NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20034

PERFORMANCE OF CONTAINERSHIP WITH OVERLAPPING PROPELLER ARRANGEMENT

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and
Robert F. Roddy, Jr.

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SHIP PERFORMANCE DEPARTMENT
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September 1972

Report 3750

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Naval Ship Research and Development Center

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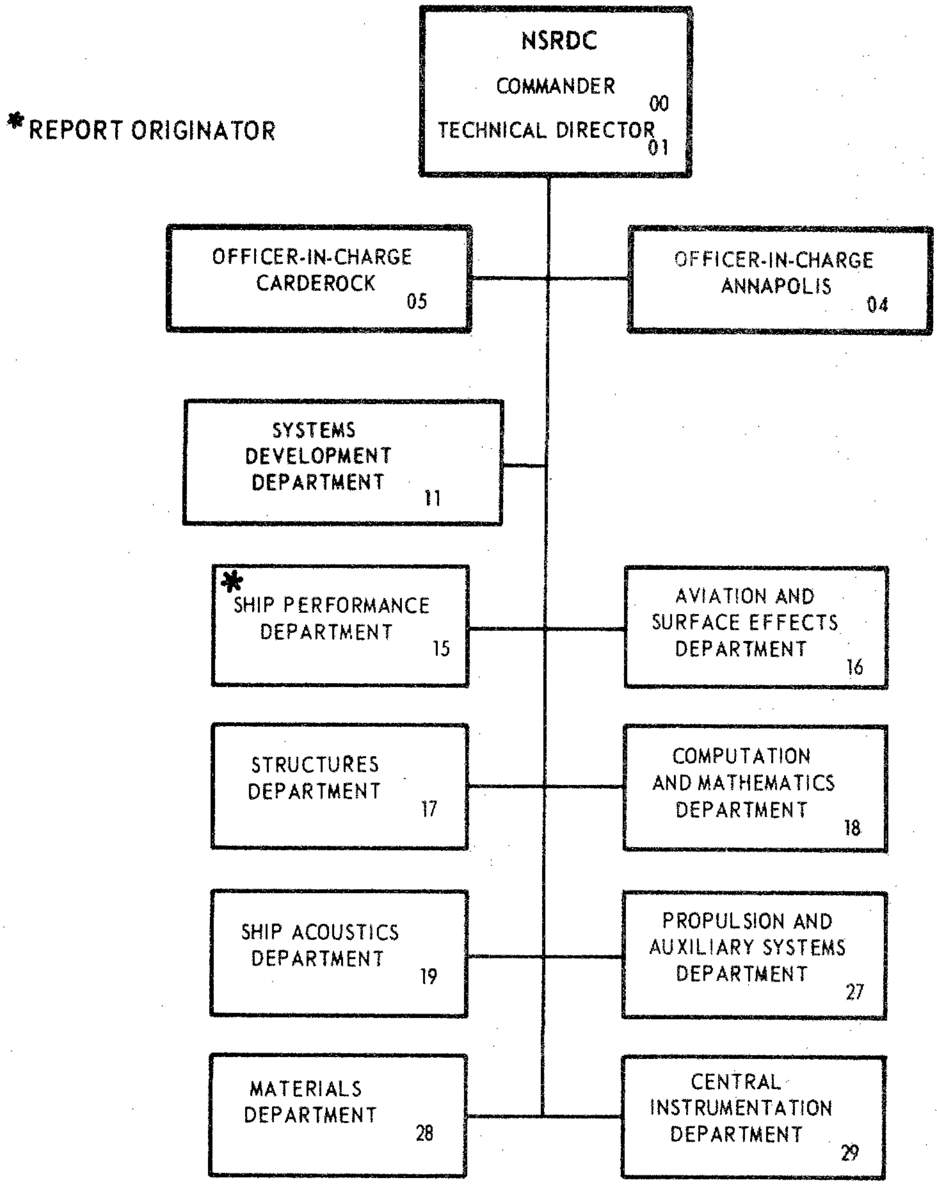

DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
BETHESDA, MD. 20034

PERFORMANCE OF CONTAINERSHIP WITH OVERLAPPING PROPELLER ARRANGEMENT

by

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NOTATION

The notation used throughout the report conforms to the standard proposed by the International Towing Tank Conference (ITTC) and adopted in the American-British-Canadian Navies Standardization Program, ABC-NAVY-STD-30B.

ABSTRACT

A model test program was carried out at the Naval Ship Research and Development Center to determine the performance of a high-speed containership with overlapping propellers. The afterbody lines and propulsion arrangement was developed as a modification to the 25.5-knot contrarotating version of the U.S. Maritime Administration C9-ST-86a design. Results of the model tests are compared with the performance of the twin-screw C9-ST-86a design and the contrarotating parent form. Conclusions and recommendations for future investigations of the overlapping propeller arrangement are given.

ADMINISTRATIVE INFORMATION

This project was authorized and funded by the Maritime Administration, Office of Research and Development, under Purchase Order P1-MA70-142 of 5 September 1969, with amendments of 19 December 1969 and 21 October 1970.

INTRODUCTION

The study outlined in the following text was initiated when the American Export Isbrandtsen Lines twin-screw containerships C9-ST-86a were being considered for construction. The possibility of converting one of the ships to a contrarotating propulsion arrangement was investigated, and model tests were funded by the Maritime Administration, Office of Research and Development, and were carried out at the Naval Ship Research and Development Center. To provide a complete comparison between contrarotating propulsion and other systems, it was decided to include in the program a preliminary investigation of an overlapping propeller arrangement.

An outline of the overall investigation has been presented in Reference 1. Details of the design and testing of the overlapping propeller arrangement and a comparison with the twin-screw and contrarotating designs are presented in the following.

THE OVERLAPPING PROPELLER ARRANGEMENT

The horsepower that needs to be installed in the containership is so large that a single-screw arrangement most likely would result in cavitation and vibration problems. In a two-propeller arrangement—twin-screw or contrarotating—these problems are greatly reduced, primarily because the thrust would be transmitted on two rather than one propeller. Past experience has shown that a conventional twin-screw ship can be designed safely for the power being considered, although the total power might increase due to appendage drag and reduced hull efficiency. The contrarotating design gives a high performance but this must be weighed against the added complexity of the shafting.

[1] Strom-Tejsen, J., "A Comparison of Contrarotating Propellers with Other Propulsion Systems: Results of Model Experiments," Marine Technology, Vol 9 (Jan 1972).

The overlapping propeller arrangement was suggested in Reference 2 as an alternative two-propeller solution. In this arrangement the two propellers of a normal twin-screw system are moved aft to the longitudinal position of a normal single-screw propeller and inwards until the two propellers are partially overlapped. This combines the advantage of the twin-screw systems, which are high propeller efficiency and reduced problems due to cavitation and vibration, with those of the ordinary single-screw systems, which are low appendage resistance and high hull efficiency due to recovery of viscous wake behind the ship.

In comparison with conventional twin-screw systems, application of overlapping propellers might result in a simplified engine arrangement. With a shorter shafting, it is possible to locate the engineroom further aft, eventually making room for additional containers.

In comparison with a contrarotating arrangement, the overlapping system can be designed on the basis of conventional machinery and shafting.

The advantages of the overlapping propeller arrangement were demonstrated in Reference 2 with the system adapted to a tanker model, and the results were compared with results from other propulsion systems. Tests reported in Reference 3 indicated the potential of the system when applied to high-speed ships similar to the containership being considered in the present study.

Munk and Prohaska[4,5] studied the application of the arrangement to a large tanker and found a reduction in power of approximately 15 percent when compared with a single-screw design. They also explored the effect of the horizontal distance between the shafts and found an optimum at approximately 0.80 times the propeller diameter. Tests with the propellers mounted in the same plane and with a longitudinal spacing between the propellers of $0.2D$* showed no measurable effect on the performance. Stress measurements indicated that vibration-generating forces will be smaller for the overlapping than for the single-screw arrangement.

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[2]Pien, P.C. and Strom-Tejsen, J., "A Proposed New Stern Arrangement," NSRDC Report 2410 (May 1967).

[3]Pien, P.C. and Strom-Tejsen, J., "A Hull Form Design Procedure for High-Speed Displacement Ships," Society of Naval Architects and Marine Engineers, Diamond Jubilee Meeting, Paper 13 (June 1968).

[4]Munk, T. and Prohaska, C.W., "Unusual Two-Propeller Arrangements," Seventh Symposium on Naval Hydrodynamics, Rome, Italy (Aug 1968).

[5]Munk, T. and Prohaska, C.W., "Tests with Interlocking and Overlapping Propellers," Hydro- and Aerodynamics Laboratory, Lyngby, Denmark, Report Hy-12 (Jan 1969).

*See Notation on page iv.

Kerlen, Esveldt, and Wereldsma recently[6] published a most complete study of the overlapping arrangement when applied to a high-speed containership similar to the ship being considered in this report. Their study included the effect of afterbody form, horizontal shaft distance, and longitudinal spacing between the propellers. They also reported results of vibration measurements and the first known cavitation experiments carried out on the system. Comparing the best overlapping design with a twin-screw ship, they found a reduction in power of approximately 7 percent in the range from 25 to 27 knots.

DEVELOPMENT OF STERN ARRANGEMENT–MODEL 5218–1

In developing an overlapping propeller arrangement, it is desirable that the afterbody lines be typically single screw, preferably with U-type sections. Such lines should result in high propulsive efficiency due to recovery of energy in the viscous wake.

The afterbody developed for the contrarotating version of the C9-ST-86a containership was designed with moderate-to-U-type sections and consequently could be considered suitable for an overlapping stern arrangement. It was decided that the contrarotating design Model 5218 could be used without any changes, except that the bossing cone was removed and the rudder was moved forward to a position where the trailing edge was in line with the transom stern. The lines of Model 5218 are given in Figure 1, and corresponding ship and model data are given in Table 1.

The diameters of the overlapping propellers were chosen to be 22.75 ft, corresponding to an optimum design when operating at a shaft speed of approximately 90 rpm. (This is the same rpm value as was used in the propeller design for the contrarotating version.) With a 3-in. tip clearance at the baseline, this propeller diameter has resulted in a hull propeller clearance which, following the recommendations given by Lloyds for twin-screw ships, should be adequate.

The horizontal distance between the two propeller shafts has been taken as 0.75 times the propeller diameter, which according to the tanker experiments by Munk and Prohaska (References 4 and 5) and the containership study by Kerlen et al., (Reference 6) should be close to the optimum. It was decided to locate the propellers in different longitudinal positions to obtain complete freedom in phasing the propellers or eventually to allow the two propellers to operate at different rpm values if desirable. A longitudinal spacing between the propellers of 0.2 times the propeller diameter was considered adequate. This is somewhat less than the spacing used for contrarotating propellers, normally from 0.25 to 0.3 times the diameter, and has made it possible to move the rudder forward as mentioned previously. From the results given in References 5 and 6, it appears that a longitudinal propeller spacing has only a small effect on performance. With the propellers

[6]Kerlen, H., et al., "Propulsions-, Kavitations- and Vibrationsverhalten von überlappenden Propellern für ein Containerschiff," Schiffbautechnische Gesellschaft, Hamburg, West Germany (Nov 1970).

mounted in different planes, however, the design becomes asymmetric, and the two propeller designs will have to be slightly different in order to obtain a proper balance.

The propeller shafts were supported by struts. Afterbody lines with details of the shafting, struts, rudder, and propeller arrangement are shown in Figure 2. Figure 3 shows fitting room photographs of the model, giving a general impression of the propulsion arrangement.

OUTLINE OF MODEL TEST PROGRAM

The model experiments carried out with the overlapping propeller arrangement consisted of a number of resistance and propulsion tests as outlined in Table 2. All of the tests were carried out at a design condition corresponding to a 30.0-ft molded draft, even keel, and a displacement of 38,520 tons. Resistance tests were conducted with and without struts and shafting in order to determine the appendage drag associated with this type of propulsion arrangement.

Propulsion tests were carried out with inboard and outboard rotating propellers and with and without rudder. Tests were furthermore carried out with one propeller at a time to provide as much information as possible about the somewhat unusual hull-propeller interaction, and the mutual interference between the two propellers.

The propulsion experiments were performed using a set of twin-screw stock propellers with the following data:

Propellers		Stock No.	
		4346	4347
Diameter	D	22.75 ft	
Pitch Ratio at 0.7 R	$P_{0.7}/D$	1.222	
Number of Blades	Z	3	
Expanded Blade-Area Ratio	A_E/A_O	0.537	
Rotation		R.H.	L.H.

Open water characteristics for the propellers are given in Figure 4.

In propulsion tests with twin propellers, the two propeller shafts were geared together so that they would operate at the same rpm values. Because of the asymetric arrangement this meant that the propellers would not absorb exactly the same horsepower or deliver the same thrust.

Propulsion experiments with one propeller were carried out with half of the model resistance compensated for by a towrope force.

PRESENTATION AND DISCUSSION OF TEST RESULTS

Powering predictions reported in the following paragraphs were made in accordance with Center practice for operating in smooth, deep, salt water, having a temperature of 59 F. A correlation allowance of 0.0002 was used in the friction calculation for predicting full-scale power from model test data. The International Towing Tank Conference (ITTC) frictional formulation of 1957 was used for all predictions. No corrections for scale effects on propeller performance or wake and thrust deduction were used.

RESISTANCE TESTS

Results of the resistance tests and a comparison with the performance of the twin-screw design Model 5209 are given in Figure 5. The results for the twin-screw hull in the bare-hull condition correspond to a condition with rudder but without bilge keels and shaft and strut supports. No similar bare-hull test is available for the overlapping propeller arrangement in that the model in Test 21 was fitted with bilge keels (but without rudder, shaft, and strut supports). From tests carried out on the contrarotating version, it appears that the bilge keels result in an additional resistance of approximately 1000 hp at the 25.5-knot design speed. Taking this into account, the difference between the two hull forms in the bare-hull condition amounts to less than 2 percent.*

Fully appended, the overlapping propeller arrangement shows its advantage in comparison with the conventional twin-screw arrangement. With less drag associated with the strut and shaft arrangement, the overlapping arrangement performs slightly better, the difference amounting to a little more than 2 percent.

