8440	7910	8000	4930	0
40	0	5770	11020	10330	10450	6440	0

FIGURE 2


ESTIMATED WIND FORCE
SEACON
PROJECTED AREAS & CENTROIDS
FRONTAL: 1564 FT² @ ℄
LATERAL: 5352 FT² @ 109.7 FT AFT F.P.
LATERAL WIND FORCE
(WIND @ 110° RELATIVE)
LONGITUDINAL WIND FORCE
(WIND @ 000° RELATIVE)
WIND FORCE, LBS.
WIND SPEED, MPH
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
10
20
30
40
50

pull tests the lateral wind force varied from 1200 to 1550 pounds based on the Isherwood work. For the 20.7 and 20 mph wind conditions which prevailed during the ahead tests the longitudinal wind forces were 600 and 550 pounds. Error bounds on these force predictions are estimated at ± 20%.

Estimation of the wave forces presented more difficulty. Originally an existing ship motion program developed by Professor J.R. Paulling of University of California, Berkeley, was applied; however results were not credible. In the matter of wave drift forces second order effects are important and the state-of-the-art leaves much to be desired. Theories due to Havelock, Maruo, Kim and Chou, Faltinsen and Loken and others were considered. The approach of Salvesen, Reference 3, was finally selected using wave drift force coefficients applicable to merchant ship forms. The results shown in Figure 3 indicate a lateral wave force in the 1-ft. x 50-ft. wave conditions estimated for all tests of 1950 pounds and a longitudinal wave force of 250 pounds. Error bounds on these force predictions are estimated at ± 20%. The results of the Bollard Pull Tests with wind and wave corrections applied are tabulated in Table II and shown graphically in Figure 4. The following comments apply to the interpretation of these displays.

(a) There are some points which exhibit considerable scatter. The shortened schedule and operational pressures forced taking data very rapidly. Inspection of the run times documented in Appendix A reveals that often there were only two to four minutes between data points. The scatter in the data, although within acceptable bounds for a full scale experiment such as this, could probably have been reduced had it been possible to pursue a more deliberate pace and assure that steady state conditions were achieved for each point. In several cases it appears that the bollard

FIGURE 3

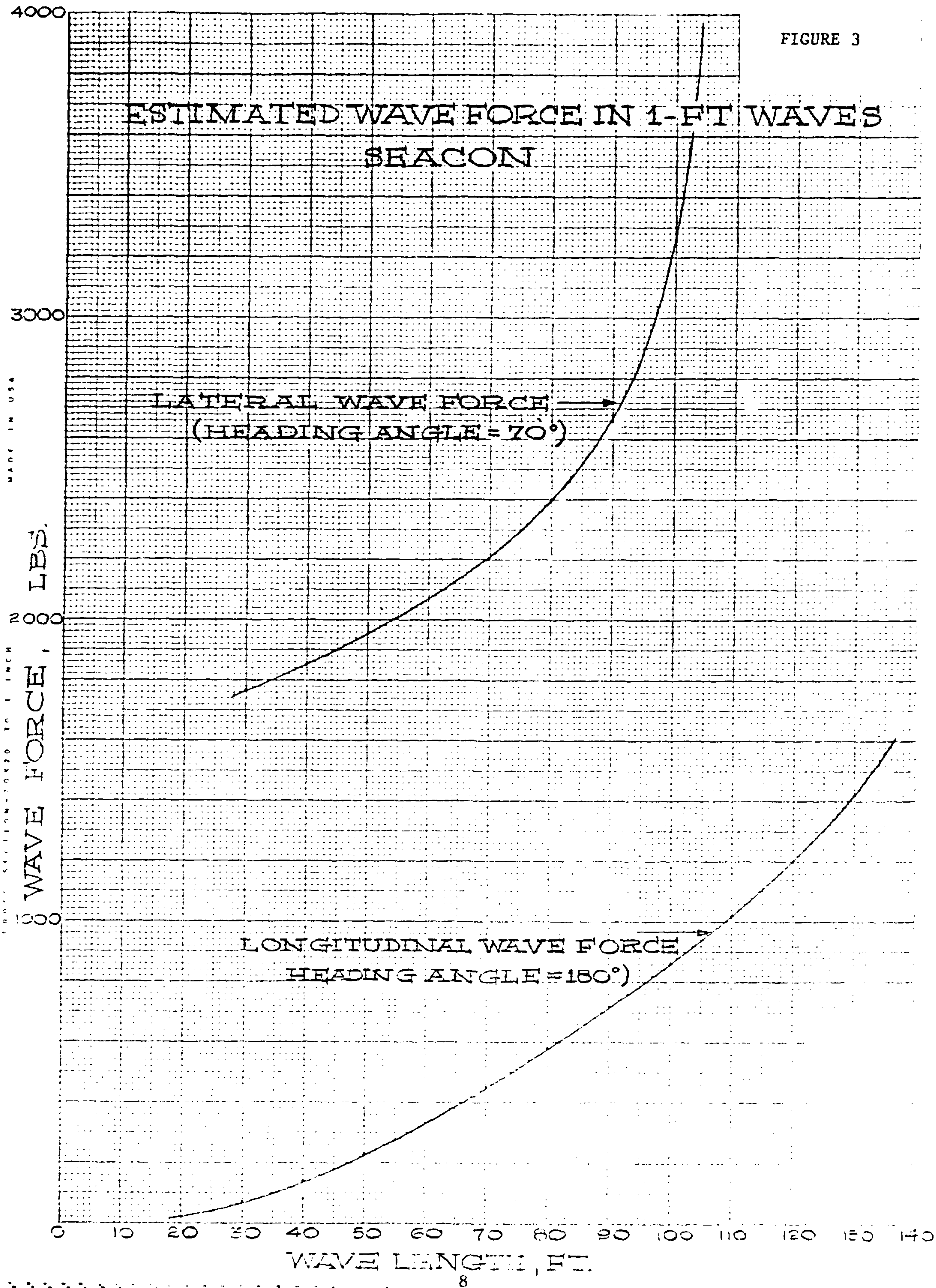
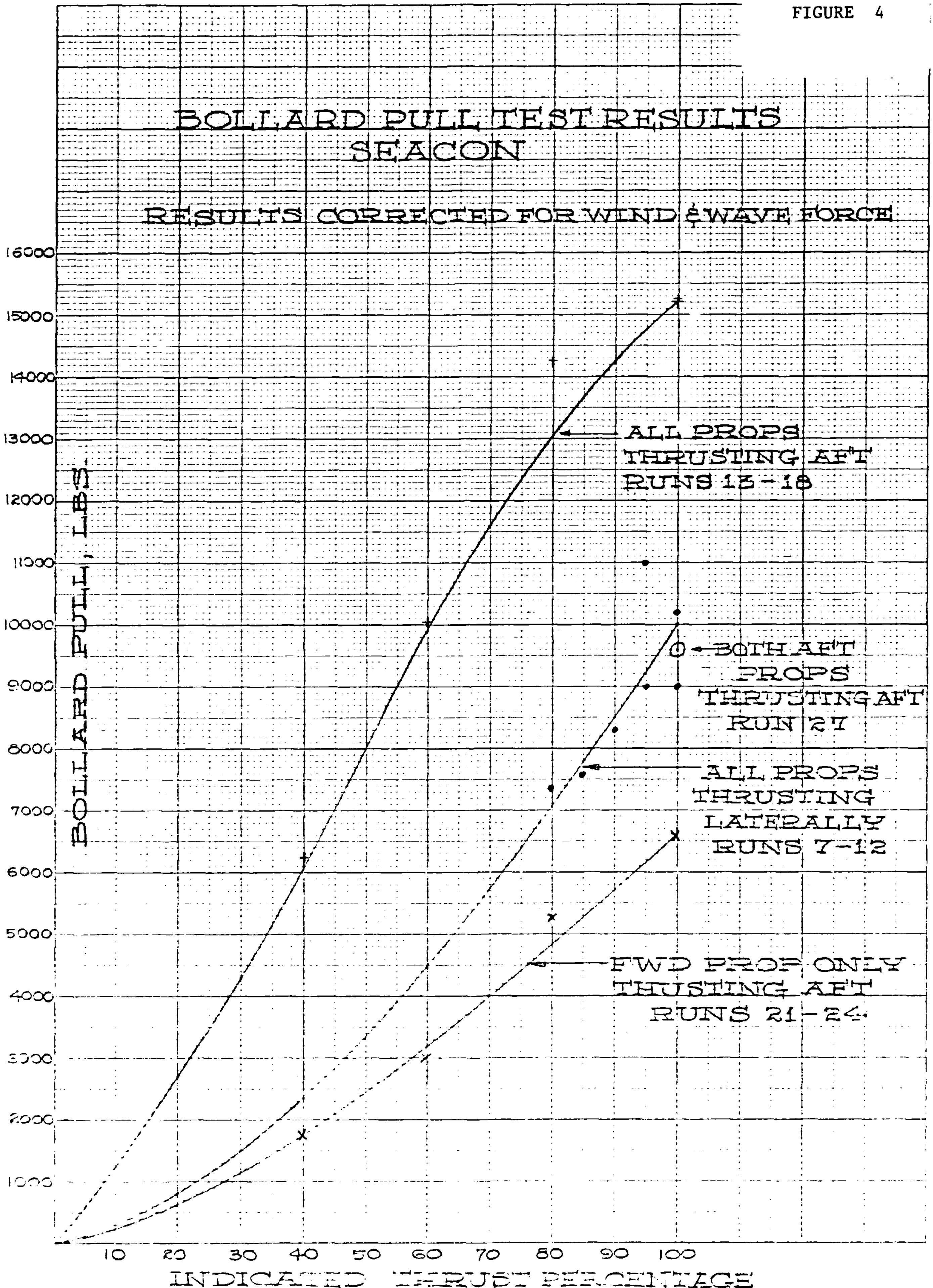

