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船体及び推進器の汚損が推進性能に及ぼす影響に関する研究
················第4研究部会

Investigation into the Effect of Fouling of a Ship and Propeller upon Propulsive Performances of a Ship
················The 4th Research Committee

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Preface

Since a perfect anti-fouling paint has not yet been discovered, the important problem concerning the effects of fouling upon the propulsive performances remains to be investigated.

This report is intended to give a comprehensive account of the results dealing with the fouling of hull surfaces and propellers, obtained in full-scale and model experiments.

The full-scale measurements were carried out in cooperation with the Transportation Technical Research Institute, the University of Mercantile Marine and others. The model experiments were performed in the tank and wind tunnel of the Transportation Technical Research Institute.

April, 1956

CONTENTS

Notations	Description
c	......Cord length of blade section of propeller
C_f	......Frictional resistance coefficient
D	......Diameter of propeller
F	......Froude's number
g	......Acceleration of gravity
h	......Height of protuberance excluding the base plate
k	......Height of protuberance including the base plate
L	......Length of ship between perpendiculars
n	......Revolution coefficient
N	......Number of revolutions per second
p'	......Power coefficient
q	......Torque constant
Q	......Torque
R	......Resistance
R_{fs}	......Frictional resistance of ship
R_{fm}	......Frictional resistance of model
R_s	......Total resistance of ship
R_m	......Total resistance of model
r_{fm}	......Frictional resistance coefficient of model
r_{fs}	......Frictional resistance coefficient of ship
r_m	......Total resistance coefficient of model
r_s	......Total resistance coefficient of ship
r_w	......Residual resistance coefficient
R_e	......Reynolds' number
S	......Wetted surface
T	......Thrust
t	......Thrust constant, Thrust deduction coefficient, Thickness of the base plate
t_s'	......Thrust coefficient
V	......Speed of ship in m/sec
V_s'	......Speed of ship in knots
v	......Advance constant
w	......Wake fraction
w_n	......Nominal wake fraction
w_e	......Effective wake fraction
ρ	......Density of water
ν	......Kinematic viscosity of water
η	......Propulsive efficiency
η_p	......Propeller efficiency
η_p'	......Propeller efficiency behind the ship
η_h	......Hull efficiency
η_r	......Relative rotative efficiency
λ_s	......Friction constant of ship
λ_m	......Friction constant of model
λ_{sF}	......Froude's friction constant of ship
∇	......Volmatic displacement
DHP	......Delivered horse power
EHP	......Effective horse power
RPM	......Number of revolutions per minute

INVESTIGATION INTO THE EFFECT OF A SHIP AND PROPELLER UPON PROPULSIVE PERFORMANCES OF A SHIP

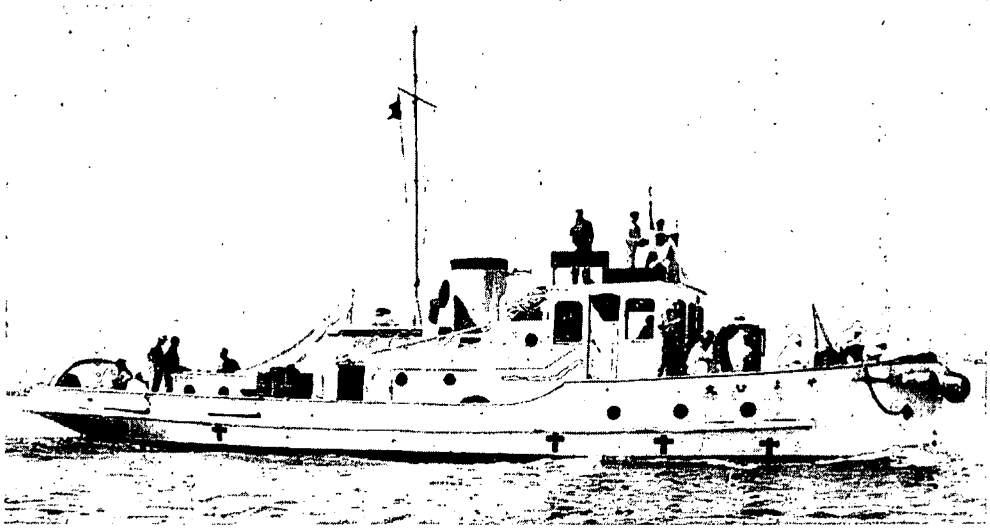
Introduction

It has been generally recognized that the fouling of a ship's hull and propeller surface greatly reduces the propulsive performance of the ship.

A few investigations have been performed in this scope of research. The Fourth Committee of the Shipbuilding Research Association of Japan intended to clear the problems concerning the fouling of a ship, and carried out systematic full-scale measurements and model tests.

In July, 1952, preliminary measurements on the actual ship were performed. Following the first experiments, several full-scale measurements were conducted, wake, resistance, thrust, DHP and other factors being measured under different conditions of fouling of hull surface. Corresponding to these conditions of the actual ship, model experiments with roughened hull surface were carried out, from March to September, 1953.

Immediately after these tests, model experiments on the propeller with roughened blade surface were performed.



Training Ship "YAYOI MARU"

Full-scale measurements on the actual ship with roughened propeller were carried out in June of 1954, after the preliminary tests at the end of 1953.

This report contains the experiments mentioned above.

In the appendix are shown wind tunnel tests, which were performed to analyse the data of the full-scale measurements on the actual ship, and some investigations into marine growths on the surfaces of the ship's hull and propeller.

In addition to the above-mentioned experiments, twelve sample plates were painted with the same paints as used on the hull, and were exposed to the water in Orido Bay at the position near the ship moored, in order to examine the rate of fouling and to subject them to resistance tests in the tank at the same time as that of the full-scale tests.

Unfortunately, however, all the plates except the one already tested were swept away by a Tsunami due to an earthquake which occurred in the Kamchatka district.

PART I. EFFECTS OF FOULING OF A SHIP'S HULL UPON PROPULSIVE PERFORMANCES

Chapter 1

Full-Scale Measurements on the Actual Ship

1. Descriptions of ship and the methods of tests

The Yayoi-maru, a small-size training vessel of the University of Mercantile Marine, was chosen as the actual ship because of her installation of a thrust meter, although she was built in 1930 and the surface of the bottom plate was somewhat corroded.

Principal particulars of the ship are as follows:—

Length (between perpendiculars)	18.288 m
Length (overall)	19.866 m
Breadth (including skin)	4.284 m
Depth (including skin)	2.414 m
Main engine . . . 200 BHP × 380 RPM diesel,	one set

The lines and general arrangement of the ship are shown in Figs. 1–1 and 1–2. Since the draft could not be kept constant throughout the whole period of experiments, displacement varies a little in each experiment.

The mean values of draft, displacement, coefficients, etc., are as follows:—

Draft (from the bottom of keel)	1.934 m
Displacement	78.6 tons
Wetted surface	95.0 m^2
Block coefficient	0.540
Prismatic coefficient	0.584
Midship section coefficient	0.925
Immersion of the propeller	1.165 m

The principal particulars of the propeller are shown in Fig. 1–3.

The Yayoi-maru had been moored in Orido Bay, Shimizu, for about fifteen months after being cleaned and repainted at the end of June, 1952.

In the course of time, several sets of experiments were performed, the proper time being chosen with the view to the rate of fouling. The extent of fouling of the ship's bottom was inspected at each experiment when she was on a slip.

At the time of the wake and resistance tests, the ship was towed by a tug-boat, Hakuryu-maru, belonging to the Shimizu Harbour Office of the Ministry of Transportation.

Principal particulars of the Hakuryu-maru are as follows:—

Length (between perpendiculars)	20.00 m
Breadth (moulded)	4.80 m
Depth (moulded)	2.35 m
Draft (moulded)	1.65 m
Displacement	48.66 tons
Main engine	210 BHP × 380 RPM diesel, one set

The tow line had a length of 140 m, seven times as long as the length of the tug. This length was determined with reference to the

Members who took share in the full-scale measurements

Name	Position
Masao Yamagata	Faculty of Technology, University of Tokyo
Iwakichi Tanaka	University of Mercantile Marine
Takeo Nohara	do.
Hatsuzo Tani	do.
Yasushi Nakashima	do.
Fumihiko Kawamoto	do.
Shoichi Kamouchi	do.
Noboru Akahori	do.
Masaji Nagasaka	do.
Sakuichi Togino	Tokyo College of Science
Toshio Sekikawa	do.
Ryoichi Odazawa	Shimizu Shipyard, Nippon Steel Tube Co., Ltd.
Shoichi Sakura	do.
Shiro Kan	Transportation Technical Research Institute
Hisamitsu Shiba	Ship Performance Division, Transportation Technical Research Institute
Yasubumi Yamanouchi	do.
Naoyoshi Matsumoto	do.
Kiyoshi Tsuchida	Ship Propulsion Division, Transportation Technical Research Institute
Koichi Yokoo	do.
Atsuo Yazaki	do.
Ryo Tazaki	do.
Hajime Takahashi	do.

results of the model experiments in the tank of the Transportation Technical Research Institute and the experiences obtained by the ex-Navy.

It was inevitable that the propeller should have been fouled when the ship was at rest in the berth. In this experiment, however, we confined ourselves to an investigation of the effects of fouling of the ship's bottom. The surface of the propeller, therefore, was brushed when she was slipped just before the self-propulsion tests.

The experiments were generally performed on the properly arranged course off the Nippon Light Alloy Co., Ltd., and sometimes the measured mile trial course off Okitsu was added for reference.

In case of unfavourable sea conditions, Orido Bay or its entrance channel was used, where the sea surface was comparatively smooth. But this happened only a few times.

The minimum depths of these waters were 14, 18, 9 and 8 m, respectively. For the depth of more than 10 m, no shallow water effect can be considered to exist in the case of the Yayoi-maru; therefore, both in Orido Bay and entrance channel the shallow water effects are considered to be negligible.

2. Test conditions

Several days after repainting, the first full-scale experiments were carried out, but they failed because of incomplete preparations for the tests. The second full-scale experiments were performed at the end of August, and the third at the beginning of October. But, contrary to our expectation, fouling was very slight during these periods. This was probably because of the effectiveness of anti-fouling paints. Thus, further experiments were postponed to the next year and the experiments with clean bottom were again performed after these experiments with fouled bottom. The extent of fouling of the ship's bottom was inspected when the Yayoi-maru was slipped before each experiment, and their results are shown in Appendix II.

Test conditions of all the experiments are shown in Table 1–1, together with the sea conditions of that time. In this table are shown mean values in each test. All the experiments, except the self-propulsion tests on October 14, 1952, and the wake tests on October 23, 1953, were performed on the course off the Nippon Light Alloy Co., Ltd. Although there were sometimes small waves, the sea was generally very smooth. It can be considered, therefore, that the effect of waves was not appreciable.

Displacement shown in the table was read from the hydrostatic curves and corresponds to the clean bottom. This will be increased in fouled condition, but its amount will be small enough to be negligible.

The fourth experiment was performed in January of 1953 only as a self-propulsion test. But all the measurements in this experiment failed.

3. Measuring instruments employed

(1) Speed meter

On the shore of the Light Alloy Co., Ltd., temporary mile-posts were built at intervals of 325.7 m. The ship was run on a course parallel to these and her speed over the ground was measured.

Since, however, it is preferable to measure the speed through the water, a Shiba speed meter*[1] and a pitot tube type of speed meter were used. The principle of the former shown in Fig. 1–4 is to count the number of Kármán vortices behind a triangular cylinder. The pitot tube type of speed meter attached to the stem is shown in Fig. 1–5.

(2) Wake measuring instruments

In order to measure the wake of the ship at the position of her propeller, 25 pitot tubes, each of which has two holes of static head and total head, were arranged as shown in Fig. 1–6. Each of them was connected by a rubber pipe with a glass tube of the manometer on the deck. Water heads shown in the manometer were recorded by a camera, and the wake velocity at each position was calculated from the

*1. Experiment Tank Committee of Japan, "An Investigation into the Sea-Going Qualities of the Single-Screw Cargo Ship Nissei-Maru by Actual and Model Ship Experiments," 1954.

difference between total and static heads. The manometer is shown in Fig. 1-7.

(3) Resistance measuring instrument

A spring type of tension meter was attached to the end of tow line on the side of the Yayoi-maru as shown in Fig. 1-8, and the resistance was measured by the contraction of the spring. At the same time, the angle between the horizontal and the tangent to the tow line, together with the yaw angle of the line from the ship course, was measured in order to correct the values of resistance recorded by tension meter.

(4) Thrust meter

Thrust was measured by a Michel type thrust meter, to which some improvements were added. That is, a compressed air chamber was installed, to which 40 atm. of air pressure were given constantly from a starting air tank. Thus the oil pressure was gradually added to the back of the piston through a small opening of a released valve, and the oil pressure was read by a pressure gauge at the instant when the safety valve was opened. The Michel type thrust meter is shown in Fig. 1-9.

(5) Torsion meter*2

Torsion of the shaft was measured by a Togino torsion meter, shown in Fig. 1-10, and SHP was calculated from the value of torsion and number of revolutions of the propeller.

(6) Other instruments

Other factors necessary to know the propulsive performances of the ship are wind direction and its force, helm angle, angles of pitching and rolling, etc. The relative direction of wind was measured by a simple wind direction indicating disc, and the wind velocity by a Robinson Cup annemometer attached to the mast head.

The helm angle was measured by recording the rotation of the

*2. Sakuichi Togino, "Optical Torsion Meter for Small Vessel," Journal of The Society of Naval Architects of Japan, Vol. 93, 1953, p. 133.

rudder head. Bob weights were used for the measurement of rolling and pitching.

Furthermore, general meteorological observations and measurements of the temperature and specific gravity of sea water were performed every hour.

4. Wake experiments

Taking the photographs of the water heads on the manometer several times in each run, the wake velocity at the position of each pitot tube was obtained from the difference between static and total heads. The wake fraction, which was obtained as a ratio of the average wake velocity to the ship speed through the water, is shown in Fig. 1–11 on a base of Froude's number.

Notations 1–1, etc., show the positions of the pitot tubes which are shown in Fig. 1–6. The wake curve corresponding to Notations 3–6 is omitted in this report for want of space.

It is clear from this figure that the wake is constant near the bottom independent of the ship speed, while near the water line it increases with the ship speed owing to ship waves.

In Fig. 1–12 is shown the wake distribution for each condition of fouling. In any case, the value of the wake attains nearly to unit near the center line of the ship. The reason why the results of No. 6 experiment are not given in Fig. 1–11, is that the measurements failed except in one run.

By integrating the wake values obtained as above over the propeller disc, the mean wakes will be obtained. They are shown in Fig. 1–13 on a base of lapse of time since last repainting. The mean wake for the most fouled condition of the bottom takes a value of about twice as that for the clean bottom.

5. Resistance experiments

Measured values in the resistance tests are shown in Table 1–2. Resistance values corrected for the angle of the tow-rope, wind force and displacement are shown in Fig. 1–14 on a base of the ship speed through the water, and Table 1-3 is their calculation sheet. There, the value obtained from the wind tunnel tests described in Appendix I is used as the wind direction effect coefficient.

Since in No. 6 experiment the record of the Shiba speed meter failed, the values of the ship speed are those obtained by the stem pitot tube, to which some corrections were added.

Compared with the resistance values of No. 2 and No. 3 experiments in which marine growths could hardly be found, the resistance values of No. 5 experiment show a remarkable increase over the resistance values of No. 9 experiment corresponding to the clean bottom. The resistance values of No. 7 experiment—about 15 months after repainting—show an increase of as much as 100% or thereabouts over the resistance values in the clean bottom. In Fig. 1-15 is shown the increase of resistance due to fouling on a base of the lapse of time since repainting.

6. Self-propulsion experiments

Measured values in the self-propulsion tests are shown in Table 1-5. Thrust, DHP and RPM corrected for wind force and displacement are shown in Fig. 1-16 on a base of the ship speed, and their calculation sheet is Table 1-6. Since in No. 2 experiment the readings of thrust were very inaccurate owing to insufficient adjustment, they are omitted in this figure.

DHP is obtained by reducing the friction loss, which was measured in the friction test performed without the propeller, from SHP measured in the runs. DHP for No. 2 experiment could not be obtained owing to lack of a friction test. Increases of DHP and thrust in the most fouled condition, that is, in No. 8 experiment, attain to about 120～130% over those in the clean bottom or No. 9 experiment. Fig. 1-17 shows the increase of DHP, thrust and RPM against the lapse of time since repainting.

7. Analysis of the test results and general considerations

Thrust deduction coefficient, calculated from the corresponding resistance and thrust curves, is shown in Fig. 1-18.

In Fig. 1–19 is shown the wake fraction, obtained from the results of the self-propulsion tests by using the characteristic curves of the actual propeller which will be described later.

Principal results, obtained from the experiments above mentioned, are as follows:—

(1) Wake, resistance, thrust, DHP and RPM greatly increase owing to the bottom fouling, and the increase will amount to over 100% in cases where all the bottom of the ship is covered with marine growths.

(2) Wake, resistance, thrust, DHP and RPM greatly increase owing to even slight fouling, but when the fouling has progressed to a certain extent, the rate of increase will diminish.

(3) Thrust deduction coefficient changes little inspite of the bottom fouling and the ship's speed.

Chapter 2
Model Experiments

1. Model ship and propeller

The model ship of the Yayoi-maru was made to a scale of 1/5.225 and has principal dimensions as shown in Table 2–1, where the draft corresponds to the average value of the actual ship in the full-scale measurements. The model propeller was made similarly to the actual propeller. Diameter of the model propeller is 24.21 cm.

2. Method of experiments and measuring instruments

The model experiments were performed under conditions corresponding to the actual ship.

Table 2–1. Principal Dimensions and Coefficients of Model

Length (between perpendiculars)	3.5000 m
Length (on L.W.L.)	3.4790 m
Breadth (including skin)	0.8200 m
Draft (〃)	0.3474 m
Displacement	0.5409 m^3
Wetted Surface Area	3.9057 m^2
Block Coefficient	0.539
Prismatic Coefficient	0.584
Midship Coefficient	0.924

Besides the resistance and self-propulsion experiments with several different kinds of roughened surfaces, the wake over the propeller disc was directly measured on a model by pitot tubes similar to those in the full-scale measurements. However, because of the small size of the model pitot tubes, both holes of total and static heads could not be made on one tube, and therefore, 25 pitot tubes with only the total head hole, and the same number of tubes with only the static head hole were arranged symmetrically on the starboard and port sides.

A Gebers' resistance dynamometer was used for the resistance tests, and his propeller dynamometer for the self-propulsion tests.

In the case of self-propulsion tests with clean bottom, several kinds of friction correction were adopted, but the tests with roughened surface were performed at only the self-propulsion point of the model.

3. Test conditions and methods of surface roughening

In the case of the tests with clean bottom, several kinds of trim and displacement were adopted in order to investigate their effects upon resistance, while with roughened bottom the experiments were performed at only one draft corresponding to the average draft of the actual ship in the full-scale measurements.

Three kinds of sands were used to roughen the hull surface of the model, and they were glued with "Cemedine" over the whole surface below the water line. The sizes of sands are shown in Table 2-2.

An example of the roughened model is shown in Fig. 2-1.

Though the draft was kept constant throughout the whole period of experiments, the displacement naturally increased owing to sand

Members who took share in the model experiments

Name	Position
Masao Yamagata	Faculty of Technology, University of Tokyo
Shiro Kan	Transportation Technical Research Institute
Kiyoshi Tsuchida	Ship Propulsion Division, Transportation Technical Research Institute
Koichi Yokoo	do.
Hajime Takahashi	do.
Atsuo Yazaki	do.
Hisamitsu Shiba	Ship Performance Division, Transportation Technical Research Institute

Table 2-2. Dimension of Sand used for Roughening Hull

Size of Sand	Average Dimension	Mesh used
Small	0.75 mm	20～24
Medium	1.50 mm	10～12
Large	2.20 mm	8～ 9

roughening. But the amount of the increase is only about 10 kg., even in the most roughened condition, and, therefore, its effect is small enough to be negligible as compared with the other effects of roughness of the bottom.

4. Wake experiments

50 pitot tubes, arranged at the position of the propeller disc, were connected with the manometer on the towing carriage by rubber tubes. Taking the photographs of the height of water column in each glass tube of the manometer during the test, the velocity at each point is obtained from the difference between the total and static heads of the corresponding pitot tubes at the position symmetrical to the center line of the model ship.

The wake fraction, therefore, is calculated as the fraction of the wake velocity to the speed of the model.

The wake fraction at the position of each pitot tube is shown in Fig. 2-2 on a base of Froude's number for each condition of roughness. These figures show that the wake near the hull and the surface of water has a greater value than expected, and that the effect of roughness becomes larger near the hull and the surface of water but insignificant at far distances from them. This shows the same tendency as in the case of the actual ship. The variation of the wake due to the ship's speed occurs to some extent near the water surface. Near the bottom of the model, the wake value is nearly constant independent of the ship speed. The pitot tubes at the position nearest the hull surface (that is, the pitot tubes of the upper parts of No. 4 and 5 columns) are in the eddies behind the model and, therefore, the values of the total heads less static heads fluctuated in the neighbourhood of zero. This phenomenon was remarkable in the case of the tests with roughened hull surface. Use of the pitot tubes in such a region is considered to be inadequate, but, for the moment, the wake fraction at each point was calculated from the mean value of them. When the mean value becomes negative, it was assumed that the wake fraction $w=1.0$.

Wake distribution on the propeller disc for each condition of roughness is shown in Fig. 2–3, which was obtained from the results in Fig. 2–2, where the speed of the model corresponds to Froude's number= 0.25. The effect of roughness upon the wake will be recognized more clearly from these figures. In the region of $w=0.10$ or less, the wake seems to be nearly independent of both the ship speed and roughness of the bottom.

5. Resistance experiments

Resistance experiments with clean bottom were performed for several kinds of displacements and trims. The results are shown in Fig. 2–4. R_{mf} was calculated by Froude's friction formula. Among the test conditions, 'C' corresponds to the average condition of the actual ship in the full-scale measurements, and the experiments with roughened bottom were performed always under this condition. Variations of the resistance due to the trim can, more or less, be seen in this figure, but this may be considered to be unimportant, because all the conditions of the actual ship in the full-scale experiments were much the same. The results of the resistance experiments for each condition of roughness are shown in Fig. 2–5, together with the results for clean bottom, for reference. The value of r_s in this figure is the total resistance coefficient for the actual ship estimated from the model results.

The resistance increases considerably even in the condition where the bottom is covered with sands of small size, but the rate of increase of the resistance falls off with increase of the size of sand grains.

Assuming that the wave making resistance is independent of roughness of the bottom, the frictional resistance coefficient, obtained by deducting the wave making resistance from the total resistance for each condition of roughness, is shown in Fig. 2-6 on a base of Reynolds' number. The coefficient has a nearly constant value, as expected, independent of the ship's speed.

6. Self-propulsion experiments

Before the experiments with roughened bottom, self-propulsion tests with the clean bottom were performed, by using various friction corrections. The results are shown in Fig. 2-7. As the friction coefficient for the ship λ_s, values of one, two and three times as Froude's were adopted.

Increase of λ_s implies the increase of frictional resistance, but the increase of power coefficient p' is greater than that of λ_s. This is mainly due to the drop of the propeller efficiency caused by the increase of propeller load.

The results of the self-propulsion experiments with roughened bottom are shown in Fig. 2-8. This figure shows that the roughness of the hull surface causes the values of thrust coefficient t'_s, power coefficient p' and revolution coefficient n to increase considerably and even in the smallest size of roughness, it has an appreciable influence upon these coefficients, and that the rates of increase of these coefficients fall off with the increase of the degree of roughness.

DHP curves and others obtained from the results of Fig. 2-8, are shown in Fig. 2-9.

7. Analysis and considerations on the results of experiments

Thrust deduction coefficient t, calculated from the results both of the resistance and self-propulsion experiments, is shown in Fig. 2-10. It has been generally said that the thrust deduction coefficient has a certain relation to the wake fraction. But the results of these experiments show that the thrust deduction coefficient retains a nearly constant value for every condition of roughness in spite of the remarkable increase of the wake fraction due to roughness. The thrust deduction coefficient, however, tends to increase very slightly with the increase of roughness of hull surface of the model ship. From these results it will be considered that the thrust deduction coefficient depends mainly on the potential wake and not much on the frictional wake.

In Fig. 2–11 are shown the effective wake fractions, obtained by the same 'thrust' method from the results of the self-propulsion tests with the use of the characteristic curves of the model propeller which will be described later. The increase of the wake fraction due to roughness is almost similar to that obtained in the wake tests. Fig. 2–12 shows the hull efficiency calculated from the results of Figs. 2–10 and 2–11. As expected from the results of Figs. 2–11 and 2–12, hull efficiency increases with the degree of roughness.

In Fig. 2–13 is shown the relative rotative efficiency. This is an ordinary value in the case of a type of ship such as the Yayoi-maru.

Chapter 3

Comparison of the Results of the Model Experiments with those of the Full-Scale Experiments

1. Resistance

In comparing the results of the model experiments with those of the full-scale measurements, it is the most simple to use the results of the resistance tests.

Here, it was assumed that the wave making resistance, obtained by deducting the frictional resistance, calculated by Froude's friction formula, from total resistance measured on the model with clean bottom, remains unchanged not only in the case of the model with roughened surface, but also in the case of the actual ship. Upon this assumption, the frictional resistance for each roughness condition was obtained by deducting the wave making resistance from the total resistance. Frictional resistance coefficients thus obtained are plotted on a base of Reynolds' number in Fig. 3–1.

As the bottom conditions of the actual ship do not exactly correspond to those of the model ship, direct comparison can not be made.

The frictional resistance coefficients give nearly a constant value, independent of Reynolds' number, in the case of heavy fouling, but with light fouling or clean bottom, they diminish with the increase of Reynolds' number. The frictional resistance coefficients for the actual ship with clean bottom show rather higher values, compared with the Schoenherr's turbulent friction line, but this is reasonable if we took into account the roughness of the corroded shell plates of the Yayoi-maru.

2. Thrust, DHP and RPM

As there is no exact correspondence between the roughness of the actual ship and that of the model, the comparisons were made at the equal point of frictional resistance coefficients. DHP, thrust and RPM are plotted on a base of c_f in Fig. 3-2. All points both for the model experiments and for the full-scale tests lie nearly on a straight line. This means that the same frictional resistance coefficients will give the same DHP, thrust and RPM, irrespective of the variation of fouling.

3. Thrust deduction coefficients and wake fractions

Thrust deduction coefficients and wake fractions both of actual ship and model are plotted on a base of c_f in Fig. 3-3. It can be seen from Fig. 3-3 that the effective and nominal wakes for the actual ship are in reasonably good agreement with the results of model experiments. On the other hand, there is a considerable difference between the effective and nominal wakes, which increases with the degree of fouling, but with clean bottom these two wakes are in good agreement with each other.

There might be some reasons for the difference of the wake with fouled bottom, but further researches will be necessary to clear this problem.

In Fig. 3-3 is also shown the hull efficiency, obtained from the thrust deduction coefficient and effective wake fraction.

Table 1-1. Test Conditions

Experiment No.	2				3			
Kind of Test	Self-Propulsion	Wake	Resistance	Self-Propulsion	Wake	Resistance	Self-Propulsion	Self-Propulsion
Date	1952 Aug. 18	Aug. 20	Aug. 20	Aug. 22	1952 Oct. 4	Oct. 4	Oct. 5	Oct. 14
Weather*1	B	B	B	B	B C	B C	B C	B C
Wind Direction & Force	NE~SE, 1	E~ENE 1~2	S~SW 2~4	ENE~NE, 1	NE~ENE, 1	SSE~SSW, 1	E~NE 3~1	NE~ESE, 3
Wave Scale	Calm	Calm	Smooth	Calm	Calm	Calm	Calm	Calm
Temp. of Sea Water (deg. C)	27.5	28.1		27.3	23.1		22.6	21.9
Specific Gravity of Sea Water	1.019	1.018		1.020	1.021		1.019	1.020
Draft (m) Fore	1.94	1.94	1.95	1.90	1.91	1.91	1.90	1.89
Draft (m) Aft	2.03	1.96	1.95	2.01	1.97	1.96	2.03	2.03
Draft (m) Mean	1.985	1.95	1.95	1.955	1.94	1.935	1.965	1.96
Displacement (tons)	81.2	79.4	79.4	79.8	79.0	78.8	80.6	80.0

Experiment No.	5			6			7			8	9			
Kind of Test	Wake	Resistance	Self-Propulsion	Wake	Resistance	Self-Propulsion	Wake	Resistance	Self-Propulsion	Self-Propulsion	Wake	Wake	Resistance	Self-Propulsion
Date	May 28	May 28	May 29	1953 July 8	July 8	July 9	Sep. 16	Sep. 16	Sep. 17	1953 Oct. 20	1953 Oct. 23	Oct. 24	Oct. 24	Oct. 25
Weather*1	C	C	R	C	D	C	C	C	C	B C	B C	C	C	B C
Wind Direction & Force	NNE, 2	E, 2	NNE, 2	ENE, 1	ENE, 1	SW, 1	NE, 2	SSW, 2	SSW, 3	ENE~ESE, 1	NE, 2	NE, 3	NE~SW 1~2	NE~ESE, 2
Wave Scale	Calm	Smooth	Smooth	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm
Temp. of Sea Water (deg. C)	20.6		20.3	27.3		24.8	26.1		27.5	21.6	21.0	20.6		20.6
Specific Gravity of Sea Water	1.023		1.021	1.019		1.018	1.018		1.017	1.020	1.021	1.021		1.021
Draft (m) Fore	1.85	1.87	1.87	1.86	1.84	1.85	1.82	1.82	1.80	1.80	—	1.84	1.83	1.80
Draft (m) Aft	2.01	1.99	1.98	2.00	2.01	1.93	2.05	2.03	2.03	2.03	—	2.01	2.02	2.03
Draft (m) Mean	1.93	1.93	1.925	1.93	1.925	1.89	1.935	1.925	1.915	1.915	—	1.925	1.925	1.915
Displacement (tons)	78.5	78.5	78.2	78.5	78.2	75.6	78.8	78.2	77.6	77.6	—	78.2	78.2	77.6

Remarks: *1. B=Blue sky; BC=Blue sky with cloud; C=Cloudy; D=Drizzling rain; R=Rain

Table 1-2. Measured Values

Exp. No.	Date	Number of Run	Engine Load	Direction of Run	Time at Inning	Time on Course	Ship Speed (knots)		
							Over Ground	Through Water	
								V_s*1	$(V_s)_p$*1
					h m	m s			
2	Aug. 20 1952	227	O.L.	W→E	14—40	1—14.8	8.46	8.72	
		228	〃	E→W	14—49	1—22.8	7.65	7.98	
		229	4/4	W→E	15—00	1—19.8	7.93	8.16	
		230	〃	E→W	15—10	1—28.7	7.14	7.39	
		231	3/4	W→E	15—19	1—26.7	7.31	7.58	
		232	〃	E→W	15—29	1—38.1	6.45	6.68	
		233	1/2	W→E	15—38	1—34.7	6.69	6.90	
		234	〃	E→W	15—52	1—45.9	5.98	6.24	
3	Oct. 4 1952	319	4/1	E→W	15—20	2—15.5	4.67	4.87	5.13
		320	〃	W→E	15—35	1—58.6	5.34	5.40	5.00
		321	1/2	E→W	15—45	1—42.9	6.16	6.56	6.50
		322	〃	W→E	15—53	1—33.0	6.81	6.93	6.51
		323	3/4	E→W	16—02	1—34.5	6.70	7.07	7.09
		324	〃	W→E	16—10	1—26.1	7.35	7.43	7.01
		325	4/4	E→W	16—18	1—28.4	7.16	7.62	7.51
		326	〃	W→E	16—25	1—21.4	7.82	7.84	7.53
		327	O.L.	E→W	16—33	1—22.7	7.66	8.03	7.92
		328	〃	W→E	16—40	1—16.5	8.28	8.26	7.93
5	May 28 1953	512	1/2	W→E	15—27	2—19.7	4.53	4.65	4.60
		513	〃	E→W	15—40	2—11.8	4.80	5.08	4.83
		514	3/4	W→E	15—52	1—43.3	6.13	6.36	6.22
		515	〃	E→W	16—02	1—36.7	6.55	6.79	6.37
		516	4/4	W→E	16—11	1—30.1	7.02	7.31	7.15
		517	〃	E→W	16—20	1—25.0	7.45	7.87	7.37
		518	〃	E→W	16—35	1—25.1	7.44	7.83	7.27
		519	O.L.	W→E	16—44	1—26.3	7.34	7.97	7.39
		520	〃	E→W	16—55	1—23.1	7.62	7.91	7.61
6	July 8 1953	631	1/2	W→E	15—20	2—10.9	4.84	4.66	4.40
		632	〃	E→W	15—35	2—28.4	4.27	4.86	4.59
		633	3/4	W→E	15—48	1—49.0	5.81	5.90	5.64
		634	〃	E→W	15—57	1—53.6	5.57	5.98	5.68
		635	4/4	W→E	16—08	1—37.9	6.47	6.60	6.36
		636	〃	E→W	16—13	1—40.6	6.29	6.60	6.37
		637	O.L.	W→E	16—23	1—28.4	7.16	7.38	7.12
		638	〃	E→W	16—30	1—31.6	6.91	7.40	7.14
7	Sep. 16 1953	719	1/4	W→E	14—10	2—34.7	4.09	4.16	3.85
		720	〃	E→W	14—25	2—52.9	3.66	4.22	3.92
		721	1/2	W→E	14—37	2—21.6	4.47	4.62	4.36
		722	〃	E→W	14—51	2—33.5	4.13	4.40	4.25
		723	3/4	W→E	15—01	1—50.5	5.73	5.92	5.55
		727	O.L.	E→W	16—00	1—37.6	6.49	7.01	6.66
		728	〃	W→E	16—07	1—51.6	6.91	6.95	6.72
		729	3/4	E→W	16—20	1—58.2	5.36	5.62	4.49
9	Oct. 24 1953	924	1/4	W→E	12—43	2—29.2	4.24	4.37	4.07
		926	1/2	W→E	13—05	2—10.0	4.87	4.88	4.67
		928	3/4	W→E	13—25	1—41.9	6.22	6.39	6.03
		930	4/4	W→E	13—44	1—31.1	6.95	7.14	6.71
		932	O.L.	W→E	14—00	1—23.8	7.56	7.72	7.41

Remarks: *1. V_s: speed measured by Shiba speed meter.