PROPULSION TESTS–METHOD OF ANALYSIS

Results from propulsion tests with overlapping propellers, Tests 23 to 26, have been analyzed in two different ways. First, they have been considered similar to conventional twin-screw, with all of the hull propeller coefficients and efficiencies derived using average open-water curves and adding thrust and torque readings from the port and starboard propeller as follows:

$$\eta_D = \frac{P_E}{P_D} = \frac{R \cdot V}{2\pi Q n} = \frac{(T_P + T_S)(1 - t)}{2\pi (Q_P + Q_S) n} \; \frac{V_A}{(1 - W)} = \eta_O \, \eta_R \, \eta_H$$

where subscripts P and S refer to the port and starboard propellers, respectively.

However, since the propeller arrangement was asymmetric with the port propeller mounted in front of the starboard, and since the propeller open-water curves for the two

*This result is better than what was obtained when comparing the contrarotating version Model 5218 with the twin-screw Model 5209. The difference is due to the propeller cone and indicates that the effect of the cone is somewhat detrimental.

propellers were slightly different, as seen in Figure 3, the results were analyzed a second time with the port and starboard measurements referred to their individual propeller characteristics. In this way, it was possible to determine the wake, propeller efficiency, and relative rotative efficiency of the individual propellers without ambiguity. Futhermore, assuming that thrust deduction is the same for each propeller, it is possible to define all of the well known efficiencies relative to each propeller as follows:

$$\eta_D = \frac{P_E}{P_D} = \frac{P_{EP} + P_{ES}}{P_{DP} + P_{DS}} = \frac{(T_P + T_S)(1 - t)V}{2\pi(Q_P + Q_S)n} = \frac{T_P(1 - t)}{2\pi Q_P n} \frac{V_{AP}}{1-W_P} \frac{P_{DP}}{P_D}$$

$$+ \frac{T_S(1-t)}{2\pi Q_S n} \frac{V_{AS}}{1-W_S} \frac{P_{DS}}{P_D} = \eta_{OP} \cdot \eta_{RP} \cdot \eta_{HP} \frac{P_{DP}}{P_D} + \eta_{OS} \cdot \eta_{RS} \cdot \eta_{HS} \cdot \frac{P_{DS}}{P_D}$$

$$= \eta_{DP} \frac{P_{DP}}{P_D} + \eta_{DS} \frac{P_{DS}}{P_D}$$

Results from Tests 23 to 26 analyzed according to the two methods are presented in Tables 3 through 6. Taking results from Test 23, Table 3 as an example, it can be seen that results from the conventional twin-screw analysis method are presented on the first page of the table, and results of the analysis referring the measurements to the individual propellers on the following.

Some of the results are presented graphically. Figures 6 and 7 show results using the twin-screw method of analysis, with Figure 6 comparing inward and outward turning propellers (Tests 23 and 26) and Figure 7 a similar comparison from the tests without rudder (Tests 24 and 25). Figure 8 presents results from Test 26 (with rudder and outward turning propellers) when analyzed for each propeller separately, showing two sets of curves for the port and starboard propeller, respectively.

Results from tests with one propeller only, Tests 27.1 and 27.2, were analyzed as usual for single screw operation. Tables 7 and 8 show the data for starboard and port propeller, respectively, and Figure 9 gives a composite plot of the results obtained from the two tests.

A summary of the results obtained from the propulsion test at the 25.5-knot design speed is given in Table 9. The table gives results as obtained when using both methods of analysis wherever this is relevant.

DISCUSSION OF RESULTS

Comparing results from tests with inward and outward rotating propellers, it is seen that outward turning is the most advantageous, the difference between Tests 23 and 26 at 25.5 knots amounting to 7 1/2 percent. Such an effect has been observed on most previous tests with overlapping propeller arrangements at the Center. Munk and Prohaska (Reference 5) similarly measured a large difference due to rotation amounting to more than 20 percent for their tanker, whereas Kerlen et al. (Reference 6) obtained a 9-percent difference. In all of the known results, outward rotation has been the most beneficial for an overlapping arrangement.

Some of the difference in performance between inward and outward rotation is due to a change in thrust deduction. In order to explain the difference completely, it is helpful to consider the concept of a rotational wake component. It appears that the inflow to the propeller contains a rotational component or swirl which amounts to approximately 2.5 rpm inward rotation at 25.5 knots.

The tests carried out with and without rudder indicate that at least for the outboard rotating propellers, the rudder has a somewhat similar effect as for a single-screw ship in that it improves the propulsive efficiency η_D. The effect is, however, less pronounced than normal for a single-screw arrangement. There seems to be no reason to speculate that a twin-rudder arrangement (sometimes found beneficial when using contrarotating propellers) would be advantageous for the present arrangement.

The relative rotative efficiency obtained from the experiments is lower than what is common for conventional twin-screw arrangements. This could eventually be explained as a result of the method of analysis since the propellers have been tested independently in open water and not as an overlapping unit. The results obtained from the tests with one propeller only are on the other hand in close agreement with the values from the tests with overlapping propellers, and it appears more likely that the low value is due to the unsymmetry of the flow entering the propellers. Results given by Kerlen et al. (Reference 6) are similar; they also result in a lower η_R value for the forward propeller as shown here.

The asymmetry of the propulsion arrangement is quite apparent when comparing wake and efficiencies for the individual propellers. The large unbalance in thrust and torque in the case of the outward turning propellers is partly due to the difference in the two propellers. It is quite obvious, however, that a set of design propellers should have a slightly different pitch value in order to absorb the same power at the same rpm value.

The effects of overlapping the propellers can be studied when comparing Test 26 with results obtained when testing one propeller at a time (Tests 27.1 and 27.2). The most obvious effect can be noticed in the wake coefficient, which for the overlapping propellers becomes smaller due to the induced velocity from the other propeller. This interference effect is less on the forward port propeller than on the aft propeller as could be expected.

The difference in thrust deduction obtained in Tests 27.1 and 27.2 is small, and the assumption about thrust deduction made previously in outlining the method of analysis seems to be acceptable.

PROGNOSIS OF PERFORMANCE WITH DESIGN PROPELLERS

The propulsion tests discussed in the previous section were carried out with a set of stock propellers, the performance of which differs somewhat from a set of designed propellers. In order to compare the overlapping propeller arrangement with other propulsion systems, it is desirable that a prognosis be prepared taking the difference in performance between stock and design propellers into account.

Such a prognosis was prepared on the basis of the results obtained from Test 26 with outboard rotating propellers. The performance of a set of designed propellers was determined from the Wageningen Troost Series; see Reference 7. The propellers were optimized for the same diameter as used in the model experiments, and they were designed to deliver equal thrust at the same shaft speed. The design was carried out on the basis of the wake coefficient and relative rotative efficiency obtained from the propulsion test for the individual propellers and from assuming that these coefficients remained the same. It was also assumed that the thrust deduction would be the same for the two propellers.

The design was carried out for a four-bladed propeller, and the blade area was determined to give adequate cavitation margin. The dimensions of the Troost Series "design propellers" and their open-water characteristics are shown in Table 10. It can be seen that there is a slight difference in the pitch of the starboard and port propeller due to the asymmetry of the design.

The prognosis for the overlapping propeller arrangement using the Troost Series design propellers is given in Table 11. Data are given in the table in the same way as for the results obtained from propulsion tests with results for the average open-water curves and for the individual propellers. The results at the 25.5-knot design speed have been included in Table 9. It is seen that the design propellers would result in a thrust balance whereas there is a slight unbalance in the torque being absorbed by the two propellers.

The prognosis for the design propellers indicates an increase in power as compared with the result from Test 26 with stock propellers. This is primarily due to reduced propeller efficiency of the design propellers associated with the increased blade area ratio.

COMPARISON WITH TWIN-SCREW AND CONTRAROTATING DESIGN

A comparison of the overlapping propeller arrangement with results from Reference 1 for the twin-screw Model 5209 and the contrarotating propulsion arrangement Model 5218 is shown in Figure 10. The results for the twin-screw prognosis and the contrarotating design have similarly been included in Table 9.

It is seen from the prognosis for the twin-screw and the overlapping arrangements (Figure 10) that an application of overlapping propellers would result in an improved

[7] Van Lammeren, W. P. A. et al., "The Wageningen B-Screw Series," Transactions, Society of Naval Architects and Marine Engineers, Vol. 77 (1969).

performance amounting to approximately 4 percent at 25.5 knots. An application of the contrarotating design would result in an additional reduction of 10 percent.

When judging the performance it should be recalled that the twin-screw design is one regarded as having exceptionally good performance, developed through considerable experimentation and benefiting from past design experience. This is in contrast to the overlapping arrangement, which likely could be improved somewhat by further experiments and optimization of the hull-propellers-rudder interaction. The 7-percent difference obtained by Kerlen et al. (Reference 6) is in line with these comments, and the two sets of experiments indicate that a 4- to 7-percent difference between the two propulsion arrangements is likely when applied to the ship type under consideration.

A survey of the various propulsive coefficients obtained for the overlapping, twin-screw, and contrarotating arrangements, as summarized in Table 9, is instructive in that it clearly shows the difference in wake, thrust deduction, and propeller efficiency, etc. These differences are in agreement with expectations and can be explained when considering the location of propellers, loading, and so on. The very large difference in relative rotative efficiency η_R, which in general accounts for the total difference between the overlapping and contrarotating designs, is difficult to explain satisfactorily at the present. The result is however in agreement with previous contrarotating experiments and the results from Reference 6 for the overlapping propellers.

Based on the results of the investigation reported here, an attempt has been made to analytically determine the effect of the horizontal spacing between propeller shafts in an overlapping arrangement. Considering the three arrangements, contrarotating, overlapping, and twin screw, as basically twin-propeller designs of the same family, where the shaft spacing has been varies from 0.0 to 0.75 to 1.95 times the propeller diameter, it appears quite logical to consider whether an optimum spacing might exist.

The results of this analysis are given in Figure 11, showing the predicted performance of a twin-propeller arrangement as a function of propeller-shaft distance from the centerline. The effective horsepower values, thrust, and wake coefficients assumed for the calculation are shown in the figure. The result is shown for a 22-ft propeller over the complete range of shaft spacings and for a 22.5- and 23-ft propeller near the overlapping region.

Interestingly, an optimum twin-propeller arrangement, disregarding the contrarotating, apparently would be obtained for a shaft spacing slightly larger than the propeller diameter. The difference in performance between a spacing corresponding to the overlapping arrangement used in this investigation and the optimum would amount to less than 1 percent. The larger spacing, however, might nevertheless be quite attractive in that the two propellers could be positioned free of interference and eventually symmetrically in the same longitudinal position. An additional gain not taken into consideration in the calculation might show up due to a reduced rudder drag, since the rudder in its zero position would be out of the slipstream from the propellers.

CONCLUSIONS AND RECOMMENDATIONS

Model experiments on a high-speed container ship with an overlapping propeller arrangement have shown that this arrangement in comparison with conventional twin-screw propulsion would result in a performance improvement corresponding to a 4-percent reduction in shaft power at design speed. It is anticipated that further experimentation with the overlapping arrangement, optimizing propeller shaft spacing and rudder and propeller location, could result in an additional reduction amounting to a few percent.

Comparing the overlapping with a contrarotating design, the latter shows a better performance corresponding to an additional reduction in shaft power of approximately 10 percent. The overlapping system, however, can be designed and built on the basis of conventional machinery, gear and shafting arrangement.

The large difference in results for outward and inward rotation and the small relative rotative efficiency found for the overlapping system indicate that the flow field entering the propellers is very nonuniform. It is recommended that a wake survey be carried out in way of the propellers to establish the inflow more accurately. Results from a wake survey in connection with application of an analytical method for predicting propeller performance in a nonuniform flow field could eventually clarify the low relative rotative efficiency and indicate ways to further improvements.

A study of cavitation and vibration problems associated with the overlapping propeller arrangement has not been carried out as part of this investigation. Such a study would be most desirable in order to establish its overall performance and to make a true comparison between this arrangement and the conventional twin-screw arrangement. Since the forward propeller of the overlapping propeller arrangement is operating in a very inhomogeneous wake field, it is likely that both cavitation and vibratory propeller forces could become serious problems. A wake survey could be used as basis for a preliminary analytical evaluation of both cavitation and vibration characteristics; however, a more complete experimental investigation is recomended, should the system be considered seriously for application to high-speed high-powered ship types.

The present investigation was carried out using a set of stock propellers from which a prognosis for the performance of a set of design propellers has been prepared. An actual propeller design could be carried out on the basis of the test results in that the wake and interaction between the two propellers have been determined from the method of analysis employed. Due to the asymmetry of the propulsion arrangement, with the port propeller in front of the starboard, the two propellers of an optimum design would be slightly different.

If the propulsion arrangement were modified somewhat with the spacing between the two propeller shafts increased to be slightly larger than the propeller diameters, it would be possible to position the propellers in the same longitudinal plane symmetrically around the centerline. That such an arrangement might be as efficient as a true overlapping design has been discussed in the report. Certain advantages other than symmetry in propeller design would furthermore be gained, for instance, phasing between propellers could be arranged to reduce undesirable vibratory propeller forces, and risk of cavitation due to impingement of the forward propeller slipstream on the aft would be eliminated. It is recommended that such a symmetrical arrangement with increased shaft spacing be incorporated in future investigations of the overlapping system.