ESTIMATED WAVE FORCE IN 1-FT WAVES
SEACON
LATERAL WAVE FORCE
(HEADING ANGLE = 70°)
LONGITUDINAL WAVE FORCE
HEADING ANGLE = 180°)
WAVE FORCE, LBS.
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
WAVE LENGTH, FT.

TABLE II

CORRECTED BOLLARD PULL TEST RESULTS

RUN NO.	WIND SPEED, MPH	WIND FORCE, LBS.	WAVE FORCE, LBS.	MEASURED BOLLARD PULL, LBS.	CORRECTED BOLLARD PULL, LBS.	INDICATED THRUST PER CENT
Lateral Tests (Thrusting to port with all propulsors. Wind, seas from stbd)						
7	16	1200	1950	0	3340	80
8	16	1200	1950	4000	7340	85
9	18	1550	1950	4400	7550	90
10	18	1550	1950	4800	8300	95
11	18	1550	1950	5500-7500	9000-11000	100
12	18	1550	1950	5500-6500	9000-10000	100
Anead Tests (Thrusting aft with all propulsors. Wind, seas dead ahead)						
13	20.7	600	230	0	830	17
14	20.7	600	230	5400	6230	40
15	20.7	600	230	9200	10030	60
16	20.7	600	230	13450	14280	80
17	20.7	600	230	14600	15230	100
18	20.7	600	230	14630	15260	100
20	20.7	600	230	5000	5830	40
Ahead Tests (Thrusting aft with fwd propulsor only)						
21	20	550	230	1000	1780	40
22	20	550	230	2200	2980	60
23	20	550	230	4500	5280	80
24	20	550	230	5800	6580	100
Ahead Tests (Thrusting aft with both aft engines only)						
25	20	550	230	6000	6780	40
26	20	550	230	7000	7780	50
27	20	550	230	8800	9580	100


BOLLARD PULL TEST RESULTS
SEACON
RESULTS CORRECTED FOR WIND & WAVE FORCE
BOLLARD PULL, LBS
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
ALL PROPS THRUSTING AFT RUNS 13-18
BOTH AFT PROPS THRUSTING AFT RUN 27
ALL PROPS THRUSTING LATERALLY RUNS 7-12
FWD PROP ONLY THUSTING AFT RUNS 21-24
10
20
30
40
50
60
70
80
90
100
INDICATED THRUST PERCENTAGE

pull dynamometer readings were taken after the engine order for the next case had been placed. Such is the case in Runs 11, 20, 25 and 26. These points have been either lightly weighted or omitted in fairing lines through the data.

(b) The maximum bollard pull with all engines thrusting is 15,250 pounds. With the forward unit only thrusting aft, a bollard pull of 6,580 pounds was produced while the case of both the aft units thrusting aft with the forward unit clutched out produced a pull of 9,580 pounds, or 4,790 pounds each. The lower pull from the aft units is due principally to the fact that these units are located just aft of a rise in the bottom and just forward of a slanted step in the bottom, regions susceptible to reduced pressures induced by the propulsor. The increment of thrust required to overcome this reduced pressure region is known variously as "thrust augment" or "thrust deduction". The forward unit is free of such hull influences and will not experience this effect. From the data the "thrust deduction factor", t, for the aft units is computed as:

$$t = \frac{6,480 - 4,790}{6,580} = .27$$

This is a high value, much higher in fact than the value of .17 estimated in G&A's previous SEACON propulsion study, Reference 4, although that estimate was predicted on a forward speed of 7.9 knots, not zero speed as in this case. The direct interpretation of this is that 27% of the thrust of the aft propulsors is lost in hull interactions in the bollard pull situation. An explanation for this high value may be that there is a flow separation problem in the slanted step just aft of the aft V-S units. In this event, fluid momentum in the propulsor race could be disapated in macro flow turbulence. To fully evaluate the extent to which this is influencing hull efficiency would require self-propelled flow visualization model tests in a circulating water channel, an expensive test program. It would be less expensive simply to make a shipyard alteration to the barge which fairs the step into the after hull lines as shown in Figure 5. A gross estimate of the cost of such a modification would be on the order of $15,000 subject to the cost of detailed engineering.

While the observations here have been made only for the zero speed case the modification suggested would have a beneficial effect on performance in the ahead speed case. Both the bare hull resistance and and the thrust deduction would be affected in a favorable way. The speed improvements which would result from such an improvement is difficult to estimate without self-propelled model test data but might range from .1 knots, minimum, to .5 knots, maximum. The suggested alteration is recommended for consideration in future budgets.

The combined totals of the bollard pulls of the forward and aft units operating individually is 9,580 + 6,580 = 16,160 pounds. The lower figure of 15,250 pounds achieved when all engines were operating together is due in part to the fact that the aft units are experiencing some inflow from the wake of the forward unit. Refer to Figure 6 taken from Reference 4 which shows the results of open water tests on a series of cycloidal propulsors. Although not of identically the same design these propulsors are sufficiently similar to justify using the results for