$(V_s)_p$: speed measured by pitot tube type of speed meter.

*2. Positive sign means "trim by the stern."

in Resistance Tests

Relative Wind		Helm Angle (deg.)			Trim*2	Angle*3 of Heel	Angle of Tow Line		Resistance*4
Direction (deg.)	Speed (knots)	Mean	Maximum		(cm)	(deg.)	To Horizontal Plane	To Vertical Plane	(kg)
			Port	Starboard					
S 97	17.6	S0.5	11.5	12.0		0	3.2	8.0	807
P 52	25.3	S0.8	8.0	11.0		0	3.9	2.4	833
S 90	16.4	S1.5	7.0	9.1		+1	4.5	7.0	650
P 53	25.2	S4.0	5.9	10.0		0	5.7	9.2	676
S 98	16.3	0	8.0	8.0		0	4.8	7.4	513
P 57	22.6	S5.0	2.5	7.5		0	6.2	3.9	496
S100	18.5	S1.2	4.0	2.5		0	6.6	3.6	386
P 60	21.4	S4.0	2.0	8.5		0	6.8	4.3	400
P 63	8.2	S3.5	8.8	6.0	−3	0	9.3	0.1	235
S 73	8.8	P0.3	5.0	4.0	−2	0	9.1	1.2	228
P 38	11.0	S4.5	7.5	9.5	−1	0	8.0	0	444
S 60	8.8	S2.8	6.5	9.0	0	0	7.6	5.1	440
P 32	11.0	S5.0	4.0	10.0	−1	0	6.6	0.1	530
S 47	8.7	S4.5	9.0	11.5	1	0	5.7	7.6	530
P 27	10.3	S1.0	9.0	10.0	0	0	5.4	0.9	680
S 45	9.0	S5.0	10.7	14.0	1	0	5.4	4.8	640
P 27	12.5	S2.0	13.5	10.5	0	0	5.6	1.2	820
S 38	8.0	S4.5	7.5	13.0	−2	0	5.2	4.6	764
P 27	15.6	0	3.1	2.2	0		9.3	3.8	300
S130	6.3	P1.0	3.0	1.0	0		9.9	6.2	280
P 19	20.0	P0.6	6.0	4.5	0		7.9	4.2	580
S158	8.8	P0.5	3.4	1.0	−1		7.3	7.4	540
P 8	21.1	P1.1	3.0	1.9	−7		6.0	5.2	800
P168	6.8	S1.0	6.0	11.0	−1		5.3	9.5	800
P162	6.9	S2.3	5.5	6.0	3		4.7	9.9	780
0	20.9	P1.1	10.0	5.0	9		4.2	5.6	1020
P158	6.6	S1.7	5.0	7.0	3		8.8	8.8	810
P 24	11.2	S3.8	2.5	6.0	−12	0	8.1	1.9	305
S125	9.0	S1.0	4.5	5.0	−11	−1	8.9	1.4	300
P 38	15.9	S3.2	1.5	8.5	−10	+1	7.0	1.9	492
S103	8.7	0	8.5	6.0	−12	−1	7.6	1.7	491
P 22	16.8	0	3.5	5.0	−11	+1	6.0	1.7	635
	0	S1.9	1.0	3.0	−11	0	6.5	1.6	652
S 5	11.9	S1.0	4.0	5.5	−11	0	5.6	2.2	817
	0	S1.7	4.5	7.0	−9	0	6.0	2.1	800
S 60	12.4	P2.2	3.0	−1.5	−31	0	8.8	1.2	265
P 56	9.5	P4.5	7.0	−2.5	−28	0	9.1	4.0	262
S 78	9.5	P0.6	1.5	0.7	−25	0	8.5	3.1	320
P 62	9.3	P1.1	2.0	0.6	−27	0	8.3	4.0	305
S 56	8.9	P1.4	3.5	0.7	−28	0	6.5	3.4	551
P 47	13.4	0	3.5	4.5	−34	0	5.9	2.9	825
S 67	11.1	S0.2	4.0	5.0	−34	−1	5.6	4.2	827
P 62	10.5	S0.1	2.5	4.0	−30	0	6.7	2.9	493
P 18	6.6	P0.2	3.5	2.0	−17	−1	11.5	7.3	134
P 23	5.1	P1.8	2.5	1.0	−12	−1	10.9	14.5	170
S 10	9.2	P0.7	6.3	3.0	−16	−1	7.9	8.3	325
0	10.4	P2.2	7.0	4.3	−12	−1	7.8	7.4	430
S 13	8.4	P0.8	10.0	10.7	9	−1	5.9	6.8	562

*3. Positive sign means "heel to starboard."

*4. These values are already corrected for the angle of tow-line.

Table 1-3. Analysis of the

Process of analysis

1. θ and V_w are the values corrected from the wind tunnel tests.
2. k was read from Fig. I-7.
3. $R''=R_a'-(R_a'-R_w')\frac{kV_{wa}^2-V_s^2}{kV_{wa}^2-kV_{ww}^2}$

Suffixes a and w indicate the runs against wind and with wind, respectively.

Exp. No.	Date	Number of Run	Engine Load	Measured Data: Ship Speed through the Water V_s (knots)	Measured Data: Resistance R' (kg)	Relative Wind: Direction θ (deg.)	Relative Wind: Speed V_w (knots)
2	Aug. 20 1952	227	O.L.	8.72	807	S 102	16.95
		228	〃	7.98	833	P 57	27.47
		229	4/4	8.16	650	S 96	15.60
		230	〃	7.39	676	P 60	27.96
		231	3/4	7.58	513	S 103	15.70
		232	〃	6.68	496	P 62	24.93
		233	2/4	6.90	386	S 104	17.87
		234	〃	6.24	400	P 66	23.18
3	Oct. 4 1952	319	1/4	4.87	235	P 69	8.67
		320	〃	5.40	228	S 79	8.75
		321	2/4	6.56	444	P 40	11.38
		322	〃	6.93	440	S 66	9.45
		323	3/4	7.07	530	P 35	11.73
		324	〃	7.43	530	S 51	9.13
		325	4/4	7.62	680	P 30	11.21
		326	〃	7.84	640	S 48	9.32
		327	O.L.	8.03	820	P 30	13.53
		328	〃	8.26	764	S 40	8.22
5	May 28 1953	512	2/4	4.65	300	P 30	16.96
		513	〃	5.08	280	S 130	6.43
		514	3/4	6.36	580	P 18	20.00
		515	〃	6.79	540	S 158	9.32
		516	4/4	7.31	800	P 9	19.81
		517	〃	7.87	800	S 168	7.31
		518	〃	7.83	780	P 162	7.34
		519	O.L.	7.97	1020	0	18.50
		520	〃	7.91	810	P 158	7.01
6	July 8 1953	631	2/4	4.66	305	P 26	11.85
		632	〃	4.86	300	S 125	9.09
		633	3/4	5.90	492	P 40	16.39
		634	〃	5.98	491	S 107	8.45
		635	4/4	6.60	635	P 24	17.50
		636	〃	6.60	652		0
		637	O.L.	7.38	817	S 6	10.97
		638	〃	7.40	800		0
7	Sep. 16 1953	719	1/4	4.16	265	S 66	13.37
		720	〃	4.22	262	P 61	10.56
		721	2/4	4.62	320	S 84	9.18
		722	〃	4.40	305	P 68	9.89
		723	3/4	5.92	551	S 61	9.89
		727	O.L.	7.01	825	P 51	14.03
		728	〃	6.95	827	S 73	11.44
		729	3/4	5.62	493	P 68	11.17
9	Oct. 24 1954	924	1/4	4.37	134	P 20	6.67
		926	2/4	4.88	170	P 25	5.37
		928	3/4	6.39	325	P 11	8.76
		930	4/4	7.14	430	P 3	9.41
		932	O.L.	7.72	562	S 14	8.20

Remarks: Analysis could not be made for the results of 7th and 9th Experiments

Results of Resistance Tests

4. R was corrected for the displacement. Standard displacement is 78.7 tons.
5. R_w was obtained from the model tests.
6. $R_f = R - R_w$
7. $C_f = \dfrac{R_f}{1/2\rho S V^2}$

Wind Direction Effect Coeff. k	Resistance Corrected for Wind Force R'' (kg)	Resistance Corrected for Displacement R (kg)	Wave Making Resistance R_w (kg)	Frictional Resistance R_f (kg)	Frictional Resistance Coeff. $C_f \times 10^3$	Reynolds' Number $R_e = VL/\nu \times 10^{-7}$
−0.13	866	861	513	348	3.45	9.65
0.80	635	631	370	261	2.79	8.83
−0.07	683	679	400	279	2.86	9.03
0.75	502	499	258	241	3.01	8.18
−0.13	542	539	290	249	2.95	8.39
0.73	385	383	190	193	2.95	7.40
−0.15	413	410	205	205	2.94	7.64
0.72	311	309	145	164	2.88	6.91
0.71	187	187	68	119	3.42	4.88
0.45	219	219	90	129	3.01	5.41
0.89	354	354	180	174	2.76	6.57
0.81	405	405	210	195	2.77	6.94
0.84	459	458	220	238	3.25	7.08
0.88	501	500	260	240	2.96	7.44
0.82	562	561	295	167	3.14	7.63
0.87	614	613	345	268	2.97	7.85
0.82	649	648	380	268	2.84	8.04
0.89	752	751	420	331	3.31	8.27
0.82	245	245	59	186	5.87	4.33
−0.70	297	297	76	221	5.84	4.73
0.83	503	504	157	347	5.85	5.92
−1.07	585	586	199	387	5.73	6.31
0.93	688	689	246	443	5.66	6.81
−1.02	852	853	352	501	5.52	7.33
−1.07	832	833	345	488	5.43	7.29
1.00	886	887	370	517	5.55	7.43
−1.07	862	863	359	504	5.50	7.37
0.82	294	296	60	236	7.41	4.93
−0.59	309	311	68	243	7.02	5.14
0.89	472	475	124	351	6.88	6.24
−0.16	496	499	127	372	7.10	6.32
0.83	605	609	183	426	6.67	6.98
	659	663	183	480	7.52	6.98
0.88	800	805	257	548	6.86	7.80
	818	823	260	563	7.01	7.82
0.78		266	46	220	8.67	4.35
0.74		263	47	216	8.26	4.41
0.26		321	58	263	8.40	4.83
0.71		306	51	255	8.98	4.60
0.74		553	125	428	8.33	6.19
0.88		828	214	614	8.52	7.33
0.63		830	211	619	8.75	7.27
0.71		495	106	389	8.40	5.88
0.83		134	55	79	2.82	4.24
0.82		171	69	102	2.92	4.59
0.89		326	161	165	2.76	6.01
1.00		431	225	206	2.76	6.72
0.84		564	323	241	2.76	7.26

owing to nearly same values of wind forces in each group of runs.

Table 1-4. Measured Values

Exp. No.	Date	Number of Run	Engine Load	Direction of Run	Time at Inning	Time on Course	Ship Speed (knots) Over Ground	Through Water V_s*1	$(V_s)_p$*1
					h m	m s			
3	Oct. 14 1952	349	D. Slow	S E→NW	14—07	0—20.0		5.38	
		350	〃	NW→S E	14—15	〃		4.80	
		351	Slow	S E→NW	14—21	〃		6.44	
		352	〃	NW→S E	14—26	〃		6.33	
		353	1/4	S E→NW	14—32	〃		7.50	
		355	〃	NW→S E	15—10	〃		7.25	
		356	1/2	S E→NW	15—14	〃		8.47	
		357	〃	NW→S E	15—19	〃		8.50	
		358	3/4	S E→NW	15—24	〃		9.70	
		359	〃	NW→S E	15—29	〃		9.58	
5	May 29 1953	525	4/4	W→E	10—27	1—06.4	9.53	9.66	9.38
		526	〃	E→W	10—34	1—07.9	9.33	9.60	9.45
		527	3/4	W→E	10—43	1—10.4	9.00	9.15	8.88
		529	〃	E→W	11—00	1—11.4	8.87	9.06	8.88
		530	1/2	W→E	11—08	1—21.1	7.81	8.00	7.71
		531	〃	E→W	11—13	1—21.5	7.77	8.00	7.71
		532	1/4	W→E	11—20	1—34.3	6.71	6.86	6.65
		533	〃	E→W	11—25	1—36.5	6.56	6.74	6.51
		534	S	W→E	11—32	1—48.6	5.83	6.08	5.77
		535	〃	E→W	11—37	1—50.1	5.75	6.09	5.70
		536	D. Slow	W→E	11—45	2—20.0	4.52	4.76	4.50
		537	〃	E→W	11—51	2—17.5	4.61	4.91	4.41
6	July 9 1953	639	D. Slow	W→E	15—59	2—22.5	4.44	4.42	4.27
		640	〃	E→W	16—10	2—49.4	3.74	3.90	4.19
		641	Slow	W→E	16—20	1—47.9	5.86	5.94	5.56
		642	〃	E→W	16—25	2—01.9	5.19	5.04	5.53
		643	1/4	W→E	16—35	1—35.3	6.64	6.69	6.35
		644	〃	E→W	16—41	1—46.2	5.96	5.99	6.29
		645	1/2	W→E	16—50	1—21.3	7.79	7.87	7.46
		646	〃	E→W	16—55	1—27.4	7.24	7.66	7.49
		647	3/4	W→E	17—00	1—11.9	8.81	8.94	8.56
		648	〃	E→W	17—06	1—14.3	8.52	8.98	8.72
7	Sep. 17 1953	734	3/4	W→E	16—10	1—13.5	8.62	8.52	8.22
		735	〃	E→W	16—17	1—17.4	8.18	8.48	8.62
		736	1/2	W→E	16—36	1—22.9	7.64	7.75	7.27
		737	〃	E→W	16—42	1—28.8	7.13	7.41	7.50
		738	1/4	W→E	16—44	1—39.5	6.36	6.64	6.16
		739	〃	E→W	16—54	1—45.2	6.02	6.15	6.28
		742	D. Slow	W→E	17—17	2—21.3	4.48	4.83	4.33
		743	〃	E→W	17—24	1—24.8	4.37	4.24	4.65
8	Oct. 20 1953	818	D. Slow	W→E	10—15	2—30.8	4.20	4.22	4.51
		820	〃	E→W	10—30	2—14.4	4.71	4.63	4.66
		821	Slow	W→E	10—41	2—04.2	5.10	5.18	5.27
		823	〃	E→W	11—01	1—58.2	5.36	5.37	5.28
		824	1/4	W→E	11—17	1—43.9	6.10	6.22	6.13
		825	〃	E→W	11—23	1—38.8	6.41	6.51	6.31
		826	1/2	E→W	11—29	1—26.6	7.31	7.49	7.27
		827	〃	W→E	11—35	1—24.8	7.46	7.64	7.37
		828	3/4	E→W	11—41	1—15.9	8.34	8.56	8.36
		829	〃	W→E	11—47	1—15.1	8.43	8.66	8.42
		830	4/4	W→E	11—53	1—10.9	8.93	9.08	8.97
		831	〃	E→W	11—57	1—11.0	8.92	9.13	9.02
9	Oct. 25 1953	933	D. Slow	W→E	10—03	2—06.2	5.02	4.93	5.39
		934	〃	E→W	10—10	1—55.8	5.47	5.43	5.29
		935	Slow	W→E	10—18	1—43.7	6.11	6.02	6.32
		936	〃	E→W	10—24	1—36.8	6.54	6.64	6.20
		937	1/4	W→E	10—29	1—27.7	7.22	7.01	7.47
		938	〃	E→W	10—35	1—23.2	7.61	7.84	7.41
		939	1/2	W→E	10—40	1—15.9	8.34	8.08	8.55
		940	〃	E→W	10—45	1—12.5	8.74	8.90	8.47
		941	3/4	E→W	10—49	1—08.2	9.28	9.44	9.47
		942	〃	W→E	10—53	1—06.3	9.55	9.96	9.33

Remarks: *1. V_s: by Shiba speed meter. $(V_s)_p$: by pitot tube type speed meter.

in Self-Propulsion Tests

Relative Wind		Helm Angle (deg.)			Trim (cm) *2	Angle of Heel (deg.)*3	RPM		Thrust (kg)	DHP
Direction (deg.)	Speed (knots)	Mean	Maximum				Engine Room	Shaft Tunnel		
			Port	Starboard						
S 140	12.3	P2.4	2.2	−2.2	−13		168	167	302	11.4
P 28	21.9	P1.5	2.0	−1.5	−13		168	162	297	11.2
S 143	14.3	P3.0	5.0	−2.8	−12		210	208	483	22.6
P 31	23.4	P1.5	1.5	−1.5	−16		216	212	518	24.6
S 130	14.1	P1.8	1.8	−1.8	−13		258	253	738	41.8
P 25	20.3	P2.0	2.0	−2.0	−13		258	247	726	39.5
S 120	11.5	P2.0	2.0	−2.0	−20		300	295	1067	68.9
P 27	22.7	P1.0	1.0	−0.8	−18		300	301	1185	75.5
S 123	13.3	P0.5	1.0	0	−11		348	347		121.1
P 23	22.9	P1.4	1.5	0	−18		360	352		129.8
P 54	18.8	P1.7	3.0	0	−17		372	376		158.4
S 65	17.2	P0.7	3.0	1.1	−15		373	374		155.9
P 59	17.5	P1.1	3.0	3.0	−11		343	343	1722	121.3
S 57	17.2	P0.4	2.0	1.0	−11		341	342	1736	120.3
P 56	15.6	P2.0	4.5	−0.5	−13		292	293	1213	76.0
S 69	14.3	P1.1	4.0	3.5	− 5		289	291	1213	74.7
P 65	16.1	P1.9	5.0	0	− 8		241	238	794	42.3
S 75	14.7	P2.2	3.1	0	− 5		236	234	781	40.4
P 60	17.9				− 5		207	207	600	27.8
S 73	15.1	P2.3	6.0	0	−11		207	207	610	27.8
P 66	14.5	S1.1	3.0	3.0	−11		160	158	357	11.9
S 88	13.9	P3.3	5.0	−0.5	−11		162	163	370	13.1
S 111	12.5	P4.5	7.0	−2.0	−13	+2	150	152	323	14.0
P 42	15.6	P3.0	3.5	−3.0	−13	+2	149	149	327	14.0
S 116	10.9	S3.5	S3.5	3.5		+1	206	208	574	30.0
P 42	16.4	P4.0	4.0	−4.0	−14	+2	208	209	602	33.1
S 107	12.0	P5.0	7.0	−4.0	−16	+1	242	244	824	46.2
P 33	19.8	P4.6	4.5	−3.0	−19	+1	242	243	835	48.0
S 81	10.7	P4.2	6.0	−1.5	−19	+1	294	296	1303	84.0
P 26	18.6	P4.3	5.5	−3.0	−20	+1	294	296	1332	85.4
S 74	7.1	P4.2	6.0	−3.0	−19	+1	346	348	1929	145.4
P 30	13.9	P2.4	5.5	−0.5	−20	+1	347	351	2010	150.4
S 70	15.8	P3.2	4.0	−2.7	−23	+1	350	349	1981	137.3
P 46	15.8	P3.2	4.6	−3.0	−22	+1	346	346	1981	134.3
S 67	12.1	P3.3	4.0	−2.5	−24	+1	297	298	1474	88.9
P 45	15.3	P4.0	4.0	−4.0	−23	+1	296	297	1441	89.7
S 71	12.0	P4.0	4.0	−4.0	−23	+1	244	244	937	50.4
P 42	12.3	P4.0	4.0	−4.0	−23	0	245	245	944	52.7
S 92	8.2	P4.5	7.0	−2.5	−24	+1	167	168	455	16.6
P 50	11.4	P2.9	3.1	−1.3	−24	+1	174	176	500	20.2
0	14.1	P4.0	5.0	−3.2	− 9	+1	170	166	501	20.7
S 148	2.3	P3.5	4.5	−2.5	− 6		172	171	513	18.9
P 4	15.2	P1.5	2.5	0.2	− 6	+1	205	207	701	32.8
S 108	3.9	P1.3	1.5	−0.7	− 6	+1	200	199	645	28.1
P 2	16.0	P1.7	2.5	−1.2	−11	+1	246	246	981	49.6
Calm	0	P1.5	1.5	−1.5	− 4	0	249	250	994	51.3
P 5	16.2	P1.2	2.0	0.5	− 9	+1	298	298	1497	89.2
Calm	0	P0.9	0.9	−0.9	− 6	0	297	297	1460	87.3
P 4	16.9	P0.5	2.0	0	−12	0	345	345	2051	140.0
Calm	0	0	0.3	0.7	− 8	0	348	347	2070	140.9
S 6	17.5	S0.3	1.0	2.5	−10	0	374	377	2547	184.8
S 6	17.8	S0.2	0	0.5	−12	0	372	374	2497	176.4
0	13.5	P2.5	3.0	0	−23	+1	166	167	312	12.6
S 81	5.6	P1.1	1.3	−1.0	−22	+1	164	164	292	10.9
P 5	13.5	P2.5	2.5	−2.5	−24	+1	203	203	474	22.5
S 77	6.0	P1.7	2.5	1.0	−23	+1	202	204	463	21.1
P 5	13.9	P2.2	2.5	2.0	−25	+1	248	249	737	41.7
S 18	6.1	P1.7	2.5	−1.5	−23	+1	251	251	725	39.7
P 4	15.5	P1.1	3.0	2.5	−29	+1	296	294	1090	70.6
0	7.4	P1.9	3.0	−1.0	−22	+1	297	300	1091	71.0
P 6	16.4	P1.5	2.0	−1.5	−28	+1	345	347	1644	121.0
0	10.0	P1.8	2.2	0.3	−25	0	346	349	1701	121.5

*2. Positive sign means "trim by the stern." *3. Positive sign means "heel to starboard."

Table 1-5. Analysis of the Results of Self-Propulsion Tests

Process of Analysis

1. θ and V_w are the values corrected from the wind tunnel tests.
2. k was read from Fig. I-7.
3. $q'=\frac{Q}{\rho N^2 D^5}=\alpha\frac{\text{DHP}}{(\text{RPM})^3}$, $\alpha=\frac{75\times 60^3}{2\pi\rho D^5}$
4. $q=q_a'-(q_a'-q_w')\frac{kV_{wa}^2-V_s^2}{kV_{wa}^2-kV_{ww}^2}$

   Suffixes a and w indicate the runs against wind and with wind, respectively. The values of q in this table are those read from the fair curve of q plotted on a base of RPM.
5. Corrected DHP $=\frac{(\text{RPM})^3}{\alpha}q$
6. Corrected speed $V_s'=V_s+\Delta V_s$, $\Delta V_s=\frac{N}{\beta}(q-q')$

   $\beta=\frac{\Delta q}{\Delta v}$ and it was calculated from the characteristic curves of model propeller.
7. $t'=\frac{T}{\rho N^2 D^4}=\delta\frac{T}{(\text{RPM})^2}$, $\delta=\frac{60^2}{\rho D^4}$
8. $t=t_a'-(t_a'-t_w')\frac{kV_{wa}^2-V_s^2}{kV_{wa}^2-kV_{ww}^2}$
9. Corrected thrust $T=\frac{(\text{RPM})^2}{\delta}t$
10. DHP and T were corrected for the displacement. Standard displacement is 78.7 tons.

Exp. No.	Date	Number of Runs	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	Measured Data: RPM (Shaft Tunnel)	Measured Data: DHP	Measured Data: Thrust T' (kg)	Relative Wind: Direction θ (deg.)	Relative Wind: Speed V_w (knots)	Wind Direction Effect Coeff. k	Correction for Wind Force: Torque Constant q'	Corrected Torque Constant q	Corrected DHP	Corrected Speed V_s' (knots)	Thrust Constant t'	Corrected Thrust Constant t	Corrected Thrust T (kg)	Correction for Disp.: DHP	Correction for Disp.: Thrust T (kg)
3	Oct. 14 1952	349	D. Slow	5.38	167	11.4	302	S139	12.7	−0.86	0.0188	0.0191	11.6	5.27	0.146	0.148	306	11.5	303
		350	〃	4.80	162	11.2	297	P 30	23.8	0.81	0.0201	0.0191	10.6	5.13	0.153	0.149	289	10.5	287
		351	Slow	6.44	208	22.6	483	S142	14.9	−0.90	0.0192	0.0193	22.7	6.40	0.151	0.153	489	22.5	485
		352	〃	6.33	212	24.6	518	P 34	24.9	0.82	0.0198	0.0193	24.0	6.55	0.156	0.153	508	23.8	504
		353	1/4	7.50	253	41.8	738	S129	14.2	−0.70	0.0198	0.0199	42.1	7.45	0.156	0.158	747	41.8	740
		355	〃	7.25	247	39.5	726	P 28	21.8	0.82	0.0201	0.0198	39.0	7.41	0.161	0.157	708	38.7	702
		356	2/4	8.47	295	68.9	1067	S121	11.5	−0.45	0.0205	0.0206	69.1	8.41	0.166	0.169	1082	68.6	1073
		357	〃	8.50	301	75.5	1185	P 30	24.7	0.81	0.0212	0.0208	74.1	8.75	0.177	0.171	1145	73.5	1135
		358	3/4	9.70	347	121.1		S124	13.3	−0.54	0.0222	0.0224	122.3	9.56				121.2	
		359	〃	9.58	352	129.8		P 25	24.1	0.81	0.0228	0.0225	127.8	9.78				126.7	
5	May 29 1953	525	4/4	9.66	376	158.4		P 59	20.9	0.76	0.0228							159.0	
		526	〃	9.60	374	155.9		S 71	17.9	0.68	0.0228							156.5	
		527	3/4	9.15	343	121.3	1722	P 65	19.0	0.73	0.0230				0.198			121.8	1730
		529	〃	9.06	342	120.3	1736	S 62	18.9	0.74	0.0230				0.200			120.8	1743
		530	2/4	8.00	293	76.0	1213	P 61	17.3	0.74	0.0231				0.191			76.3	1218
		531	〃	8.00	291	74.7	1213	S 75	14.6	0.57	0.0232				0.195			75.0	1218
		532	1/4	6.86	238	42.3	794	P 71	16.8	0.68	0.0240				0.189			42.5	797
		533	〃	6.74	234	40.4	781	S 81	14.4	0.39	0.0241				0.192			40.6	784
		534	Slow	6.08	207	27.8	600	P 66	19.2	0.69	0.0240				0.189			27.9	602
		535	〃	6.09	207	27.8	610	S 79	15.0	0.46	0.0240				0.192			27.9	612

		536	D. Slow	4.76	158	11.9	357	P 72	15.1	0.66	0.0231				0.193			12.0	358
		537	〃	4.91	163	13.1	370	S 94	13.1	−0.05	0.0232				0.188			13.2	371
6	July 9 1953	639	D. Slow	4.42	152	14.0	323	S 114	12.3	−0.27	0.0305	0.0308	14.1	4.34	0.189	0.191	327	14.5	336
		640	〃	3.90	149	14.0	327	P 45	15.8	0.82	0.0324	0.0312	13.5	4.25	0.199	0.192	315	13.9	324
		641	Slow	5.94	208	30.0	574	S 118	10.8	−0.39	0.0255	0.0262	30.8	5.67	0.179	0.181	581	31.7	597
		642	〃	5.04	209	33.1	602	P 45	16.6	0.82	0.0277	0.0261	31.1	5.71	0.186	0.181	586	32.0	602
		643	1/4	6.69	244	46.2	824	S 110	11.8	−0.18	0.0243	0.0245	46.5	6.58	0.187	0.188	828	47.8	851
		644	〃	5.99	243	48.0	835	P 36	20.8	0.85	0.0256	0.0245	46.0	6.53	0.191	0.188	822	47.3	845
		645	2/4	7.87	296	84.0	1303	S 87	10.2	−0.13	0.0248	0.0249	84.4	7.84	0.201	0.202	1308	86.8	1345
		646	〃	7.66	296	85.4	1332	P 29	20.0	0.82	0.0252	0.0249	84.4	7.82	0.206	0.202	1308	86.8	1345
		647	3/4	8.94	348	145.4	1929	S 80	7.0	0.42	0.0264	0.0264	145.4	8.94	0.215	0.216	1933	149.5	1987
		648	〃	8.98	351	150.4	2010	P 33	15.0	0.83	0.0266	0.0265	149.8	9.01	0.220	0.216	1973	154.0	2028
7	Sep. 17 1953	734	3/4	8.52	349	137.3	1981	S 76	16.0	0.54	0.0247	0.0245	136.2	8.63	0.220		1981	137.3	1997
		735	〃	8.48	346	134.3	1981	P 50	16.5	0.88	0.0247	0.0245	132.7	8.63	0.223		1981	133.8	1997
		736	2/4	7.75	298	86.1	1474	S 73	12.5	0.63	0.0249	0.0249	86.1	7.75	0.224		1474	86.8	1485
		737	〃	7.41	297	87.0	1441	P 48	15.8	0.87	0.0254	0.0249	85.3	7.70	0.221	-	1441	86.0	1453
		738	1/4	6.64	244	48.4	937	S 77	12.1	0.52	0.0255	0.0257	48.8	6.54	0.213		937	49.2	944
		739	〃	6.15	245	50.7	944	P 45	12.4	0.82	0.0262	0.0256	49.2	6.46	0.212		944	49.6	953
		742	D. Slow	4.83	168	16.6	455	S 98	7.8	−0.09	0.0268	0.0274	17.0	4.62	0.218		455	17.1	459
		743	〃	4.24	176	20.5	500	P 54	12.3	0.83	0.0288	0.0271	19.3	4.84	0.218		500	19.4	504
8	Oct. 20 1953	818	D. Slow	4.22	166	20.7	501	0	12.6	1.00	0.0346	0.0301	18.0	4.44	0.245	0.243	495	18.1	499
		820	〃	4.63	171	18.9	513	S 147	2.4	−0.97	0.0289	0.0296	19.3	4.60	0.237	0.238	516	19.4	520
		821	Slow	5.18	207	32.8	701	P 5	13.9	−0.98	0.0283	0.0271	31.4	5.40	0.220	0.218	687	31.7	693
		823	〃	5.37	199	28.1	645	S 111	3.7	−0.21	0.0273	0.0276	28.4	5.27	0.220	0.220	645	28.6	650
		824	1/4	6.22	246	49.6	981	P 3	14.6	0.99	0.0255	0.0253	49.2	6.25	0.219	0.216	968	49.6	977
		825	〃	6.51	250	51.3	994		0		0.0251	0.0252	51.5	6.38	0.215	0.216	998	51.9	1007
		826	2/4	7.49	298	89.2	1497	P 6	15.0	0.97	0.0258	0.0256	88.5	7.55	0.228	0.226	1484	89.2	1496
		827	〃	7.64	297	87.3	1460		0		0.0255	0.0256	87.6	7.50	0.224	0.225	1466	88.3	1478
		828	3/4	8.56	345	140.0	2051	P 5	15.5	0.98	0.0261	0.0259	139.0	8.49	0.233	0.232	2048	140.1	2065
		829	〃	8.66	347	140.9	2070		0		0.0258	0.0259	141.4	8.52	0.232	0.232	2070	142.5	2087
		830	4/4	9.08	377	184.8	2547	S 7	16.2	0.96	0.0264	0.0261	182.7	9.11	0.242	0.242	2547	184.2	2567
		831	〃	9.13	374	176.4	2497	P 7	16.5	0.96	0.0258	0.0261	178.4	9.04	0.241	0.242	2508	179.9	2528
9	Oct. 25 1953	933	D. Slow	4.93	167	12.6	312	0	12.1	1.00	0.0206	0.0191	11.7	5.42	0.151	0.148	305	11.8	307
		934	〃	5.43	164	10.9	292	S 87	5.3	0.14	0.0188	0.0191	11.1	5.33	0.147	0.148	294	11.2	296
		935	Slow	6.02	203	22.5	474	P 6	12.5	0.97	0.0205	0.0192	21.0	6.54	0.155	0.151	461	21.2	465
		936	〃	6.64	204	21.1	463	S 83	5.8	0.28	0.0190	0.0192	21.3	6.57	0.150	0.151	466	21.5	470
		937	1/4	7.01	249	41.7	737	P 6	12.9	0.97	0.0208	0.0195	39.1	7.63	0.161	0.157	719	39.4	725
		938	〃	7.84	251	39.7	725	S 20	6.2	0.83	0.0193	0.0196	40.4	7.68	0.156	0.157	729	40.7	735
		939	2/4	8.08	394	70.9	1090	P 5	14.2	0.98	0.0212	0.0203	67.6	8.60	0.170	0.164	1052	68.1	1061
		940	〃	8.90	300	71.0	1091	0	6.6	1.00	0.0202	0.0204	71.8	8.79	0.164	0.165	1098	72.4	1107
		941	3/4	9.44	347	121.0	1644	P 7	15.2	0.96	0.0221	0.0216	118.2	9.79	0.184	0.182	1626	119.1	1640
		942	〃	9.96	349	121.5	1701	0	8.9	1.00	0.0215	0.0217	122.6	9.86	0.183	0.183	1701	123.6	1715

Remarks: Analysis could not be made for the results of 5th Experiment owing to nearly same values of wind forces in each group of runs.