ACKNOWLEDGMENTS

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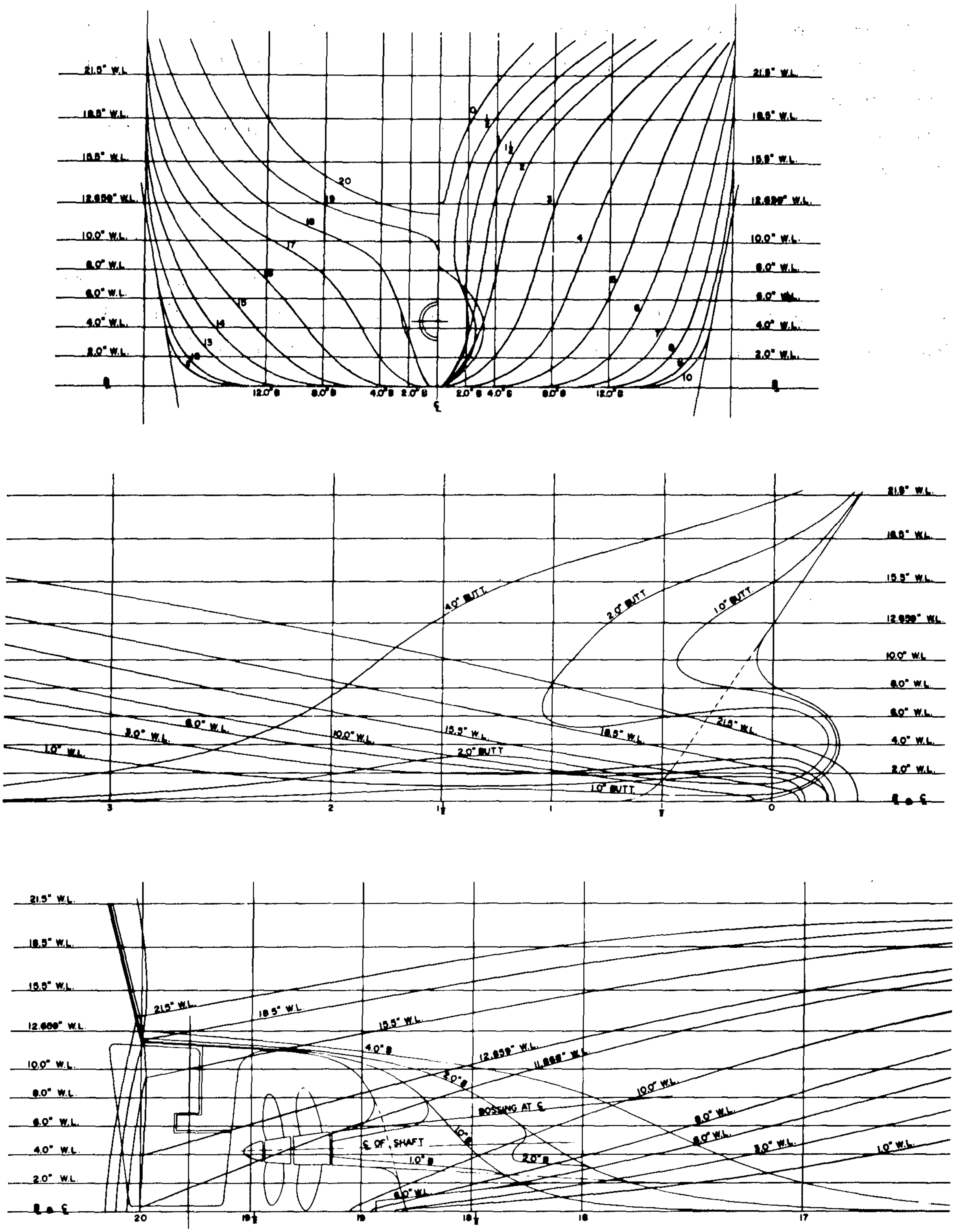


Figure 1 – Lines Drawing for Model 5218, Representing Contrarotating Single Rudder Containership Design

(Model Scale λ = 30.334)

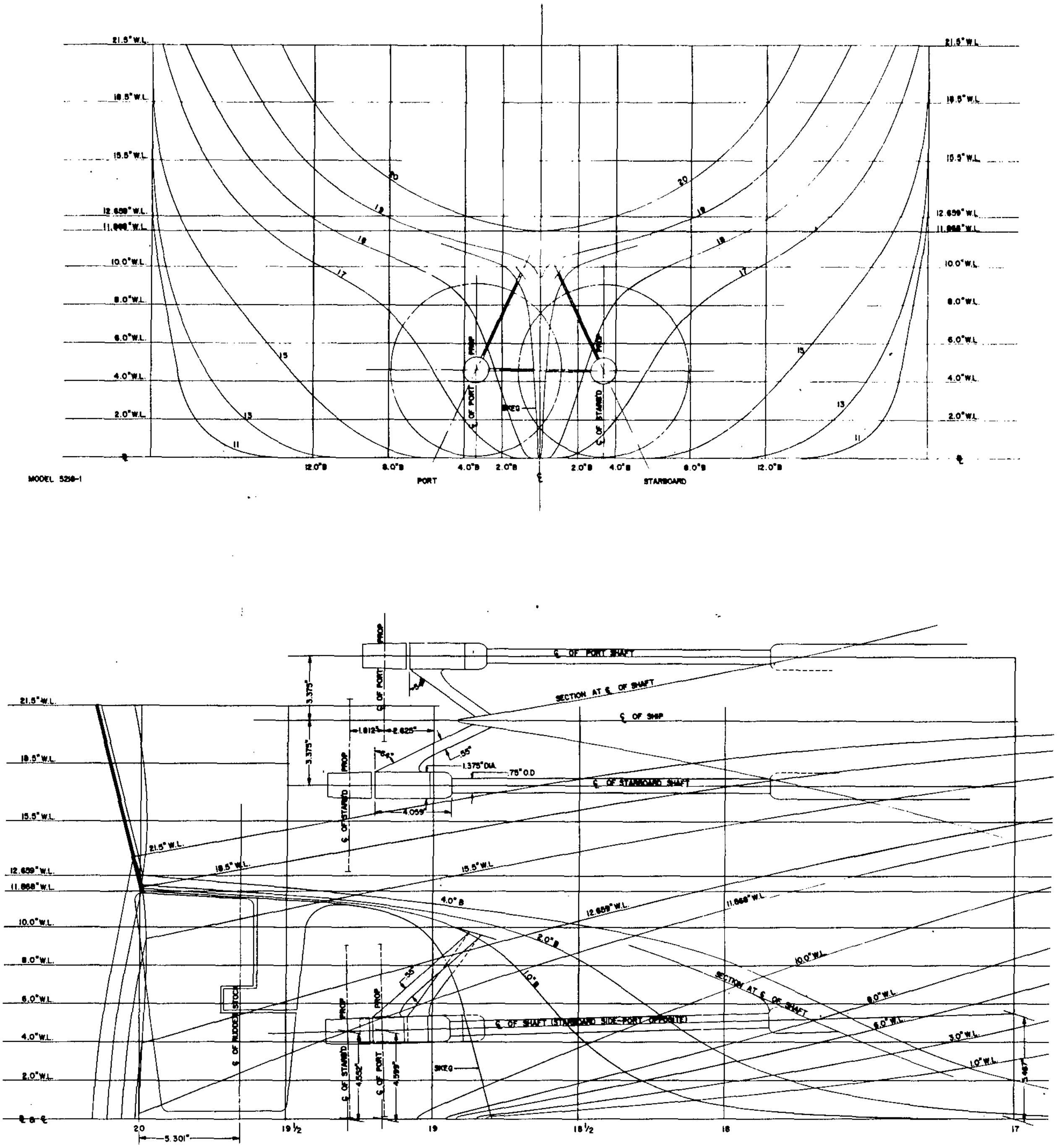


Figure 2 – Afterbody Lines Drawing for Overlapping Propeller Design Model 5218–1, Showing Shafting, Struts, Rudder, and Propeller Arrangement

(Model Scale $\lambda = 30.334$)

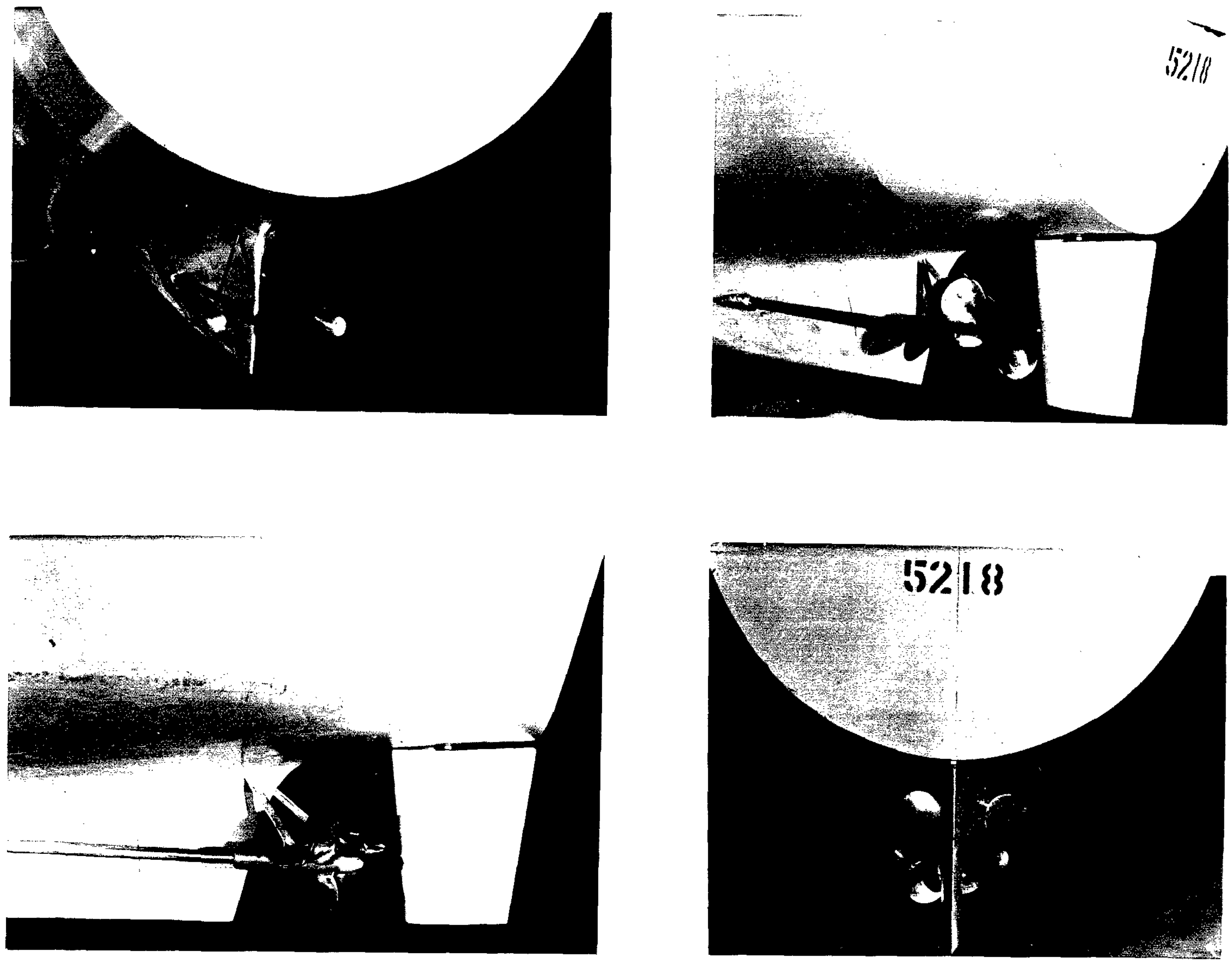


Figure 3 – Fitting Room Photographs of Overlapping Propeller Arrangement Model 5218–1, with Single Rudder (*Stock* Propellers 4346 and 4347)

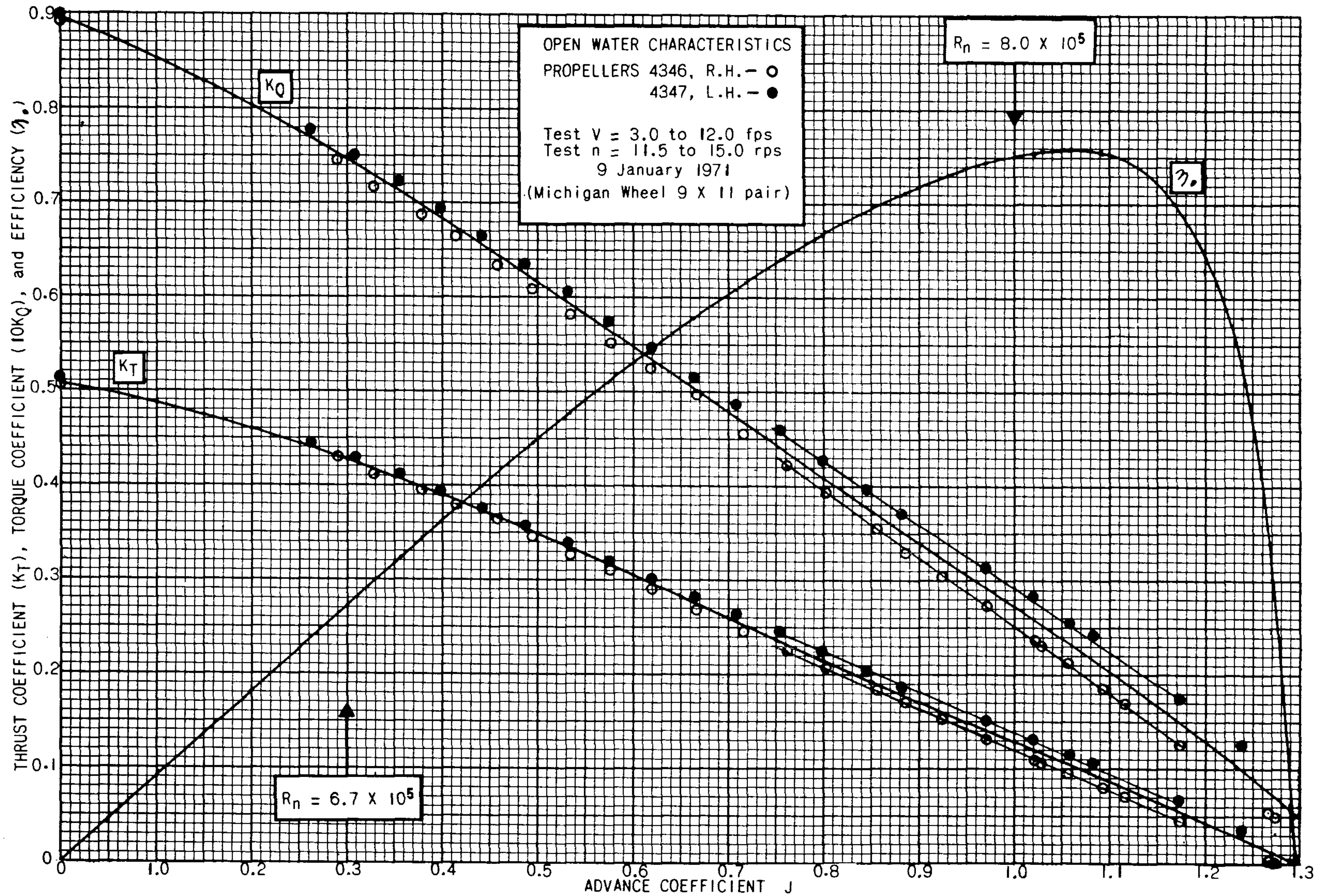


Figure 4 – Open Water Propeller Characteristics for Stock Propellers 4346 and 4347