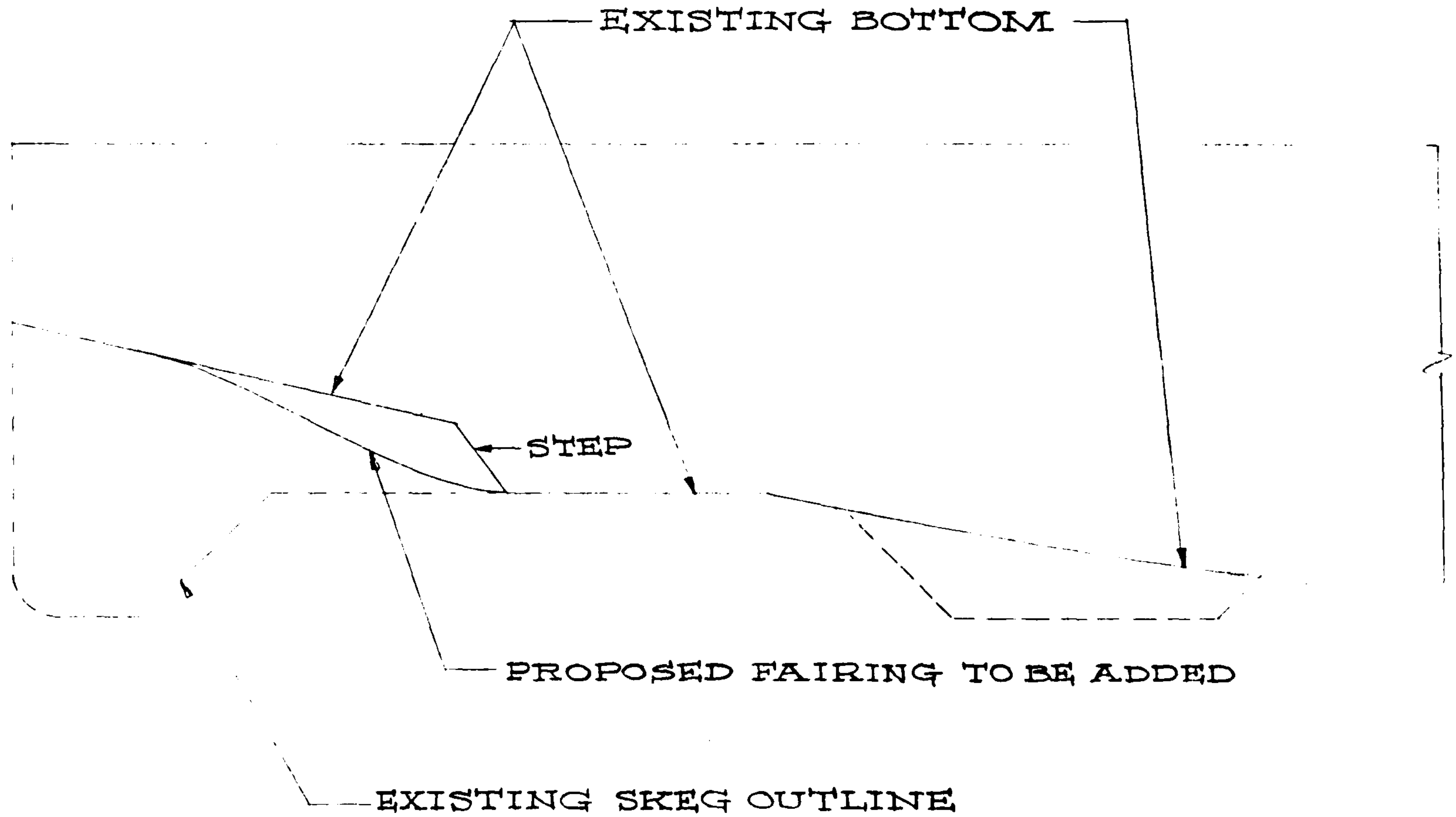


FIGURE 5

Suggested modification to aft hull lines.

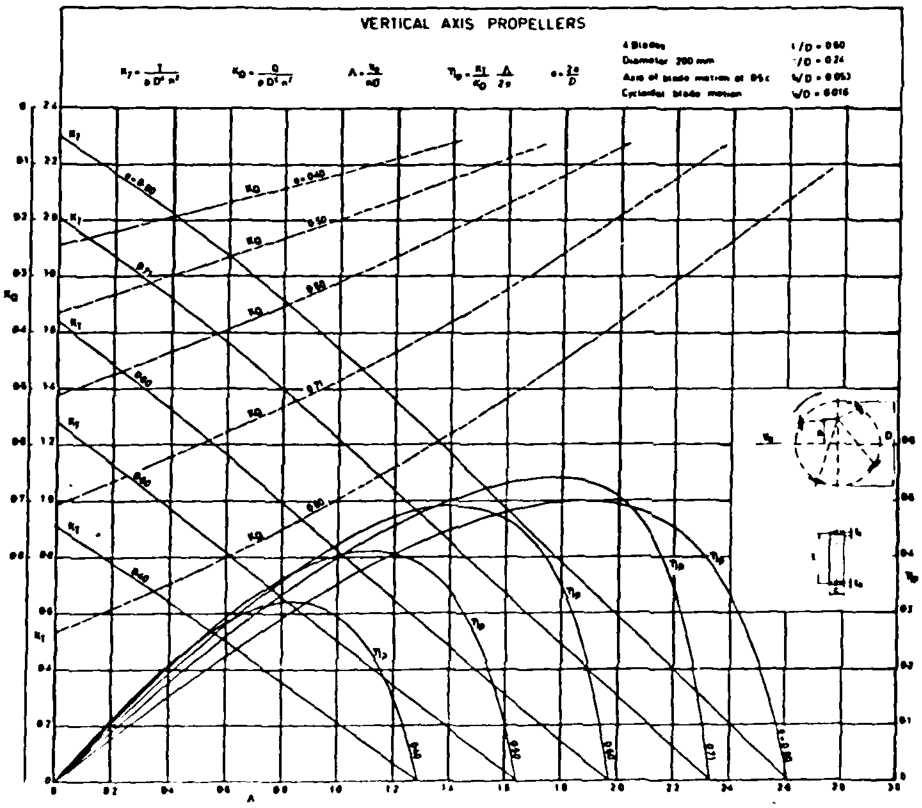


FIGURE 6

Open water test results for a four-bladed series with cycloidal blade motion (c/l=0.40).

our purposes. The abscissa of the plot is the Advance Coefficient,

$$\Lambda = \frac{Va}{nD}$$

Three families of curves with parameter, e, eccentricity, are plotted; K_T, Thrust Coefficient; K_Q, Torgue Coefficient; and η_p, Propulsor Efficiency,

$$K_T = \frac{T}{\rho D^4 n^2}, \quad K_e = \frac{Q}{\rho D^5 n^2}, \quad \eta_p = \frac{K_T}{K_Q} \cdot \frac{\Lambda}{z\pi}$$

The forward propulsor is operating in a zero inflow velocity climate, thus $\Lambda = 0$ and the thrust may be computed from the K_T values shown on the right ordinate of the graph. In the case of the aft units the inflow from the wake of the forward unit will lead to an Advance Coefficient greater than zero, thus for a given eccentricity a lower value of K_T and a lower thrust. A further possibility which we are not really in a position to fully evaluate is that the V-S control system with either the forward or aft engines clutched out does not respond in the same way as it does with all engines on line. This will be discussed again in a subsequent section on engine responses.

(c) Returning to Figure 4 the curve "All Props Thrusting Laterally" indicates a maximum lateral thrust of about 10,000 pounds. Although not shown on the figure this would decompose approximately to 3,250 pounds lateral pull from the forward unit and 6,750 pounds from the two aft units. Compare these figures to the values of 6,580 pounds and 9,580 pounds when the units are thrusting aft. In the case of the aft units an easy explanation of the discrepancies is the interactive effects between the two units. The port unit thrusting to port is pulling water away from the starboard unit while the starboard unit is flushing its wake into the port unit. In the case of the forward unit the explanation is not easy since this unit is placed in a relatively undisturbed environment. The matter will also be further discussed in the section on engine responses.

3.2 ENGINE RESPONSES

An auxiliary purpose of the bollard pull experiments was to determine whether the engine power is being fully developed and absorbed by the propulsors. The characteristics of the Detroit Diesel Allison 12V-71 engines are shown in Figures 7(a), 7(b), and 7(c).