Principal Dimensions

Length (overall)	19.866M
Length (between perpendiculars)	18.288M
Breadth (including skin)	4.284M
Depth (〃)	2.414M
Sheer (fore)	0.521M
〃 (aft)	0.216M
Camber	0.110M
Rise of Floor	0.230M
Bilge Circle	0.549M
Starting Point of Rise of Floor from Centre Line	0.017M
Mean Thickness of Shell Platings	0.009M

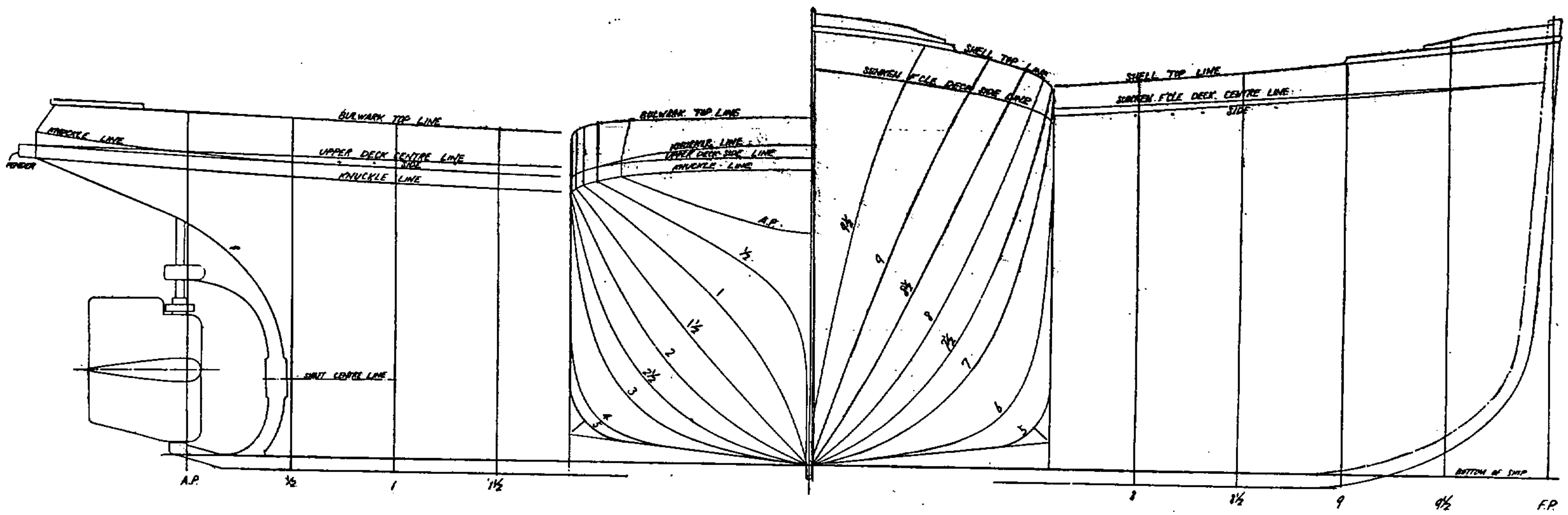


Fig. 1-1. Body plan and Contours of Yayoi-maru

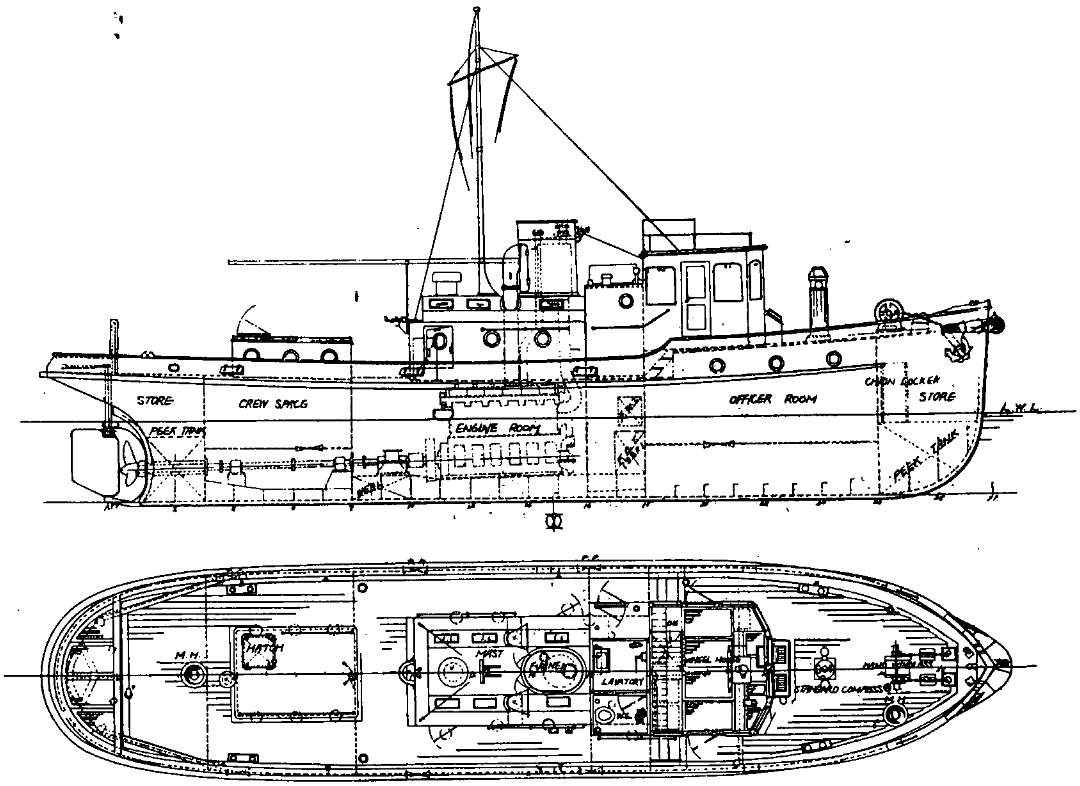


Fig. 1–2. General Arrangement of Yayoi-maru

Diameter 1.265m
Boss Ratio......0.182
Pitch Ratio.....0.777
Expanded Area
Ratio 0.438
Max. Blade Width
Ratio 0.335
Blade Thickness
Ratio.........0.0434
Angle of Rake
.... 11°～0′
Number of Blades...3
Direction of Turning
.........Right handed
Material...Mn. Bronze

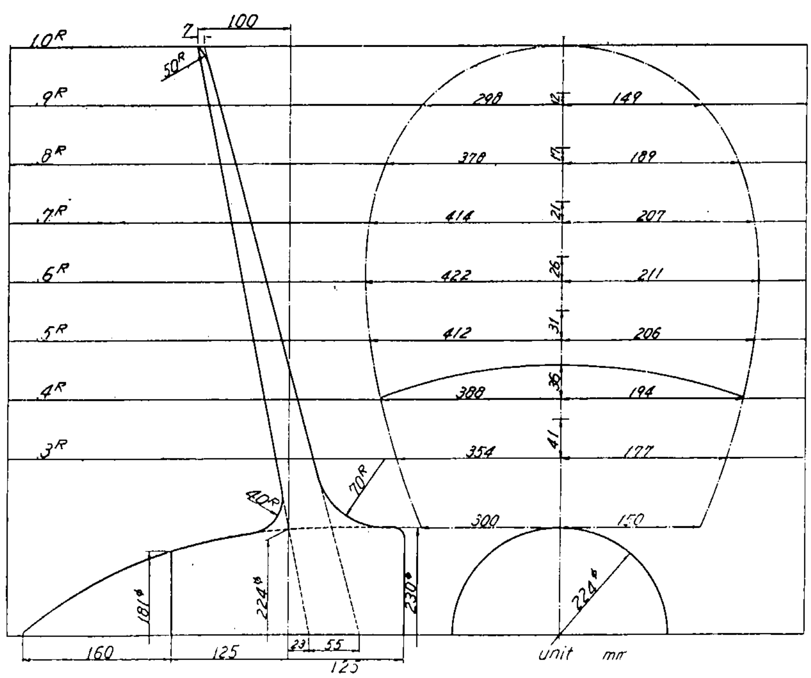


Fig 1–3. Propeller of Yayoi-maru

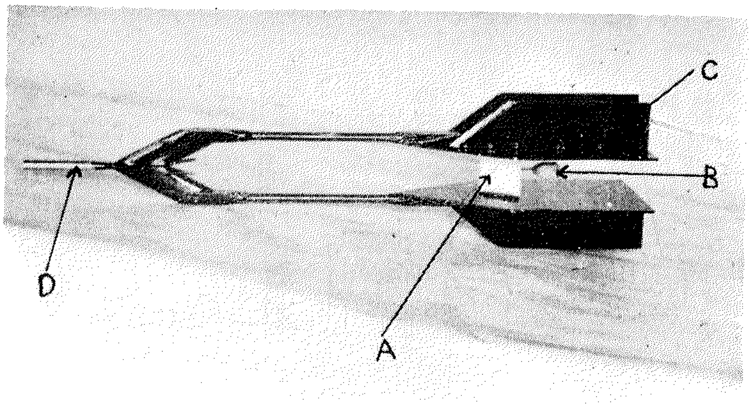


Fig. 1-4.
Shiba Speed Meter

A: Triangular Cylinder
B: Vibrating Plate
C: Guide Plate
D: Connecting Part to Cabtire Cable

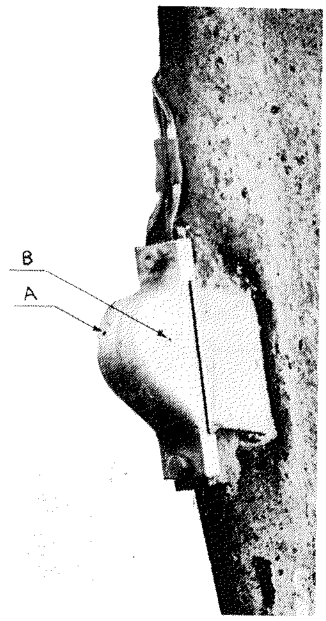
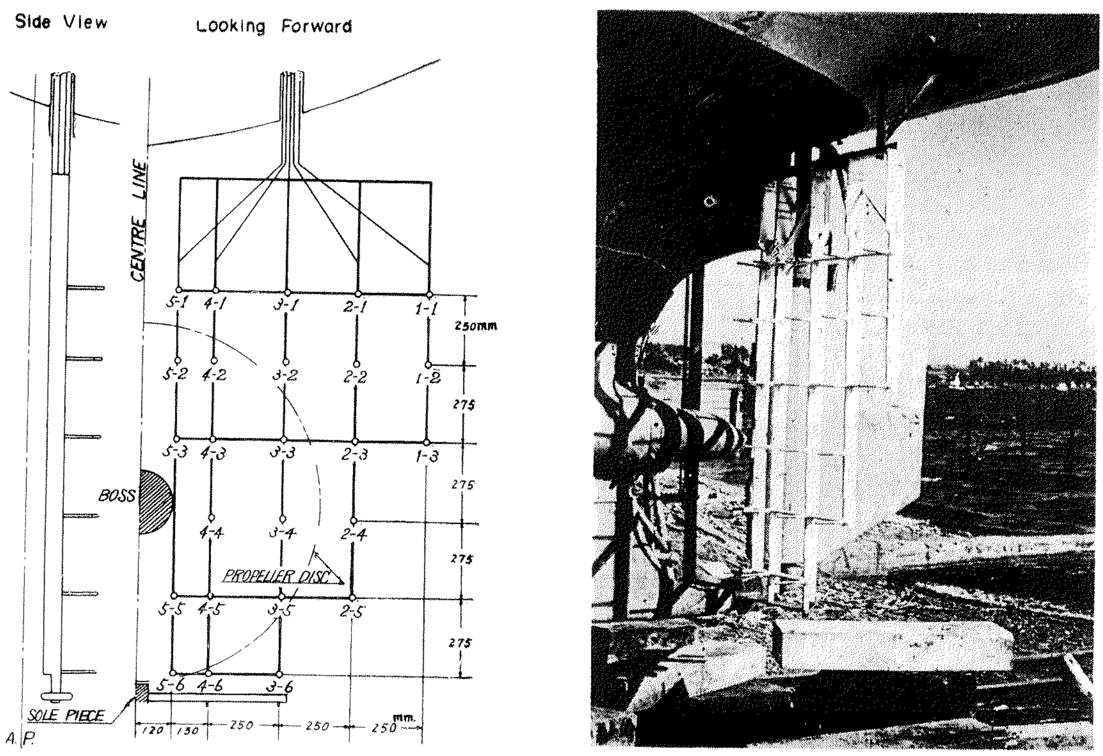


Fig. 1-5.
Pitot Tube Type of Speed Meter

A: Total Head Hole
B: Static Head Hole



(a) (b)

Fig. 1-6. Arrangement of Pitot Tubes for Ship

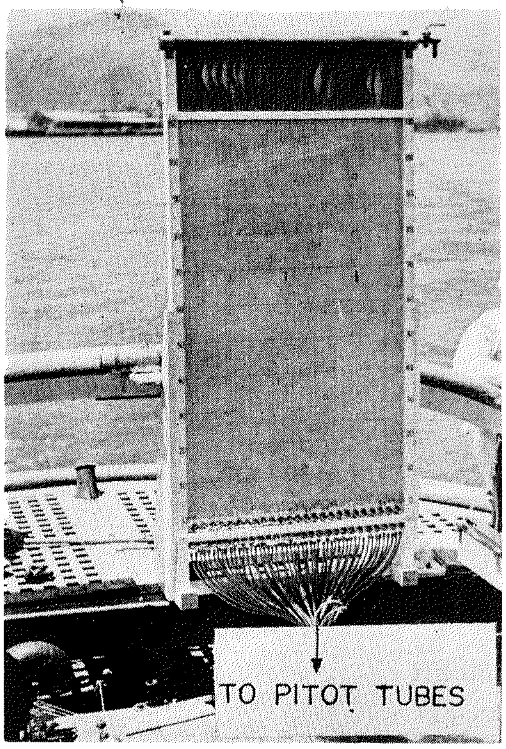


Fig. 1–7. Manometer

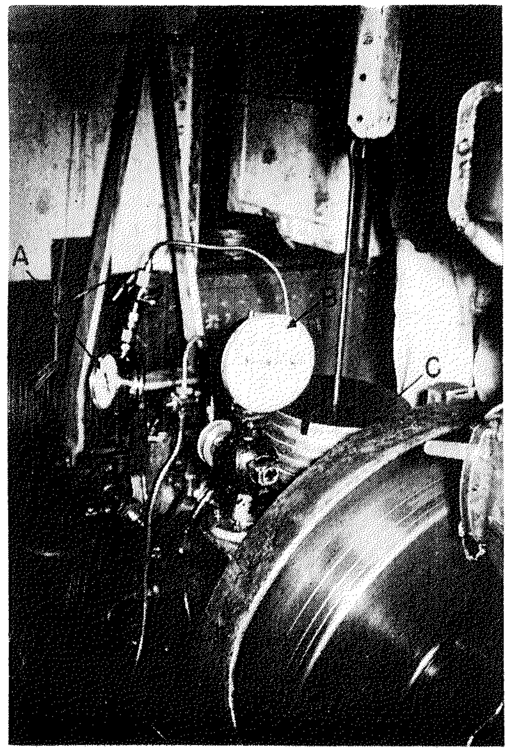


Fig. 1–9. Thrust Meter

A: Pressure Gauge (Thrust Indicator)
B: Pressure Gauge (Air Chamber)
C: Weights for Thrust Calibration

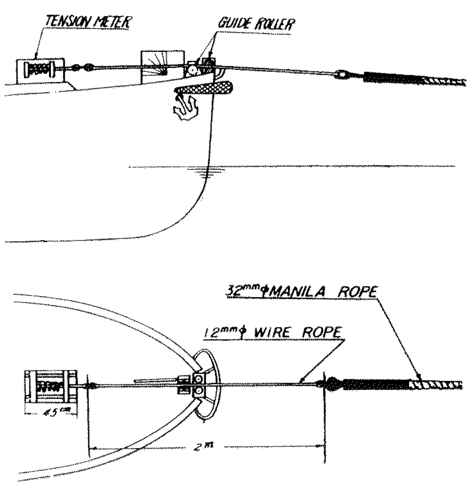


Fig 1–8 Towing Arrangement on the Side of Yayoi-maru

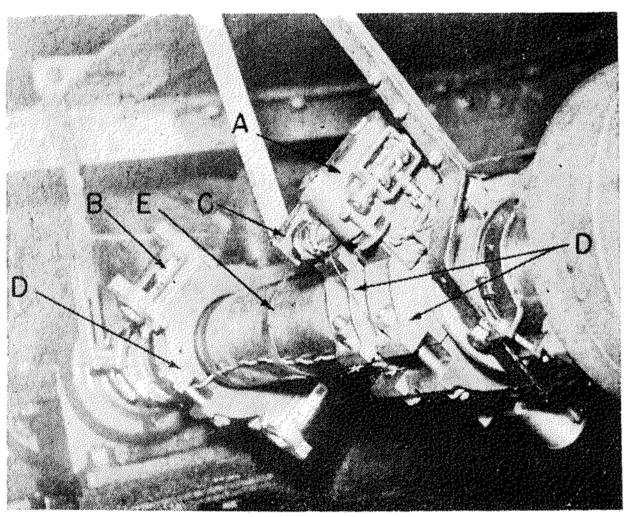
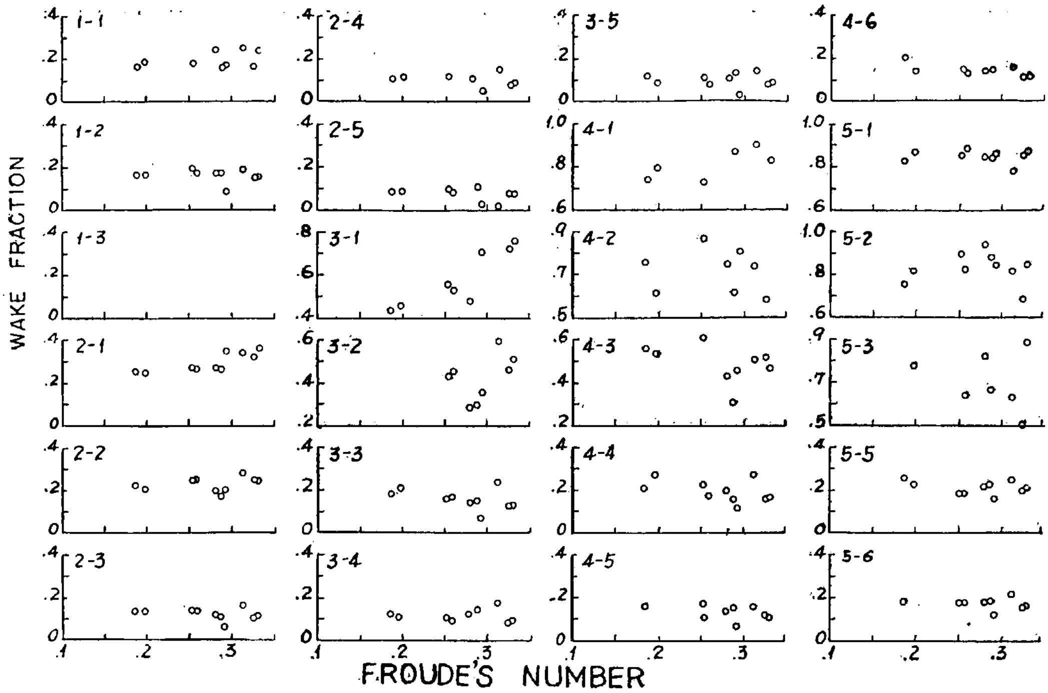
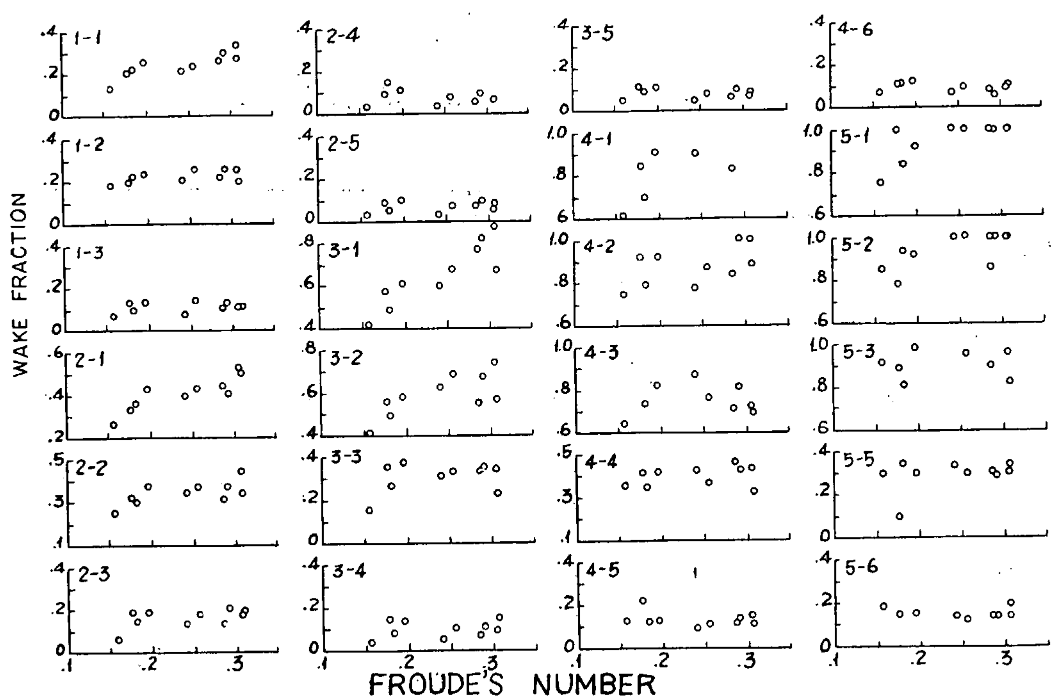


Fig. 1–10. Torsion Meter

A: Camera
B: Prism
C: Light Sourse
D: Ring
E: Shaft

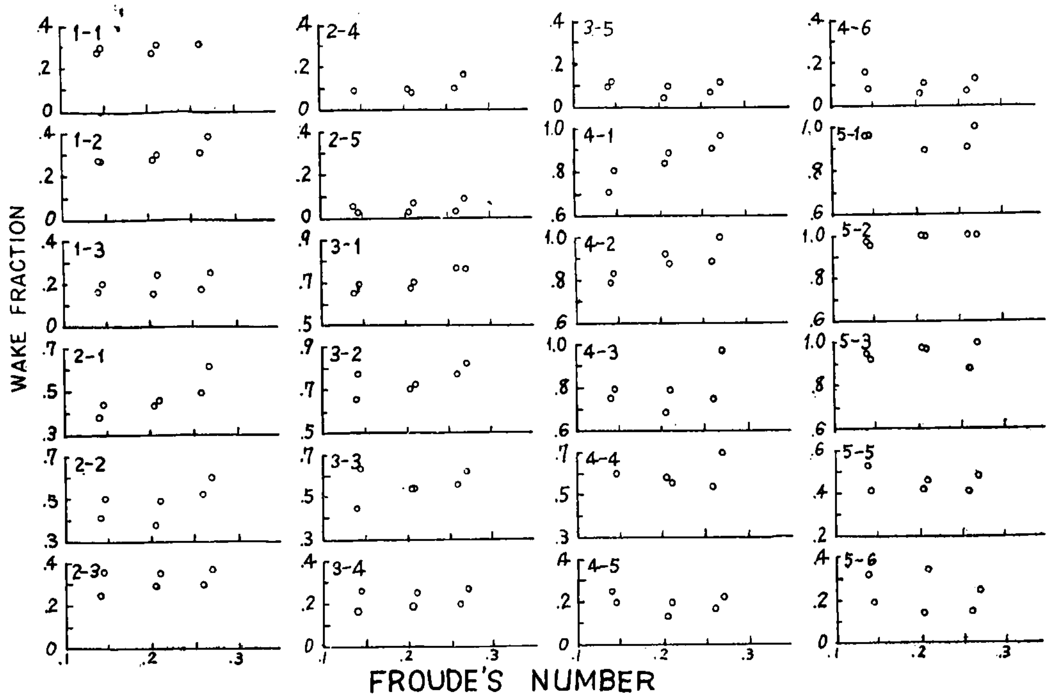


(a) 2nd Exp.

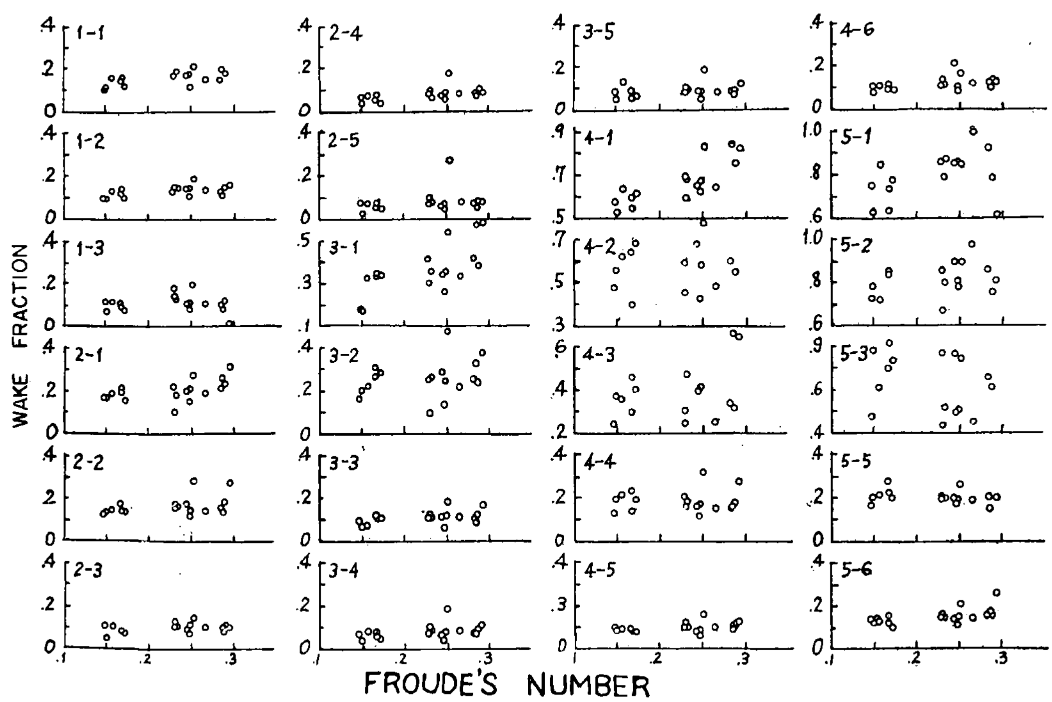


(b) 5th Exp.