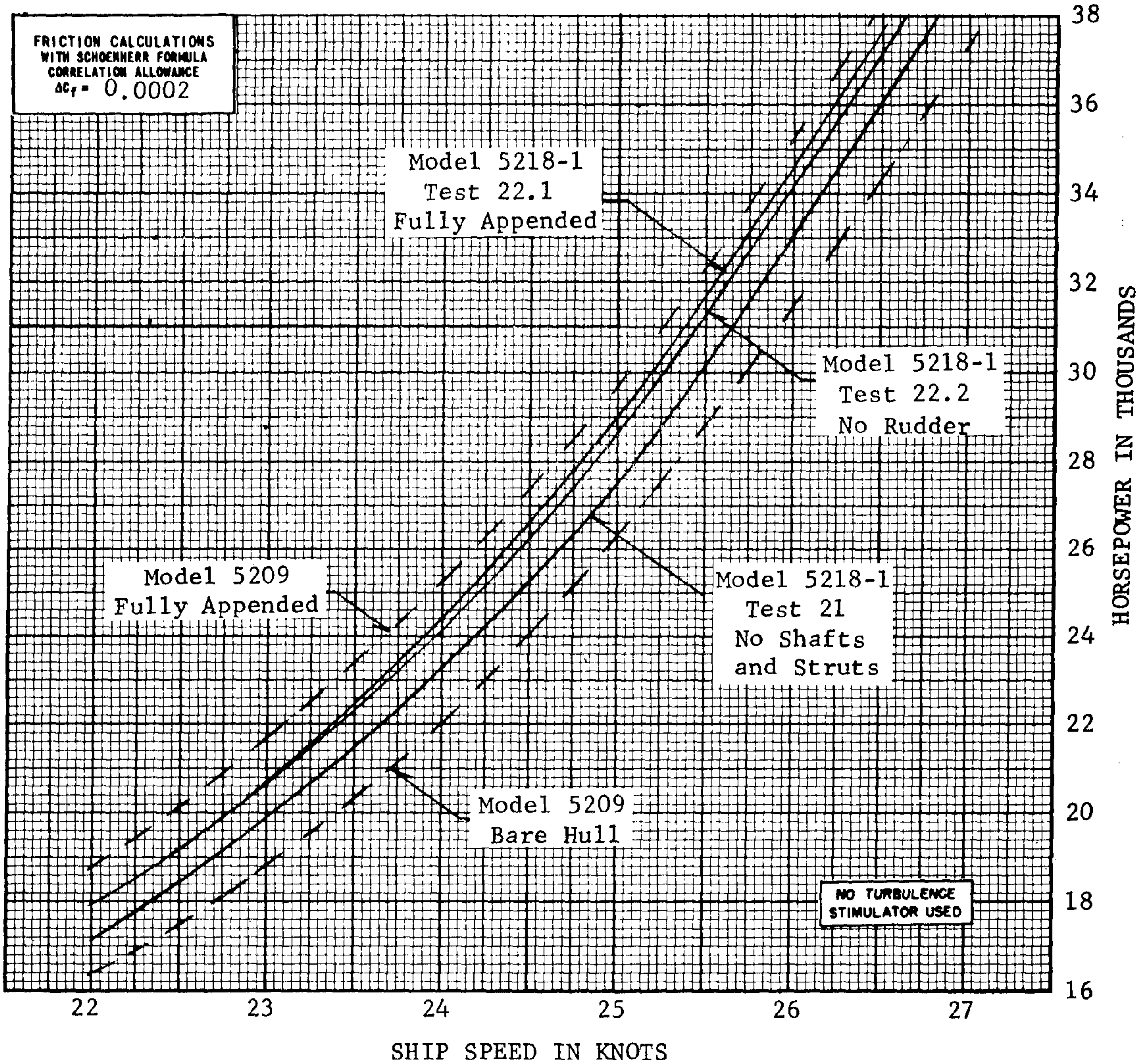


Figure 5 – Comparison of Effective Horsepower Curves for Overlapping Propeller Design Model 5218–1 and Twin-Screw Design Model 5209

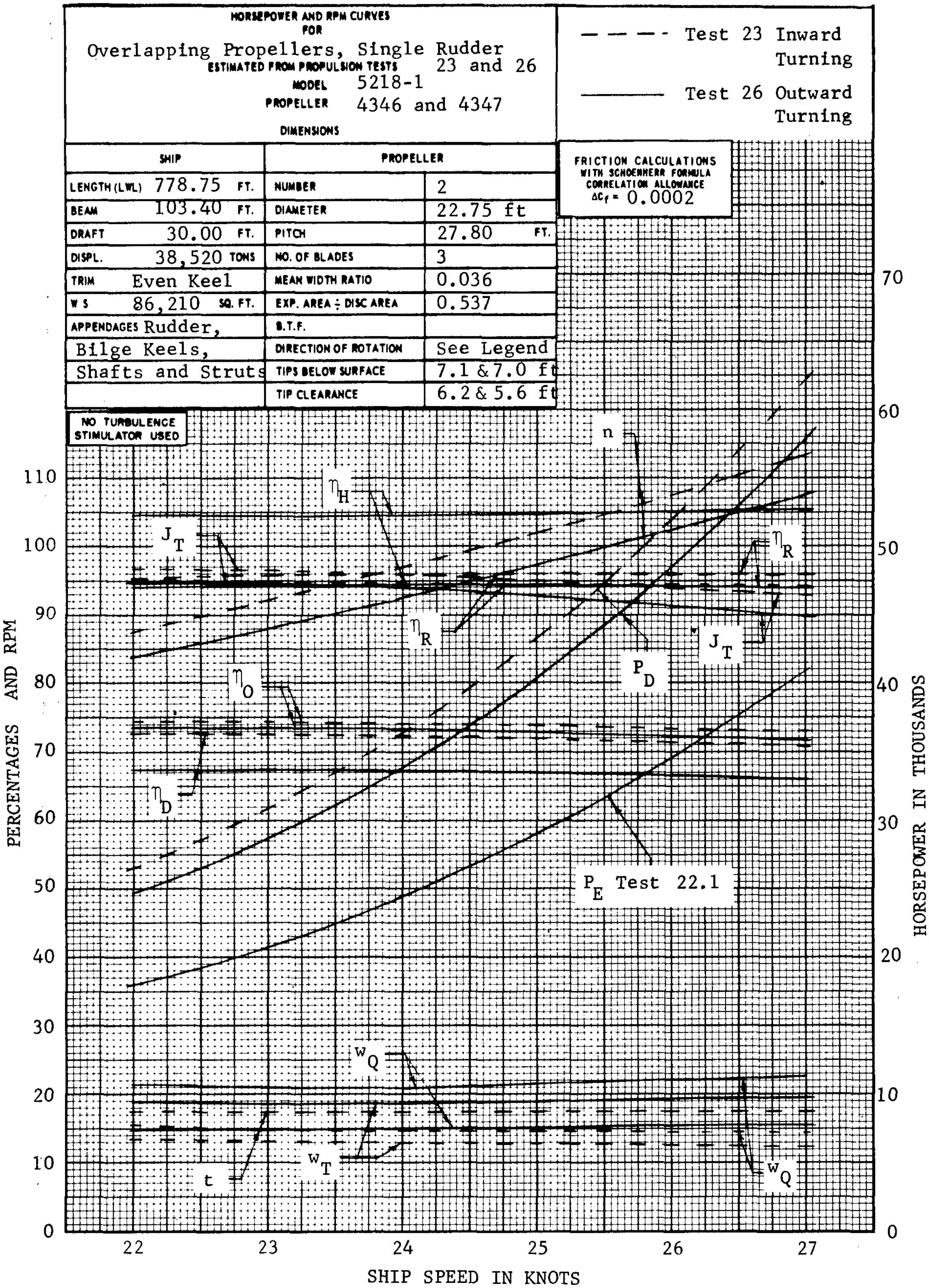


Figure 6 – Results from Propulsion Tests 23 and 26 with Overlapping Propellers, Single Rudder Arrangement–Stock Propellers 4346 and 4347 Rotating Inward (Test 23) and Outward (Test 26)

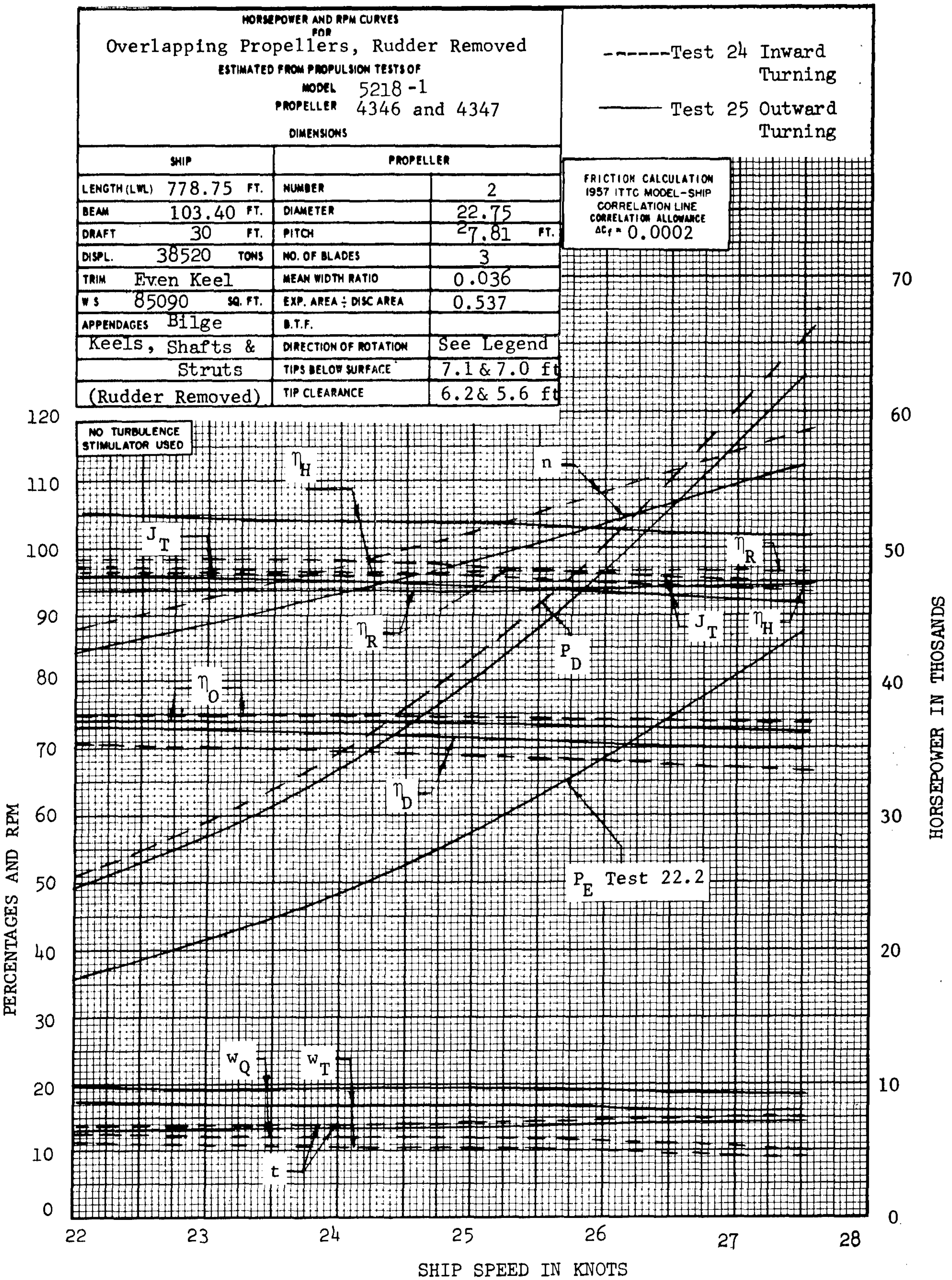


Figure 7 – Results from Propulsion Tests 24 and 25 with Overlapping Propeller Arrangement, Single Rudder Removed–Stock Propellers 4346 and 4347 Rotating Inward (Test 24) and Outward (Test 25)

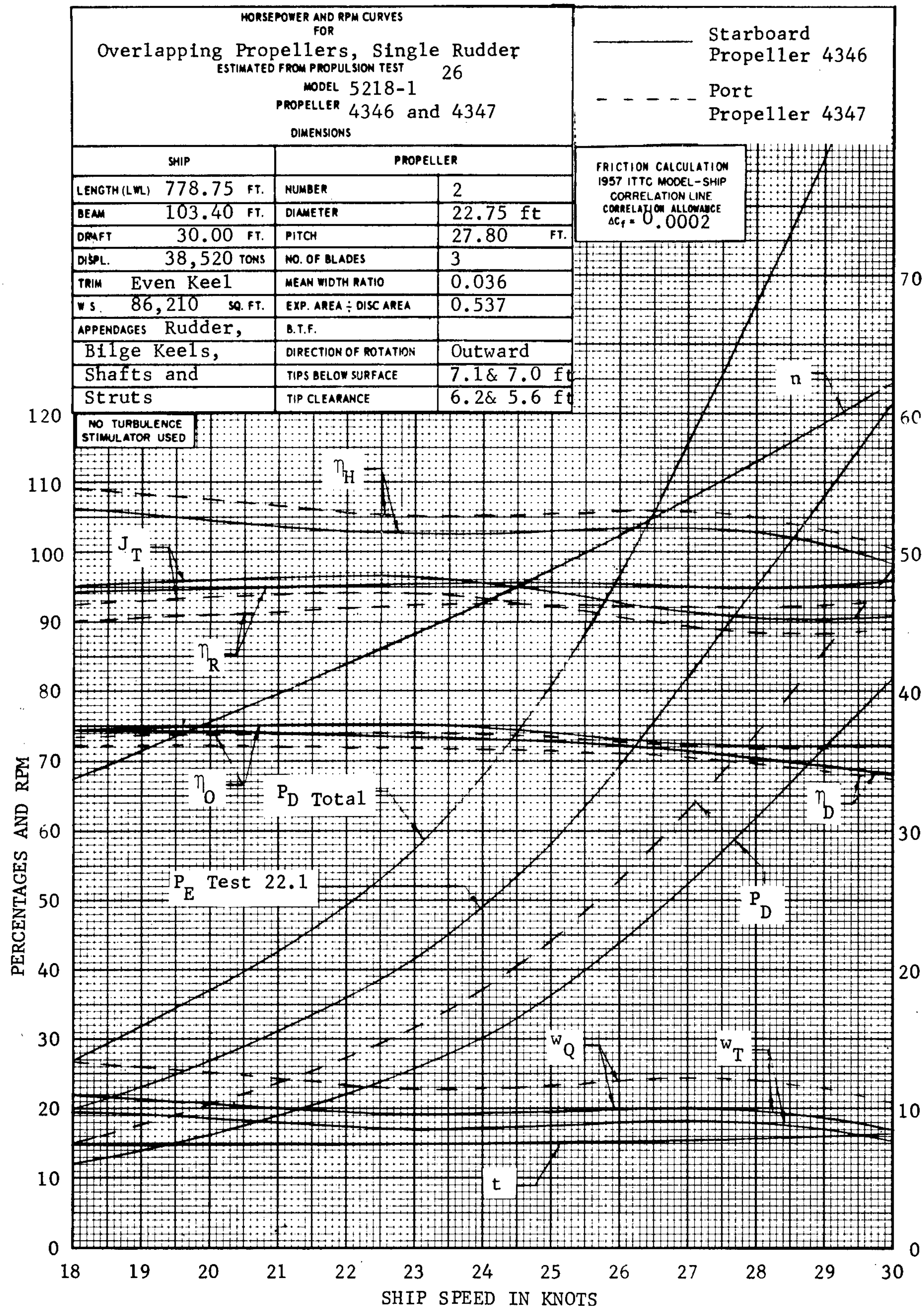


Figure 8 – Results from Propulsion Test 26 with Overlapping Propellers, Single Rudder Arrangement–Stock Propellers 4346 (Starboard) and 4347 (Port) Outward Rotating