Parameters which reflect engine power output are RPM, fuel rate, and engine exhaust temperature. For example, the tabular data of Figure 7(c) indicates the following relationships at full load:

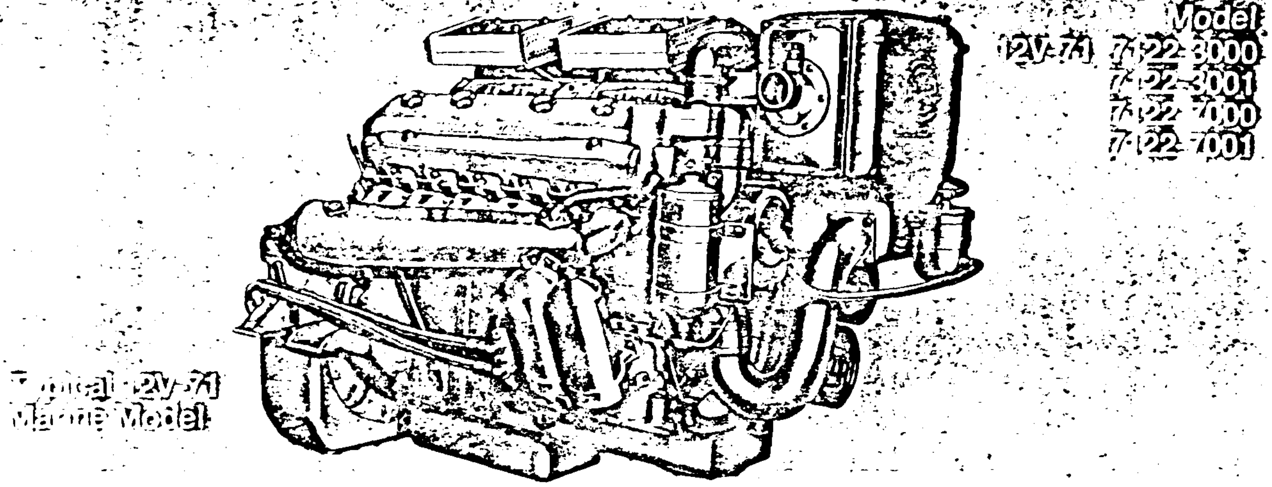
SHP	340	400	480
RPM	1800	2100	2300
Ex. Temp.	730°F	800°F	930°F
Fuel Rate	19.4 gph	22.4 gph	30.0 gph

Over the output range the power developed varies approximately linearly with the amount of fuel burned and this in turn is reflected in the exhaust temperatures. The limiting fuel rate is controlled by the type of injectors installed. For the "continuous" duty ratings applicable to the SEACON plant N55 injectors are installed. At partial loads the fuel rate is reduced by throttle setting and although the engine may be running at its rated RPM, 1800 in this case, the reduced amount of fuel burned is reflected in reduced temperatures. If more torque is demanded of the engine than its rated output at full fuel rate then engine RPM will fall off as the engine adjusts to its load conditions.

For these tests pyrometers were installed in the left and right exhaust manifolds of each of the three engines. Exhaust temperatures and engine RPM as indicated on the installed engine tachometers were recorded on each run. An additional measurement which would have been helpful would have been fuel rate; however, purchase and installation of fuel rate meters was beyond the experiment budget.

The relationship inferred between exhaust temperature and SHP is shown in Figure 8. The curve was established by plotting both temperature and RPM shown in Figures 7(a) and 7(c) against fuel

12V-71
525 hp

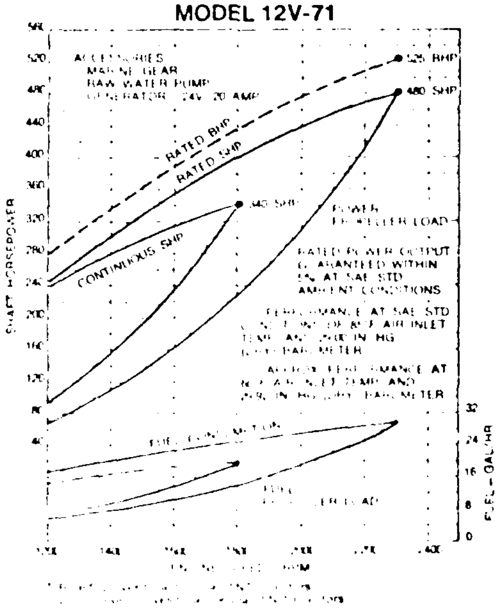


specifications

Basic Engine	12V-71
Model	7122-3000 (port) 7122-3001 (port) 7122-7000 (starboard) 7122-7001 (starboard)
Engine Type	Two Cycle
Number of Cylinders	12
Bore and Stroke	4¼ in. x 5 in.
Two Cycle Displacement (Every Downstroke a Powerstroke)	852 cu. in.
Rated Brake Horsepower* 60°F and Sea Level	525 @ 2300 RPM
Rated Sh·ft Horsepower* 85°F and 500 ft.	480 @ 2300 RPM
Continuous Shaft Horsepower	340 @ 1800 RPM
Compression Ratio	18.7 to 1
Approx. Net Weight (dry) with Standard Equipment	4925 lbs.

*Models 7122-3000, 7122-7000 only.

ENGINE PERFORMANCE*
MODEL 12V-71



Rating Explanation

RATED BRAKE HORSEPOWER Approximate basic engine power at conditions of 60°F and Sea Level.

RATED SHAFT HORSEPOWER -Net power available at the marine gear output shaft; this rating is recommended for pleasure craft applications.

CONTINUOUS SHAFT HORSEPOWER -Net power available at the marine gear output shaft for continuous duty or workboat applications.

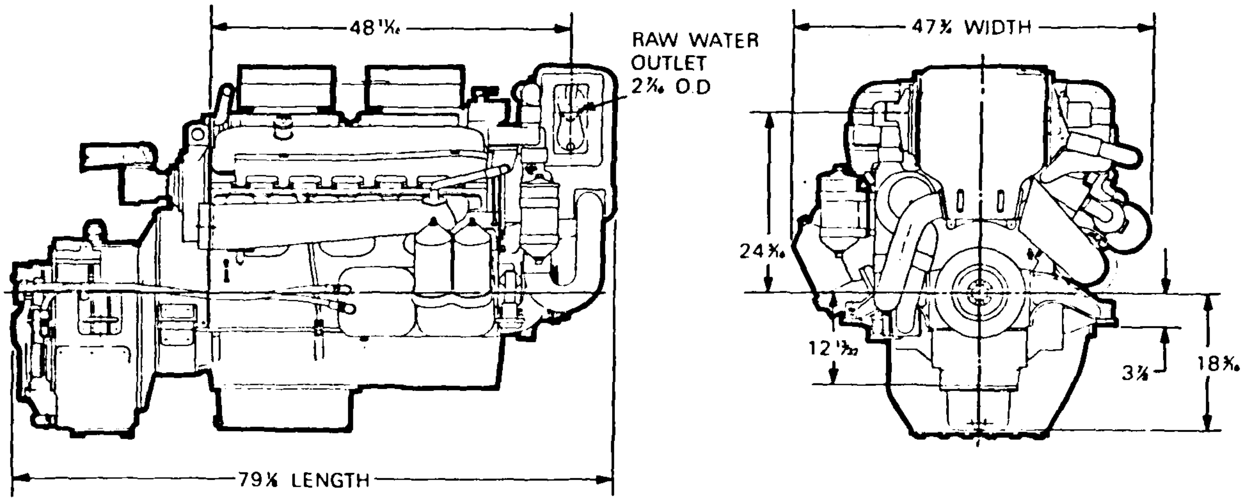
PROPELLER LOAD -Indicates horsepower absorbed by a typical propeller and the corresponding fuel consumption throughout the speed range.