Fig. 1-11. Wake Fraction for Ship

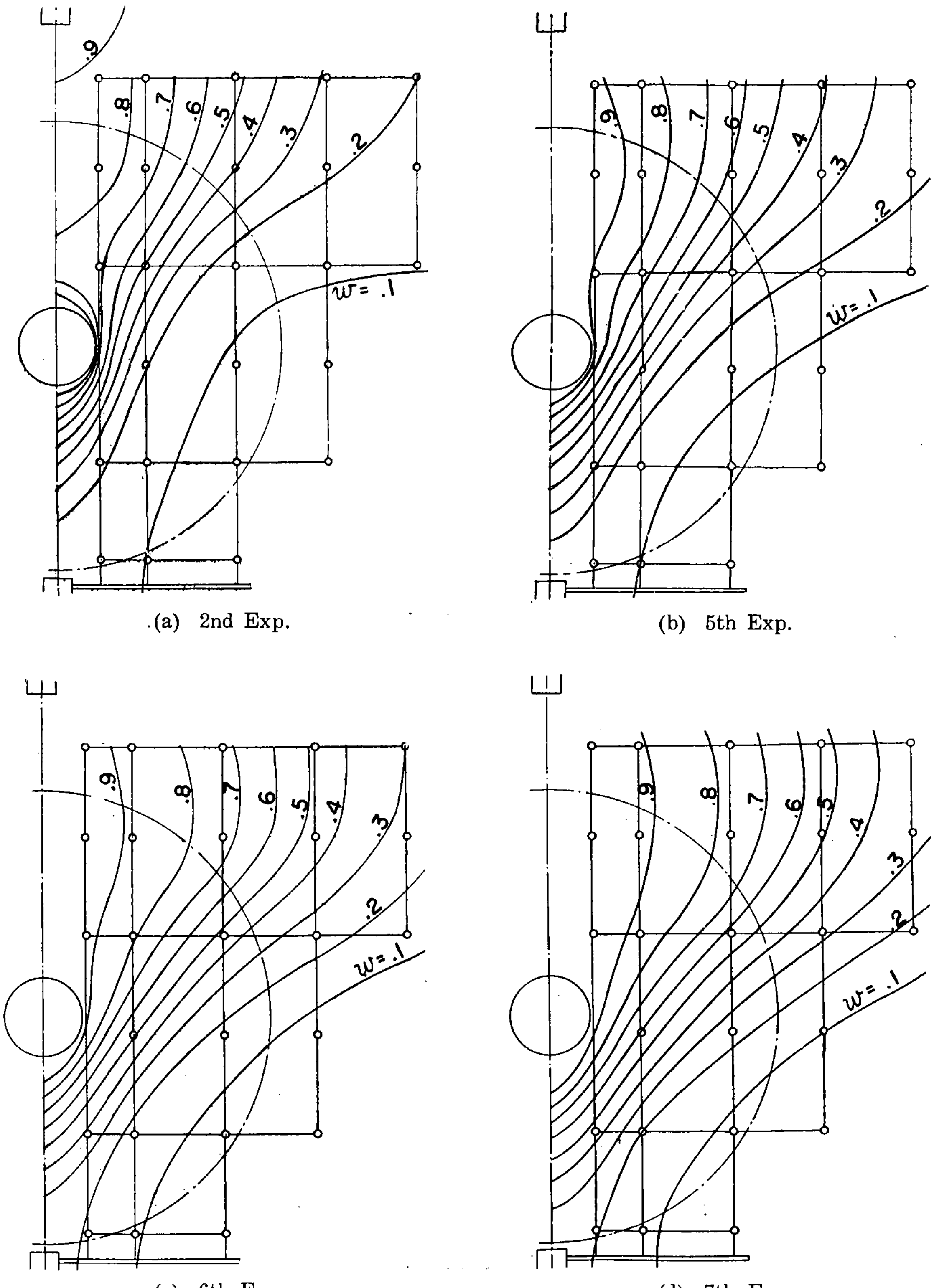


(c) 7th Exp.



(d) 9th Exp.

Fig. 1-11. Wake Fraction for Ship



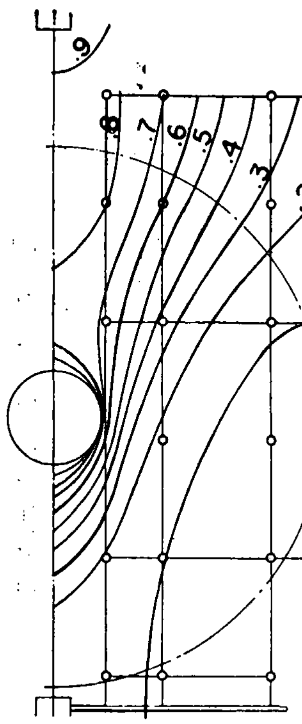
(a) 2nd Exp.

(b) 5th Exp.

(c) 6th Exp.

(d) 7th Exp.

Fig. 1-12. Wake Distribution for Ship



(e) 9th Exp.

Fig. 1-12. Wake Distribution for Ship

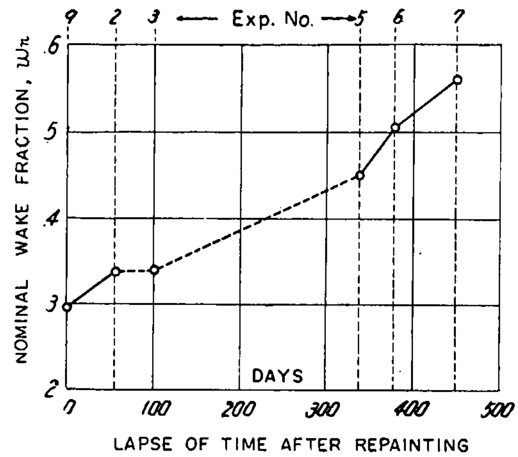


Fig. 1-13.
Variation of Nominal Wake Fraction for Ship due to Bottom Fouling

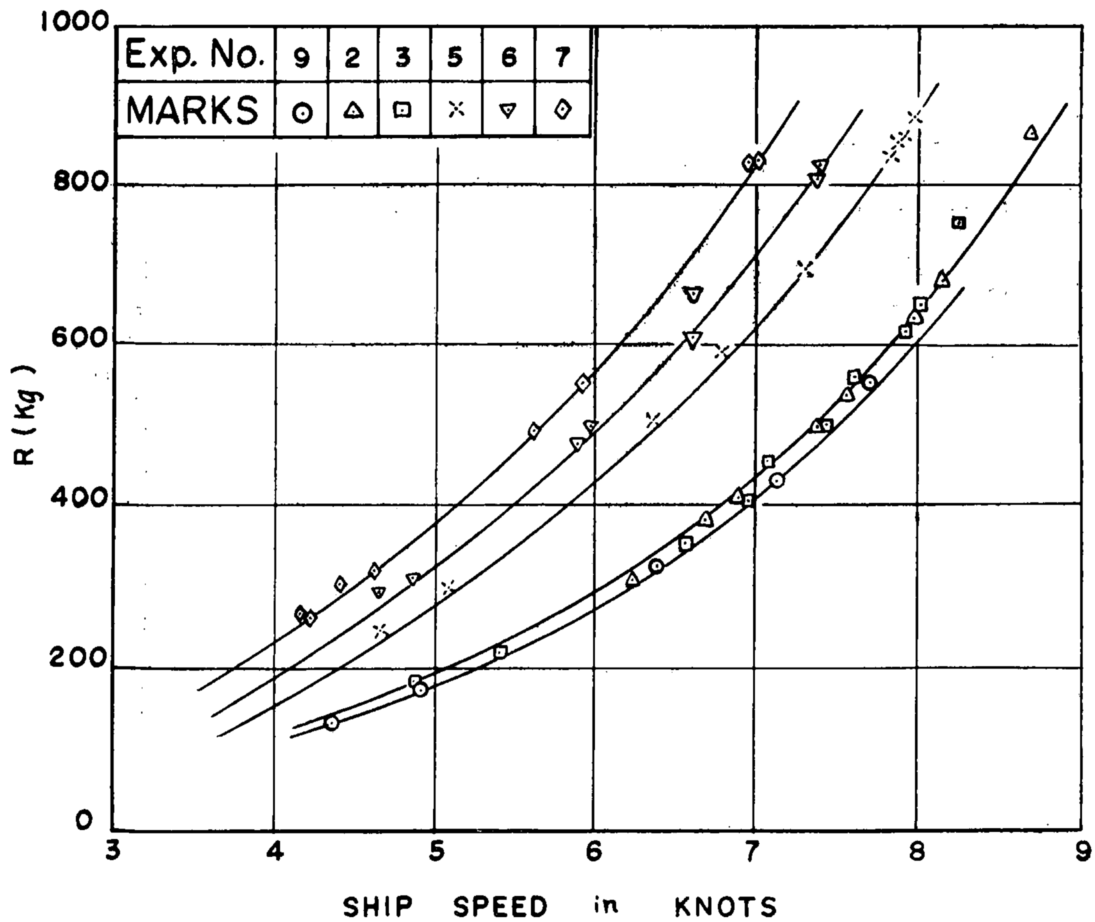


Fig. 1-14. Resistance Curves for Ship

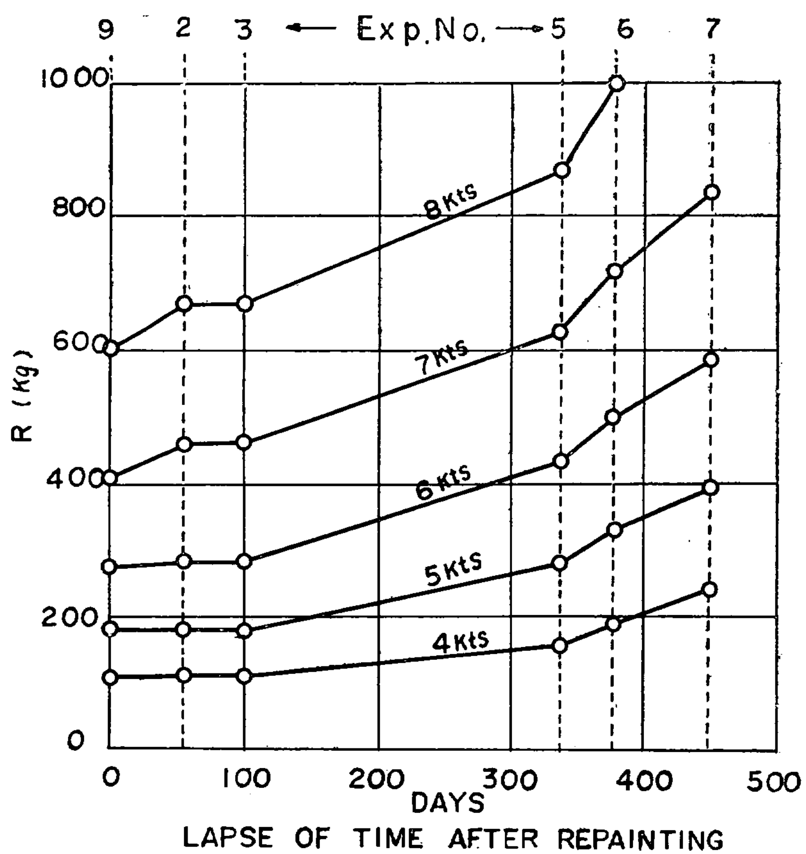


Fig. 1-15. Variation of Resistance for Ship due to Bottom Fouling

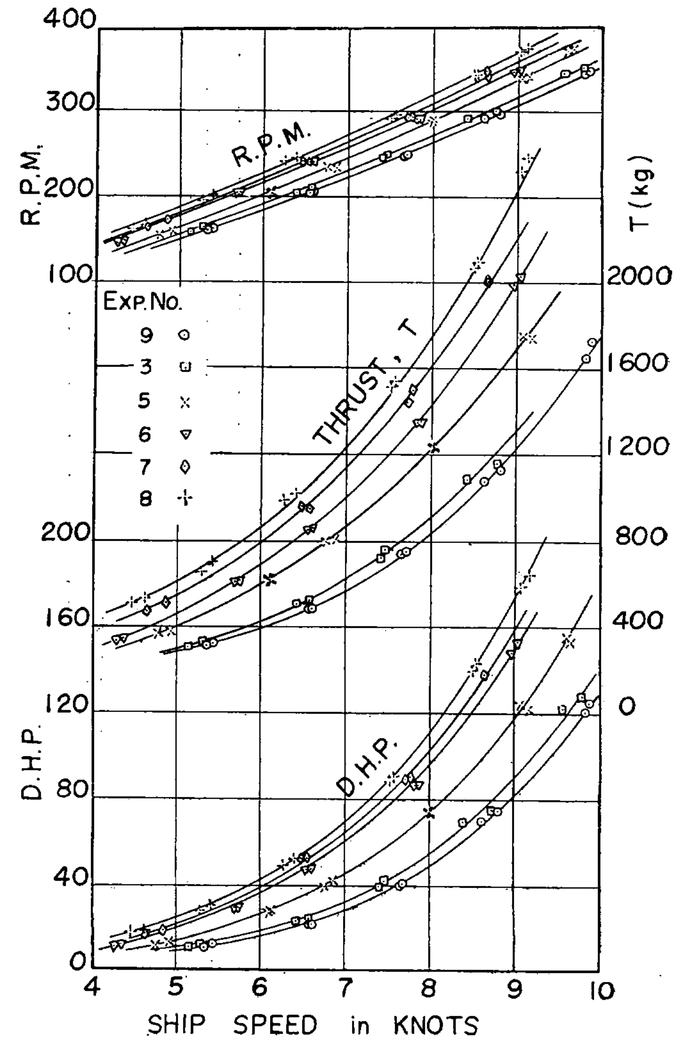


Fig. 1-16. DHP ect. for Ship

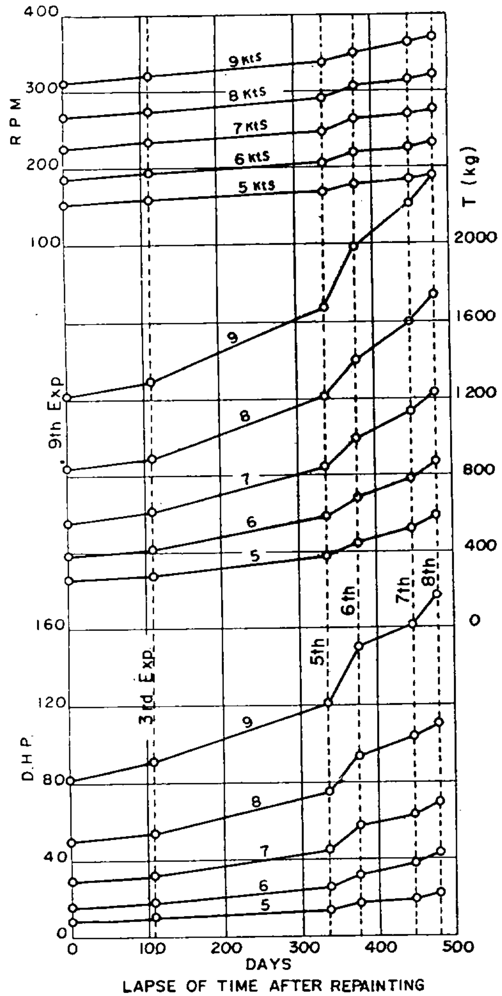


Fig. 17. Variation of D.H.P. etc., for Ship due to Bottom Fouling

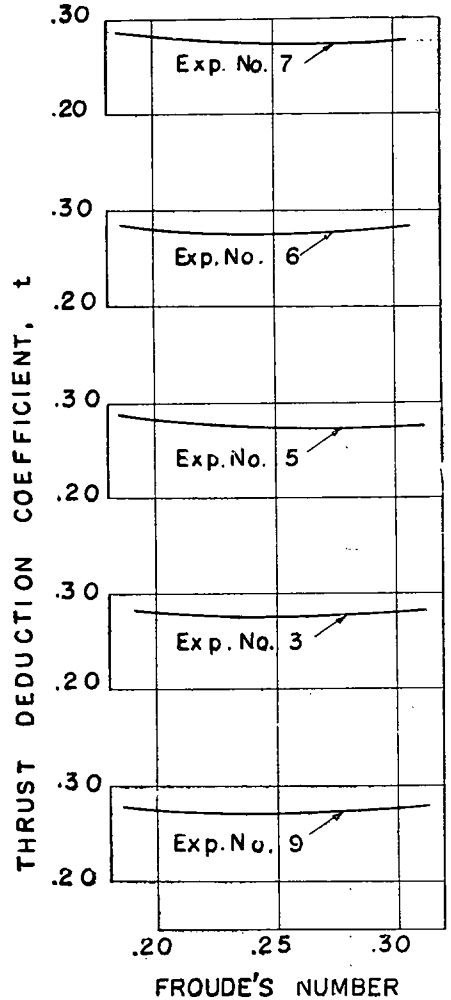


Fig. 1–18. Thrust Deduction Coefficient for Ship

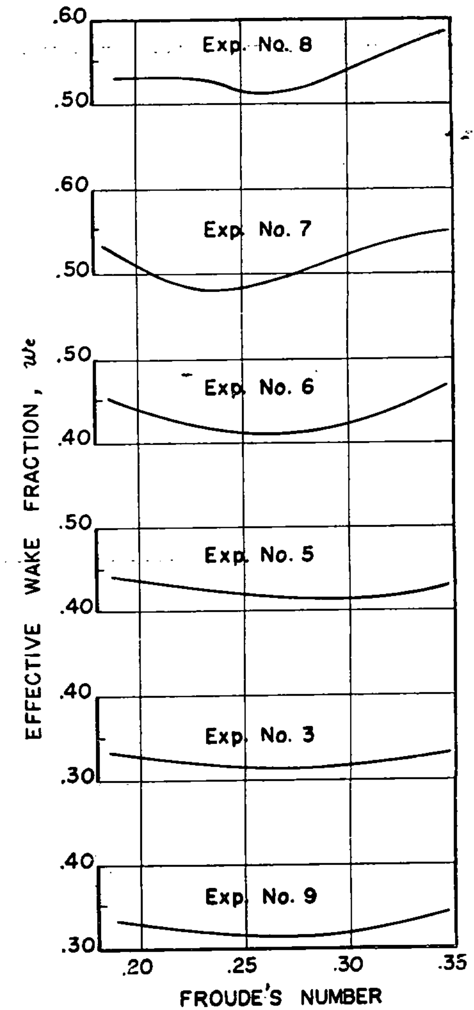


Fig. 1–19. Effective Wake Fraction for Ship

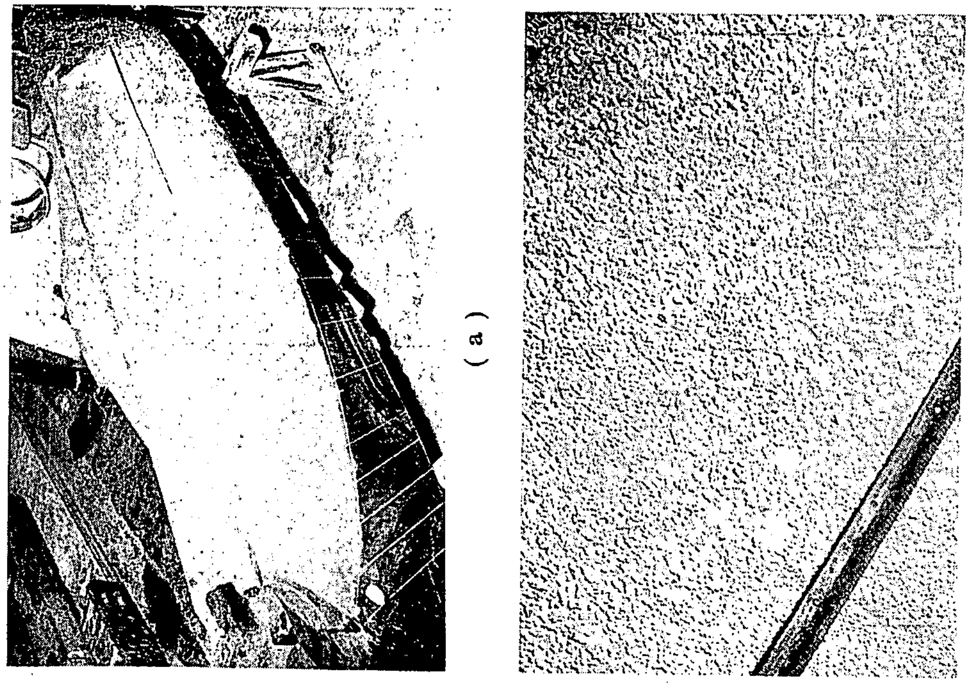
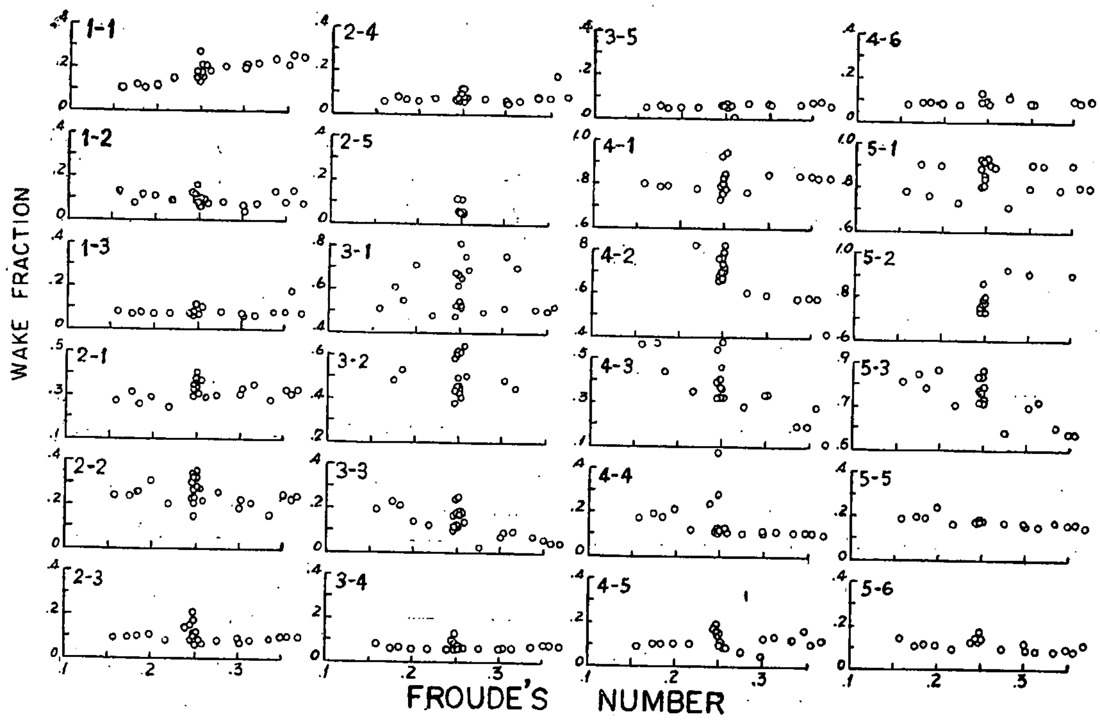
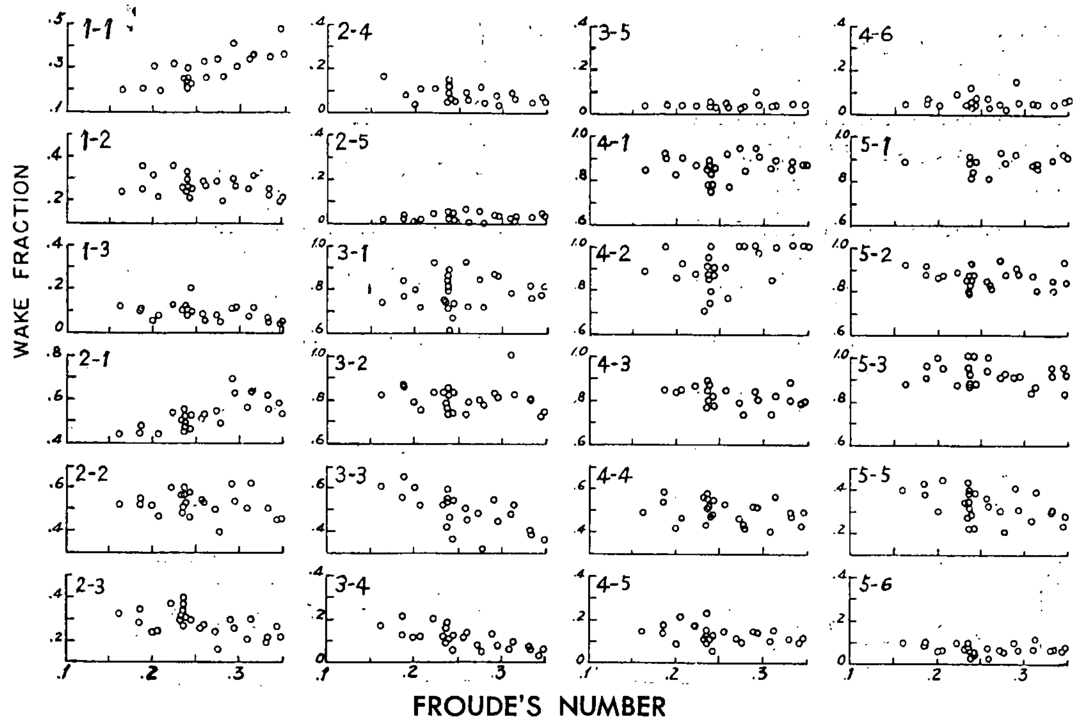


Fig. 2-1. Roughened Model (medium sand)