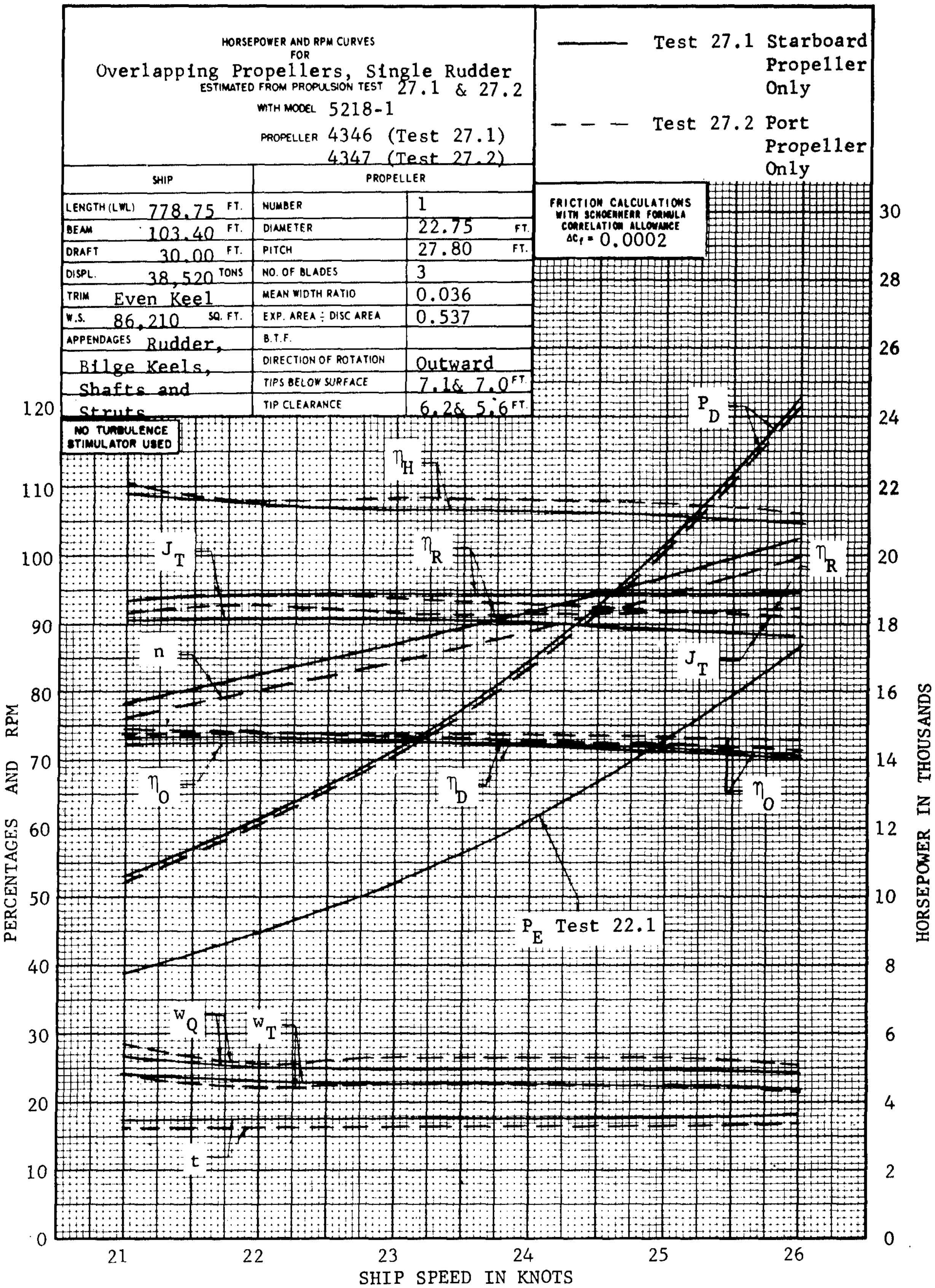


Figure 9 – Results from Propulsion Tests 27.1 and 27.2 with Overlapping Propeller, Single Rudder Arrangement–Starboard Propeller Only (Test 27.1) and Port Propeller Only (Test 27.2)–Stock Propellers 4346 (Starboard) and 4347 (Port) Outward Rotating

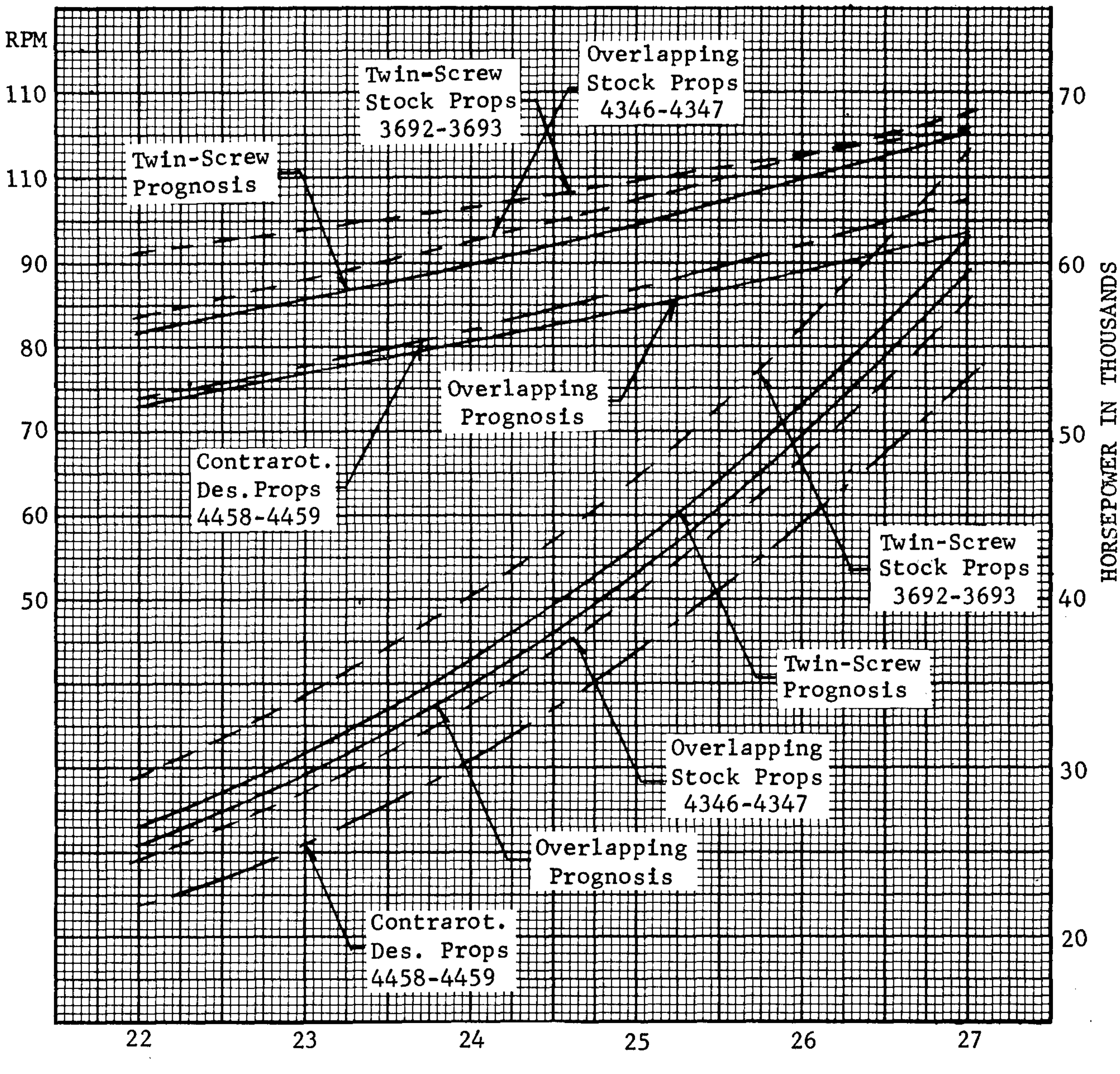


Figure 10 – Comparison of Performance of Overlapping Propeller Arrangement with Single Rudder (Model 5218–1), Contrarotating Design with Single Rudder (Model 5218), and Twin-Screw Arrangement (Model 5209)

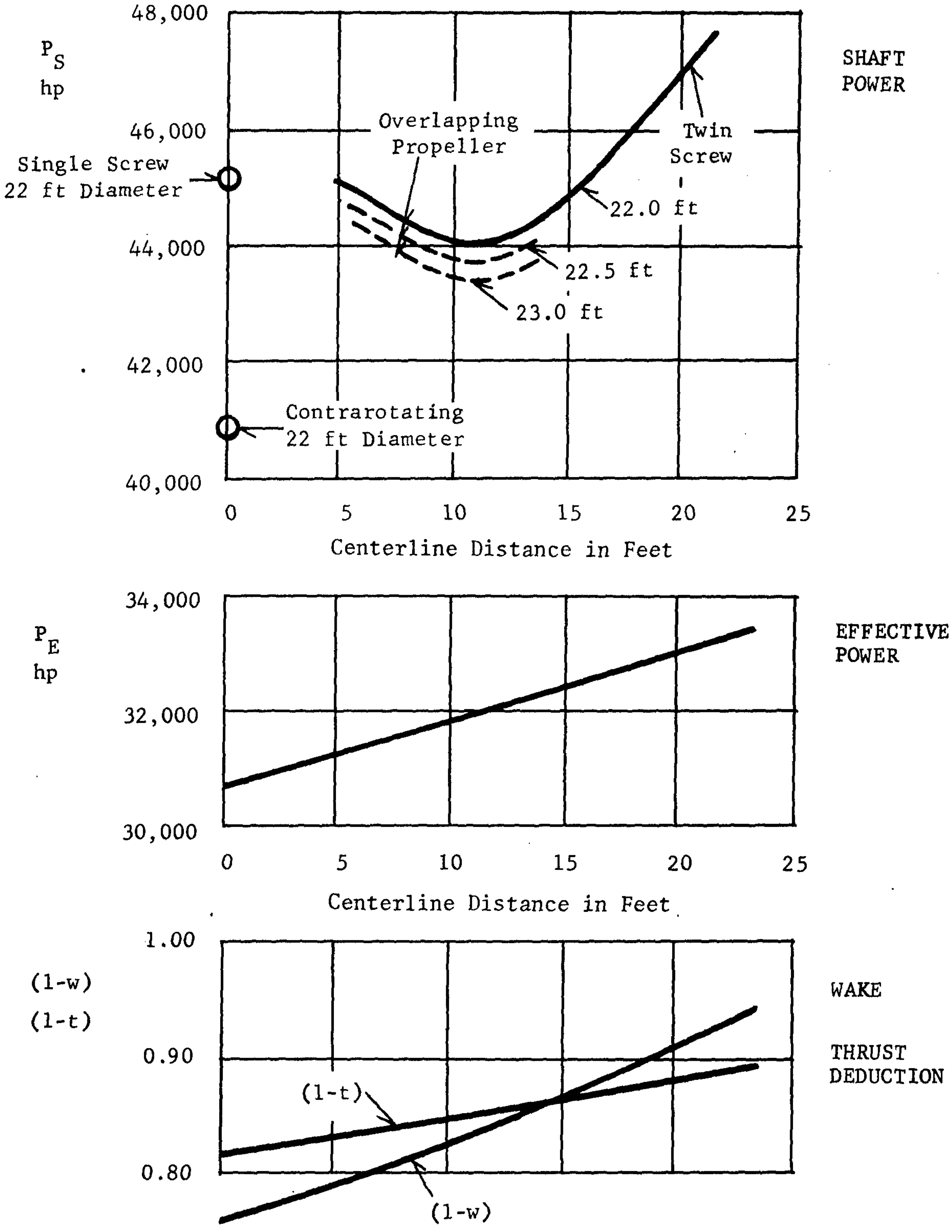
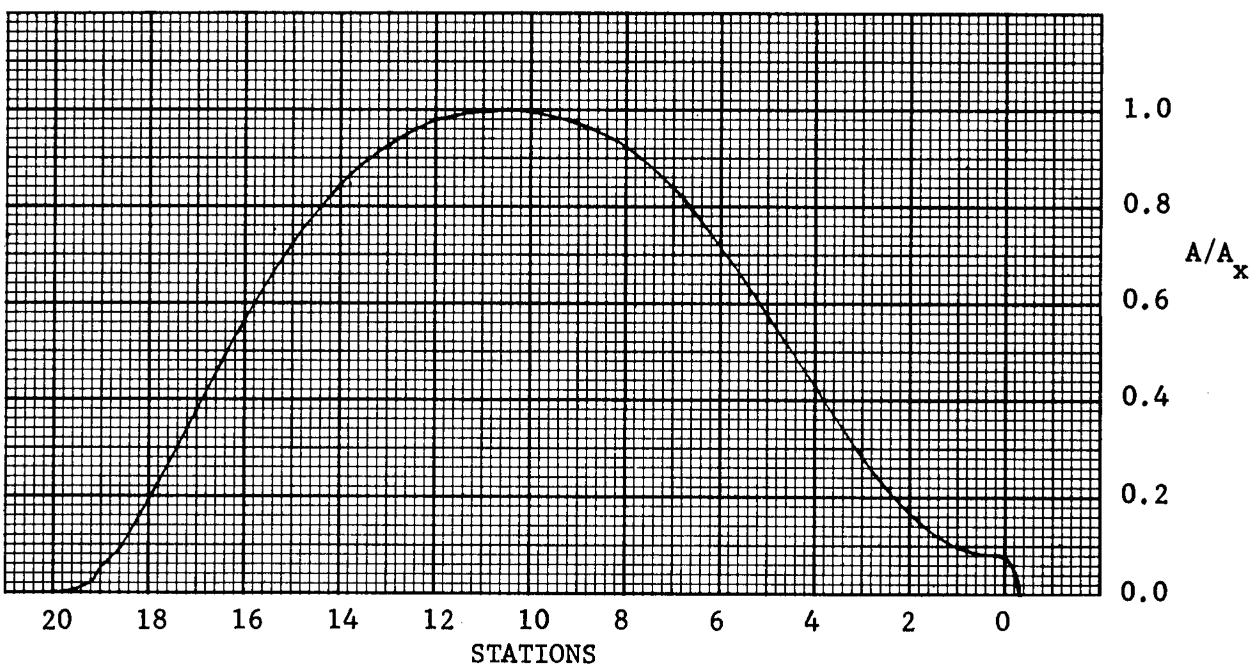