Propeller load and shaft horsepowers as shown are based on ambient conditions of 85°F, Bar. (dry) 29.00 in. HG and include deduction for standard marine accessory equipment.

FIGURE 7(a)

principal dimensions

Model 7122-3000



For complete dimensional information regarding Models 7122-3000, 7122-3001, 7122-7000, and 7122-7001, refer to installation drawing 2SA236.

standard equipment

Air Inlet Housing—Aluminum housing with manual shutdown. Includes air silencer

Crankshaft Pulley—7.5 in. diameter, 3-groove, Models 7122-3000, 7122-7000

Engine Mounts—Includes mounts for engine and marine gear

Exhaust Manifold—Water-cooled with flange

Flywheel—SAE #1

Flywheel Housing—SAE #1

Front Power Take-Off—Models 7122-3001, 7122-7001

Generator—Battery-charging, 24 volt, 20 amp, AC

Governor—Variable speed, includes throttle controls

Heat Exchanger—Includes raw water pump and piping

Injectors—Cam-operated, unit type, clean tip

Instruments—Includes ammeter, tachometer, water temperature gauge, oil pressure gauges for engine and reverse gear

Lube Oil Filter—Full-flow filter, dual can

Marine Gear—Twin Disc Hydraulic reverse and reduction gear:
- to 1 ratio, Models 7122-3000, 7122-7000
- 4.13 to 1 ratio, Models 7122-3001, 7122-7001

Oil Pan and Distribution System—For 0-15 degree installation angle

Starting Equipment—24 volt starting motor, sprag over-running clutch

Water Filter—Fresh water filter with 30-gallon capacity

For a complete listing of standard and optional equipment, consult your authorized Detroit Diesel Allison representative.

Specifications subject to change without notice

Detroit Diesel Allison
Division of General Motors Corporation

13400 West Outer Drive Detroit, Michigan 48228

SA81 Rev. 4-72

In Canada: Diesel Division General Motors of Canada Limited London Ontario

Litho in U.S.A.

FIGURE 7(b)

SPECIFICATIONS: MARINE APPLICATION

TYPE	12 CYLINDER, 63.5° VEE, 2 CYCLE DIESEL 851.2 CU. IN. DISPLACEMENT		
MODEL	7122-7000 R.H. (STARBOARD UNIT SHOWN) 7122-3000 L.H. (PORT UNIT OPPOSITE ROTATION)		
OUTPUT SHAFT ROTATION: (VIEWED FROM REAR)			
STARBOARD UNIT	CLOCKWISE (FOR R.H. PROPELLER)		
PORT UNIT	COUNTERCLOCKWISE (FOR L.H. PROPLLLER)		
WEIGHT DRY:	4925 LBS.		
REVERSE AND REDUCTION GEAR			
TYPE	TWIN DISC MODEL 512 (HYDRAULIC)		
REDUCTION RATIO	1.5:1, 2.00:1, 3.00:1		
LUBE OIL CAPACITY	24 QTS.		
ELECTRICAL SYSTEM	24 OR 32 VOLTS		
MAXIMUM INSTALLATION ANGLE	15°		
ENGINE LUBE OIL PAN CAPACITY (APPROX.)			
INSTALLATION ANGLE 0°-15°	35 QTS. DEEP PAN		
INSTALLATION ANGEL 0°-8°	34 QTS. SHALLOW PAN		
	INTERMITTENT (PLEASURE CRAFT)	CREW BOAT	CONTINUOUS (WORK BOAT)
RATING (85°F., 29.0 IN. HG. (DRY) BAROMETER SAE)	480 SHP @ 2300 RPM	400 SHP @ 2100 RPM	340 SHP @ 1800 RPM
AIR CONSUMPTION	1430 CFM	1305 CFM	1125 CFM
SUGGESTED MINIMUM ENGINE ROOM VENT AREA	137 $IN.^2$	125 $IN.^2$	108 $IN.^2$
COOLING SYSTEM (H.E. OR KEEL COOLING OPTIONAL):			
HEAT REJECTION TO COOLANT	17,750 BTU/MIN.	14,800 BTU/MIN.	12,600 BTU/MIN.
FRESH WATER CAPACITY	25 GALS.	25 GALS.	25 GALS.
FRESH WATER FLOW (TO KEEL COOLER)	200 GALS./MIN.	185 GALS./MIN.	150 GALS./MIN.
MAX. PRESS. DROP THROUGH KEEL COOLER	6 PSI	6 PSI	6 PSI
RAW WATER FLOW	107 GPM	100 GPM	88 GPM
MAXIMUM INLET RESTRICTION AT PUMP	5 IN. HG.	5 IN. HG.	5 IN. HG.
MAXIMUM PUMP PRESSURE	10 PSI	10 PSI	10 PSI
SUGGESTED PIPE SIZE	2-1/2 IN.	2-1/2 IN.	2-1/2 IN.
SUGGESTED SEA STRAINER SIZE - SIMPLEX	3 IN.	3 IN.	3 IN.
- DUPLEX	4 IN.	4 IN.	4 IN.
FUEL SYSTEM:			
FUEL CONSUMPTION	30 GPH	22.4 GPH	19.4 GPH
PUMP FLOW	90 GPH	90 GPH	90 GPH
MAXIMUM INLET RESTRICTION AT PUMP	6 IN.HG.(CLEAN FILTER)	6 IN. HG. (CLEAN FILTER)	6 IN. HG. (CLEAN FILTER)
SUGGESTED PIPE SIZE	1/2 IN.(5/8 TUBING)	1/2 IN. (5/8 TUBING)	1/2 IN. (5/8 TUBING)
EXHAUST SYSTEM:			
GAS FLOW	101.2 LB./MIN.	92.4 LB./MIN.	79.6 LB./MIN.
TEMPERATURE	930°F.	800°F.	730°F.
MAX. EXH. BACK PRESSURE AT MFD. OUTLET	5.5 IN. HG.	4.4 IN. HG.	3.3 IN. HG.
SUGGESTED PIPE SIZE - TWIN	5 IN.	5 IN.	4 IN.
SINGLE PIPE	8 IN.	6 IN.	6 IN.
SUGGESTED EXH. SILENCER SIZE - TWIN	6 IN.	5 IN.	5 IN.
SINGLE SILENCER	8 IN.	8 IN.	8 IN.

P/N 5122980
LATEST REVISION DATE 5-16-69

SHEET 3 OF 3

DATE	LTR.	REVISION RECORD	DR.	CHK.
5/16/69		Revised and retyped		

DO NOT SCALE – ERRORS MUST BE REPORTED
THE FOLLOWING ITEMS APPLY UNLESS OTHERWISE SPECIFIED

DWG. DATE 3/18/66	DR. J. MacLellan	CHK.
SCALE	REFERENCE	APPD.
FIRST USED		APPD.
MATL. SPEC.	MODEL 7122-3000 -7000	
NAME	INSTALLATION DRAWING 12V-71 MARINE ENGINE	
PART NO.	5122980	DWG. SIZE B

FIGURE 7(c)

rate, extrapolating to lower fuel rate values, then cross plotting temperature versus RPM as shown. Also shown in Figure 8 is the RPM versus SHP curve replotted directly from Figure 7(a).

The actual state-of-affairs is considerably more complex than represented in Figure 8. Actually there should be a family of curves which parametrically depict the inter-relationship of all the four variables described. In addition each engine would have its own characteristic calibration curve which would reflect the particulars of its manufacture and instrument installation. Such was beyond the scope of this experiment, and for our purposes the curve of Figure 8 is adequate.