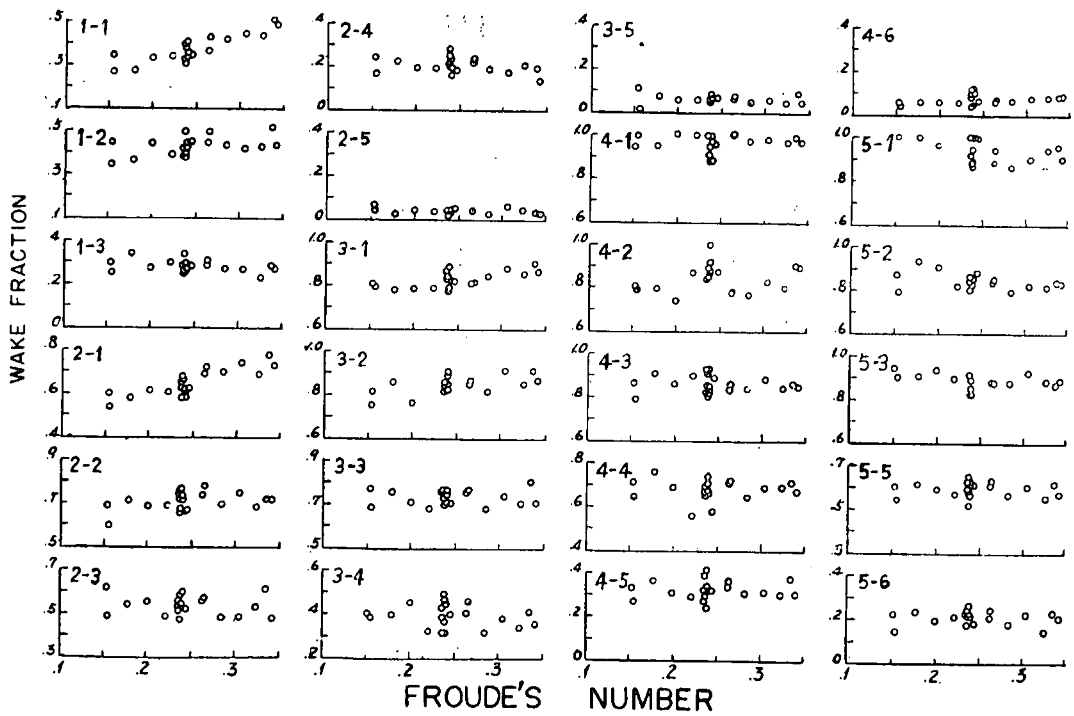


(a) Clean

Fig. 2-2. Wake Fraction for Model

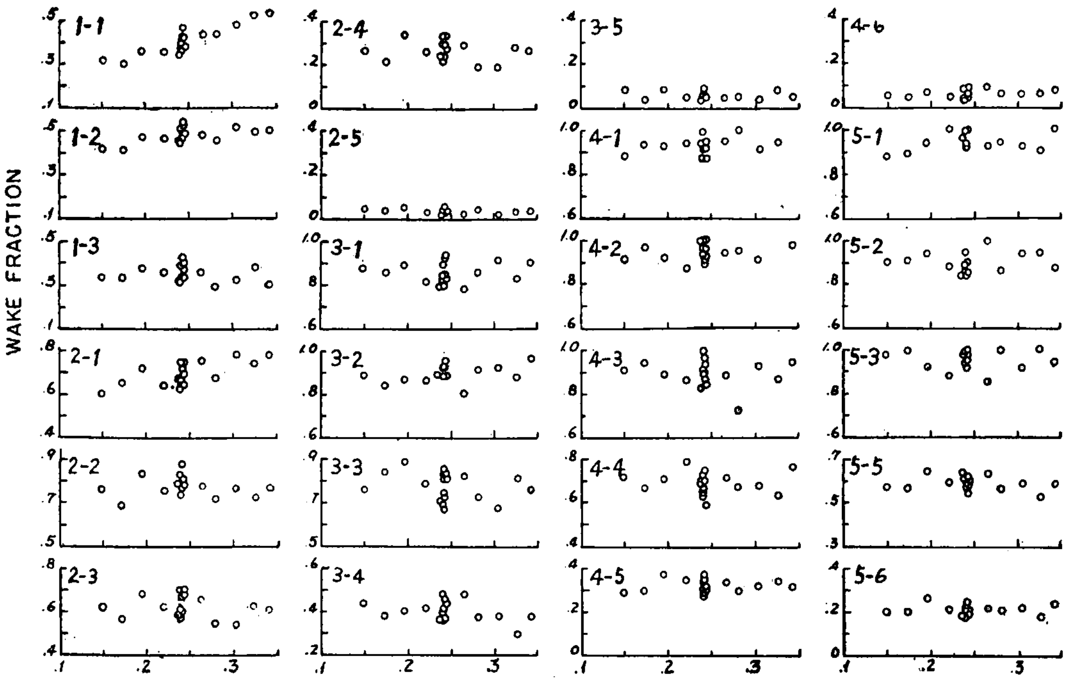


(b) Roughened with Small Sand



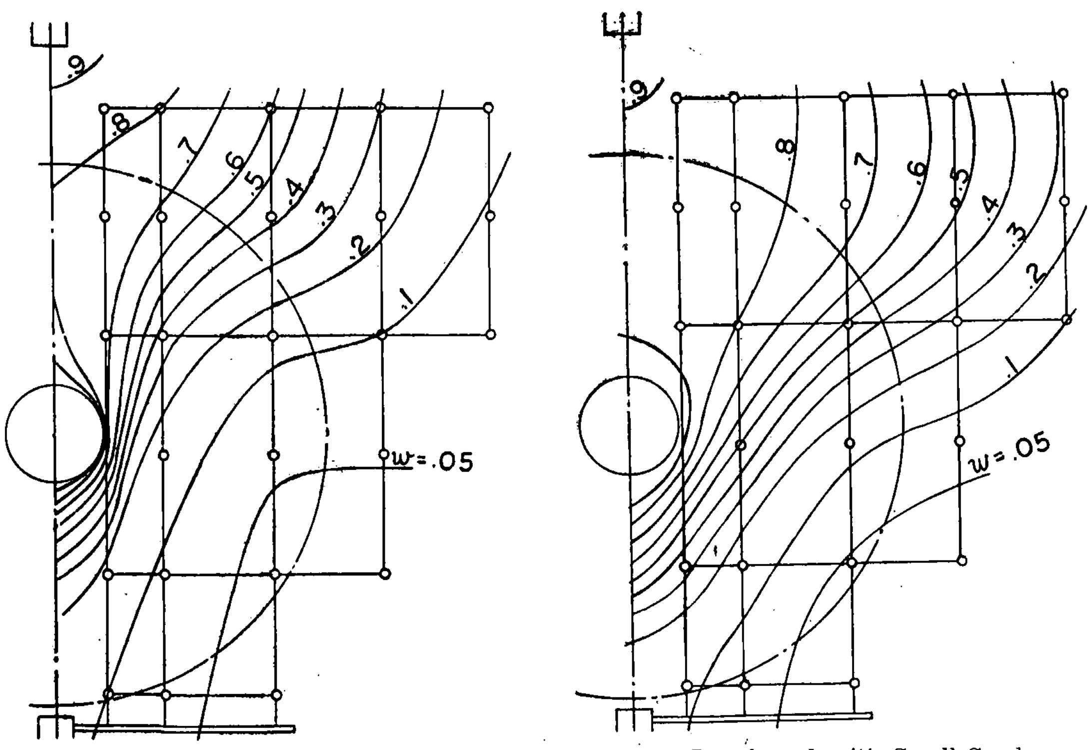
(c) Roughened with Medium Sand

Fig. 2–2. Wake Fraction for Model



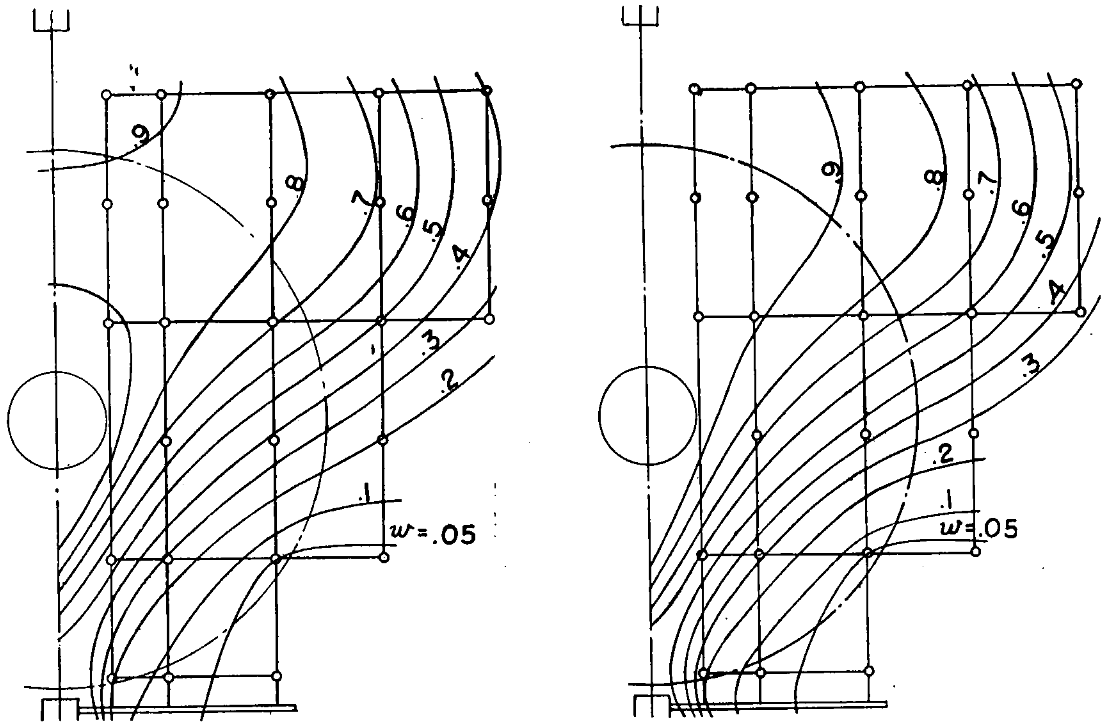
(d) Roughened with Large Sand

Fig. 2–2. Wake Fraction for Model



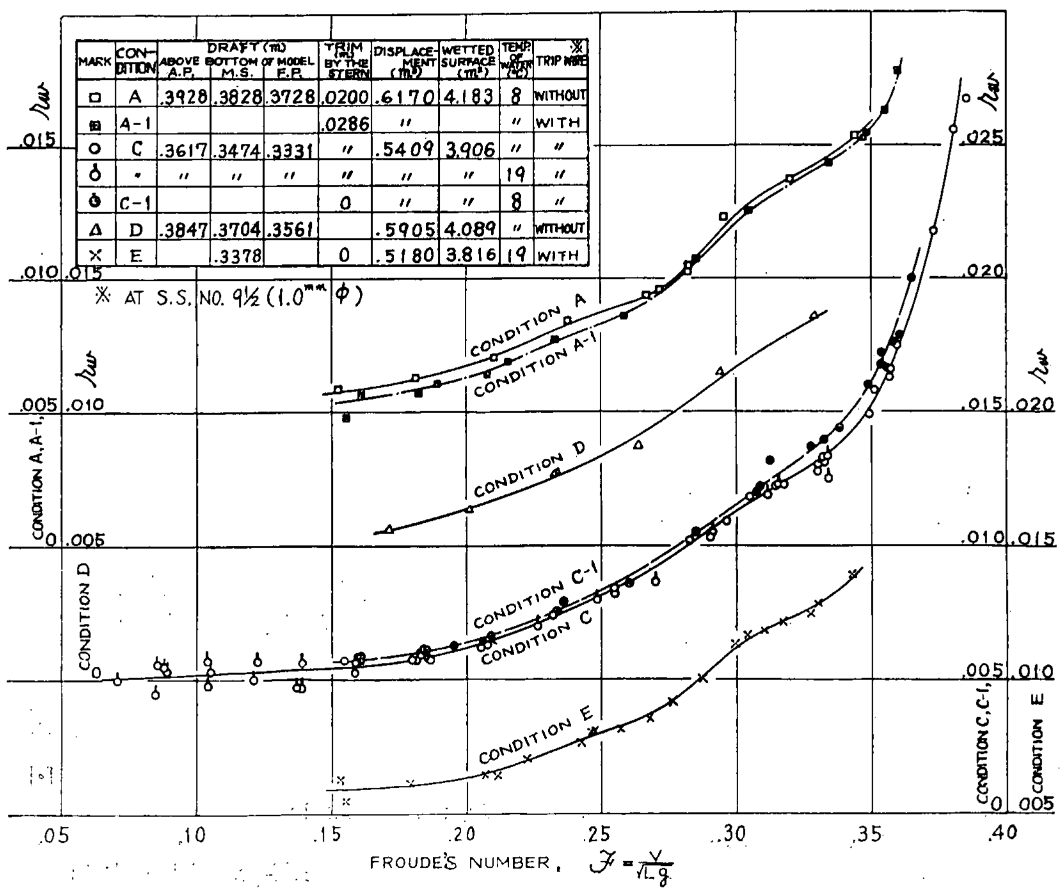
(a) Clean (b) Roughened with Small Sand

Fig. 2–3. Wake distribution for Model



(c) Roughened with Medium Sand (d) Roughened with Large Sand

Fig. 2-3. Wake Distribution for Model (a~d)



MARK	CONDITION	DRAFT (m) ABOVE BOTTOM OF MODEL A.P.	M.S.	F.P.	TRIM (m) BY THE STERN	DISPLACEMENT (m³)	WETTED SURFACE (m²)	TEMP. OF WATER (°C)	※ TRIP WIRE
□	A	.3928	.3828	.3728	.0200	.6170	4.183	8	WITHOUT
■	A-1				.0286	〃		〃	WITH
○	C	.3617	.3474	.3331	〃	.5409	3.906	〃	〃
♂	〃	〃	〃	〃	〃	〃	〃	19	〃
●	C-1				0	〃	〃	8	〃
△	D	.3847	.3704	.3561		.5905	4.089	〃	WITHOUT
×	E		.3378		0	.5180	3.816	19	WITH

※ AT S.S. NO. 9½ (1.0mm φ)

Fig. 2-4. Residual Resistance Coefficient for Model with Clean Bottom

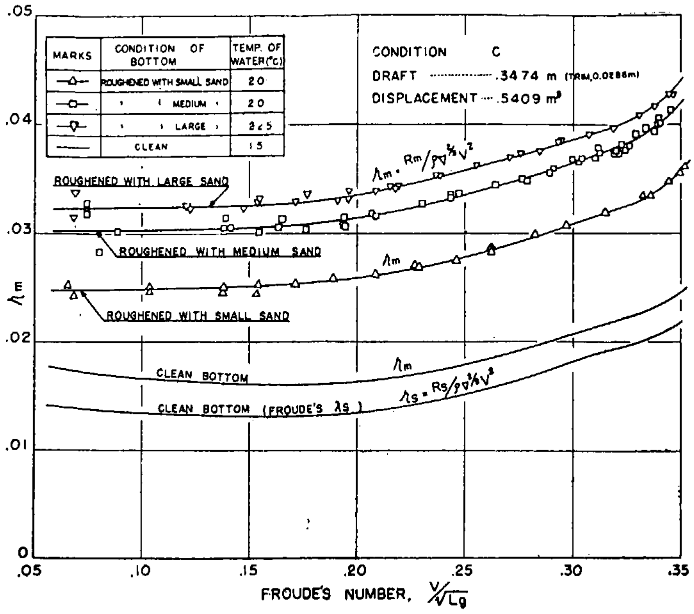


Fig. 2-5. Total Resistance Coefficient for Model

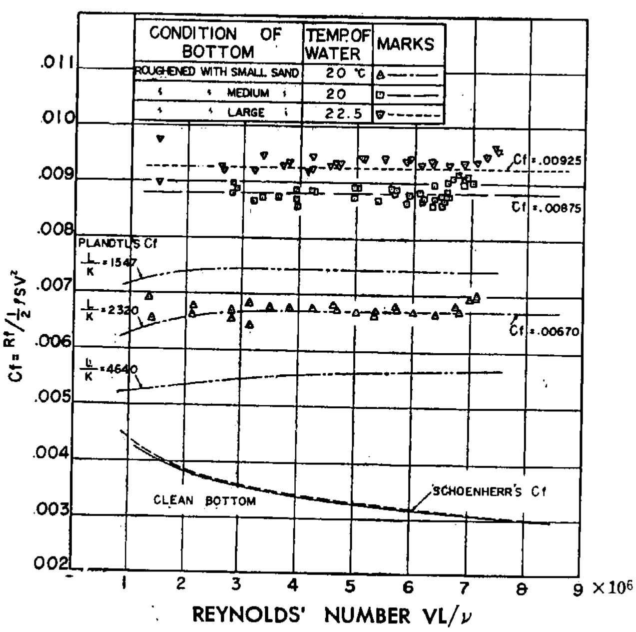
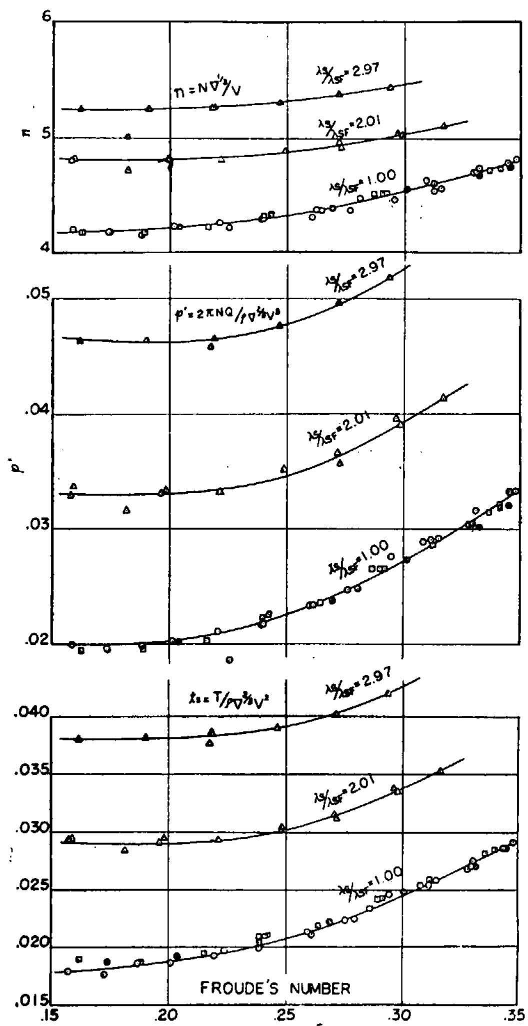


Fig. 2-6. Frictional Resistance Coefficient for Model



Condition	Draft (m) Above Bottom of Model			Trim (m) by the Stern	Displacement (m³)	$\lambda s/\lambda s_F$ *1	Temp. of Water (°C)	Marks
	A.P.	M.S.	F.P.					
C	0.3617	0.3474	0.3331	0.0286	0.5409	1.00*2	8	⊙
〃	〃	〃	〃	〃	〃	2.01	〃	△
〃	〃	〃	〃	〃	〃	2.97	〃	▲
〃	〃	〃	〃	〃	〃	1.00	9	●
C—1	—	—	—	0	〃	〃	〃	⊡

*1. λs: Friction Constant of Actual Ship λs_F: Froude's λs

*2. Mean Values of $\lambda s/\lambda s_F$ in Experiment

Fig. 2-7. Effect of Friction Correction upon Results of Self-propulsion Tests —Propeller and Hull Clean—

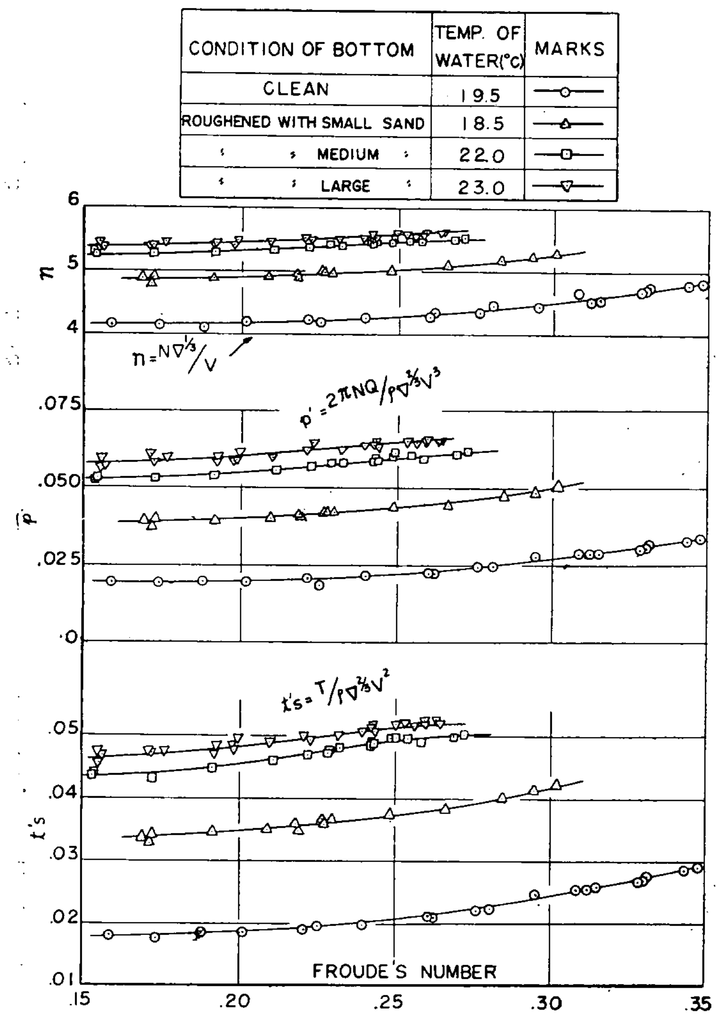


Fig. 2-8. Results of Self-Propulsion Tests for Roughened Hull with Clean Propeller

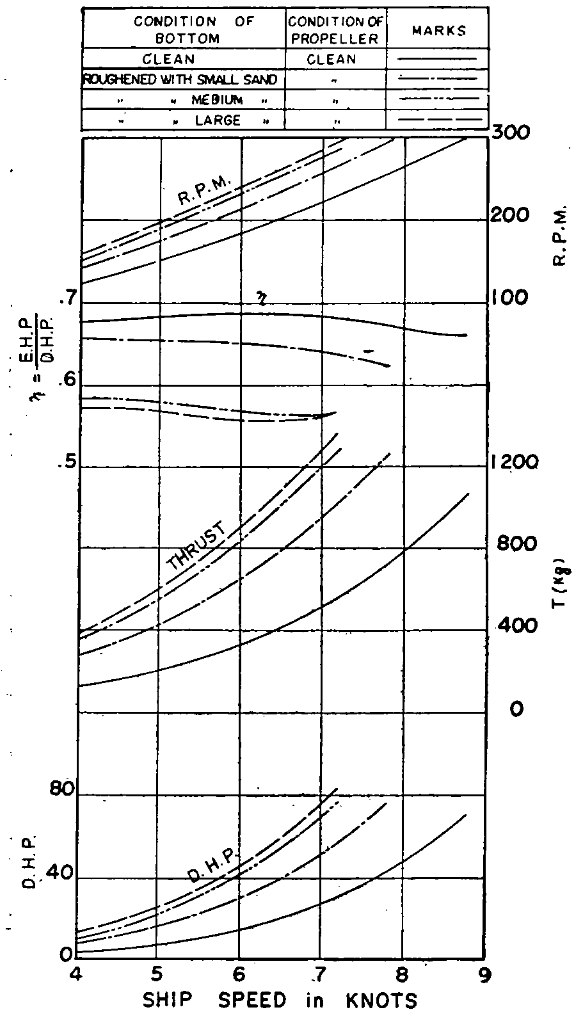


Fig. 2-9. DHP, etc., estimated from the Model Tests, Roughened Hull with Clean Propeller

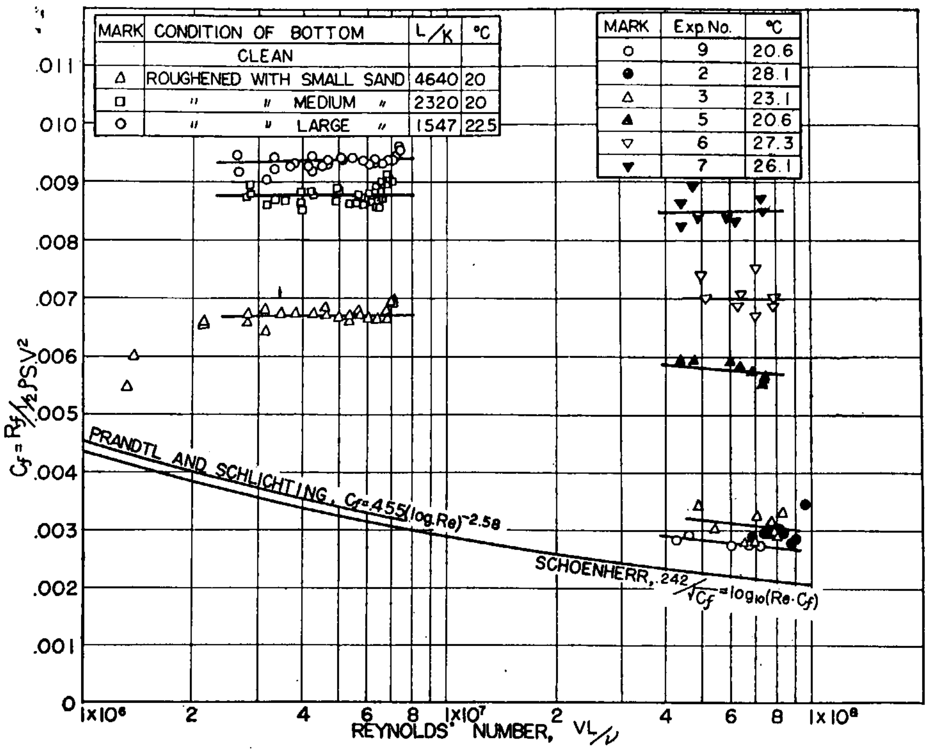
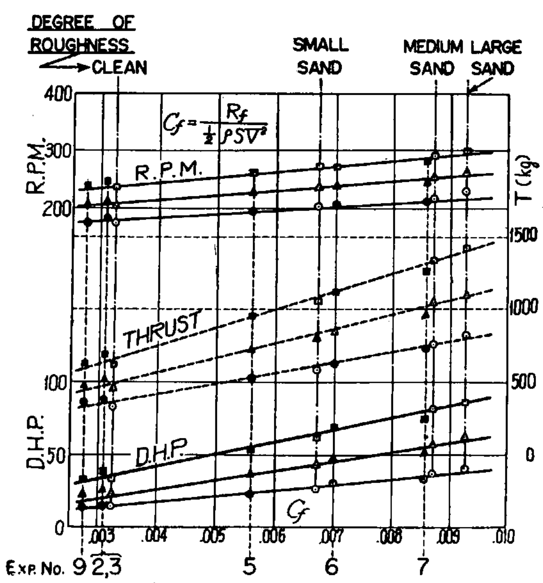
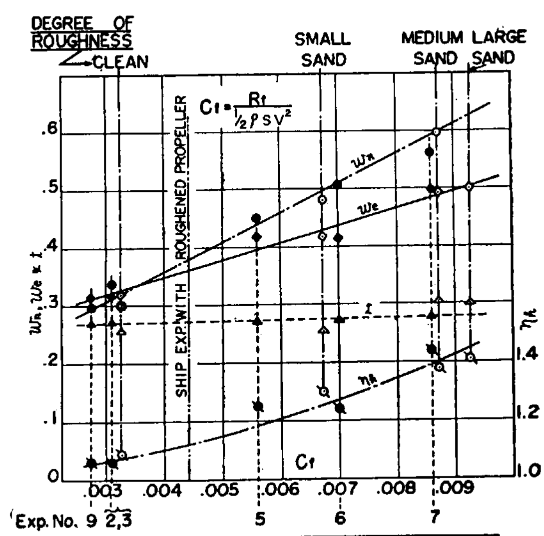


Fig. 3-1. Comparison of the Frictional Resistance Coefficients



FROUDE'S NUMBER	MODEL	SHIP
.22	○	●
.25	Δ	▲
.28	□	■

Fig. 3-2. Comparison of the Results of Self-Propulsion Tests



ITEMS		MODEL	SHIP
NOMINAL WAKE FRACTION, w_n	MEASURED BY PITOT TUBE	⊙	●
	MEASURED BY BLADE WHEEL	⊡	
EFFECTIVE WAKE FRACTION, w_e		◇	◆
THRUST DEDUCTION COEFFICIENT, t		Δ	▲
HULL EFFICIENCY, η_h		⌓	⌓

Fig. 3-3. Comparison of Self-Propulsion Factors at Froude's Number = 0.25

PART II. EFFECTS OF FOULING OF A PROPELLER UPON PROPULSIVE PERFORMANCES OF A SHIP

Chapter 4

Full-Scale Measurements

1. Method of the tests

In order to investigate the characteristics of the roughened propeller, it is preferable to make a test in which the propeller can work in the region outside the wake of the ship. But this method was impracticable. Therefore, by means of the ordinary self-propulsion tests, the characteristics of the propeller behind the ship were obtained. The wake at the position of the propeller disc was estimated by referring to the full-scale measurements with fouled bottom in part I.

In order to vary the value of advance constant, both bollard tests and self-propulsion tests with towing one or three sea anchors were carried out. Although the clean bottom is preferable in investigating the effect of the roughened propeller alone, the tests were made after about half a year since the last repainting, owing to unavoidable circumstances. Therefore, slight fouling was found on the bottom. Since, however, the effect of this fouling is considered to be constant throughout the period of these tests, it will be possible to pick up the effect of roughened propeller alone.

In these experiments, differently from the case of full-scale measurements with the fouled bottom, the measured mile posts were not employed and the speed through the water was measured by Shiba speed meter and pitot tube type of speed meter.

The ship was run on a course to which the wind direction was always parallel. In most cases of 'with wind', the relative wind velocities were nearly zero. Since it was necessary to accomplish the tests in short days, the spare propeller was also used.

2. Method of roughening and the test conditions

Since it was impracticable to foul the propeller with growths in the sea, the surface of each blade was covered with rubber plates which themselves were roughened with a number of protuberances. Three sizes of protuberances were adopted, as shown in Table 4-1, which gives the typical dimensions of barnacles in process of growth.

At first, these rubber plates were only glued to the blades with "Cemedine," an adhesive paint, but it was found, from the preliminary experiments made at the end of 1953, that the force due to rotation of the propeller was great enough to tear them off. Then the rubber plates were covered with wire nets. An example of the propeller roughened in this way is shown in Fig. 4-1.

The surface of each blade, both of its face and back, was divided into three nearly equal areas along the radial direction, each of which was covered with rubber plates and wire netting (refer to Table 4-1).

At first, the measurements were performed with the propeller wholly roughened, and then the rubber plates of the tip portion, one-third of a blade surface, were torn off by divers. The next measurements were made with the propeller roughened by two-thirds. Then, the rubber plates of the middle portion were torn off and the measurements were made. Finally, the measurements with the clean propeller were carried out.

The test conditions of the propeller are shown in Table 4-1. In such a notation as F 1-1, the former numeral indicates the size of the protuberance and the latter shows the degree of distribution of the protuberances.

The draft and displacement are shown in Table 4-2, together with the conditions of sea and weather. Although the draft could not be kept constant throughout the experiments, it was intended to keep the draft as constant as possible. The average of mean drafts was about 1.9 m and the corresponding displacement about 76.5 tons. As shown in this table, the sea in these experiments were generally calm, except in the tests with F 2-2/3 (see Fig. 4-2).

3. Results of the measurements

Results of the measurements are shown in Table 4-3. Corrections for the wind force were made as shown in Table 4-4. The corrected DHP, thrust and RPM are plotted in Figs. 4-3 and 4-4, in which, for reference, both the results with clean propeller and those obtained in Chapter 1 for the condition of the clean hull and propeller are also shown. These curves, shown for reference, correspond to the condition without sea anchor, and the difference between these curves show the effect of fouling of the bottom, which is included in every experiment in this chapter. The difference between the curves of F 1-1 without sea anchor and those with clean propeller shows the effect of roughness of the propeller. There is no appreciable change in thrust, but DHP shows a remarkable increase due to the roughness of the propeller.

4. Characteristics of the propeller behind the ship

The effective wake fraction in these full-scale measurements is estimated from Fig. 3-4. c_f in this case was estimated from the thrust which was obtained by the experiments with the clean propeller. That is, the value of the wake fraction was estimated as 0.36. By using this value, advance constant v was calculated for each experiment in Figs. 4-3 and 4-4, and the thrust constant t and torque constant q were plotted against v as shown in Fig. 4-5. From this figure it will be seen that the propeller efficiency is reduced greatly owing to the roughness of the propeller.

5. Considerations on the results

As it is easily concluded from Fig. 4-4, the roughness of the propeller has an important effect upon the propulsive performance, and as a rule the effect is greater in the case of F 1-1, F 2-1 and F 3-1, corresponding to the condition where the whole surface of the blade was covered with barnacles. Owing to the extraordinarily great force due to the rotation of the propeller, the marine growths near the propeller tip are torn off, but still remain intact at other areas of the blades. Therefore, the propeller efficiency shows a considerable fall, as is evident from the results in F 2-2/3. Even the fouling near the boss of the propeller makes the thrust constant lower, resulting in a decrease of the propeller efficiency.

There may be some questions about this method of roughening the propeller blade surface, but it may be considered that a general idea of the effects of roughness of the propeller upon the propulsive performances and of the necessity of an anti-fouling device for the propeller has been obtained. It may be considered a fairly good method to use sea anchors, in order to obtain a wide range of advance constants.

Chapter 5

Model Experiments

1. Method of roughening and the test conditions

In order to roughen the blade surface of the propeller, as in the case of the full-scale measurements, rubber plates with regular-shaped protuberances were used in the same way, but without wire netting. Three sizes of protuberances were adopted, each size corresponding to that used in the full-scale measurements. Distribution of roughness on the blade surface was changed in the same way as in the full-scale measurements. The dimensions and shapes of protuberances are shown in Table 5-1.

Open water tests of the propeller were carried out for many types of roughness, but the self-propulsion tests were confined to the typical cases. Since in the full-scale experiments the propeller blade of the actual ship was bound by wire netting to prevent the rubber plates from falling off, the tests under condition similar to F 2-1 were added for the model propeller, for reference. Moreover, the open water tests of the propeller with rubber plates of different thicknesses, but without protuberances, were performed to investigate the effect of the basal parts of the rubber plates with protuberances. Furthermore, to compare the effect of rubber roughness with that of sand roughness upon the propeller characteristics, open water and self-propulsion tests were performed with the propeller roughened with sands. Various conditions of the tests are shown in Table 5-2. Fig. 5-1 shows an example of the roughened model propeller.

2. Open water tests of the model propeller

The results of open water tests of the propeller for f 1, f 2 and f 3 are shown in Fig. 5-2 (a), (b) and (c). In the case where the whole blade surface is covered with rubber plates with protuberances, the decrease of thrust constant and the increase of torque constant are very remarkable, and the propeller efficiency falls to about a half of that of the clean propeller. From these figures it will be found that the thrust constant t decreases nearly proportional to the roughness area of the blade, while torque constant q increases remarkably with the extending of roughness towards the propeller tip. The thrust constant shows appreciable variations even in the case of roughness at the root, in spite of little variation of torque constant. The above-mentioned rapid increase of torque constant is due to the increase of lever of the force applied to the blade. f 2-1+wire in Fig. 5-2 (b) is a condition nearly corresponding to the roughness of the actual propeller, which was wholly roughened by rubber plates and covered with nets of wire (1.3 mm dia.) and, moreover, bound up with wires of 2.5 mm diameter. The results of the experiments on the propeller roughened with sands, nearly equal in size to the protuberances in f 2, are also shown in Fig. 5-2 (b). They give slightly inferior results than f 2-1, but their differences are unimportant.

In order to investigate the effect of the basal parts of rubber plates with protuberances upon the propeller characteristics, open water tests were carried out on the propeller covered with flat rubber plates, one of which was as thick as the basal parts, and the other of a thickness nearly equal to the height of the protuberances plus the thickness of the basal parts. The results are also shown in Fig. 5-2 (b). For the sake of convenience in comparing the effects of the different degrees of roughness, the curves of propeller efficiency are summarized in Fig. 5-3.

Fig. 5-4 shows the decrease of thrust constant and the increase of torque constant of the propeller due to roughness against k/c representing the measure of roughness. k represents the height of protuberances including the bed blate, and c the cord length of the blade at 0.7 R. From this figure it will be seen that the variations of thrust and torque constants are remarkable even if the protuberances are small, but the rate of variation decreases with increase of the height of roughness. Fig. 5-5 shows a drop of the propeller efficiency due to roughness, which includes the effect of the base plate. In Fig. 5-5 are also plotted the results of theoretical calculations by Lerbs*3.

3. Self-propulsion experiments

Self-propulsion tests were carried out on the propeller wholly roughened to investigate the effect of size of roughness, and on the propeller for f 2 to investigate the effect of distribution of roughness. The results of these experiments are shown in Fig. 5-6. Thrust coefficient t_s' has only a slight variation, while power coefficient p' increases very greatly owing to roughness of the propeller. The increase of p' has an aspect of torque constant q in the propeller open tests.

DHP, thrust and RPM obtained from the results in Fig. 5-6 are shown in Fig. 5-7. Fig. 5-7 (a) gives the effect of size of roughness and Fig. 5-7 (b) the effect of distribution of roughness. It will be seen from Fig. 5-7 (a) that even the small size of roughness causes a great increases of DHP, and that the rate of increase of DHP decreases with the increase of size of roughness. Increase in thrust due to roughness is very slight and its variation due to size of roughness cannot be distinguished clearly. Fig. 5-7 (b) shows that DHP increases very slightly when the roughness is confined near the root of the blade, while it increases rapidly as the roughness extends to the tip. The variations of thrust due to different distributions of roughness are very small as in the case of the effect of size of roughness.

*3. Hermann W. Lerbs, "On the Effects of Scale and Roughness on Free Running Propellers", Journal of the American Society of Naval Engineers, Vol. 63, No. 1, February, 1951.

The reason for the slight increase of thrust due to roughness of the propeller, is considered to be that the higher revolution of the propeller in consequence of the drop of the efficiency due to roughness causes an increase of the inflow velocity of the flow near the stern and hence the drop of the pressure thereabout.

4. Analysis and considerations on the test results

Variations of thrust deduction coefficient t, effective wake fraction w_e and hull efficiency η_h due to the variation of size of roughness are shown in Fig. 5-8 (a), and those due to the variation of the distribution of roughness are shown in Fig. 5-8 (b). From these figures it will be seen that the roughness of the propeller does not produce any important effect upon thrust deduction coefficient and wake fraction, but only has a tendency to increase them slightly. Hence there is little variation in hull efficiency.

Principal results obtained in these experiments are as follows:—

(1) The roughness all over the surface of the blade generally produces a worse effect on the propulsive efficiency of the ship than that of the corresponding fouling of hull surface.

(2) When the whole surface of the blade was roughened, even if the protuberances were small, both torque constant and DHP increase remarkably, but their rate of increase decreases as the protuberances become larger.

(3) In self-propulsion tests the increase of thrust due to roughness is very small, and therefore, thrust deduction coefficient increases very slightly.