Figure 11 – Predicted Performance of Twin-Screw Propulsion Arrangement as a Function of Propeller Shaft Distance from Centerline

TABLE 1 – SHIP AND MODEL DATA FOR MODEL 5218
CONTRAROTATING CONTAINERSHIP DESIGN

APPENDAGES: Propeller Bossing (No Rudder or Bilge Keels)

DIMENSIONS			LWL COEFFICIENTS			
	SHIP	MODEL	C_B	0.555	C_{WF}	0.62
LENGTH (LWL) FT	778.8	25.673	C_P	0.590	C_{WA}	0.78
LENGTH (LBP) FT	780.0	25.714	C_X	0.940	L_E/L	0.52
BEAM (B_X) FT	103.4	3.408	C_W	0.697	L_P/L	0.00
DRAFT (H) FT	30.0	.989	C_{PF}	0.57	L_R/L	0.48
DISPL. IN TONS	38520 S.W.	1.342 F.W.	C_{PA}	0.62	L/B_X	7.53
WETTED SURF. SQ. FT.	83920	91.2	C_{PE}	0.58	B_X/H	3.45
DESIGN V IN KTS.	25.5	4.63	C_{PR}	0.60	$\Delta/(.01L)^3$	81.1
LCB_{LWL} = 394.8 AFT OF F.P.			C_{PV}	0.80	$S/\sqrt{\Delta L}$	15.45
LCB_{LBP} = 395.5 AFT OF F.P.			C_{PVA}	0.74	f	0.09
WL ENTRANCE HALF ANGLE = 7.0°			C_{PVF}	0.86	t	0.05
λ = 30.334	$V/\sqrt{L_{LWL}}$ = 0.914		LBP COEFFICIENTS			
Ⓚ = 2.561	Ⓟ = 0.887		C_B	0.555	L/B_X	7.53
LINES: NSRDC Afterbody lines, Model 5218, 10 Nov 69			C_P	0.590	$\Delta/(.01L)^3$	81.1



Sectional Area Curve

TABLE 2 – SUMMARY OF TEST PROGRAM WITH MODEL 5218–1

Test No.	Type of Test	Appendages	Rudder	Stock Prop. Stbd.	Stock Prop. Port	Rotation	Results	Remarks
21	Resistance	Bilge Keels					Figure 5	
22.1	Resistance	Bilge Keels, Rudder Shafts and Struts	Single					
22.2	Resistance	Bilge Keels Shaft and Struts						
23	Propulsion	Bilge Keels, Rudder Shaft and Struts	Single	4347	4346	Inward	Table 3 Figure 6	Propeller shaft geared to give same rpm value for starboard and port propeller
24	Propulsion	Bilge Keels Shaft and Struts		4347	4346	Inward	Table 4 Figure 7	
25	Propulsion	Bilge Keels Shaft and Struts		4346	4347	Outward	Table 5 Figure 7	
26	Propulsion	Bilge Keels, Rudder Shaft and Struts	Single	4346	4347	Outward	Table 6 Figs. 6,8,10	
27.1	Propulsion	Bilge Keels, Rudder Shaft and Struts	Single	4346		Outward	Table 7 Figure 9	Test with one propeller. Half of model resistance compensated by towrope force.
27.2	Propulsion	Bilge Keels, Rudder Shaft and Struts	Single		4347	Outward	Table 8 Figure 9	

TABLE 3 – SHAFT HORSEPOWER PREDICTION AND PROPULSION DATA FOR OVERLAPPING PROPELLER ARRANGEMENT WITH SINGLE RUDDER INWARD ROTATING PROPELLERS–TEST 23

MØDEL 5218-1	TEST 23		
MØDEL LENGTH =	25.67 FT	SHIP LENGTH =	779. FT
MØDEL DISPL. =	3006. LBS	SHIP DISPL. =	38520. TØNS
MØDEL W.S. =	93.69 SQ FT	SHIP W.S. =	86210. SQ FT
RHØ-MØDEL =	1.9367	RHØ-SHIP =	1.9905
NU -MØDEL =	1.0836E-05	NU -SHIP =	1.2817E-05
NØ. ØF SHAFTS=	2	PRØP DIAM-S-=	22.75 FEET
DELTA CF =	.0002	LAMBDA =	30.334

RESULTS ARE FRØM FAIRED CØEFFICIENTS   ITTC FRICTIØN USED

Propulsion Data for Propellers 4346 and 4347 Combined

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	17930.	26600.	87.6	.674	.968	.946	1.118
23.00	20770.	30820.	92.1	.674	.967	.947	1.112
24.00	24430.	36330.	96.9	.673	.960	.941	1.103
24.50	26630.	39650.	99.4	.672	.956	.937	1.097
25.00	29030.	43310.	102.0	.670	.951	.932	1.091
25.50	31680.	47410.	104.7	.668	.945	.926	1.084
26.00	34600.	51940.	107.5	.666	.939	.920	1.077
26.50	37720.	56890.	110.3	.663	.933	.914	1.069
27.00	40950.	62090.	113.3	.660	.929	.910	1.061
27.50	44200.	67510.	116.2	.655	.927	.907	1.053

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.866	.846	.824	.953	.743	.952
23.00	.869	.852	.824	.957	.743	.948
24.00	.871	.853	.824	.959	.741	.946
24.50	.871	.854	.824	.960	.740	.946
25.00	.871	.854	.824	.960	.738	.946
25.50	.872	.854	.824	.961	.736	.945
26.00	.872	.855	.824	.961	.734	.945
26.50	.873	.855	.824	.961	.731	.944
27.00	.876	.857	.824	.960	.730	.941
27.50	.880	.861	.824	.960	.729	.936

TABLE 3 – Continued

Propulsion Data for Starboard Propeller - Stock Propeller 4347

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	8930.	13590.	87.6	.657	.986	.963	1.118
23.00	10340.	15740.	92.1	.657	.985	.964	1.112
24.00	12150.	18550.	96.9	.655	.981	.959	1.103
24.50	13250.	20250.	99.4	.654	.977	.955	1.097
25.00	14440.	22120.	102.0	.653	.974	.950	1.091
25.50	15750.	24210.	104.7	.651	.969	.945	1.084
26.00	17200.	26530.	107.5	.648	.965	.939	1.077
26.50	18740.	29050.	110.3	.645	.960	.933	1.069
27.00	20340.	31710.	113.3	.641	.957	.929	1.061
27.50	21950.	34480.	116.2	.637	.955	.926	1.053

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.882	.862	.824	.946	.743	.935
23.00	.886	.867	.824	.950	.743	.930
24.00	.889	.870	.824	.950	.744	.927
24.50	.891	.871	.824	.949	.745	.925
25.00	.892	.871	.824	.948	.745	.923
25.50	.894	.872	.824	.947	.746	.921
26.00	.896	.872	.824	.946	.745	.919
26.50	.898	.873	.824	.944	.745	.917
27.00	.902	.875	.824	.943	.744	.914
27.50	.907	.879	.824	.942	.744	.909

Propulsion Data for Port Propeller - Stock Propeller 4346

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	9010.	13000.	87.6	.693	.948	.930	1.118
23.00	10440.	15060.	92.1	.693	.947	.931	1.112
24.00	12280.	17750.	96.9	.691	.940	.926	1.103
24.50	13380.	19380.	99.4	.690	.935	.922	1.097
25.00	14590.	21170.	102.0	.689	.929	.917	1.091
25.50	15930.	23170.	104.7	.688	.923	.912	1.084
26.00	17400.	25390.	107.5	.685	.917	.906	1.077
26.50	18980.	27800.	110.3	.683	.912	.901	1.069
27.00	20610.	30340.	113.3	.679	.908	.897	1.061
27.50	22260.	32990.	116.2	.675	.905	.894	1.053

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.848	.832	.824	.960	.742	.972
23.00	.851	.837	.824	.965	.742	.968
24.00	.852	.839	.824	.969	.738	.967
24.50	.852	.840	.824	.971	.736	.967
25.00	.852	.840	.824	.972	.733	.968
25.50	.852	.841	.824	.974	.730	.967
26.00	.852	.842	.824	.975	.727	.967
26.50	.853	.843	.824	.976	.724	.966
27.00	.855	.845	.824	.976	.722	.963
27.50	.859	.849	.824	.976	.721	.959

TABLE 4 – SHAFT HORSEPOWER PREDICTION AND PROPULSION DATA FOR OVERLAPPING PROPELLER ARRANGEMENT WITHOUT RUDDER INWARD ROTATING PROPELLERS–TEST 24

MØDEL 5218-1	TEST 24		
MØDEL LENGTH =	25.67 FT	SHIP LENGTH =	779. FT
MØDEL DISPL. =	3006. LBS	SHIP DISPL. =	38520. TØNS
MØDEL W.S. =	92.47 SQ FT	SHIP W.S. =	85090. SQ FT
RHØ-MØDEL =	1.9367	RHØ-SHIP =	1.9905
NU -MØDEL =	1.0836E-05	NU -SHIP =	1.2817E-05
NØ. ØF SHAFTS=	2	PRØP DIAM-S-=	22.75 FEET
DELTA CF =	.0002	LAMBDA =	30.334

RESULTS ARE FRØM FAIRED CØEFFICIENTS ITTC FRICTIØN USED

Propulsion Data for Propellers 4346 and 4347 Combined

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	17980.	25510.	88.1	.705	.986	.972	1.112
23.00	20670.	29510.	92.5	.701	.987	.972	1.107
24.00	24110.	34700.	97.2	.695	.982	.967	1.099
24.50	26280.	37980.	100.7	.692	.983	.973	1.084
25.00	28650.	41640.	102.4	.688	.972	.956	1.087
25.50	31270.	45700.	105.3	.684	.967	.951	1.078
26.00	34150.	50220.	108.3	.680	.962	.946	1.069
26.50	37230.	55180.	111.4	.675	.957	.942	1.059
27.00	40420.	60320.	114.4	.670	.953	.937	1.051
27.50	43630.	65410.	117.1	.667	.949	.933	1.045

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.887	.874	.864	.967	.749	.974
23.00	.891	.878	.862	.967	.749	.967
24.00	.894	.880	.861	.965	.748	.963
24.50	.907	.898	.859	.977	.748	.947
25.00	.895	.880	.858	.964	.745	.959
25.50	.897	.882	.856	.965	.743	.954
26.00	.900	.885	.854	.966	.742	.949
26.50	.904	.890	.852	.967	.740	.943
27.00	.907	.892	.851	.967	.739	.938
27.50	.908	.893	.850	.966	.737	.936

TABLE 4 – Continued

Propulsion Data for Starboard Propeller - Stock Propeller 4347

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	8890.	13000.	88.1	.684	.998	.986	1.112
23.00	10230.	15040.	92.5	.680	.998	.986	1.107
24.00	11930.	17690.	97.2	.675	.996	.982	1.099
24.50	13010.	19360.	100.7	.672	.996	.987	1.084
25.00	14190.	21230.	102.4	.668	.990	.973	1.087
25.50	15490.	23290.	105.3	.665	.986	.969	1.078
26.00	16920.	25600.	108.3	.661	.983	.964	1.069
26.50	18450.	28130.	111.4	.656	.979	.961	1.059
27.00	20030.	30750.	114.4	.651	.976	.956	1.051
27.50	21630.	33340.	117.1	.649	.973	.952	1.045

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.898	.887	.864	.966	.736	.962
23.00	.902	.891	.862	.966	.736	.956
24.00	.906	.894	.861	.963	.738	.950
24.50	.919	.911	.859	.974	.738	.935
25.00	.911	.895	.858	.957	.742	.942
25.50	.915	.899	.856	.956	.743	.936
26.00	.919	.902	.854	.956	.744	.929
26.50	.925	.907	.852	.956	.745	.921
27.00	.929	.910	.851	.954	.746	.916
27.50	.931	.911	.850	.953	.746	.913

Propulsion Data for Port Propeller - Stock Propeller 4346

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	9090.	12490.	88.1	.728	.966	.955	1.112
23.00	10450.	14450.	92.5	.723	.967	.955	1.107
24.00	12180.	16990.	97.2	.717	.962	.950	1.099
24.50	13270.	18600.	100.7	.713	.963	.956	1.084
25.00	14460.	20390.	102.4	.709	.950	.938	1.087
25.50	15780.	22380.	105.3	.705	.945	.934	1.078
26.00	17230.	24590.	108.3	.701	.940	.929	1.069
26.50	18780.	27020.	111.4	.695	.935	.925	1.059
27.00	20390.	29540.	114.4	.690	.930	.921	1.051
27.50	22000.	32030.	117.1	.687	.926	.917	1.045