Engine exhaust temperature data for each run are recorded in Appendix A. Inspection of the tabular data indicates considerable variation in the temperature measured in the left exhaust manifold (LB) and right exhaust manifold (RB). This may be explained, in part, as reflecting the characteristics of each engine, and, in part, by the fact that the data runs were of necessity taken quickly in some cases without full opportunity for the engines to develop steady state conditions. The average of the left and right exhaust manifold temperatures is plotted in Figure 9 for the forward engine and for both aft engines for the various test conditions. It is noted that for the case "Both Aft Props Thrusting Aft, Run 27" no curve is plotted since Runs 25 and 26 at lower thrust ratings were discarded.

Several interesting inferences may be made from Figure 9. First, with all propulsors thrusting aft the forward engine experiences higher temperature ($\sim 760^oF$) than the aft engines ($\sim 700^oF$) indicating that more power was being developed by the forward engine and absorbed by the propulsor than for the aft engines. This confirms the effect noted in Section 3.1 that the aft propulsors are experiencing an effect from the inflow of the wake of the forward propulsor.

Consider next the cases in which the forward and aft units were tested independently, Runs 21-24 and Run 27. The forward

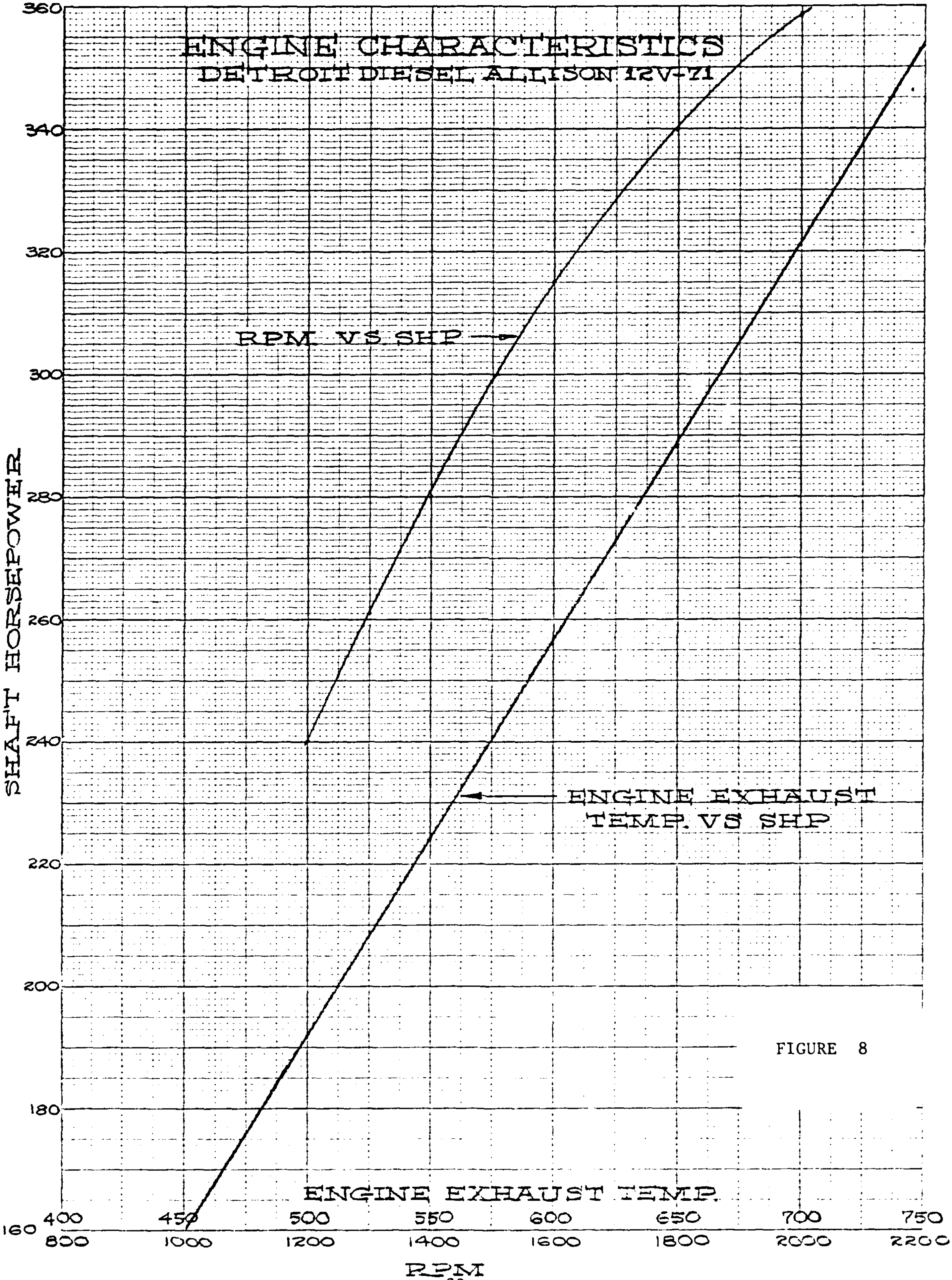

ENGINE CHARACTERISTICS
DETROIT DIESEL ALLISON 12V-71
RPM VS SHP
ENGINE EXHAUST TEMP. VS SHP
SHAFT HORSEPOWER
360
340
320
300
280
260
240
220
200
180
160
ENGINE EXHAUST TEMP.
400
450
500
550
600
650
700
750
800
1000
1200
1400
1600
1800
2000
2200
RPM