(4) In open water tests the remarkable decrease of thrust constant with the rate of roughness, together with the increase of torque constant, causes the propeller efficiency to fall off greatly.

(5) Variation of wake fraction is very small.

Chapter 6

Comparison between the Results of the Full-Scale Measurements and those of the Model Experiments

1. Comparison of the characteristics of the clean propeller

Concerning the results of self-propulsion tests for the ship with the clean propeller, comparison was already made in Chapter 3. Therefore, in this section, only the comparison of the characteristics of the clean propeller will be made.

The advance constant v for the actual propeller was calculated by using the wake fraction w obtained from Fig. 3–3, and on a base of v plotted torque constant q and thrust constant t. Their results are shown in Fig. 6–1, together with the results for the model propeller. Both results are in comparatively good agreement. But, as the results obtained from the actual propeller are for 'behind the ship', and those from the model propeller for 'open water', it is difficult to give a definite conclusion on the problem of the scale effect of the propeller.

2. Comparison of the results with the roughened propeller

The experiments in both cases were intended to have been carried out with the propeller roughness in a perfect state of similarity. However, many circumstances made it impossible. That is, the base plate of rubber protuberances could not be made in similar thickness for the actual and model propellers, and, moreover, wire nets attached to the propeller made the similarity more difficult. Even the results of the tank tests for the roughened propeller with wire nets (f 2-1+wire), corresponding to the condition of the actual propeller, did not show very good agreement with those obtained by the full-scale measurements. In order to clear the problem of scale effect of the roughened propeller, further detailed experiments will be necessary.

Table 4-1. Condition of Roughness of Actual Propeller

NOTATIONS	DIMENSION OF PROTUBERANCE (mm) H X D1 X D2 X t	DISTRIBUTION OF ROUGHENED AREA
F1-1	3.3X3X5X0.5	
F1-1/3	〃	
F2-1	6.7X6X10X0.5	
F2-2/3	〃	
F2-1/3	〃	
F3-1	10X9X15X0.5	
F3-1/3	〃	
F4	WIRE	
CLEAN		

REMARK t ······ Thickness of Base Plate

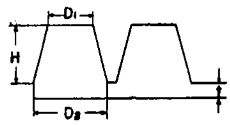


Table 4-2. Experiment Conditions for Ship

Date	1954 May 19		May25	May26	May 28		May29	May 31		June 1	
Roughening Condition of Propeller	F1-1	F1-1/3	F3-1	F3-1/3	F2-1	F2-2/3	F2-1/3	Clean		F4	Clean
Weather*1	C		C	C	C		C	C	R	C	
Wind Direction & Force	E,1	S,1	NE~E,3	NE,1	N,3		NE,1	W~Calm	Calm	ENE~E,2	ESE~SSW.1
Wave Scale	Smooth		Sm.	Sm.	Slight		Sm.	Sm.	Calm	Smooth	
Temp. of Sea Water (deg. C)	20.7		21.0	19.4	20.7		19.4	19.0		22.8	
Specific Gravity of Sea Water	1.022		1.023	1.023	1.019		1.021	1.019		1.021	
Draft (M) Fore	1.78		1.80	1.80	1.80	1.79	1.78	1.80		1.77	1.78
Draft (M) Aft	2.02		2.00	1.99	1.99	2.00	2.01	1.99		2.02	2.01
Draft (M) Mean	1.90		1.90	1.895	1.895		1.90	1.895		1.895	
Displacement (tons)	76.5		76.5	76.0	76.0		76.5	76.0		76.0	

Remarks: *1. C=Cloudy; R=Rain

Table 4-3. Measured Values in Self-Propulsion

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Ship Speed* Through Water V_s (knots)	Relative Wind Direction (deg.)	Relative Wind Speed (knots)
May 19 1954	F1-1	Without Sea Anchor	1	Slow	5.02	P 10	6.45
			2	1/4	6.13	P 15	7.56
			3	2/4	6.76	P 20	9.19
			4	3/4		P 10	10.61
			5	3/4	7.66	P 10	9.46
			6	2/4	7.22	0	7.29
			7	1/4	6.63	P 14	6.30
			8	Slow	5.92	P 4	6.20
		With One Sea Anchor	9	Slow	4.45	0	10.17
			10	1/4	5.69	0	12.11
			11	2/4	6.55	P 10	13.06
			12	3/4	6.64	P 5	13.08
			13	3/4	7.21	Calm	0
			14	2/4	6.78	Calm	〃
			15	1/4	5.81	Calm	〃
			16	Slow	4.86	P 90	〃
		With Three Sea Anchors	17	Slow	3.79	S 15	11.10
			18	1/4	4.47	0	11.55
			19	2/4	5.16	0	11.86
			20	〃	5.63	Calm	0
			21	1/4	4.58	Calm	〃
			22	Slow	3.89	Calm	〃
	F1-1/3	Without Sea Anchor	29	D. Slow	5.23	Calm	0
			30	Slow	6.28	〃	〃
			31	1/4	7.12	〃	〃
			32	2/4	8.20	〃	〃
			33	3/4	9.20	S 60	6.49
			34	4/4	9.25		
			35	〃	8.89	P 5	18.66
			36	3/4	8.73	P 5	24.72
			37	2/4	7.45	P 10	16.70
			38	1/4	6.43	P 25	15.03
			39	Slow	5.47	P 30	13.47
			40	D. Slow	4.72	P 15	13.86
		With One Sea Anchor	41	Slow	5.36	Calm	0
			42	1/4	6.53	〃	〃
			43	2/4	7.58	〃	〃
			44	3/4	8.64	〃	〃
			45	4/4	8.89	〃	〃
			46	〃	8.33	P 20	17.96
			47	3/4	7.88	P 15	17.83
			48	3/4	6.71	P 20	15.61
			49	1/4	5.54	P 25	13.03
			50	Slow	4.47	P 25	11.57
		With Three Sea Anchors	51	Slow	4.48	Calm	0
			52	1/4	5.28	〃	〃
			53	2/4	6.47	〃	〃
			54	3/4	7.53	〃	〃
			55	〃	6.89	P 20	11.18
			56	2/4	5.83	P 15	11.45
			57	1/4	4.84	P 10	10.89
			58	Slow		0	10.42

Tests with Roughened Propeller

Remark: *: by Shiba Speed Meter

Helm Angle (deg.)			RPM		Thrust	DHP
Mean	Maximum		Engine	Shaft		
	Port	Starboard	Room	Tunnel	(kg)	
S1.0	−0.9	1.3	204	204	413	43.8
S1.0	1.4	2.5	248	250	627	80.0
S1.2	−1.1	1.5	284	266	710	96.8
P3.0	6.0	1.3	308			
P2.3	5.6	2.7	312	292	863	127.8
P1.2	3.3	2.7	284	275		106.2
S0.7	1.0	−2.5	248	245	600	73.9
P2.0	2.0	−2.0	204	206	421	43.6
P1.8	2.4	−0.2	204	202	483	43.5
P1.7	2.5	−0.2	240	247	675	77.1
P1.0	5.2	−4.9	284	288	882	123.8
P1.0	2.0	−1.6	304	297	941	137.2
P0.6	4.0	−2.0	304	302	945	143.1
P1.8	1.8	−1.1	288	286	846	120.0
P1.0	1.5	−0.6	244	247	654	76.2
P2.0	2.1	−1.5	208	200	453	41.5
S0.1	0.5	0.8	204	204	520	45.6
S0.8	0	1.5	248	239	727	73.8
P0.8	2.2	1.1	288	279	970	117.7
P0.2	0.3	−0.1	288	280	952	116.4
P1.5	2.1	−1.1	244	235	698	69.8
P2.0	2.0	−1.9	200	198	470	41.0
			172	147	380	15.1
			208	208	527	27.0
			248	246	714	43.0
			300	290	1041	74.2
			352	346	1425	124.6
			368	364	1610	153.4
			368	364	1618	152.4
			344	346	1412	124.2
			292	296	1002	73.9
			244	242	801	38.4
			204	204	553	19.6
			172	173	427	11.8
			208	203	560	26.0
			244	250	813	47.7
			296	295	1154	80.1
			344	345	1596	128.8
			364	361	1733	149.6
			364	365	1747	151.6
			348	348	1671	128.2
			296	297	1144	73.7
			248	243	809	42.6
			200	201	563	19.0
			204	205	625	28.8
			248	240	826	46.4
			298	300	1312	90.1
			356	352	1782	144.2
			348	347	1775	141.9
			296	287	1233	80.0
			244	235	834	44.3
			204	191		

Table 4-3.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Ship Speed* Through Water V_s (knots)	Relative Wind Direction (deg.)	Relative Wind Speed (knots)
May 25	F3-1	Without Sea Anchor	59	Slow	5.26	P 10	22.49
			60	1/4	6.11	S 5	25.24
			61	2/4	7.11	P 5	26.38
			62	3/4	7.56	S 20	23.38
			63	〃	8.14	P140	8.46
			64	2/4	7.83	P140	7.91
			65	1/4	7.00	P145	8.01
			66	Slow	5.54	P155	9.14
		With One Sea Anchor	67	Slow	4.28	S 10	17.36
			68	1/4	5.31	S 15	18.29
			69	2/4	6.42	S 20	17.98
			70	3/4	6.82	S 15	17.69
			71	〃	7.27	P130	8.75
			72	2/4	6.98	P160	18.49
			73	1/4	6.04	P170	16.95
			74	Slow	5.10	P155	8.75
		With Three Sea Anchors	75	Slow	3.95	P 10	18.49
			76	1/4	4.58	P 10	16.95
			77	2/4	5.44	P 10	17.42
			78	3/4	5.52	P 25	16.68
			79	〃	6.08	Calm	0
			80	2/4	5.73	〃	〃
			81	1/4	4.75	〃	〃
			82	Slow	3.87	〃	〃
		Ballord Test	83	Slow		S 90	9.39
			84	1/4		S 90	6.22
			85	2/4		S 90	7.58
			86	〃		S 90	6.77
			87	1/4		S 90	8.81
			88	Slow		S 90	9.50
May 26	F3-1/3	Without Sea Anchor	89	D. Slow	4.53	P 5	14.72
			90	Slow	5.58	P 5	14.44
			91	1/4	6.73	P 5	16.31
			92	2/4	7.78	P 10	16.48
			93	3/4	8.76	P 10	16.62
			94	〃	9.24	Calm	0
			95	2/4	8.12	〃	〃
			96	1/4	7.05	〃	〃
			97	Slow	5.86	〃	〃
			98	D. Slow	5.35	〃	〃
		With One Sea Anchor	99	D. Slow	4.19	0	11.47
			100	Slow	4.68	P 5	11.82
			101	1/4	5.72	P 5	12.63
			102	2/4	6.86	P 10	13.80
			103	3/4	7.86	P 10	12.05
			104	〃	8.36	Calm	0
			105	2/4	7.25	〃	〃
			106	1/4	6.15	〃	〃
			107	Slow	5.08	〃	〃
			108	D. Slow	4.39	〃	〃

(Continued)

Helm Angle (deg.)			RPM		Thrust	DHP
Mean	Maximum		Engine	Shaft	(kg)	
	Port	Starboard	Room	Tunnel		
P0.3	2.6	2.2	188	205	450	45.0
P1.8	3.2	0.1	256	245	636	80.5
P2.8	5.7	2.2	296	234	895	148.0
P1.6	5.0	2.4	300	308	979	172.0
P3.3	6.3	0.8	304	306	927	165.5
P3.3	5.3	−1.2	300	294	834	142.7
P2.9	5.4	−1.3	244	247	584	78.5
P2.1	6.0	0.3	204	204	429	42.7
S0.7	3.3	4.0	200	205	459	48.3
P0.7	2.8	0.7	248	247	644	85.3
P1.1	4.9	0.7	292	294	905	151.5
P1.3	5.0	−0.1	316	306	996	172.8
P4.8	8.4	−0.3	312	307	1002	171.0
P3.7	8.1	−1.8	288	293	895	148.2
P0.9	5.9	1.0	244	246	680	81.8
P3.3	4.9	0.8	204	203	470	44.7
P0.4	2.3	0.9	212	209	563	52.6
P2.7	5.0	−1.5	248	247	735	86.2
P1.5	4.9	0.5	296	295	1014	154.1
P1.5	4.3	0.5	300	301	1099	164.2
P2.9	6.9	1.6	304	307	1118	171.7
P4.0	7.0	−1.0	312	293	1008	147.0
P2.2	4.7	−0.7	252	244	720	80.7
P2.9	5.3	0.5	208	199	521	45.1
P6.2	8.1	−5.0	212	207	657	53.2
P2.1	2.8	−0.7	252	249	931	89.1
S2.4	2.7	3.8	304	294	1305	156.3
P1.8	3.0	2.1	296	297	1300	155.3
P0.6	1.0	0.7	232	245	931	88.2
S1.5	1.6	3.9	208	206	824	49.2
			176	171	367	15.5
			204	203	502	25.3
			248	247	725	46.0
			292	291	1030	77.1
			340	338	1482	122.0
			340	346	1411	130.0
			292	295	994	77.6
			244	244	669	43.1
			200	199	464	23.0
			176	182	379	17.5
			176	177	410	18.1
			204	203	520	27.4
			248	235	700	41.9
			292	275	950	66.6
			344	328	1360	113.0
			344	327	1410	110.1
			296	287	1020	74.4
			244	239	720	42.8
			200	198	503	24.4
			176	176	408	17.4

Table 4–3.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Ship Speed* Through Water V_s (knots)	Relative Wind Direction (deg.)	Relative Wind Speed (knots)
May 26	F3–1/3	With Three Sea Anchors	109	Slow	4.09	P 10	13.20
			110	1/4	4.76	P 15	13.70
			111	2/4	5.72	P 15	15.32
			112	3/4	7.00	P 10	15.65
			113	〃	7.26	Calm	0
			114	2/4	6.26	〃	〃
			115	1/4	5.25	〃	〃
			116	Slow	4.30	〃	〃
		Bollard Test	117	Slow		P140	9.18
			118	1/4		P140	7.78
			119	2/4		P140	7.66
			120	3/4		P140	8.26
			121	〃		P130	10.40
			122	2/4		P120	8.90
			123	1/4		P130	9.52
			124	Slow		P130	8.26
May 28	F2–1	Without Sea Anchor	125	Slow	5.60	P 5	19.50
			126	1/4	6.57	P 5	23.67
			127	2/4	7.65	P 5	25.04
			128	3/4	7.95	P 5	25.15
			129	〃	7.75	S170	8.65
			130	2/4	7.60	S170	10.12
			131	1/4	6.57	S170	11.78
			132	Slow	5.53	S170	9.95
		With One Sea Anchor	133	Slow	4.87	P 5	17.78
			134	1/4	5.76	P 5	18.36
			135	2/4	6.70	0	17.10
			136	3/4	6.76	S 10	19.08
			137	〃	6.75	S175	6.04
			138	2/4	6.69	S165	
			139	1/4	5.76	S170	12.95
			140	Slow	4.83	P175	14.11
	F2–2/3	Without Sea Anchor	141	Slow	5.69	S170	14.32
			142	1/4	6.50	S175	13.14
			143	〃	6.06	P 5	28.76
			144	S	5.14	P 5	25.84
			145	2/4	7.50	S175	14.17
			146	〃	7.12	0	24.35
			147	3/4	8.30	S170	11.93
			148	Slow	7.90	P 5	25.28
		With One Sea Anchor	149	Slow	4.80	P 90	13.84
			150	1/4	5.40	P 85	16.67
			151	〃	5.38	S 75	23.42
			152	S	4.85	S 80	21.49
			153	2/4	6.36	P 85	16.19
			154	3/4	7.15	P 65	21.76
			155	〃	7.18	S 90	14.61
			156	2/4	6.35	S 90	13.85

(Continued)

Helm Angle (deg.)			RPM		Thrust	DHP
Mean	Maximum		Engine	Shaft		
	Port	Starboard	Room	Tunnel	(kg)	
			204	206	592	31.2
			244	247	850	53.4
			296	296	1230	91.2
			344	346	1690	144.0
			344	347	1700	142.0
			300	293	1210	86.0
			240	242	815	49.0
			200	200	559	27.5
P1.0	1.6	−0.6	200	204	822	37.5
P1.1	2.1	−0.2	244	244	1306	65.8
P1.7	5.6	0	296	296	1929	119.8
P0.9	1.6	0	336	336	2181	179.4
P2.9	5.8	0.1	336	337	2255	186.9
P3.9	5.8	−2.4	292	297	1888	119.9
P3.1	4.8	−1.6	244	243	1202	63.4
P2.0	3.0	−1.6	200	202	839	37.5
S0.5	0.8	1.2	200	202	384	46.5
P1.1	2.5	0.7	248	245	622	82.7
P1.5	2.9	0.7	296	298	828	144.2
P0.5	2.8	1.2	304	313	1004	179.5
P3.1	4.5	−1.6	308	293	872	158.0
P2.8	4.1	−1.1	296	285	802	142.8
0	1.8	1.5	244	246	588	93.2
S0.6	1.5	2.5	200	204	404	53.1
			200	211	500	62.0
			252	248	691	100.0
			296	283	870	144.9
			308	284	880	146.7
			298	285	880	147.9
			290	281	860	142.1
			240	242	634	90.5
			200	208	480	58.2
			202	194	427	31.0
			232	225	570	48.8
			246	225	570	50.3
			204	192	420	31.3
			296	263	800	79.8
			296	260	780	78.6
			340	297	1020	115.2
			344	292	1000	106.5
			204	194	480	33.8
			244	214	580	45.7
			248	214	580	45.7
			204	195	480	34.4
			300	251	790	73.9
			332	283	1000	106.1
			336	283	1000	105.9
			294	249	770	72.0

Table 4-3.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Ship Speed* Through Water V_s (knots)	Relative Wind Direction (deg.)	Relative Wind Speed (knots)
May 29	F2-1/3	Without Sea Anchor	165	D. Slow	4.89	0	15.74
			166	Slow	5.61	0	16.32
			167	1/4	6.74	0	17.72
			168	2/4	7.99	0	18.69
			169	3/4	9.08	0	18.77
			170	〃	9.32	Calm	0
			171	2/4	8.37	〃	〃
			172	1/4	7.10	〃	〃
			173	Slow	6.18	〃	〃
			174	D. Slow	5.39	P160	6.84
		With One Sea Anchor	175	D. Slow	4.41	0	14.96
			179	Slow	5.01	0	15.21
			177	1/4	5.97	0	15.31
			178	2/4	7.02	0	17.72
			179	3/4	8.01	0	18.60
			180	〃	8.34	Calm	0
			181	2/4	7.34	〃	〃
			182	1/4	6.51	〃	〃
			183	Slow	5.45	P 80	5.64
			184	D. Slow	4.66	P160	6.02
		With Three Sea Anchors	185	Slow	3.92	P 5	12.34
			186	1/4	4.79	P 5	13.70
			187	2/4	5.84	P 5	14.65
			188	3/4	6.87	P 5	16.81
			189	〃	7.21	Calm	0
			190	2/4	6.15	〃	〃
			191	1/4	5.24	〃	〃
			192	Slow	4.20	〃	〃
		Bollard Test	193	Slow		S 50	8.63
			194	1/4		S 50	8.55
			195	2/4		S 50	9.45
			196	〃		S 50	9.17
			197	1/4		S 70	9.81
			198	Slow		S 90	
May 31	Clean (Propeller in use)	Without Sea Anchor	199	D. Slow	5.04	P 70	8.16
			200	Slow	6.22	P 70	9.58
			201	1/4	7.20	P 45	9.50
			202	2/4	8.30	P 35	10.10
			203	3/4	9.23	P 25	9.58
			204	4/4	9.60	P 20	8.73
			205	〃	9.67	0	14.98
			206	3/4	9.20	S 5	12.94
			207	2/4	8.25	S 5	11.50
			208	1/4	7.16	S 5	11.62
			209	Slow	5.96	S 5	12.24
			210	D. Slow	5.13	S 5	11.50
		with One Sea Anchor	211	D. Slow	4.60	Calm	0
			212	Slow	5.32	〃	〃
			213	1/4	6.38	〃	〃
			214	2/4	7.61	〃	〃

(Continued)

Helm Angle (deg.)			RPM		Thrust	DHP
Mean	Maximum		Engine	Shaft		
	Port	Starboard	Room	Tunnel	(kg)	
P1.7	3.5	−0.6	168	174	405	15.9
P3.6	4.1	−1.6	200	201	530	24.5
P2.3	4.0	−0.7	240	244	755	43.9
P2.1	4.2	1.4	288	294	1104	79.8
P1.5	2.9	0.4	332	347	1539	136.3
P2.9	5.4	2.2	344	347	1514	133.7
P3.0	6.5	2.0	292	297	1086	79.8
P2.7	4.9	0.4	232	245	736	43.4
P2.0	4.5	1.6	200	204	516	24.7
P2.0	6.0	0.7	172	173	383	15.1
P1.7	2.1	−1.0	172	175	431	18.0
P2.5	4.4	−1.3	204	204	560	27.5
P3.7	4.2	−2.0	244	248	824	48.1
P2.2	4.0	0.3	292	280	1030	70.4
P2.2	2.8	−1.3	344	329	1400	113.2
P3.1	6.7	0.4	344	326	1450	108.3
P3.6	4.0	−1.8	292	280	1030	67.8
P2.0	5.6	−0.9	236	246	784	45.6
P3.1	6.1	1.0	200	202	590	26.8
P3.6	4.2	−3.1	176	175	800	42.7
P2.0	3.2	0.6	204	198	590	26.8
P2.7	5.0	0.8	256	232	800	42.7
P3.0	4.1	−1.7	296	295	1156	86.0
P2.0	5.2	3.0	328	328	1530	21.3
P5.4	7.0	−1.4	336	335	1610	127.2
P4.0	6.0	0	292	295	1159	85.5
P2.2	4.7	0.9	248	242	855	47.2
P2.5	4.0	0.5	200	195	570	24.8
S3.3	−2.8	3.8	204	203	816	42.7
0	0.3	0.4	244	245	1251	75.7
P0.3	1.4	0.3	288	298	1753	134.5
S0.2	0	0.6	288	298	1749	137.9
0	0.4	0.4	244	244	1260	75.5
P0.6	1.0	−0.3	200	204	792	43.6
			156	160	351	12.2
			200	201	530	24.4
			256	247	791	45.5
			288	300	1140	79.1
			324	346	1507	129.4
			376	372	1794	162.2
			372	373	1793	162.9
			320	349	1534	127.0
			292	298	1131	76.1
			236	245	782	41.6
			204	202	535	24.2
			172	172	395	15.6
			180	179	450	18.7
			204	205	591	27.0
			244	246	816	45.6
			296	297	1150	81.3

Table 4-3.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Ship Speed* Through Water V_s (knots)	Relative Wind Direction (deg.)	Relative Wind Speed (knots)
May 31	Clean (Propeller in Use)	With One Sea Anchor	215	3/4	8.61	〃	〃
			216	4/4	9.11	〃	〃
			217	〃	9.24	0	14.34
			218	3/4	8.60	0	13.48
			219	2/4	7.65	S 5	14.38
			220	1/4	6.46	S 5	13.28
			221	Slow	5.60	Calm	0
			222	D. Slow	4.83	〃	〃
		Bollard Test	223	Slow		Calm	0
			224	1/4		〃	〃
			225	2/4		〃	〃
			226	〃		〃	〃
			227	1/4		〃	〃
			228	〃		〃	〃
		With Three Sea Anchor	229	Slow	4.48	0	6.33
			230	1/4	5.25	S 5	6.78
			231	2/4	6.38	0	7.58
			232	3/4	7.60	0	8.96
			233	4/4	7.51	0	7.99
			234	〃	7.75	P 5	10.53
			235	3/4	7.74	P 5	10.90
			236	2/4	6.48	P 10	7.97
			237	1/4	5.30	P 10	7.07
			238	Slow	4.42	P 10	5.46
June 1	F4	Without Sea Anchor	239	D. Slow	4.21	S 5	19.57
			240	Slow	5.11	S 5	19.80
			241	1/4	6.32	S 5	21.26
			242	2/4	7.79	S 5	21.72
			243	3/4	8.95	S 5	23.92
			244	〃	9.21	S 175	6.55
			245	2/4	8.05	S 165	7.60
			246	1/4	6.97	S 175	8.76
			247	Slow	6.26	P 170	9.17
			248	D. Slow	5.33	P 175	11.00
		With One Sea Anchor	249	D. Slow		P 65	14.56
			250	Slow	5.34	P 85	10.30
			251	1/4	6.35	P 45	16.05
			252	2/4	7.56	P 45	15.55
			253	〃	7.26	S 75	9.93
			254	1/4	5.79	S 60	12.60
			255	Slow	4.99	S 50	15.86
			256	D. Slow		S 40	15.16
			257	3/4	8.42	P 70	10.88
			258	〃	8.43	S 30	16.36
		With Three Anchors	259	Slow	4.41	P 70	8.33
			260	1/4	5.11	P 25	8.71
			261	2/4	6.15	P 15	14.44
			262	〃	5.97	S 75	9.50
			263	1/4	4.75	S 60	9.15
			264	Slow	3.63	S 45	10.36
			265	3/4	7.07	S 20	14.48
			266	〃	6.97	P 75	6.51

(Continued)

Helm Angle (deg.)			RPM		Thrust	DHP
Mean	Maximum		Engine Room	Shaft Tunnel	(kg)	
	Port	Starboard				
			332	346	1569	130.7
			356	371	1855	169.8
			360	372	1825	171.0
			344	348	1579	128.5
			292	294	1165	74.7
			244	244	802	45.5
			204	205	563	26.7
			176	176	429	16.6
			202	206	801	40.6
			244	248	1312	70.3
			288	294	1830	116.9
			292	298	1842	119.4
			240	247	1333	67.4
			212	204	817	38.4
			208	204	672	28.9
			240	245	933	47.0
			300	297	1326	85.4
			352	349	1777	135.5
			356	359	1852	152.2
			352	351	1834	136.1
			340	349	1786	136.6
			304	297	1306	85.5
			252	245	889	
			204	204	672	28.0
S4.5	−3.1	6.6	172	175	380	22.5
S5.0	−2.5	6.5	208	202	494	34.0
S4.8	−2.5	7.0	240	232	642	50.3
S2.4	−1.0	3.6	296	285	980	92.2
S3.4	−2.3	5.0	340	351	1459	171.1
S1.3	2.0	6.9	352	351	1441	169.5
S0	1.5	3.0	288	287	957	92.8
S0.9	0.6	4.3	244	234	631	50.1
S1.1	0.4	3.3	200	204	487	32.6
S3.4	−2.3	4.0	176	176	367	20.8
S5.1	−4.0	5.8	172			
S1.7	−1.7	1.7	208	208	550	37.0
S4.2	−3.8	4.5	244	235	687	51.6
S2.3	−2.2	2.5	296	286	1011	93.6
S4.0	−3.4	5.4	284	285	1040	94.2
S4.9	−3.3	5.3	240	234	713	52.6
S1.3	−0.4	2.5	200	203	567	35.4
S3.6	−3.4	4.0	172			
S2.0	−1.2	3.5	348	339	1471	159.5
S2.8	−1.4	5.0	348	346	1559	170.6
P7.0	7.9	−6.0	200	207	612	40.1
P5.7	6.3	−4.6	244			
P6.2	6.4	−6.0	292	278	1053	95.5
P5.9	6.1	−5.0	288	278	1087	96.7
P2.9	4.7	−1.7	240			
P6.1	6.1	−6.1	200	192	567	32.3
P6.3	6.8	−4.7	332	322	1428	149.4
P3.1	3.9	−1.6	344	330	1540	162.9

Table 4-3.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Ship Speed* Through Water V_s (knots)	Relative Wind Direction (deg.)	Relative Wind Speed (knots)
June 1	F4	Bollard Test	267	Slow		Calm	0
			268	1/4		〃	〃
			269	2/4		〃	〃
			270	〃		〃	〃
			271	1/4		〃	〃
			272	Slow		〃	〃
	Clean (Spare Propeller)	Bollard Test	273	Slow		S 140	7.23
			274	1/4		S 115	8.12
			275	2/4		S 140	
			276	〃		S 120	8.30
			277	1/4		S 145	5.83
			278	Slow		S 135	7.81
		Without Sea Anchor	279	D. Slow	4.82	S 5	8.42
			280	Slow	5.68	S 5	8.76
			281	1/4	6.65	S 5	9.72
			282	2/4	7.35	S 10	13.55
			283	3/4	8.71	S 10	14.04
			284	4/4	9.58	S 10	12.77
			285	〃	9.95	P 15	11.12
			286	〃	9.09	P 10	9.66
			287	2/4	8.23	P 20	7.97
			288	1/4	7.09	P 25	8.01
			289	Slow	6.11	P 35	6.65
			290	D. Slow	5.15	P 60	
		With One Sea Anchor	291	D. Slow	4.56	S 5	11.27
			292	Slow	5.24	S 5	11.10
			293	1/4	6.28	S 5	9.76
			294	2/4	7.64	S 5	11.72
			295	3/4	8.70	S 10	17.30
			296	4/4	9.16	S 10	16.97
			297	〃	9.31	Calm	0
			298	3/4	8.59	〃	〃
			299	2/4	7.60	Calm	0
			300	1/4	6.34	〃	〃
			301	Slow	5.42	〃	〃
			302	D. Slow	4.69	〃	〃
		With Three Sea Anchors	303	Slow	4.55	Calm	0
			304	1/4	5.25	〃	〃
			305	2/4	6.44	S 30	5.58
			306	3/4	7.55	S 5	6.67
			307	4/4	8.00	P 10	8.55
			308	〃	7.42	P 10	11.47
			309	3/4	6.92	P 10	12.94
			310	2/4	5.80	P 10	9.54
			311	1/4	4.76	Calm	0
			312	Solw	3.94	P 15	9.37

(Continued)

Helm Angle (deg.) Mean	Maximum Port	Maximum Starboard	RPM Engine Room	RPM Shaft Tunnel	Thrust (kg)	DHP
P2.5	2.9	−2.3	204	203	816	42.7
P2.8	3.0	−2.7	244	245	1251	75.7
P4.6	5.0	−3.9	296	298	1753	134.5
P6.0	6.6	−5.7	288	298	1749	137.9
P3.9	4.5	−2.4	244	244	1260	75.5
P3.0	3.4	−2.7	204	204	792	43.6
P3.5	4.3	−2.8	200	207	779	39.1
P3.0	4.7	−1.3	248	251	1406	70.2
P3.9	7.5	−0.9	292	295	1759	122.0
P2.0	4.5	0.4	292	297	1769	125.9
P2.2	2.9	−1.4	248	248	1406	67.5
P5.2	5.4	−4.9	200	206	817	38.3
P3.8	4.0	−3.5	168	176	448	16.5
P3.4	5.5	−2.0	200	205	572	25.4
P4.8	6.3	−3.3	268	248	788	44.9
P5.6	7.2	−3.9	300	297	1071	79.8
P3.9	5.4	−2.0	332	347	1488	129.4
P5.3	6.4	−3.2	376	376	1790	167.4
P5.7	9.1	−2.0	376	374	1760	162.0
P6.8	9.1	−4.1	348	343	1428	119.2
P9.5	11.9	−7.9	292	292	1010	69.0
P7.8	8.7	−6.5	244	241	708	38.8
P4.8	5.8	−3.1	196	200	518	22.0
P5.6	7.0	−4.8	176	176	448	15.5
P5.6	7.2	−4.4	176	177	459	17.9
P5.8	6.6	−5.1	208	206	591	25.8
P3.9	4.2	−3.5	244	237	864	44.0
P5.7	7.5	−3.1	296	299	1122	81.8
P6.6	7.9	−5.8	344	344	1530	128.8
P6.5	7.1	−5.5	388	377	1963	170.4
P5.4	8.2	−2.5	380	382	1959	171.3
P5.3	5.5	−5.0	348	344	1568	128.2
P2.9	4.0	−1.0	292	294	1197	77.3
P4.0	4.8	−3.1	240	243	864	41.6
P4.0	5.3	−3.0	200	200	622	23.0
P4.4	6.6	−2.6	172	174	472	13.9
P5.9	7.6	−4.2	208	208	667	29.1
P5.9	7.1	−5.2	240	242	896	46.4
P4.7	5.4	−4.1	292	295	1332	84.0
P2.2	2.4	−2.1	352	353	1926	145.5
P2.8	5.1	0.2	376	376	2192	178.1
P6.9	9.4	−2.4	372	377	2151	180.9
P6.1	8.0	−4.5	344	346	1860	135.3
P6.9	7.8	−5.1	296	294	1302	80.5
P4.7	7.0	−3.2	244	243	911	43.7
P7.2	7.5	−7.0	200	201	712	25.5

Table 4-4. Analysis of the

Process of Analysis

1. θ and V_w are the values corrected from the wind tunnel tests.
2. k was read from Fig. I-7.
3. $q' = \dfrac{Q}{\rho N^2 D^5} = \alpha \dfrac{\text{DHP}}{(\text{RPM})^3}$, $\alpha = \dfrac{75 \times 60^3}{2\pi\rho D^5}$
4. $q = q_a' - (q_a' - q_w') \dfrac{k V_{wa}^2 - V_s^2}{k V_{wa}^2 - k V_{ww}^2}$

   Suffixes a and w indicate runs against wind and with wind, respectively. The values of q in this table are those read from the fair curve of q plotted on a base of RPM.
5. Corrected DHP $= \dfrac{(\text{RPM})^3}{\alpha} q$

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	Measured Data: R P M	Measured Data: Thrust (kg)	Measured Data: D H P
May 19 1954	F1-1	Without Sea Anchor	1	Slow	5.02	204	413	43.8
			2	1/4	6.13	250	627	80.0
			3	2/4	6.76	266	710	96.8
			4	3/4				
			5	〃	7.66	292	863	127.8
			6	2/4	7.22	275		106.2
			7	1/4	6.63	245	600	73.9
			8	Slow	5.92	206	421	43.6
		With One Sea Anchor	9	Slow	4.45	202	483	43.5
			10	1/4	5.69	247	675	77.1
			11	2/4	6.55	288	882	123.8
			12	3/4	6.64	297	941	137.2
			13	〃	7.21	302	945	143.1
			14	2/4	6.78	286	846	120.0
			15	1/4	5.81	247	654	76.2
			16	Slow	4.86	200	453	41.5
		With Three Sea Anchors	17	Slow	3.79	204	520	45.6
			18	1/4	4.47	239	727	73.8
			19	2/4	5.16	279	970	117.7
			20	〃	5.63	280	952	116.4
			21	1/4	4.58	235	698	69.8
			22	Slow	3.89	198	470	41.0
	F1-1/3	Without Sea Anchor	29	D. Slow	5.23	174	380	15.1
			30	Slow	6.28	208	527	27.0
			31	1/4	7.12	246	714	43.0

6. Corrected speed $V_s' = V_s + \Delta V_s'$, $\quad \Delta V_s = \frac{N}{\beta}(q - q')$

$\beta = \frac{\Delta q}{\Delta v}$ and it was calculated from the characteristic curves of model propeller.