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.869	.858	.864	.975	.751	.994
23.00	.873	.863	.862	.974	.751	.988
24.00	.875	.864	.861	.973	.749	.984
24.50	.889	.882	.859	.984	.749	.967
25.00	.875	.864	.858	.973	.743	.981
25.50	.877	.866	.856	.975	.741	.976
26.00	.879	.869	.854	.977	.738	.972
26.50	.883	.874	.852	.979	.736	.965
27.00	.885	.876	.851	.979	.733	.961
27.50	.886	.878	.850	.979	.731	.959

TABLE 5 – SHAFT HORSEPOWER PREDICTION AND PROPULSION DATA FOR OVERLAPPING PROPELLER ARRANGEMENT WITHOUT RUDDER OUTWARD ROTATING PROPELLERS–TEST 25

```
MØDEL 5218-1       TEST 25
MØDEL LENGTH = 25.67 FT             SHIP LENGTH =   779. FT
MØDEL DISPL. =  3006. LBS           SHIP DISPL. =  38520. TØNS
MØDEL W.S.   =  92.47 SQ FT         SHIP W.S.   =  85090. SQ FT
RHØ-MØDEL    = 1.9367               RHØ-SHIP    = 1.9905
NU -MØDEL    = 1.0836E-05           NU -SHIP    = 1.2817E-05
NØ. ØF SHAFTS= 2                    PRØP DIAM-S-= 22.75 FEET
DELTA CF     = .0002                LAMBDA      = 30.334

RESULTS ARE FRØM FAIRED CØEFFICIENTS     ITTC FRICTIØN USED
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Propulsion Data for Propellers 4346 and 4347 Combined

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	17980.	24570.	84.3	.732	.958	.929	1.162
23.00	20670.	28440.	88.6	.727	.960	.930	1.156
24.00	24110.	33420.	93.1	.722	.955	.924	1.148
24.50	26280.	36600.	95.5	.718	.949	.918	1.142
25.00	28650.	40070.	98.0	.715	.943	.912	1.135
25.50	31270.	43980.	100.7	.711	.938	.906	1.127
26.00	34150.	48340.	103.7	.707	.933	.902	1.116
26.50	37230.	53020.	106.6	.702	.928	.898	1.106
27.00	40420.	57790.	109.4	.699	.922	.893	1.099
27.50	43630.	62510.	112.0	.698	.918	.890	1.093

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.825	.800	.869	.938	.741	1.054
23.00	.830	.805	.868	.938	.741	1.046
24.00	.832	.805	.866	.937	.739	1.041
24.50	.831	.804	.865	.936	.737	1.041
25.00	.831	.803	.863	.936	.735	1.039
25.50	.832	.804	.862	.936	.733	1.036
26.00	.835	.808	.860	.939	.731	1.029
26.50	.838	.812	.858	.942	.729	1.023
27.00	.840	.813	.856	.943	.727	1.020
27.50	.840	.814	.856	.945	.725	1.019

TABLE 5 – Continued

Propulsion Data for Starboard Propeller - Stock Propeller 4346

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	7950.	10810.	84.3	.736	.986	.960	1.162
23.00	9180.	12550.	88.6	.732	.985	.960	1.156
24.00	10760.	14800.	93.1	.727	.978	.953	1.148
24.50	11760.	16240.	95.5	.724	.971	.946	1.142
25.00	12860.	17800.	98.0	.722	.964	.940	1.135
25.50	14060.	19590.	100.7	.718	.957	.934	1.127
26.00	15390.	21570.	103.7	.714	.952	.930	1.116
26.50	16830.	23710.	106.6	.710	.946	.925	1.106
27.00	18310.	25920.	109.4	.706	.940	.920	1.099
27.50	19700.	28110.	112.0	.701	.937	.916	1.093

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.848	.826	.869	.942	.762	1.024
23.00	.852	.830	.868	.943	.762	1.018
24.00	.852	.830	.866	.944	.758	1.016
24.50	.850	.828	.865	.943	.755	1.017
25.00	.849	.828	.863	.946	.751	1.016
25.50	.850	.829	.862	.946	.748	1.014
26.00	.852	.833	.860	.950	.745	1.009
26.50	.855	.836	.858	.954	.742	1.003
27.00	.855	.838	.856	.956	.739	1.001
27.50	.858	.838	.856	.952	.737	.998

Propulsion Data for Port Propeller - Stock Propeller 4347

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	10040.	13750.	84.3	.730	.945	.902	1.162
23.00	11490.	15870.	88.6	.724	.947	.905	1.156
24.00	13350.	18600.	93.1	.718	.943	.900	1.148
24.50	14520.	20350.	95.5	.714	.939	.8)3	1.142
25.00	15790.	22240.	98.0	.710	.934	.887	1.135
25.50	17210.	24370.	100.7	.706	.929	.881	1.127
26.00	18760.	26740.	103.7	.701	.924	.878	1.116
26.50	20410.	29280.	106.6	.697	.920	.875	1.106
27.00	22110.	31840.	109.4	.694	.915	.871	1.099
27.50	23930.	34360.	112.0	.696	.909	.868	1.093

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.813	.777	.869	.922	.741	1.069
23.00	.819	.783	.868	.922	.741	1.059
24.00	.82D	.780	.866	.920	.741	1.054
24.50	.822	.782	.865	.917	.739	1.052
25.00	.822	.782	.863	.917	.738	1.049
25.50	.824	.782	.862	.117	.736	1.046
26.00	.828	.786	.860	.919	.735	1.039
26.50	.831	.791	.858	.922	.733	1.031
27.00	.833	.792	.856	.923	.731	1.028
27.50	.832	.794	.856	.929	.729	1.028

TABLE 6 – SHAFT HORSEPOWER PREDICTION AND PROPULSION DATA FOR OVERLAPPING PROPELLER ARRANGEMENT WITH SINGLE RUDDER OUTWARD ROTATING PROPELLERS–TEST 26

MØDEL 5218-1	TEST 26		
MØDEL LENGTH	= 25.67 FT	SHIP LENGTH	= 779. FT
MØDEL DISPL.	= 3006. LBS	SHIP DISPL.	= 38520. TØNS
MØDEL W.S.	= 93.69 SQ FT	SHIP W.S.	= 86210. SQ FT
RHØ-MØDEL	= 1.9367	RHØ-SHIP	= 1.9905
NU -MØDEL	= 1.0836E-05	NU -SHIP	= 1.2817E-05
NØ. ØF SHAFTS	= 2	PRØP DIAM-S-	= 22.75 FEET
DELTA CF	= .0002	LAMBDA	= 30.334

RESULTS ARE FRØM FAIRED CØEFFICIENTS   ITTC FRICTIØN USED

Propulsion Data for Propellers 4346 and 4347 Combined

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
16.00	7030.	9560.	59.7	.735	.927	.886	1.192
18.00	9920.	13540.	67.6	.732	.934	.896	1.186
19.00	11610.	15900.	71.5	.731	.938	.901	1.182
20.00	13500.	18500.	75.5	.729	.942	.907	1.179
21.00	15570.	21390.	79.6	.728	.945	.914	1.174
22.00	17930.	24680.	83.8	.727	.948	.919	1.168
23.00	20770.	28650.	88.1	.725	.947	.919	1.162
24.00	24430.	33780.	92.6	.723	.939	.911	1.154
24.50	26620.	36870.	94.9	.722	.933	.905	1.149
25.00	29030.	40310.	97.3	.720	.927	.898	1.143
25.50	31680.	44130.	99.8	.718	.920	.890	1.137
26.00	34590.	48360.	102.3	.715	.912	.882	1.131
26.50	37720.	52970.	104.9	.712	.905	.873	1.125
27.00	40950.	57830.	107.5	.708	.899	.866	1.118
27.50	44200.	62800.	110.2	.704	.895	.861	1.111
28.00	47450.	67850.	112.3	.699	.887	.849	1.110
28.50	50720.	73060.	115.7	.694	.891	.859	1.096
29.00	54540.	79160.	118.6	.689	.888	.856	1.088
29.50	57360.	83960.	121.5	.683	.893	.863	1.081
30.00	60710.	89610.	124.5	.678	.895	.866	1.073

TABLE 6 – Continued

Propulsion Data for Propellers 4346 and 4347 Combined

V	$1-w_T$	$1-w_Q$	$1-t$	η_R	η_O	η_H
16.00	.777	.743	.852	.920	.729	1.096
18.00	.788	.755	.852	.925	.732	1.082
19.00	.793	.762	.852	.928	.733	1.074
20.00	.799	.770	.852	.931	.735	1.066
21.00	.805	.778	.851	.936	.736	1.057
22.00	.811	.787	.851	.940	.737	1.048
23.00	.815	.791	.851	.943	.737	1.044
24.00	.814	.790	.850	.944	.734	1.045
24.50	.812	.788	.849	.944	.731	1.046
25.00	.811	.785	.849	.943	.729	1.047
25.50	.809	.783	.848	.943	.726	1.049
26.00	.806	.779	.848	.941	.723	1.051
26.50	.805	.776	.847	.940	.720	1.053
27.00	.804	.775	.846	.939	.717	1.052
27.50	.805	.775	.845	.938	.715	1.049
28.00	.799	.765	.844	.931	.712	1.056
28.50	.813	.784	.842	.940	.714	1.035
29.00	.816	.786	.840	.940	.712	1.029
29.50	.826	.799	.838	.944	.714	1.013
30.00	.834	.808	.835	.947	.715	1.001

TABLE 6 – Continued

Propulsion Data for Starboard Propeller - Stock Propeller 4346

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
16.00	3180.	4250.	59.7	.748	.945	.918	1.192
18.00	4480.	6020.	67.6	.745	.952	.926	1.186
19.00	5250.	7070.	71.5	.743	.956	.931	1.182
20.00	6100.	8230.	75.5	.741	.959	.936	1.179
21.00	7040.	9530.	79.6	.739	.963	.941	1.174
22.00	8110.	11010.	83.8	.736	.966	.945	1.168
23.00	9400.	12810.	88.1	.734	.965	.944	1.162
24.00	11080.	15150.	92.6	.731	.956	.936	1.154
24.50	12090.	16550.	94.9	.731	.949	.930	1.149
25.00	13210.	18130.	97.3	.729	.942	.923	1.143
25.50	14440.	19880.	99.8	.726	.935	.915	1.137
26.00	15790.	21840.	102.3	.723	.927	.907	1.131
26.50	17240.	23990.	104.9	.718	.920	.899	1.125
27.00	18740.	26260.	107.5	.714	.914	.892	1.118
27.50	20260.	28580.	110.2	.709	.910	.887	1.111
28.00	21780.	30920.	112.3	.704	.903	.876	1.110
28.50	23290.	33310.	115.7	.699	.906	.884	1.096
29.00	25050.	36120.	118.6	.694	.903	.881	1.088
29.50	26360.	38310.	121.5	.688	.907	.887	1.081
30.00	27890.	40880.	124.5	.682	.909	.890	1.073

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
16.00	.793	.770	.852	.938	.742	1.075
18.00	.803	.781	.852	.942	.745	1.061
19.00	.808	.787	.852	.944	.747	1.054
20.00	.814	.794	.852	.946	.749	1.046
21.00	.821	.801	.851	.949	.751	1.037
22.00	.827	.809	.851	.952	.752	1.029
23.00	.830	.813	.851	.954	.751	1.025
24.00	.828	.811	.850	.954	.747	1.026
24.50	.826	.809	.849	.956	.743	1.028
25.00	.824	.807	.849	.956	.740	1.030
25.50	.822	.805	.848	.956	.736	1.032
26.00	.820	.802	.848	.954	.732	1.034
26.50	.818	.799	.847	.952	.729	1.035
27.00	.818	.798	.846	.951	.726	1.035
27.50	.819	.798	.845	.950	.723	1.032
28.00	.813	.789	.844	.943	.720	1.038
28.50	.827	.807	.842	.951	.722	1.018
29.00	.830	.810	.840	.952	.720	1.012
29.50	.840	.821	.838	.955	.722	.997
30.00	.847	.830	.835	.958	.723	.985

TABLE 6 – Continued

Propulsion Data for Port Propeller - Stock Propeller 4347

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
16.00	3850.	5310.	59.7	.726	.919	.857	1.192
18.00	5430.	7520.	67.6	.722	.927	.869	1.186
19.00	6360.	8820.	71.5	.722	.930	.876	1.182
20.00	7390.	10260.	75.5	.721	.934	.883	1.179
21.00	8530.	11850.	79.6	.720	.938	.890	1.174
22.00	9830.	13660.	83.8	.719	.941	.897	1.168
23.00	11370.	15830.	88.1	.718	.940	.898	1.162
24.00	13350.	18610.	92.6	.717	.933	.891	1.154
24.50	14530.	20300.	94.9	.716	.927	.884	1.149
25.00	15820.	22160.	97.3	.714	.921	.877	1.143
25.50	17250.	24220.	99.8	.712	.914	.869	1.137
26.00	18810.	26490.	102.3	.710	.907	.861	1.131
26.50	20480.	28950.	104.9	.707	.899	.852	1.125
27.00	22210.	31530.	107.5	.704	.893	.846	1.118
27.50	23940.	34180.	110.2	.700	.889	.842	1.111
28.00	25680.	36890.	112.3	.696	.882	.829	1.110
28.50	27430.	39700.	115.7	.691	.887	.840	1.096
29.00	29490.	43000.	118.6	.686	.883	.837	1.088
29.50	31010.	45600.	121.5	.680	.888	.845	1.081
30.00	32820.	48670.	124.5	.674	.890	.849	1.073

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
16.00	.771	.719	.852	.895	.733	1.105
18.00	.781	.733	.852	.901	.736	1.090
19.00	.787	.741	.852	.905	.737	1.083
20.00	.793	.749	.852	.909	.738	1.075
21.00	.799	.758	.851	.914	.739	1.065
22.00	.805	.768	.851	.920	.740	1.056
23.00	.809	.773	.851	.924	.740	1.051
24.00	.808	.772	.850	.925	.738	1.052