FIGURE 8

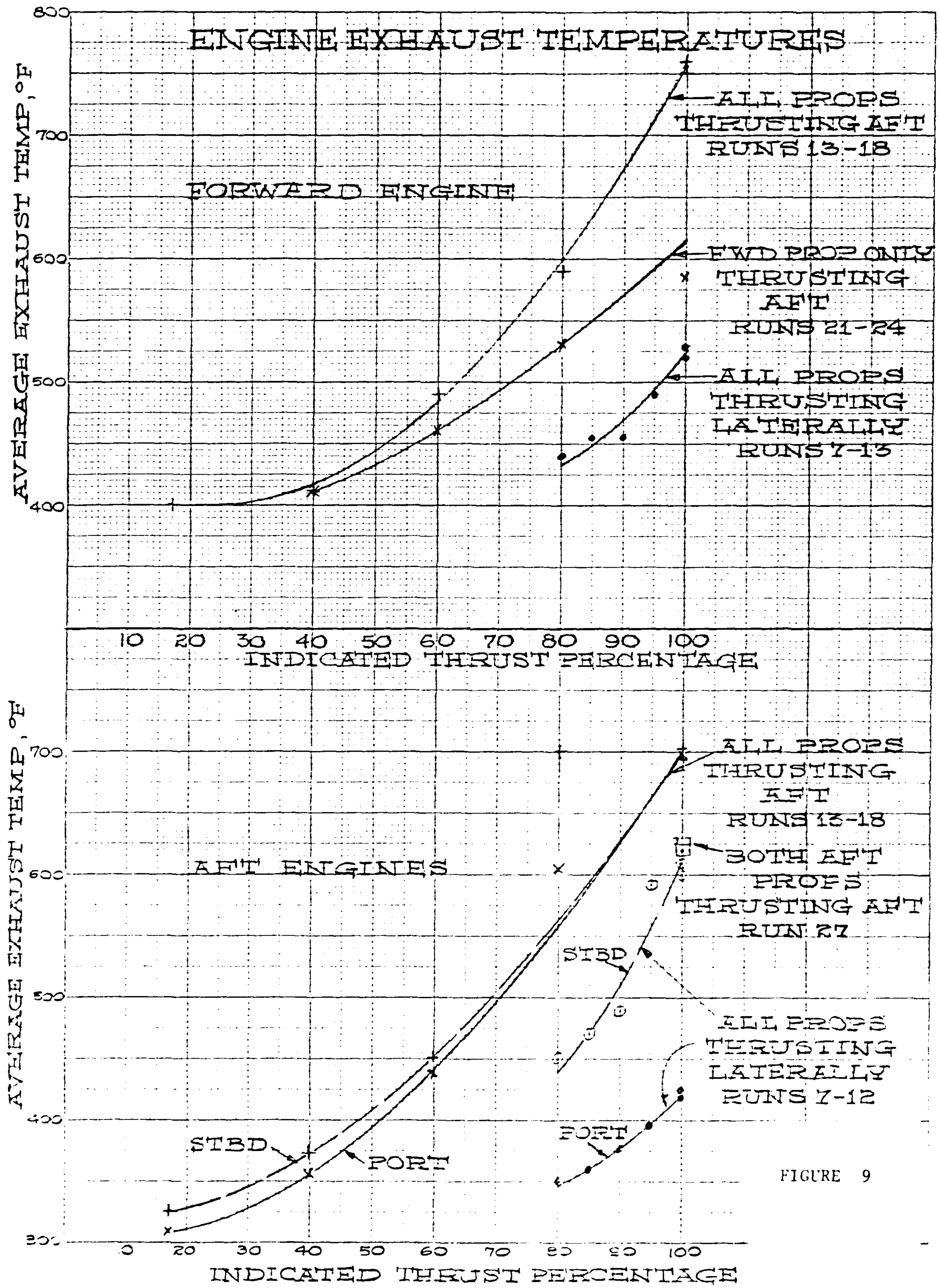

ENGINE EXHAUST TEMPERATURES
FORWARD ENGINE
AVERAGE EXHAUST TEMP, °F
800
700
600
500
400
ALL PROPS THRUSTING AFT RUNS 13-18
FWD PROP ONLY THRUSTING AFT RUNS 21-24
ALL PROPS THRUSTING LATERALLY RUNS 7-13
10 20 30 40 50 60 70 80 90 100
INDICATED THRUST PERCENTAGE
AFT ENGINES
AVERAGE EXHAUST TEMP, °F
700
600
500
400
300
ALL PROPS THRUSTING AFT RUNS 13-18
BOTH AFT PROPS THRUSTING AFT RUN 27
STBD
PORT
ALL PROPS THRUSTING LATERALLY RUNS 7-12
STBD
PORT
0 20 30 40 50 60 70 80 90 100
INDICATED THRUST PERCENTAGE

FIGURE 9

propulsor operating with the aft units clutched out develops maximum temperatures about 150° lower than when operating with the aft propulsors thrusting. There is no conspicuous reason for the forward unit absorbing less power when operating independently since the inflow conditions in both cases should be nearly the same. One possibility is that the V-S control system may not respond in the same way with aft engines clutched out as it does with all engines on line. Without particulars on the control system it is not possible to resolve this discrepancy. A similar effect is noticed when the aft units are operating with the forward unit clutched out.

The case in which all propulsors were thrusting laterally also offers some interesting observations. The forward engine experiences maximum temperatures of approximately 525°, less than either of the "thrusting aft" cases shown. Applying Figure 8 gives an estimate of 209 SHP for this case. Neither of the aft engines develop the same power as in the "thrusting aft" case; however, the starboard engines develop considerably more power than the port, and more in fact, than does the forward engine. The estimates for the maximum thrust condition, again taken from Figure 8 are 264 SHP for the starboard engine and 140 SHP (extrapolated) for the port engine. The average (202 SHP) is about the same as the forward engine. At lower thrust percentages a similar trend is noted.

The difference between starboard and port engines is, of course, due to interactions between the starboard and port propulsors. Both units are thrusting to port, thus the port propulsor is drawing water from the starboard propulsor tending to increase its loading. At the same time the starboard propulsor is flushing its race into the port propulsor which tends to reduce its loading. At this thrust percentage the port propulsor appears to be absorbing only about 53% of the power that is absorbed by the starboard engine. Looking at the figures in a different way the starboard engine is absorbing about 26% more power than the forward engine while at the same time the port engine is absorbing about 33% less.

In theory a cycloidal propeller operating at a given eccentricity in an undisturbed fluid should be capable of producing the same thrust in any direction determined by the setting. In these tests the specific numbers may be suspect, but it is clear that the system is not producing as much lateral thrust as indicated by both the bollard pull readings and the engine temperatures as would be expected. The explanation for this behavior should be addressed by Voith-Schneider.

The engine power may be inferred in yet another way. Figure 6 shows a set of generic propulsive characteristic curves which, as has been noted, are not specific to this configuration but which should be similar in character. The parameter, e, in the curves is the eccentricity which although held constant for the propulsor model tests is an unknown in our tests. However, it may be inferred by proceeding as follows. Using the definitions K_T and K_Q given in Section 3.1 and the values of thrust measured for the forward engine operating independently the value of K_T may be calculated. Since the Advance Coefficient, Λ, is essentially zero in this case the appropriate value of e may be selected by interpolating between K_T curves at $\Lambda=0$. K_Q is then selected at this value of e and $\Lambda=0$ and the torgue, Q, computed. Assuming transmission efficiencies of .91 for the reduction gear and .85 for the V-S units engine torgue and horsepower are calculated. In cases in which all engines are thrusting aft the inflow velocity to the aft units is not zero. A correction for this is made by assuming an inflow velocity to the aft units of 2.0 ft./sec. This value was arrived at by comparing Runs 18,24, and 27 and applying some discretionary judgment. No such correction was attempted in the cases of the interferences between the aft units thrusting laterally. The whole process is vulnerable to the assumptions involved, but it does give one further check on the other power estimates. In addition to the above estimates, Mr. R. Sluka of the Detroit Diesel Allison Division of General Motors was contacted by Mr. A. W. McNairy of NAVFAC (FPO-1) with the test data. Based on engine performance curves available to him he has provided estimates of the possible ranges of power outputs for Runs 12,18, and 27. A comparison of the engine power outputs computed in the various ways described above is shown in Table III. The variations of the estimated power using the various methods indicates clearly the difficulty which accompanys attempts to predict engine performance. Nevertheless, certain observations stand out.

TABLE III

Comparisons of Estimates of Engine Power

	RUN	ENGINE	BASED ON TEMPERATURES	BASED ON RPM	BASED ON PROPULSOR PERFORMANCE	PROVIDED BY GM*
100% LATERAL THRUST	11	FWD	205	333	333	
		PORT AFT	139	339	-	
		STBD AFT	256	338	-	
	12	FWD	212	334	339	
		PORT AFT	140	338	-	
		STBD AFT	264	338	-	
100% AFT THRUST	18	FWD	360	328	310	342
		PORT AFT	321	324	301	325-350
		STBD AFT	317	326	273	317-340
	24	ONLY FWD	246	328	310	
	27	ONLY PORT AFT	292	334	339	262-283
		STBD AFT	269	335	344	275-306

*Courtesy Mr. A. W. McNairy

(a) In the ahead bollard pull test with all propulsors thrusting aft (Run 18) the forward engine was approximately at its rated continuous power (340 SHP). Aft engines under these conditions were not developing their rated power.

(b) In thrusting laterally (Runs 11 and 12) the power estimated on the basis of temperature shows that the engines are developing only between 40% and 75% of their rated power.

The data taken during the return trip to the shipyard, Runs 28-31, was taken quickly as data of opportunity and should not be considered rigorous. Nevertheless, this information does tell a story. The engine power estimates based on both temperature and RPM are summarized in Table IV. The averages for the four runs indicates that the engines in this free running case are developing somewhat less than full power. The temperature-based power estimates suggest that in this condition the plant as a whole is operating at 94 horsepower under its rated capacity. Assuming a propulsive efficiency of 27% this would translate to a .2 knot speed loss. Inspection of the tabulated data for Runs 28-31 in Appendix A show that the engine RPM's varied from 1720-1800 lower, in general than the 1800 RPM rating, and that temperatures varied from 580° to 720°, well below the rated temperature of 730°. It may be possible to correct this situation by simply resetting engine speed controls. An alternative solution would be to increase injector size; however this alternative also would provide the opportunity for driving the engine and V-S units beyond their rated capacities with the consequence of increased maintenance costs.