7. $t' = \frac{T}{\rho N^2 D^4} = \delta \frac{T}{(\mathrm{RPM})^2}$, $\quad \delta = \frac{60^2}{\rho D^4}$

8. $t = t_a' - (t_a' - t_w') \frac{k V_{wa}'^2 - V_s^2}{k V_w^2 - k V_{ww}^2}$

9. Corrected thrust $T = \frac{(\mathrm{RPM})^2}{\delta}$

Relative Wind		Wind Direction Effect Coeff.	Correction for Wind Force						
Direction θ (deg.)	Speed V_w (knots)	k	Torque Constant q'	Corrected Torque Constant q	Corrected DHP	Corrected Ship Speed V_s' (knots)	Thrust Constant t'	Corrected Thrust Constant t	Corrected Thrust T (kg)
P 11	6.14	0.89	0.0394	0.0387	43.0	5.40	0.134		
P 17	9.49	0.83	0.0391	0.0387	79.2	6.40	0.136		
P 22	9.38	0.83	0.0393	0.0390	96.1	7.06	0.135		
P 11	10.12	0.89	0.0397						
S 11	9.01	1.89	0.0392	0.0392	127.8	7.66	0.137		
0	6.45	0.00	0.0390	0.0390	106.2	7.22			
P 11	6.00	0.89	0.0384	0.0386	74.3	6.50	0.135		
P 5	5.45	0.98	0.0381	0.0387	44.3	5.59	0.134		
0	9.00	1.00	0.0403	0.0398	42.9	4.72	0.160	0.155	468
0	10.70	1.00	0.0391	0.0388	76.6	5.89	0.150	0.146	657
P 11	12.44	0.89	0.0396	0.0394	123.2	6.70	0.144	0.141	863
P 5	12.00	0.98	0.0400	0.0397	136.2	6.88	0.144	0.141	922
Calm	0		0.0397	0.0399	143.8	7.05	0.140	0.141	952
〃	0		0.0392	0.0393	120.3	6.70	0.144	0.141	852
〃	0		0.0387	0.0388	76.5	5.74	0.145	0.146	659
P 95	0	−0.06	0.0397	0.0399	41.8	4.75	0.153	0.159	463
S 17	10.89	0.83	0.0410	0.0405	45.0	4.06	0.169	0.163	501
0	10.22	1.00	0.0413	0.0410	73.3	4.67	0.162	0.168	709
0	10.50	1.00	0.0414	0.0409	116.3	5.54	0.159	0.165	952
Calm	0		0.0405	0.0407	117.0	5.48	0.155	0.165	958
〃	0		0.0411	0.0412	70.0	4.51	0.157	0.172	702
〃	0		0.0404	0.0405	41.2	3.84	0.162	0.163	473
Calm	0		0.0219				0.169		
〃	0		0.0230				0.155		
〃	0		0.0221				0.169		

Table 4-4.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	RPM	Thrust (kg)	DHP
May 19, 1954	F1-1/3	Without Sea Anchor	32	2/4	8.20	290	1041	74.2
			33	3/4	9.20	346	1425	124.6
			34	4/4	9.25	364	1610	153.4
			35	〃	8.89	364	1618	152.4
			36	3/4	8.73	346	1412	124.2
			37	2/4	7.45	294	1002	73.9
			38	1/4	6.43	242	801	38.4
			39	Solw	5.47	204	553	19.6
			40	D. Slow	4.72	173	427	11.8
		With One Sea Anchor	41	Slow	5.36	203	560	26.0
			42	1/4	6.53	250	813	47.7
			43	2/4	7.58	295	1154	80.1
			44	3/4	8.64	345	1596	128.8
			45	4/4	8.89	361	1733	149.6
			46	〃	8.33	365	1747	151.6
			47	3/4	7.88	348	1671	128.2
			48	2/4	6.71	297	1144	73.7
			49	1/4	5.54	243	809	42.6
			50	Slow	4.47	201	503	19.0
		With Three Sea Anchors	51	Slow	4.48	205	625	28.8
			52	1/4	5.28	240	826	46.4
			53	2/4	6.47	300	1312	90.1
			54	3/4	7.53	352	1782	144.2
			55	〃	6.89	347	1775	141.9
			56	2/4	5.83	287	1233	80.0
			57	1/4	4.84	235	834	44.3
			58	Slow		191		
May 25	F3-1	Without Sea Anchor	59	Slow	5.26	205	450	45.0
			60	1/4	6.11	245	636	80.5
			61	2/4	7.11	234	895	148.0
			62	3/4	7.56	308	979	172.0
			63	〃	8.14	306	927	165.5
			64	2/4	7.83	294	834	142.7
			65	1/4	7.00	247	584	78.5
			66	Slow	5.54	204	429	42.7
		With One Sea Anchor	67	Slow	4.28	205	459	48.3
			68	1/4	5.31	247	644	85.3
			69	2/4	6.42	294	905	151.5
			70	3/4	6.82	306	996	172.8
			71	〃	7.27	307	1002	171.0
			72	2/4	6.98	293	895	148.2
			73	1/4	6.04	246	680	81.8
			74	Slow	5.10	203	470	44.7
		With Three Sea Anchors	75	Solw	3.95	209	563	52.6
			76	1/4	4.58	247	735	86.2
			77	2/4	5.44	295	1014	154.1
			78	3/4	5.52	301	1099	164.2
			79	〃	6.08	307	1118	171.7
			80	2/4	5.73	293	1008	147.0

(Continued)

Relative Wind		Wind Direction Effect Coeff.	Correction for Wind Fore							
Direction θ (deg.)	Speed V_w (knots)	k	Torque Con-stant q'	Cor-rected Torque Con-stant q	Cor-rected DHP	Cor-rected Ship Speed V_s' (knots)	Thrust Con-stant t'	Cor-rected Thrust Con-stant t	Cor-rected Thrust T (kg)
Calm	0		0.0232				0.167		
S 66	6.98	0.72	0.0231				0.161		
P 5	17.12	0.98							
P 5	22.68	0.98							
P 11	15.91	0.89							
P 27	15.99	0.82							
P 33	14.48	0.83							
P 17	13.72	0.83							
Calm	0		0.0237				0.184		
〃	〃		0.0235				0.174		
〃	〃		0.0238				0.180		
〃	〃		0.0240				0.182		
〃	〃		0.0243				0.180		
Calm	0		0.0256	0.0255	28.7	4.44	0.200	0.202	631
〃	〃		0.0257	0.0255	46.0	5.18	0.194	0.196	836
〃	〃		0.0255	0.0258	91.0	6.41	0.197	0.199	1318
〃	〃		0.0253	0.0255	145.3	7.39	0.194	0.197	1810
P 22	11.41	0.83	0.0260	0.0252	137.6	7.43	0.199	0.195	1739
P 17	11.34	0.83	0.0259	0.0255	78.8	6.25	0.202	0.198	1210
P 11	10.37	0.89	0.0260	0.0255	43.2	5.08	0.204	0.199	813
0	9.22								
P 11	21.42	0.89	0.0403	0.0392	43.8	5.73	0.146	0.141	436
S 5	23.16	0.98	0.0417	0.0403	77.8	6.83	0.143	0.132	588
P 5	24.20	0.98	0.0442	0.0434	143.4	7.60	0.140	0.133	849
S 22	24.10	0.83	0.0453	0.0447	169.9	7.95	0.140	0.135	943
P139	8.72	−0.88	0.0443	0.0445	166.3	8.01	0.134	0.135	933
P139	8.15	−0.88	0.0432	0.0434	142.7	7.70	0.131	0.133	847
P144	8.43	−0.94	0.0400	0.0405	79.2	6.78	0.130	0.132	594
P154	9.62	−1.03	0.0388	0.0392	43.2	5.37	0.140	0.141	432
S 11	16.53	0.89	0.0430	0.0417	46.8	4.84	0.148	0.148	459
S 17	18.11	0.83	0.0433	0.0424	83.5	5.79	0.143	0.143	644
S 22	18.53	0.83	0.0455	0.0447	148.7	6.92	0.142	0.142	905
S 17	17.52	0.83	0.0463	0.0456	170.2	7.27	0.144	0.144	996
Calm	0		0.0454	0.0456	171.7	7.14	0.144	0.144	1002
〃	〃		0.0445	0.0447	147.1	6.86	0.141	0.141	895
〃	〃		0.0423	0.0424	81.9	5.99	0.153	0.153	680
P154	9.21	−1.03	0.0411	0.0417	45.3	4.84	0.154	0.154	470
P 11	17.61	0.89	0.0443	0.0435	52.0	4.30	0.174	0.174	563
P 11	16.14	0.89	0.0438	0.0429	84.5	5.05	0.163	0.163	735
P 11	16.59	0.89	0.0456	0.0444	151.8	5.88	0.157	0.157	114
P 27	17.74	0.82	0.0461	0.0454	161.6	5.96	0.163	0.163	1099
Calm	0		0.0456	0.0457	172.1	6.01	0.161	0.161	1118
〃	〃		0.0447	0.0448	147.4	5.67	0.159	0.159	1008

Table 4-4.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	Measured Data: RPM	Measured Data: Thrust (kg)	Measured Data: DHP
May 25	F 3-1	with Three Sea Anchors	81	1/4	4.75	244	720	80.7
			82	Slow	3.87	199	521	45.1
		Bollard Test	83	Slow		207	657	53.2
			84	1/4		249	931	89.1
			85	2/4		294	1305	156.3
			86	〃		297	1300	155.3
			87	1/4		245	931	88.2
			88	Slow		206	824	49.2
May 26	F 3-1/3	Without Sea Anchor	89	D. Slow	4.53	171	367	15.5
			90	Slow	5.58	203	502	25.3
			91	1/4	6.73	247	725	46.0
			92	2/4	7.78	291	1030	77.1
			93	3/4	8.76	338	1482	122.0
			94	〃	9.24	346	1411	130.0
			95	2/4	8.12	295	994	77.6
			96	1/4	7.05	244	669	43.1
			97	Slow	5.86	199	464	23.0
			98	D. Slow	5.35	182	379	17.5
		With One Sea Anchor	99	D. Slow	4.19	177	410	18.1
			100	Slow	4.68	203	520	27.4
			101	1/4	5.72	235	700	41.9
			102	2/4	6.86	275	950	66.6
			103	3/4	7.86	328	1360	113.0
			104	〃	8.36	327	1410	110.1
			105	2/4	7.25	287	1020	74.4
			106	1/4	6.15	239	720	42.8
			107	Solw	5.08	198	503	24.4
			108	D. Slow	4.39	176	408	17.4
		With Three Sea Anchors	109	Slow	4.09	206	592	31.2
			110	1/4	4.76	247	850	53.4
			111	2/4	5.72	296	1230	91.2
			112	3/4	7.00	346	1690	144.0
			113	〃	7.26	347	1700	142.0
			114	2/4	6.26	293	1210	86.0
			115	1/4	5.25	242	815	49.0
			116	Slow	4.30	200	559	27.5
		Bollard Test	117	〃		204	822	37.5
			118	1/4		244	1306	65.8
			119	2/4		296	1929	119.8
			120	3/4		336	2181	179.4
			121	〃		337	2255	186.9
			122	2/4		297	1888	119.9
			123	1/4		243	1202	63.4
			124	Slow		202	839	37.5
May 28	F 2-1	Without Sea Anchor	125	Slow	5.60	202	384	46.5
			126	1/4	6.57	245	622	82.7
			127	2/4	7.65	298	828	144.2
			128	3/4	7.95	313	1004	179.5

(Continued)

Relative Wind Direction θ (deg.)	Relative Wind Speed V_w (knots)	Wind Direction Effect Coeff. k	Correction for Wind Force: Torque Constant q'	Corrected Torque Constant q	Corrected DHP	Corrected Ship Speed V_s' (knots)	Thrust Constant t'	Corrected Thrust Constant t	Corrected Thrust T (kg)
Calm	0		0.0428	0.0429	80.9	4.70	0.164	0.164	720
〃	〃		0.0439	0.0439	45.1	3.87	0.178	0.178	521
S 95	8.86	−0.06	0.0462				0.202		
S 95	5.87	−0.06	0.0444				0.203		
S 95	7.15	−0.06	0.0469				0.204		
S 95	6.39	−0.06	0.0453				0.199		
S 95	8.31	−0.06	0.0457				0.209		
S 95	8.96	−0.06	0.0433				0.264		
P 5	13.50	0.98	0.0237	0.0226	14.8	4.93	0.170	0.162	349
P 5	13.25	0.98	0.0231	0.0225	24.6	5.84	0.165	0.157	477
P 5	14.96	0.98	0.0233	0.0227	44.8	7.04	0.161	0.154	694
P 11	15.70	0.89	0.0240	0.0236	76.0	8.03	0.163	0.156	985
P 11	15.83	0.89	0.0242	0.0239	121.0	8.98	0.176	0.168	1415
Calm	0		0.0240	0.0241	130.5	9.17	0.160	0.164	1450
〃	〃		0.0231	0.0232	78.0	8.06	0.155	0.156	1000
〃	〃		0.0226	0.0227	43.3	7.00	0.152	0.154	677
〃	〃		0.0223	0.0225	23.2	5.78	0.158	0.157	461
〃	〃		0.0223	0.0225	17.7	5.27	0.155	0.160	391
0	10.15	1.00	0.0249	0.0245	17.8	4.34	0.176	0.176	407
P 5	10.85	0.98	0.0251	0.0243	26.6	5.03	0.171	0.171	521
P 5	11.59	0.98	0.0247	0.0242	41.0	5.98	0.170	0.170	694
P 11	13.14	0.89	0.0245	0.0242	65.8	7.05	0.170	0.170	950
P 11	11.48	0.89	0.0245	0.0243	112.0	8.10	0.172	0.172	1368
Calm	0		0.0241	0.0243	111.0	8.21	0.172	0.172	1359
〃	〃		0.0241	0.0243	75.0	7.13	0.170	0.170	1035
〃	〃		0.0240	0.0242	43.2	6.05	0.170	0.170	717
〃	〃		0.0241	0.0243	24.6	5.00	0.172	0.172	498
〃	〃		0.0244	0.0245	17.5	4.35	0.176	0.176	403
P 11	12.57	0.89	0.0273	0.0265	30.3	4.44	0.189	0.189	592
P 17	13.56	0.83	0.0272	0.0264	51.7	5.18	0.189	0.189	850
P 17	15.17	0.83	0.0269	0.0263	89.3	6.10	0.190	0.190	1230
P 11	14.91	0.89	0.0265	0.0262	142.0	7.22	0.192	0.192	1690
Calm	0		0.0261	0.0262	143.0	7.19	0.192	0.192	1700
〃	〃		0.0262	0.0263	86.2	6.20	0.190	0.190	1210
〃	〃		0.0262	0.0264	49.0	5.15	0.189	0.189	815
〃	〃		0.0263	0.0265	28.0	4.22	0.189	0.189	559
P139	9.56	−0.88	0.0340				0.268		
〃	8.10	〃	0.0346				0.296		
〃	7.98	〃	0.0355				0.299		
〃	8.60	〃	0.0363				0.262		
P130	10.61	−0.71	0.0374				0.269		
P121	8.90	−0.47	0.0352				0.290		
P130	9.71	−0.71	0.0338				0.275		
〃	8.43	〃	0.0348				0.245		
P 5	17.89	0.98							
〃	21.72	〃							
〃	22.98	〃							
〃	23.07	〃							

Table 4-4.

Data	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	RPM	Thrust (kg)	DHP
May 28	F2-1	Without Sea Anchor	129	3/4	7.75	293	872	158.0
			130	2/4	7.60	285	802	142.8
			131	1/4	6.57	246	588	93.2
			132	Slow	5.53	204	404	53.1
		With One Sea Anchor	133	Slow	4.87	211	500	62.0
			134	1/4	5.76	248	691	100.0
			135	2/4	6.70	283	870	144.9
			136	3/4	6.76	284	880	146.7
			137	〃	6.75	285	880	147.9
			138	2/4	6.69	281	860	142.1
			139	1/4	5.76	242	634	90.5
			140	Slow	4.83	208	480	58.2
	F2-2/3	Without Sea Anchor	141	Slow	5.69	194	427	31.0
			142	1/4	6.50	225	570	48.8
			143	〃	6.06	225	570	50.3
			144	Slow	5.14	192	420	31.3
			145	2/4	7.50	263	800	79.8
			146	〃	7.12	260	780	78.6
			147	3/4	8.30	297	1020	115.2
			148	Solw	7.90	292	1000	106.5
		With One Sea Anchor	149	Slow	4.80	194	480	33.8
			150	1/4	5.40	214	580	45.7
			151	〃	5.38	214	580	45.7
			152	Slow	4.85	195	480	34.4
			153	2/4	6.36	251	790	73.9
			154	3/4	7.15	283	1000	106.1
			155	〃	7.18	283	1000	105.9
			156	2/4	6.35	249	770	72.0
May 29	F2-1/3	Without Sea Anchor	165	D.Slow	4.89	174	405	15.9
			166	Slow	5.61	201	530	24.5
			167	1/4	6.74	244	755	43.9
			168	2/4	7.99	294	1104	79.8
			169	3/4	9.08	347	1539	136.3
			170	〃	9.32	347	1514	133.7
			171	2/4	8.37	297	1086	79.8
			172	1/4	7.10	245	736	43.4
			173	Slow	6.18	204	516	24.7
			174	D.Slow	5.39	173	383	15.1
		With One Sea Anchor	175	D.Slow	4.41	175	431	18.0
			176	Slow	5.01	204	560	27.5
			177	1/4	5.97	248	824	48.1
			178	2/4	7.02	280	1030	70.4
			179	3/4	8.01	329	1400	113.2
			180	〃	8.34	326	1450	108.3
			181	2/4	7.34	280	1030	67.8
			182	1/4	6.51	246	784	45.6
			183	Slow	5.45	202	534	25.9
			184	D.Slow	4.66	175	410	17.4

(Continued)

Relative Wind		Wind Direction Effect Coeff.	Correction for Wind Force							
Direction θ (deg.)	Speed V_w (knots)	k	Torque Con-stant q'	Cor-rected Torque Con-stant q	Cor-rected DHP	Cor-rected Ship Speed V_s' (knots)	Thrust Con-stant t'	Cor-rected Thrust Con-stant t	Cor-rected Thrust T (kg)
S 169	9.30	−1.02	0.0475				0.136		
〃	10.88	〃	0.0469				0.132		
〃	12.66	〃	0.0474				0.130		
〃	10.70	〃	0.0474				0.130		
P 5	16.31	0.98	0.0500				0.151		
〃	16.84	〃	0.0494				0.153		
0	15.13	1.00	0.0484				0.146		
S 11	18.17	0.89	0.0485				0.147		
S 175	16.56	−0.93	0.0484				0.146		
S 164		−1.05	0.0485				0.147		
P 169	13.53	−1.02	0.0481				0.140		
P 175	15.33	−0.93	0.0490				0.149		
S 169	15.39	−1.02	0.0322	0.0326	31.4	5.52	0.151	0.151	427
S 175	14.28	−0.93	0.0324	0.0326	49.1	6.40	0.151	0.151	570
P 5	26.59	0.98	0.0334	0.0326	49.1	6.42	0.151	0.151	570
〃	23.71	〃	0.0334	0.0326	30.5	5.48	0.152	0.152	420
S 175	15.40	−0.93	0.0332	0.0334	80.3	7.37	0.155	0.155	800
0	21.55	1.00	0.0338	0.0333	77.4	7.37	0.154	0.154	780
S 169	12.83	−1.02	0.0333	0.0334	115.6	8.23	0.155	0.155	1020
P 5	23.19	0.98	0.0335	0.0333	105.9	8.04	0.157	0.157	1000
P 95	13.06	−0.06	0.0351				0.170		
P 91	15.58	−0.01	0.0353				0.169		
S 81	22.96	0.38	0.0353				0.169		
S 86	20.47	0.17	0.0352				0.169		
P 91	15.13	−0.01	0.0354				0.167		
P 71	22.66	0.68	0.0354				0.167		
S 95	13.78	−0.06	0.0354				0.167		
〃	13.06	−0.06	0.0354				0.167		
0	13.93	1.00	0.0231	0.0226	15.5	5.07	0.181	0.176	394
〃	14.44	〃	0.0230	0.0224	23.8	5.86	0.177	0.170	504
〃	15.68	〃	0.0233	0.0226	42.7	7.10	0.172	0.166	728
〃	16.54	〃	0.0239	0.0234	78.1	8.30	0.172	0.167	1071
〃	16.61	〃	0.0250	0.0246	134.0	9.37	0.173	0.171	1522
Calm	0		0.0245	0.0246	134.1	9.25	0.170	0.171	1523
〃	〃		0.0232	0.0234	80.4	8.25	0.166	0.167	1093
〃	〃		0.0225	0.0226	43.6	7.05	0.164	0.166	784
〃	〃		0.0223	0.0224	24.8	6.14	0.168	0.170	534
P 159	7.27	−1.07	0.0225	0.0226	15.2	5.35	0.174	0.176	410
0	13.24	1.00	0.0257	0.0252	17.8	4.59	0.189		
〃	13.46	〃	0.0248	0.0242	26.9	5.27	0.182		
〃	13.55	〃	0.0241	0.0236	46.9	6.23	0.181		
〃	15.68	〃	0.0245	0.0241	69.3	7.27	0.178		
〃	16.46	〃	0.0243	0.0240	111.8	8.23	0.181		
Calm	0		0.0239	0.0240	108.6	8.27	0.181		
〃	〃		0.0236	0.0237	68.2	7.28	0.177		
〃	〃		0.0235	0.0236	45.8	6.46	0.174		
180	6.13	−0.86	0.0241	0.0243	26.1	5.36	0.177		
P 159	6.40	−1.07	0.0250	0.0252	17.5	4.59	0.181		

Table 4-4.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	RPM	Thrust (kg)	DHP
May 29	F2-1/3	With Three Sea Anchors	185	Slow	3.92	198	590	26.8
			186	1/4	4.79	232	800	42.7
			187	2/4	5.84	295	1156	86.0
			188	3/4	6.87	328	1530	121.3
			189	〃	7.21	335	1610	127.2
			190	2/4	6.15	295	1159	85.5
			191	1/4	5.24	242	855	47.2
			192	Slow	4.20	195	570	24.8
		Bollard Test	193	Slow		203	816	42.7
			194	1/4		245	1251	75.7
			195	2/4		298	1753	134.5
			196	〃		298	1749	137.9
			197	1/4		244	1260	75.5
			198	Slow		204	792	43.6
May 31	Clean (Propeller in Use)	Without Sea Anchor	199	D.Slow	5.04	160	351	12.2
			200	Solw	6.22	201	530	24.4
			201	1/4	7.20	247	791	45.5
			202	2/4	8.30	300	1140	79.1
			203	3/4	9.23	346	1507	129.4
			204	4/4	9.60	372	1794	162.2
			205	〃	9.67	373	1793	162.9
			206	3/4	9.20	349	1534	127.0
			207	2/4	8.25	298	1131	76.1
			208	1/4	7.16	245	782	41.6
			209	Slow	5.96	202	535	24.2
			210	D.Slow	5.13	172	395	15.6
		With One Sea Anchor	211	D.Slow	4.60	179	450	18.7
			212	Slow	5.32	205	591	27.0
			213	1/4	6.38	246	816	45.6
			214	2/4	7.61	297	1150	81.3
			215	3/4	8.61	346	1569	130.7
			216	4/4	9.11	371	1855	169.8
			217	〃	9.24	372	1825	171.0
			218	3/4	8.60	348	1579	128.5
			219	2/4	7.65	294	1165	74.7
			220	1/4	6.46	244	802	45.5
			221	Slow	5.60	205	563	26.7
			222	D.Slow	4.83	176	429	16.6
		Bollard Test	223	Slow		206	801	40.6
			224	1/4		248	1312	70.3
			225	2/4		294	1830	116.9
			226	〃		298	1842	119.4
			227	1/4		247	1333	67.4
			228	Slow		204	817	38.4
		With Three Sea Anchors	229	Slow	4.48	204	672	28.9
			230	1/4	5.25	245	933	47.0
			231	2/4	6.38	297	1326	85.4
			232	3/4	7.60	349	1777	135.5
			233	4/4	7.51	359	1852	152.2

(Continued)

Relative Wind		Wind Direction Effect Coeff.	Correction for Wind Force						
Direction θ (deg.)	Speed V_w (knots)	k	Torque Constant q'	Corrected Torque Constant q	Corrected DHP	Corrected Ship Speed V_s' (knots)	Thrust Constant t'	Corrected Thrust Constant t	Corrected Thrust T (kg)
P 5	11.32	0.98	0.0265	0.0259	26.4	4.18	0.205	0.205	590
〃	12.57	〃	0.0261	0.0257	41.9	5.00	0.200	0.200	800
〃	13.44	〃							
〃	15.42	〃	0.0263	0.0262	121.0	6.94	0.192	0.192	1530
Calm	0		0.0259	0.0260	128.1	7.14	0.194	0.194	1610
〃	〃								
〃	〃		0.0256	0.0257	47.8	5.19	0.197	0.197	855
〃	〃		0.0257	0.0258	25.1	4.16	0.205	0.205	570
S 55	9.28	0.82	0.0393				0.269		
〃	9.19	〃	0.0396				0.282		
〃	10.16	〃	0.0389				0.267		
〃	9.86	〃	0.0398				0.266		
S 76	9.91	0.54	0.0396				0.286		
			0.0344				0.258		
P 76	8.24	0.54	0.0230				0.185		
〃	9.67	〃	0.0230				0.177		
P 49	9.79	0.88	0.0231				0.175		
P 38	10.52	0.87	0.0226				0.171		
P 27	10.19	0.82	0.0240				0.170		
P 22	9.00	0.83	0.0241				0.175		
0	13.26	1.00	0.0241				0.174		
S 5	11.87	0.98	0.0220				0.170		
〃	10.55	〃	0.0228				0.172		
〃	10.66	〃	0.0217				0.176		
〃	11.23	〃	0.0225				0.177		
〃	10.55	〃	0.0236				0.180		
Calm	0		0.0249				0.190		
〃	〃		0.0240				0.190		
〃	〃		0.0235				0.182		
〃	〃		0.0239				0.176		
〃	〃		0.0242				0.177		
〃	〃		0.0254				0.182		
0	12.69	1.00	0.0254				0.178		
〃	11.93	1.00	0.0234				0.176		
S 5	13.19	0.98	0.0225				0.182		
〃	12.18	〃	0.0241				0.182		
Calm	0		0.0238				0.181		
〃	〃		0.0234				0.187		
Calm	0		0.0356				0.255		
〃	〃		0.0355				0.288		
〃	〃		0.0350				0.286		
〃	〃		0.0347				0.280		
〃	〃		0.0343				0.295		
〃	〃		0.0347				0.265		
0	5.60	1.00	0.0260				0.218		
S 5	6.22	0.98	0.0244				0.210		
0	6.71	1.00	0.0250				0.203		
〃	7.40	〃	0.0245				0.197		
〃	7.07	〃	0.0252				0.194		

Table 4-4.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	RPM	Thrust (kg)	DHP
May 31	Clean	With three Sea Anchors	234	4/4	7.75	351	1834	136.1
			235	3/4	7.74	349	1786	136.6
			236	2/4	6.48	297	1306	85.5
			237	1/4	5.30	245	889	
			238	Slow	4.42	204	672	28.0
June 1	F4	Without Sea Anchor	239	D.Slow	4.21	175	380	22.5
			240	Slow	5.11	202	494	34.0
			241	1/4	6.32	232	642	50.3
			242	2/4	7.79	285	980	92.2
			243	3/4	8.95	351	1459	171.1
			244	〃	9.21	351	1441	169.5
			245	2/4	8.05	287	957	92.8
			246	1/4	6.97	234	631	50.1
			247	Slow	6.26	204	487	32.6
			248	D.Slow	5.33	176	367	20.8
		With One Sea Anchor	249	D.Slow				
			250	Solw	5.34	208	550	37.0
			251	1/4	6.35	235	687	51.6
			252	2/4	7.56	286	1011	93.6
			253	〃	7.26	285	1040	94.2
			254	1/4	5.79	234	713	52.6
			255	Slow	4.99	203	567	35.4
			256	D.Slow				
			257	3/4	8.42	339	1471	159.5
			258	〃	8.43	346	1559	170.6
		With Three Sea Anchors	259	Slow	4.41	207	612	40.1
			260	1/4	5.11			
			261	2/4	6.15	278	1053	95.5
			262	〃	5.97	278	1087	96.7
			263	1/4	4.75			
			264	Slow	3.63	192	567	32.3
			265	3/4	7.07	322	1428	149.4
			266	〃	6.97	330	1540	162.9
		Bollard Test	267	Slow		203	816	42.7
			268	1/4		245	1251	75.7
			269	2/4		298	1753	134.5
			270	〃		298	1749	137.9
			271	1/4		244	1260	75.5
			272	Slow		204	792	43.6
		Bollard Test	273	Slow		207	779	39.1
			274	1/4		251	1406	70.2
			275	2/4		295	1759	122.0
			276	〃		297	1769	125.9
			277	1/4		248	1406	67.5
			278	Slow		206	817	38.3
		Without Sea Anchor	279	D.Slow	4.82	176	448	16.5
			280	Slow	5.68	205	572	25.4
			281	1/4	6.65	248	788	44.9

(Continued)

Relative Wind		Wind Direction Effect Coeff.	Correction for Wind Force							
Direction θ (deg.)	Speed V_w (knots)	k	Torque Constant q'	Corrected Torque Constant q	Corrected DHP	Corrected Ship Speed V_s' (knots)	Torust Constant t'	Corrected Thrust Constant t	Corrected Thrust T (kg)
P 5	9.66	0.98	0.0241				0.201		
〃	10.00	〃	0.0246				0.198		
P 11	7.59	0.89	0.0251				0.200		
〃	6.73	〃					0.200		
〃	5.20	〃	0.0252				0.218		
S 5	17.95	0.98	0.0320	0.0301	21.1	5.24	0.165	0.155	350
〃	18.17	0.98	0.0315	0.0301	32.4	5.72	0.163	0.156	470
〃	19.50	0.98	0.0308	0.0301	49.2	6.69	0.161	0.156	622
〃	19.93	0.98	0.0304	0.0301	90.1	7.98	0.162	0.158	950
〃	21.95	0.98	0.0303	0.0301	170.0	9.16	0.160	0.159	1450
P174	7.04	−0.95	0.0300	0.0301	170.6	9.25	0.158	0.159	1452
P164	8.08	−1.05	0.0300	0.0301	93.1	7.99	0.157	0.158	970
P174	9.42	−0.95	0.0399	0.0301	50.4	6.87	0.156	0.157	640
P169	9.86	−1.01	0.0294	0.0301	33.4	5.96	0.158	0.156	481
P174	11.82	−0.95	0.0292	0.0301	21.5	4.99	0.160	0.156	359
P 71	15.65	0.68							
P 91	9.72	−0.01	0.0314	0.0315	37.1	5.30	0.172	0.174	556
P 49	16.54	0.88	0.0304	0.0310	52.6	6.04	0.168	0.172	703
P 49	16.03	0.88	0.0306	0.0310	94.9	7.31	0.167	0.172	1040
S 81	9.74	0.37	0.0311	0.0310	93.9	7.32	0.173	0.172	1034
S 66	13.55	0.72	0.0314	0.0310	51.9	6.00	0.176	0.172	700
S 55	17.05	0.81	0.0324	0.0315	34.5	5.38	0.186	0.174	530
S 44	15.31	0.83							
P 76	10.99	0.54	0.0313	0.0313	159.5	8.42	0.173	0.173	1471
S 33	17.59	0.83	0.0315	0.0313	169.5	8.58	0.176	0.173	1533
P 76	8.46	0.54	0.0346	0.0344	39.9	4.45	0.193	0.189	599
P 27	9.26	0.82							
P 16	14.16	0.83	0.0340	0.0344	96.7	5.90	0.184	0.190	1087
S 81	9.31	0.37	0.0344	0.0344	96.7	5.97	0.190	0.190	1087
S 66	9.84	0.72							
S 49	10.68	0.88	0.0349	0.0344	31.8	3.84	0.208	0.189	516
S 22	14.92	0.83	0.0342	0.0345	150.7	6.85	0.186	0.191	1466
P 81	6.38	0.37	0.0346	0.0345	162.0	7.04	0.191	0.190	1532
Calm	0		0.0393				0.269		
〃	〃		0.0396				0.282		
〃	〃		0.0389				0.267		
〃	〃		0.0398				0.266		
〃	〃		0.0396				0.285		
〃	〃		0.0394				0.258		
S 139	7.53	−0.88	0.0335				0.245		
S 117	8.04	−0.37	0.0340				0.302		
S 139		−0.88	0.0362				0.272		
S 121	8.30	−0.48	0.0367				0.267		
S 144	6.07	−0.94	0.0338				0.223		
S 134	8.05	−0.79	0.0335				0.260		
S 5	7.72	0.98	0.0232	0.0220	15.7	5.27	0.195	0.187	430
〃	8.04	〃	0.0225	0.0213	24.0	6.24	0.184	0.175	543
〃	8.92	〃	0.0225	0.0213	42.5	7.28	0.173	0.166	755

Table 4-4.