24.50	.807	.769	.849	.924	.736	1.053
25.00	.806	.767	.849	.923	.734	1.054
25.50	.804	.764	.848	.923	.731	1.055
26.00	.801	.761	.848	.922	.728	1.058
26.50	.800	.758	.847	.921	.725	1.059
27.00	.799	.757	.846	.921	.723	1.058
27.50	.801	.758	.845	.921	.721	1.055
28.00	.794	.747	.844	.913	.718	1.062
28.50	.809	.767	.842	.923	.720	1.041
29.00	.811	.769	.840	.923	.718	1.035
29.50	.822	.782	.838	.927	.720	1.019
30.00	.830	.791	.835	.930	.721	1.005

TABLE 7 – SHAFT HORSEPOWER PREDICTION AND PROPULSION DATA FOR OVERLAPPING PROPELLER ARRANGEMENT WITH SINGLE RUDDER STARBOARD PROPELLER ONLY, OUTWARD ROTATING– STOCK PROPELLER 4346–TEST 27.1

MØDEL 5218-1 TEST 27.1

MØDEL LENGTH =	25.67 FT	SHIP LENGTH =	779. FT
MØDEL DISPL. =	3006. LBS	SHIP DISPL. =	38520. TØNS
MØDEL W.S. =	46.85 SQ FT	SHIP W.S. =	43100. SQ FT
RHØ-MØDEL =	1.9367	RHØ-SHIP =	1.9905
NU -MØDEL =	1.0836E-05	NU -SHIP =	1.2817E-05
NØ. ØF SHAFTS=	1	PRØP DIAM-S-=	22.75 FEET
DELTA CF =	.0002	LAMBDA =	30.334

RESULTS ARE FRØM FAIRED CØEFFICIENTS ITTC FRICTIØN USED

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
21.00	7780.	10600.	78.5	.734	.905	.875	1.191
22.00	8970.	12220.	82.8	.734	.909	.883	1.183
23.00	10390.	14270.	87.2	.728	.909	.884	1.174
24.00	12220.	16930.	91.8	.722	.902	.875	1.164
24.50	13310.	18540.	94.3	.718	.897	.871	1.157
25.00	14510.	20310.	96.9	.715	.892	.866	1.149
25.50	15840.	22340.	99.6	.709	.886	.860	1.140
26.00	17300.	24570.	102.4	.704	.881	.855	1.130

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
21.00	.760	.735	.827	.935	.721	1.089
22.00	.768	.747	.827	.943	.723	1.076
23.00	.774	.753	.826	.944	.723	1.067
24.00	.775	.752	.824	.943	.720	1.064
24.50	.775	.752	.823	.943	.717	1.062
25.00	.776	.754	.821	.945	.714	1.058
25.50	.777	.754	.820	.945	.712	1.054
26.00	.780	.757	.818	.946	.709	1.049

TABLE 8 – SHAFT HORSEPOWER PREDICTION AND PROPULSION DATA FOR OVERLAPPING PROPELLER ARRANGEMENT WITH SINGLE RUDDER–PORT PROPELLER ONLY, OUTWARD ROTATING–STOCK PROPELLER 4347–TEST 27.2

MØDEL 5218-1	TEST 27.2		
MØDEL LENGTH	= 25.67 FT	SHIP LENGTH	= 779. FT
MØDEL DISPL.	= 3006. LBS	SHIP DISPL.	= 38520. TØNS
MØDEL W.S.	= 46.85 SQ FT	SHIP W.S.	= 43100. SQ FT
RHØ-MØDEL	= 1.9367	RHØ-SHIP	= 1.9905
NU -MØDEL	= 1.0836E-05	NU -SHIP	= 1.2817E-05
NØ. ØF SHAFTS	= 1	PRØP DIAM-S-	= 22.75 FEET
DELTA CF	= .0002	LAMBDA	= 30.334

RESULTS ARE FRØM FAIRED CØEFFICIENTS   ITTC FRICTIØN USED

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
21.00	7780.	10440.	76.1	.746	.933	.886	1.228
22.00	8970.	12110.	80.7	.741	.941	.902	1.213
23.00	10390.	14120.	84.4	.736	.936	.890	1.213
24.00	12220.	16750.	88.9	.730	.929	.882	1.202
24.50	13310.	18330.	91.3	.726	.925	.877	1.194
25.00	14510.	20090.	93.8	.723	.919	.871	1.186
25.50	15840.	22060.	96.6	.718	.915	.867	1.175
26.00	17300.	24260.	99.6	.713	.911	.865	1.162

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
21.00	.760	.722	.838	.916	.738	1.103
22.00	.776	.743	.837	.927	.740	1.079
23.00	.772	.734	.837	.918	.739	1.085
24.00	.773	.734	.836	.916	.737	1.081
24.50	.774	.734	.835	.916	.735	1.078
25.00	.775	.734	.834	.916	.733	1.076
25.50	.778	.738	.833	.918	.731	1.070
26.00	.784	.745	.831	.921	.730	1.060

TABLE 9 – COMPARISON OF RESULTS FROM PROPULSION TESTS AT 25.5 KNOTS

Test No.	Stern Arrangement	Propellers Nos.	Propellers Diam	Propellers Rotation	Rudder	P_E hp	P_D hp	T_S/T_p	Q_S/Q_p	n rpm	η_D Unit	η_D Stb	η_D Port
23	Overlapping	Twin	22.75	Inward	Single	31,680	47,410	0.989	1.045	104.7	0.668	0.651	0.688
24	Overlapping	Twin	22.75	Inward	No rudder	31,270	45,700	0.982	1.041	105.3	0.684	0.665	0.705
25	Overlapping	Twin	22.75	Outward	No rudder	31,270	43,980	0.817	0.804	100.7	0.711	0.718	0.706
26	Overlapping	Twin	22.75	Outward	Single	31,680	44,130	0.837	0.821	99.8	0.718	0.726	0.712
27.1	OL Stb Prop Only		22.75	Outward	Single	15,840	22,340	–	–	99.6	–	0.709	–
27.2	OL Port Prop Only		22.75	Outward	Single	15,840	22,060	–	–	96.6	–	–	0.718
Pr OL*	Overlapping	Twin	22.75	Outward	Single	31,680	45,440	1.000	0.982	86.9	0.697	0.704	0.691
Pr TS**	Twin-Screw	Twin	22.00	Outward	Single	32,360	47,100	1.000	1.000	97.2	0.687	–	–
CR***	Contrarotat	Twin	22.00	Contra	Single	30,830	40,670	–	–	89.5	0.758	–	–

Test No.	1 – t	$1-W_T$ Unit	$1-W_T$ Stb	$1-W_T$ Port	$1-W_Q$ Unit	$1-W_Q$ Stb	$1-W_Q$ Port	η_H Unit	η_H Stb	η_H Port	η_R Unit	η_R Stb	η_R Port	η_0 Unit	η_0 Stb	η_0 Port
23	0.824	0.872	0.894	0.852	0.852	0.872	0.841	0.945	0.921	0.967	0.961	0.947	0.971	0.736	0.746	0.730
24	0.856	0.897	0.915	0.877	0.882	0.899	0.866	0.954	0.936	0.976	0.965	0.956	0.975	0.743	0.743	0.741
25	0.862	0.832	0.850	0.824	0.804	0.829	0.782	1.036	1.014	1.046	0.936	0.946	0.917	0.733	0.748	0.736
26	0.848	0.809	0.822	0.804	0.783	0.805	0.764	1.049	1.032	1.055	0.943	0.956	0.923	0.726	0.736	0.731
27.1	0.820	–	0.777	–	–	0.754	–	–	1.054	–	–	0.945	–	–	0.712	–
27.2	0.833	–	–	0.778	–	–	0.738	–	–	1.070	–	–	0.918	–	–	0.731
Pr OL*	0.848	0.813	0.822	0.804	0.787	0.803	0.770	1.044	1.032	1.055	0.939	0.956	0.923	0.712	0.714	0.710
Pr TS**	0.882	0.916	–	–	0.910	–	–	0.963	–	–	0.984	–	–	0.724	–	–
CR***	0.812	0.757	–	–	0.772	–	–	1.073	–	–	1.025	–	–	0.689	–	–

*Prognosis for Overlapping Propeller Arrangement, based on Test 26, using Troost Series "Design Propellers."

**Prognosis for Twin-Screw Arrangement using Troost Series "Design Propellers."

***Performance for Contrarotating Arrangement with Design Propellers, Reference 1.

TABLE 10 – DIMENSIONS OF TROOST SERIES DESIGN PROPELLERS AND OPEN WATER CHARACTERISTICS

Propellers			Starboard	Port
Diameter	D	ft	22.75	22.75
Pitch Ratio at 0.7 R	$P_{0.7}/D$		1.421	1.400
Number of Blades	Z		4	4
Expanded Blade Area Ratio	A_E/A_0		0.745	0.751
Rotation			R.H.	L.H.

Open Water Characteristics

	Starboard			Port Propeller		
J	K_T	K_Q	η_0	K_T	K_Q	η_0
.30	.5676	.11840	.229	.5590	.11523	.232
.35	.5494	.11488	.266	.5404	.11167	.270
.40	.5302	.11120	.304	.5209	.10796	.307
.45	.5101	.10738	.340	.5005	.10411	.344
.50	.4893	.10342	.377	.4794	.10013	.381
.55	.4678	.09933	.412	.4575	.09602	.417
.60	.4456	.09512	.447	.4350	.09180	.453
.65	.4228	.09080	.482	.4119	.08747	.487
.70	.3994	.08637	.515	.3883	.08305	.521
.75	.3755	.08186	.548	.3642	.07853	.554
.80	.3512	.07726	.579	.3397	.07394	.585
.85	.3265	.07258	.609	.3148	.06929	.615
.90	.3015	.06784	.637	.2897	.06457	.643
.95	.2762	.06303	.663	.2643	.05980	.668
1.00	.2507	.05819	.686	.2387	.05499	.691
1.05	.2251	.05330	.706	.2130	.05014	.710
1.10	.1994	.04837	.721	.1872	.04528	.724
1.15	.1736	.04343	.731	.1615	.04039	.732
1.20	.1478	.03848	.734	.1358	.03551	.730
1.25	.1221	.03351	.725	.1102	.03062	.716
1.30	.0965	.02856	.699	.0848	.02575	.681
1.35	.0712	.02362	.647	.0596	.02090	.613

TABLE 11 – PREDICTION OF PERFORMANCE FOR OVERLAPPING PROPELLER ARRANGEMENT, USING OPEN WATER CHARACTERISTICS OF TROOST SERIES DESIGN PROPELLERS (PROGNOSIS BASED ON PROPULSION TEST 26)

MØDEL 5218-1

MØDEL LENGTH	= 25.67 FT	SHIP LENGTH	= 779. FT
MØDEL DISPL.	= 3006. LBS	SHIP DISPL.	= 38520. TØNS
MØDEL W.S.	= 93.69 SQ FT	SHIP W.S.	= 86210. SQ FT
RHØ-MØDEL	= 1.9367	RHØ-SHIP	= 1.9905
NU -MØDEL	= 1.0836E-05	NU -SHIP	= 1.2817E-05
NØ. ØF SHAFTS	= 2	PRØP DIAM-S-	= 22.75 FEET
DELTA CF	= .0002	LAMBDA	= 30.334

RESULTS ARE FRØM FAIRED CØEFFICIENTS   ITTC FRICTIØN USED

Propulsion Data for Propellers Combined

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	17930.	25480.	73.1	.704	1.093	1.060	1.339
24.00	24430.	34840.	80.7	.701	1.083	1.051	1.324
25.00	29030.	41540.	84.8	.699	1.070	1.037	1.312
25.50	31680.	45440.	86.9	.697	1.061	1.028	1.306
26.00	34590.	49740.	89.0	.696	1.053	1.017	1.300
27.00	40950.	59430.	93.6	.689	1.039	1.002	1.284

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.816	.792	.851	.936	.721	1.042
24.00	.818	.794	.850	.939	.718	1.039
25.00	.815	.790	.849	.940	.714	1.041
25.50	.813	.787	.848	.939	.712	1.044
26.00	.810	.783	.848	.937	.709	1.047
27.00	.809	.780	.846	.936	.703	1.046

TABLE 11 – Continued

Propulsion Data for Starboard Propeller

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	8970.	12650.	73.1	.709	1.105	1.079	1.339
24.00	12220.	17300.	80.7	.706	1.095	1.070	1.324
25.00	14510.	20560.	84.8	.706	1.081	1.058	1.312
25.50	15840.	22500.	86.9	.704	1.073	1.049	1.306
26.00	17300.	24650.	89.0	.702	1.065	1.038	1.300
27.00	20470.	29470.	93.6	.695	1.050	1.022	1.284

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.825	.806	.851	.951	.723	1.031
24.00	.827	.808	.850	.953	.720	1.028
25.00	.824	.806	.849	.957	.716	1.030
25.50	.822	.803	.848	.956	.714	1.032
26.00	.819	.799	.848	.953	.711	1.036
27.00	.818	.796	.846	.952	.706	1.034

Propulsion Data for Port Propeller

V	P_E	P_D	n	η_D	J_T	J_Q	J_V
22.00	8970.	12820.	73.1	.699	1.081	1.040	1.339
24.00	12220.	17520.	80.7	.697	1.071	1.031	1.324
25.00	14510.	20950.	84.8	.693	1.058	1.015	1.312
25.50	15840.	22910.	86.9	.691	1.050	1.006	1.306
26.00	17300.	25060.	89.0	.690	1.041	.996	1.300
27.00	20470.	29920.	93.6	.684	1.027	.981	1.284

V	$1-w_T$	$1-w_Q$	1-t	η_R	η_O	η_H
22.00	.808	.777	.851	.923	.719	1.054
24.00	.809	.779	.850	.926	.716	1.051
25.00	.806	.774	.849	.924	.712	1.053
25.50	.804	.770	.848	.923	.710	1.055
26.00	.801	.766	.848	.922	.707	1.059
27.00	.800	.764	.846	.922	.701	1.058

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13. ABSTRACT

A model test program was carried out at the Naval Ship Research and Development Center to determine the performance of a high-speed containership with overlapping propellers. The afterbody lines and propulsion arrangement was developed as a modification to the 25.5-knot contrarotating version of the Maritime Administration C9-ST-86a design. Results of the model tests are compared with the performance of the twin-screw C9-ST-86a design and the contra-rotating parent form. Conclusions and recommendations for future investigations of the over-lapping propeller arrangement are given.

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