TABLE IV

Engine Power Estimates in Free Running Condition

	RUN	ENGINE	ESTIMATED ENGINE SHP BASED ON TEMPERATURES	ESTIMATED ENGINE SHP BASED ON RPM
FREE RUNNING	28	FWD	325	330
		PORT AFT	328	334
		STBD AFT	315	335
	29	FWD	306	335
		PORT AFT	302	334
		STBD AFT	319	340
	30	FWD	309	333
		PORT AFT	286	334
		STBD AFT	319	340
	31	FWD	296	332
		PORT AFT	280	334
		STBD AFT	319	340
AVERAGE	28-31	FWD	309	333
		PORT AFT	299	334
		STBD AFT	318	339

4.0 CONCLUSIONS

1. Based on the bollard pull tests in the ahead mode the SEACON develops a bollard pull of approximately 15,250 pounds. In this mode the forward engine is operating approximately at full load while the aft engines are operating slightly below full load.
2. A modification to the hull which fairs the step just aft of the propulsors into the aft hull lines would be beneficial to the bollard pull and also the free running speed.
3. The total bollard pull in the lateral direction is about 10,000 pounds. In this condition all engines are developing considerably less than full power indicating that the V-S units are absorbing only a fraction of their rated load. An inquiry to V-S representatives regarding this condition would be appropriate.
4. Based on limited data the propulsion plant is operating below its rated capacity in the free running condition. Adjustment of speed control or change in injector size should be considered in consultation with engine and V-S manufacturers.

ACKNOWLEDGEMENT

The helpful assistance of Mr. A. W. McNairy in the execution of this project is acknowledged.

REFERENCES

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2. Isherwood, R. M., "Wind Resistance of Merchant Ships", Trans. Royal Institution of Naval Architects, Volume 115, p. 327-338, 1973.
3. Salvesen, N., "Second-order Steady-state Forces and Moments on Surface Ships in Oblique Regular Waves", International Symposium on the Dynamics of Marine Vehicles and Structures in Waves, London, p. 212-226, 1974.
4. Giannotti & Associates, Inc. Report No. 78-026-002, "Inspection of the Propulsion System of the Barge "SEACON", Prepared for NAVFAC, Chesapeake Division (FPO-1), 18 October 1979.
5. van Maren, J. D., Prof. Dr. Ir., "Results of Systematic Tests with Vertical Axis Propellers", Shipbuilding Progress, Volume 13, no. 148, December, 1966.

APPENDIX A

SUMMARY OF TEST DATA

BOLLARD PULL TESTS

SUMMARY OF TEST DATA

BOLLARD PULL TESTS

"SEACON"

Ft. Lauderdale, FLA 1 November 1979

MODE	RUN NO.	BOLLARD PULL-FW'D	BOLLARD PULL-AFT	TIME	% THRUST: PRIMARY DIRECTION	% THRUST: 90° to PRIMARY DIRECTION	WIND: VEL M.P.H.	WIND: DIR. OFF BOW	ENGINE R.P.M.: FW'D	ENGINE R.P.M.: PORT AFT	ENGINE R.P.M.: STB'D AFT	EXHAUST TEMP. - °F.: FW'D LB	EXHAUST TEMP. - °F.: FW'D RB	EXHAUST TEMP. - °F.: PORT AFT LB	EXHAUST TEMP. - °F.: PORT AFT RB	EXHAUST TEMP. - °F.: STB'D AFT LB	EXHAUST TEMP. - °F.: STB'D AFT RB	WATER JACKET TO TEMP F.: FW'D	WATER JACKET TO TEMP F.: PORT AFT	WATER JACKET TO TEMP F.: STB'D AFT
RIGGED ALONGSIDE DOCK	2			1248	55	0	16	110°	1800	1825	1840	380	380	260	390	425	310	168	150	173
	3			1251	60	0	16	110°	1750	1825	1860	380	380	230	380	400	270	168	150	175
	4			1300	90	10	16	110°	1700	1800	1850	680	700	310	425	500	360	170	145	175
	5			1305	80	10	16	110°	1770	1800	1850	420	450	320	425	525	425	170	150	175
	6			1311	80	0	16	110°	1780	1850	1700	410	410	320	425	650	560	170	150	175
	7	0	4000	1315	80	5	16	110°	1780	1800	1800	410	460	300	400	500	400	168	150	175
	8	400	4000	1318	85	5	16	110°	1770	1800	1800	430	480	310	410	520	420	168	150	175
	9	600	4200	1320	90	5	18	115°	1750	1800	1800	430	480	325	425	525	450	168	150	176
	10	500-1500	5000 6000	1323	95	5	18	115°	1760	1800	1780	480	500	340	450	580	505	170	150	175
	11	500-1500	5000	1327	100	0	18	115°	1740	1780	1780	500	540	365	470	620	580	170	150	180
	12	1500	5200	1328	100	0	18	110°	1750	1780	1780	520	540	370	480	640	580	170	150	180
DEAD ASTERN TESTS – ALL 3 ENGINES	13	N.A.	0	1450	17	0	20.7	0°	1810	1810	1850	380	420	254	360	400	250	168	145	175
	14	N.A.	5400	1459	40	0	20.7	0°	1800	1790	1825	400	420	310	400	435	310	168	145	175
	15	N.A.	9200	1502	60	0	20.7	0°	1760	1790	1825	480	560	400	475	500	400	168	145	175
	16	N.A.	13450	1506	80	0	20.7	0°	1720	1775	1800	580	600	650	750	635	585	168	150	180
	17	N.A.	14600	1508	100	0	20.7	0°	1770	1700	1600	740	780	650	737	700	690	172	155	183
	18	N.A.	14630	1509	100	0	20.7	0°	1700	1750	1680	720	780	650	750	700	690	174	158	181
	19	N.A.	-	1519	- LINE PARTS)				-	-										
	20	N.A.	500	1538	40	0	20.7	0°	1770	1800	1830	400	420	325	435	435	325	168	145	175
DEAD ASTERN TESTS – AFT ONLY FW'D ENG	21	N.A.	1000	1545	40	0	20	0°	1790	625	625	400	420	125	230	320	135	168	140	175
	22	N.A.	2200	1547	60	0	20	0°	1760	625	625	450	470	125	230	320	135	170	135	175
	23	N.A.	4500	1550	80	0	20	0°	1720	620	625	520	540	125	225	320	130	170	132	170
	24	N.A.	5800	1552	100	0	20	0°	1700	620	625	530	690	120	225	320	130	170	130	170
	25	N.A.	6000	1604	40	0	20	0°	625	1800	1825	200	200	300	420	420	300	165	145	175
	26	N.A.	7000	1613	50	0	20	0°	650	1725	1800	200	200	550	630	530	490	165	145	175
	27	N.A.	8800	1620	100	0	20	0°	650	1750	1760	200	200	530	720 / 620	640	600	165	150	180
FREE RUNNING	28	N.A.	N.A.	1631	100	0	20	0°	1720	1750	1760	680	730	700	730	680	708	174	150	180
	29	N.A.	N.A	1633	100	0	20	0°	1760	1750	1800	650	700	760	580	690	700	174	155	180
	30	N.A.	N.A.	1634	100	0	20	90°	1740	1750	1800	660	700	710	580	690	700	174	155	180
	31	N.A.	N.A.	1635	100	0	20	90°	1730	1750	1800	630	690	690	580	690	700	173	155	180
		N.A.	N.A.	1030	40	15	14	115°	1750	1840	1850	390	400	250	360	450	825	168	145	173

DRAFTS

FWD 6'-0"

AFT 8'-10"

SEA WATER TEMP: 85°

END
DTIC
6-86