Date	Condition of Roughness	Number of Sea Anchors	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	RPM	Thrust (kg)	DHP
June 1	Clean (Spare Propeller)	Without Sea Anchor	282	2/4	7.35	297	1071	79.8
			283	3/4	8.71	347	1488	129.4
			284	4/4	9.58	376	1790	167.4
			285	〃	9.95	374	1760	162.0
			286	3/4	9.09	343	1428	119.2
			287	2/4	8.23	292	1010	69.0
			288	1/4	7.09	241	708	38.8
			289	Slow	6.11	200	518	22.0
			290	D.Slew	5.15	176	448	15.5
		With One Sea Anchor	291	D.Slow	4.56	177	459	17.9
			292	Solw	5.24	206	591	25.8
			293	1/4	6.28	237	864	44.0
			294	2/4	7.64	299	1122	81.8
			295	3/4	8.70	344	1530	128.8
			296	4/4	9.16	377	1963	170.4
			297	〃	9.31	382	1959	171.3
			298	3/4	8.59	344	1568	128.2
			299	2/4	7.60	294	1197	77.3
			300	1/4	6.34	243	864	41.6
			301	Slow	5.42	200	622	23.0
			302	D.Slow	4.69	174	472	13.9
		With Three Sea Anchors	303	Slow	4.55	208	667	29.1
			304	1/4	5.25	242	896	46.4
			305	2/4	6.44	295	1332	84.0
			306	3/4	7.55	353	1926	145.5
			307	4/4	8.00	376	2192	178.1
			308	〃	7.42	377	2151	180.9
			309	3/4	6.92	346	1860	135.3
			310	2/4	5.80	294	1302	80.5
			311	1/4	4.76	243	911	43.7
			312	Slow	3.94	201	712	25.5

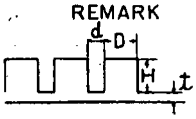
(Continued)

Relative Wind		Wind Direction Effect Coeff.	Correction for Wind Force						
Direction θ (deg.)	Speed V_w (knots)	k	Torque Constant q'	Corrected Torque Constant q	Corrected DHP	Corrected Ship Speed V_s' (knots)	Thrust Constant t'	Corrected Thrust Constant t	Corrected Thrust T (kg)
S 11	12.90	0.89	.0233	.0217	74.3	8.35	0.164	0.161	1051
〃	13.37	〃	237	229	125.0	9.30	0.167	0.165	1470
〃	12.16	〃	241	239	166.1	9.74	0.171	0.171	1790
P 16	10.90	0.83	237	238	162.8	9.87	0.170	0.170	1760
P 11	9.20	0.89	226	227	119.7	9.02	0.164	0.164	1428
P 22	8.21	0.83	212	216	70.3	7.98	0.160	0.162	1023
P 27	8.52	0.82	212	213	39.0	7.04	0.165	0.167	720
P 38	6.93	0.87	210	213	22.2	5.98	0.175	0.178	526
P 66		0.72	217	220	15.7	5.04	0.185	0.187	430
S 5	10.34	0.98	246			4.56	0.197		
〃	10.18	〃	226			5.24	0.188		
〃	8.95	〃	253			6.28	0.208		
〃	10.75	〃	235			7.64	0.170		
S 11	16.48	0.89	242			8.70	0.175		
〃	16.16	〃	243			9.16	0.187		
Calm	0		236			9.31	0.182		
〃	〃		240			8.59	0.179		
〃	〃		234			7.60	0.188		
〃	〃		221			6.34	0.197		
〃	〃		221			5.42	0.211		
〃	〃		203			4.69	0.212		
Calm	0		247			4.55	0.208		
〃	〃		249			5.25	0.206		
S 33	6.00	0.83	251			6.44	0.207		
S 5	6.21	0.98	253			7.66	0.209		
S 11	8.14	0.89	257			8.00	0.210		
P 11	10.92	〃							
〃	12.32	〃							
〃	8.13	〃							
Calm	0								
P 16	9.19	0.83							

Table 5-1. Condition of Roughness of Model Propeller

NOTATIONS	DIMENSION OF PROTUBERANCE (mm) H X D X t X d	DISTRIBUTION OF ROUGHENED AREA
f 1 - 1	0.65 X 0.8 X 0.5 X 0.4	
f 1 - 2/3	〃	
f 1 - 1/3	〃	
f 2 - 1	1.3 X 1.5 X 0.5 X 0.5	
f 2 - 2/3	〃	
f 2 - 1/3	〃	
f 3 - 1	1.9 X 2.3 X 0.5 X 0.5	
f 3 - 2/3	〃	
f 3 - 1/3	〃	
f 4	WIRE	
f SAND	1.5φ AVERAGE	

REMARK t...... Thickness of Base Plate



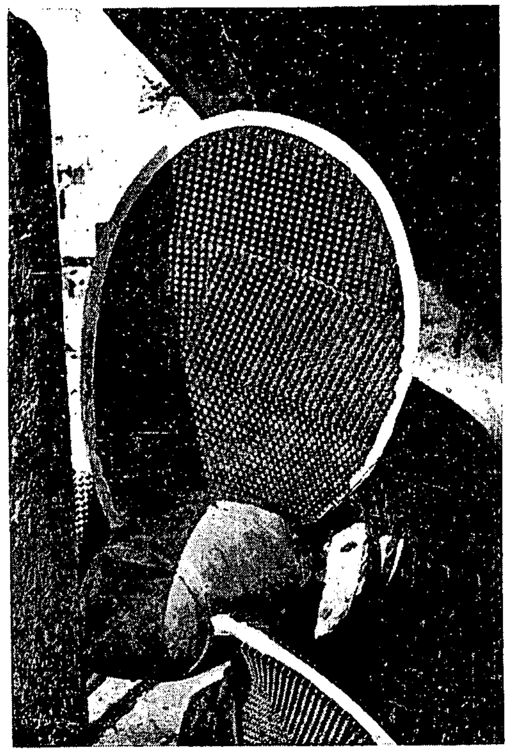


Fig. 4-1. Roughened Actual Propeller (F3-1)

Fig. 4-2. Example of Sea Condition

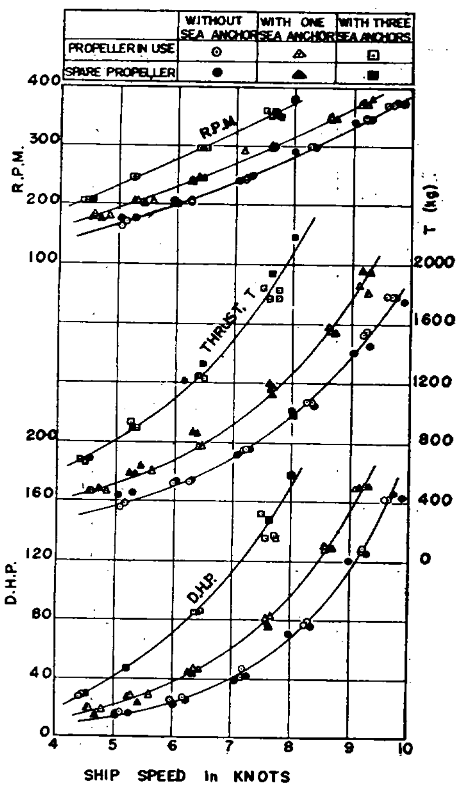


Fig. 4-3. Results of Full-Scale Measurements of Ship with Clean Propeller

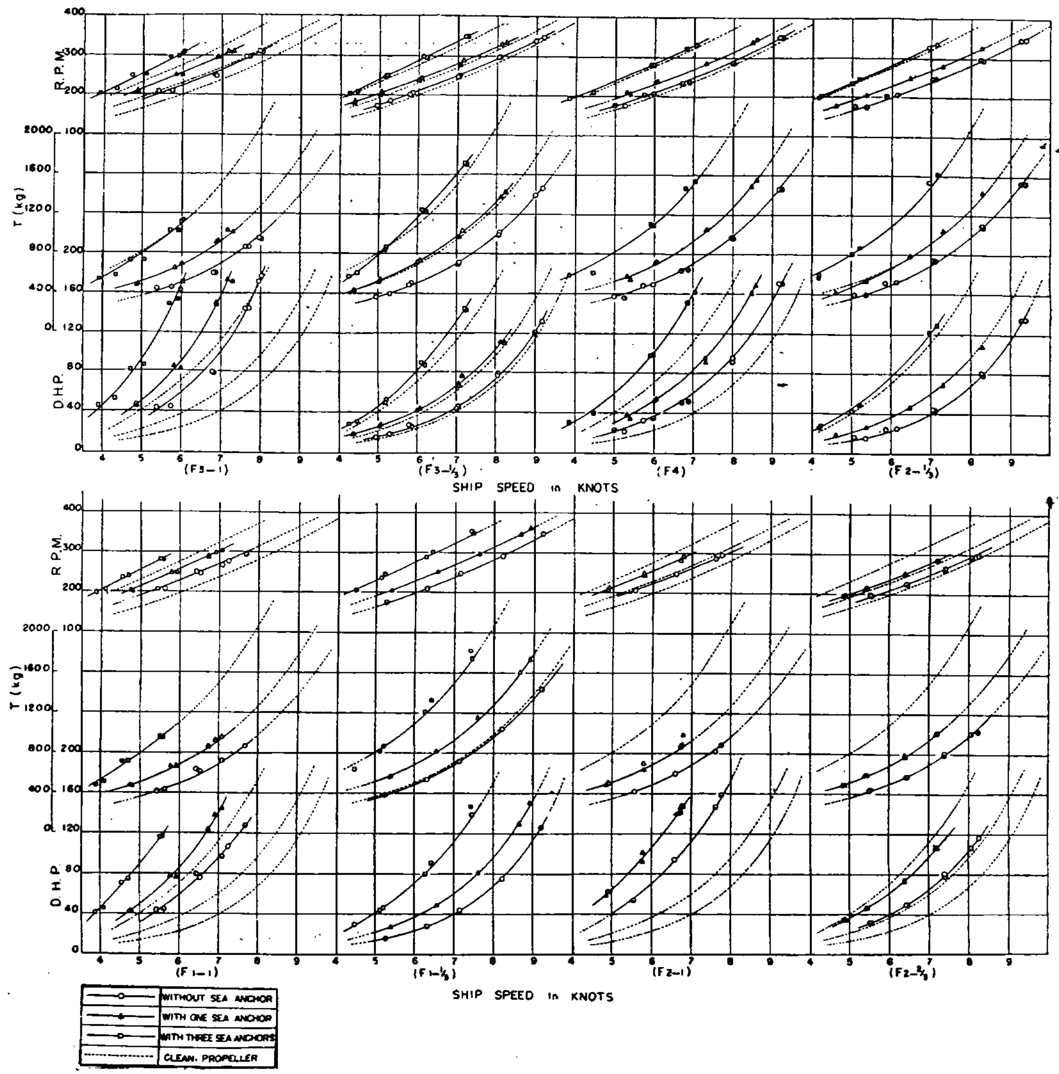


Fig. 4-4. Results of Full-Scale Measurements of Ship with Roughened Propeller

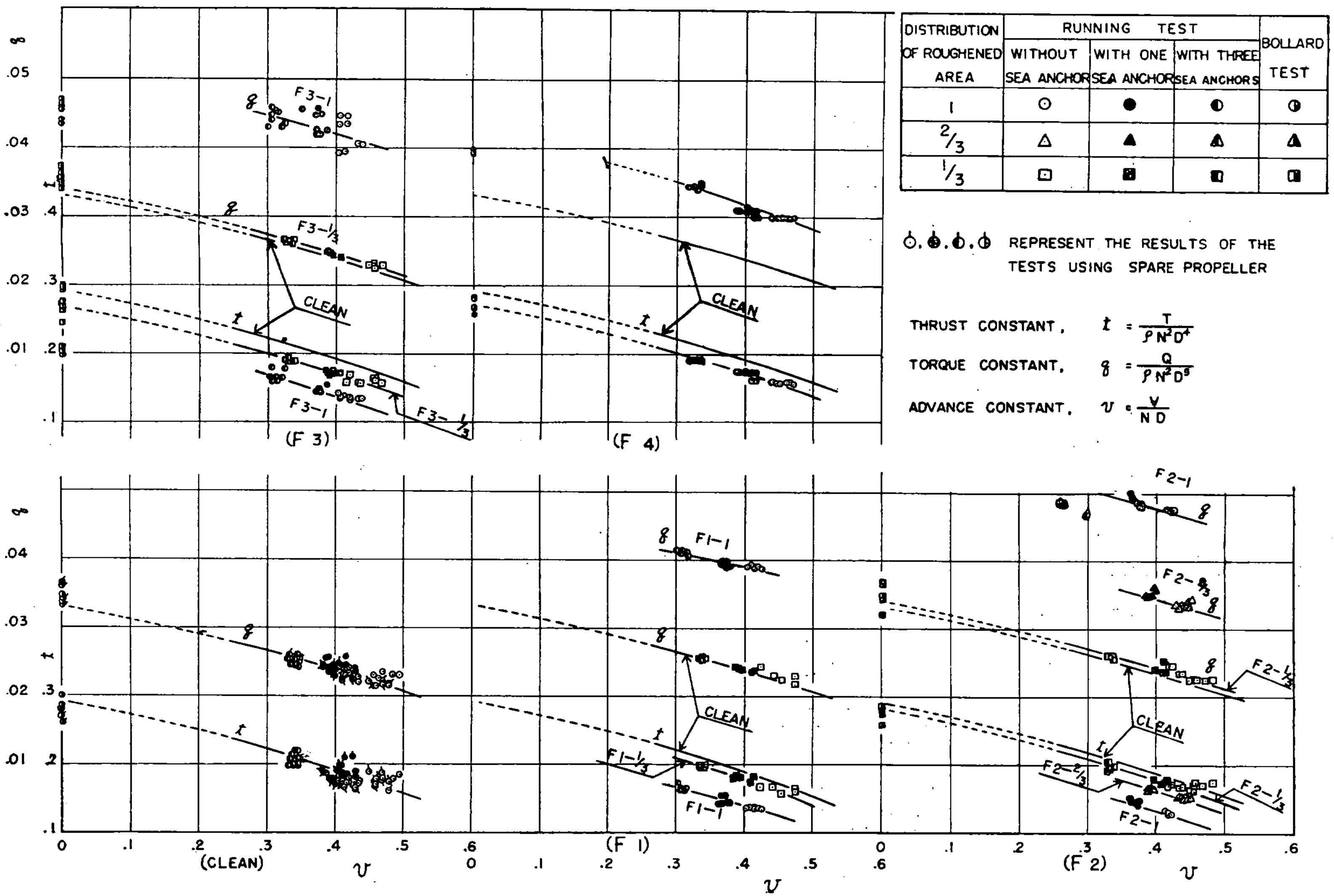


Fig. 4-5. Characteristic Curves for Actual Propeller

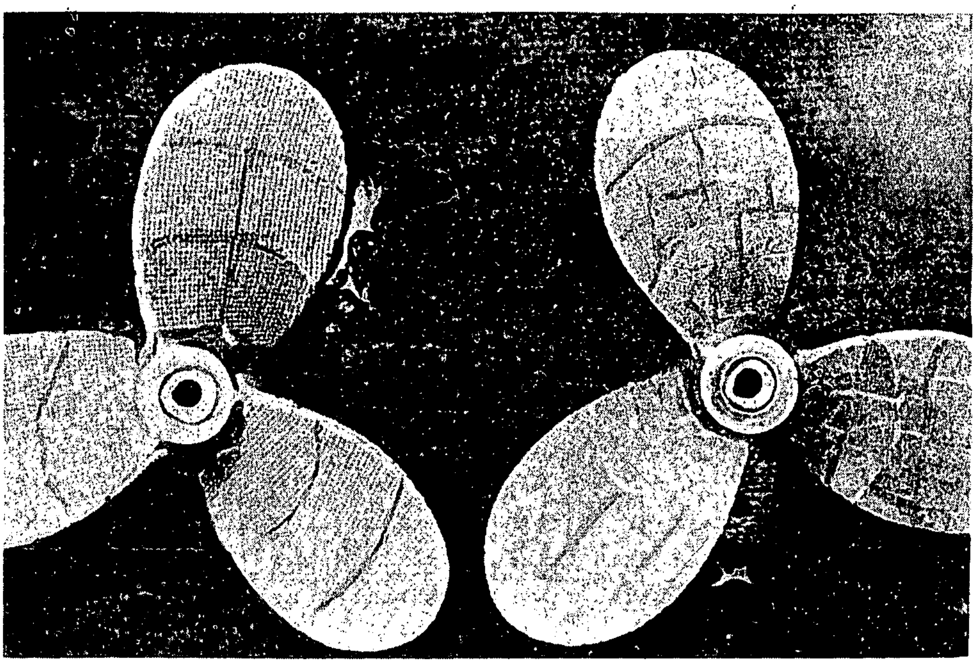
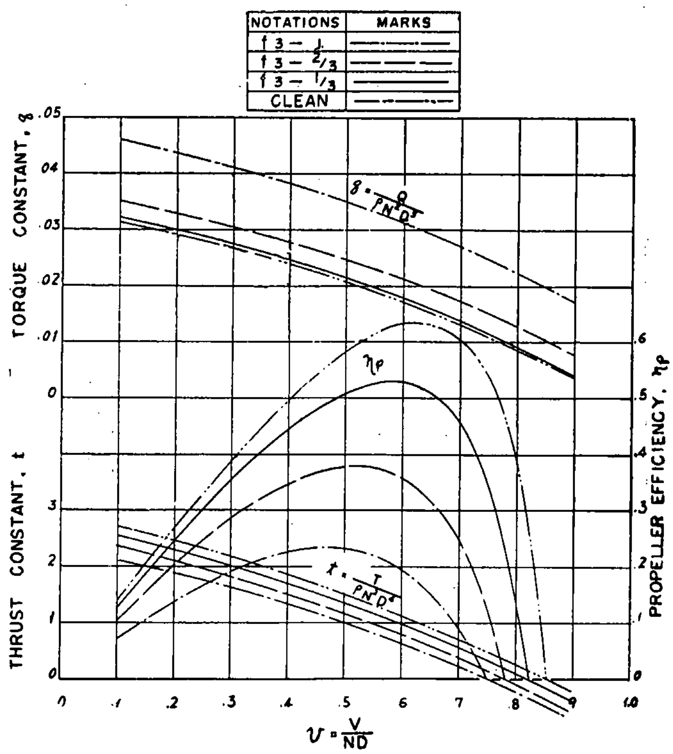
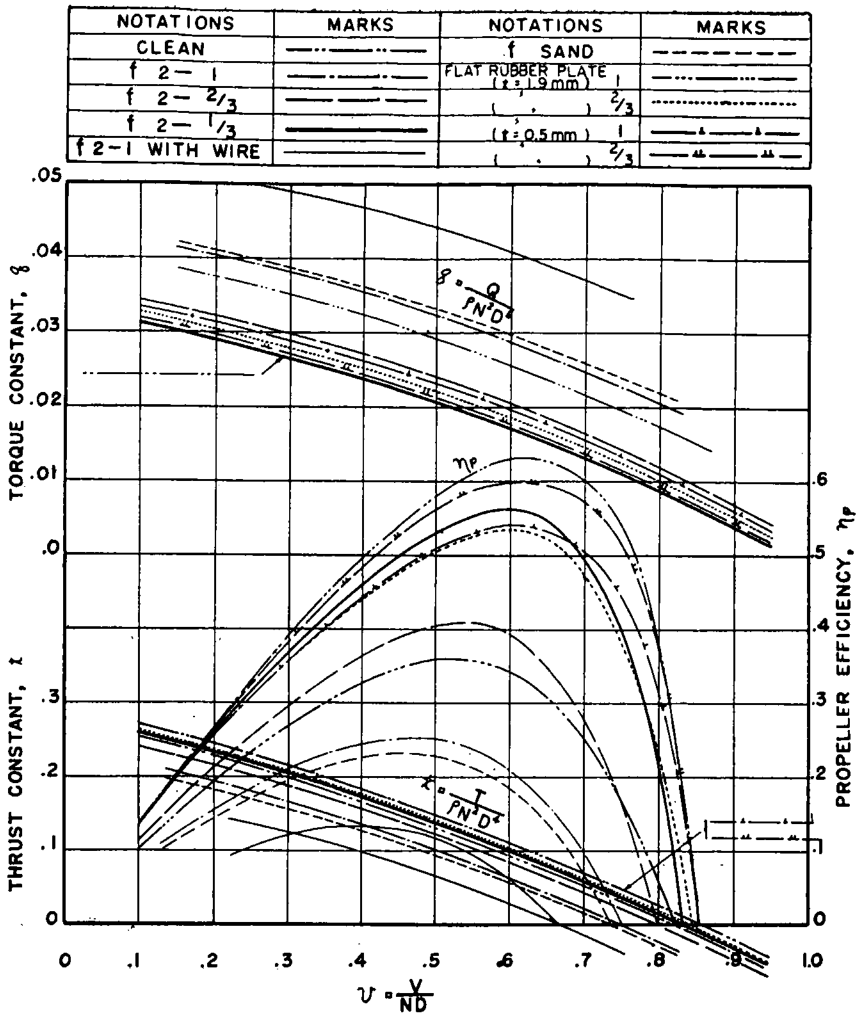


Fig. 5-1. Roughened Model Propeller (f 1-1 and f 2-1)

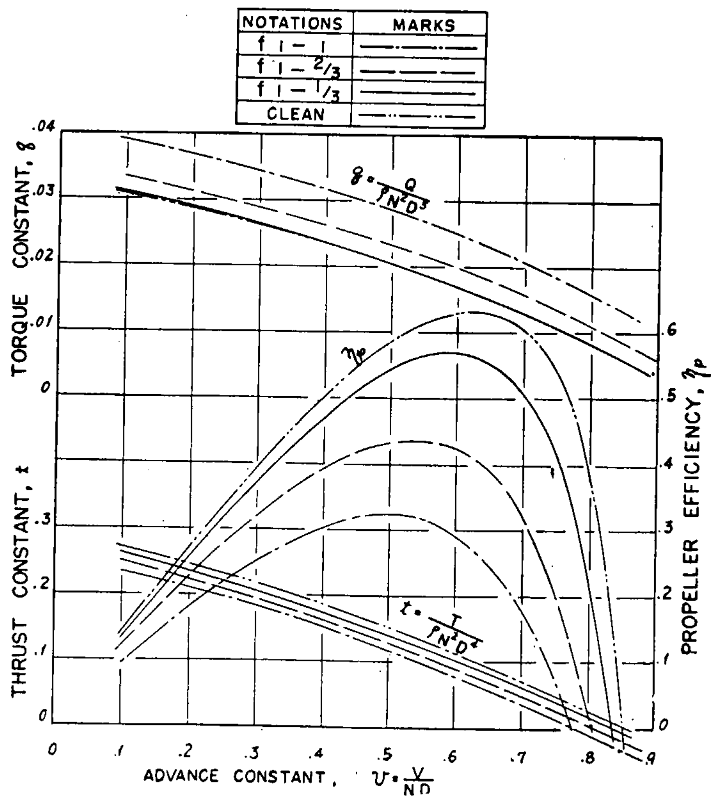


(a) Roughened with Small Protuberances

Fig. 5-2. Characteristic Curves for Model Propeller



(b) Roughened with Medium Protuberances



(c) Roughened with Large Protuberances

Fig. 5-2. Characteristic Curves for Model Propeller (a~c)

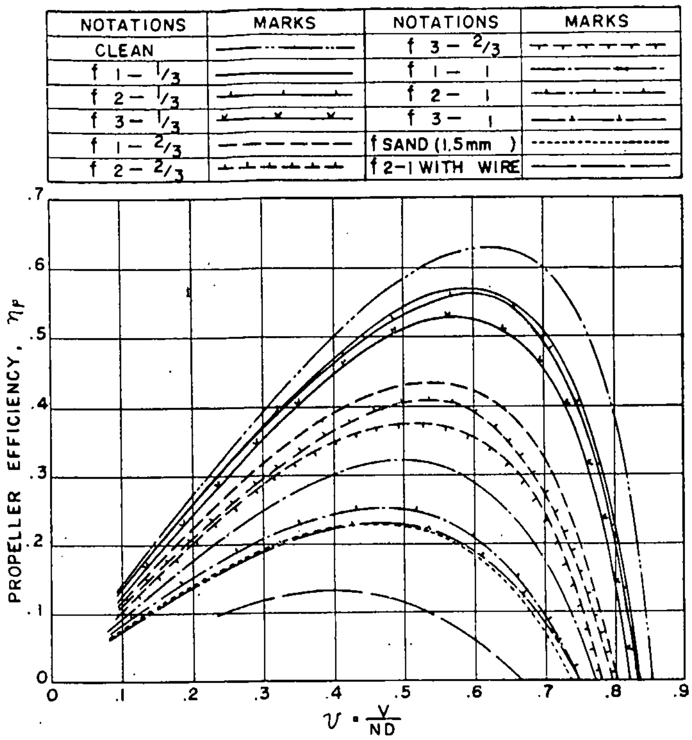


Fig. 5-3. Efficiency Curves for Roughened Model Propeller

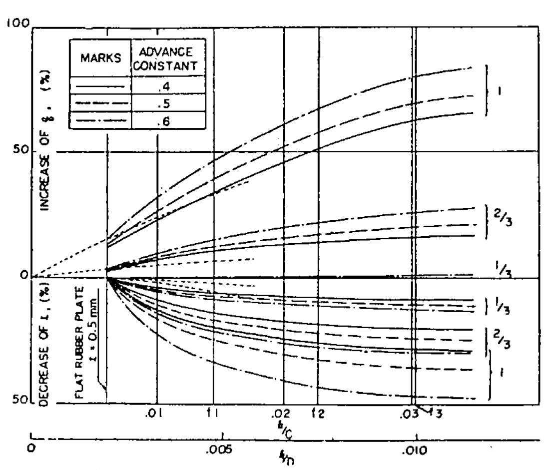
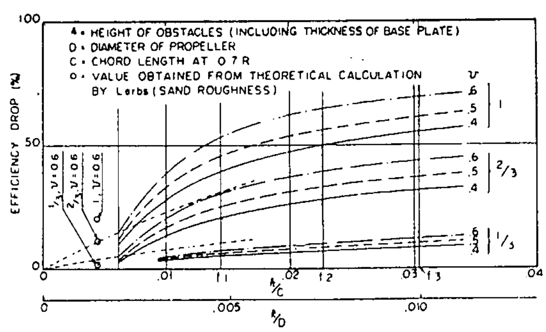
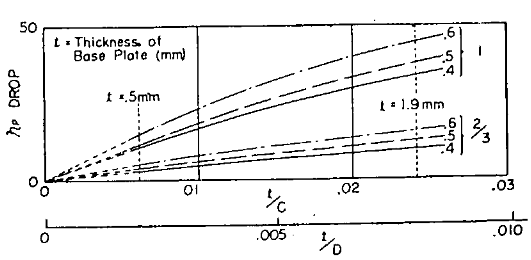


Fig. 5-4. Decrease of Thrust Constant and Increase of Torque Constant due to Roughness of Surface of Model Propeller



(a) Efficiency Drop due to Roughness



(b) Efficiency Drop due to Base Plate

Fig. 5-5. Efficiency Drop of Model Propeller

NOTATIONS	TEMP. OF WATER (°C)	MARKS
CLEAN	19.5	○
f(3-1)	19.5	●
f(2-1)	18	△
f(2-1) WITH WIRE	19.5	▲
f(1-1)	18	▽
f(2-2/3)	18	▼
f(2-1/3)	18	□

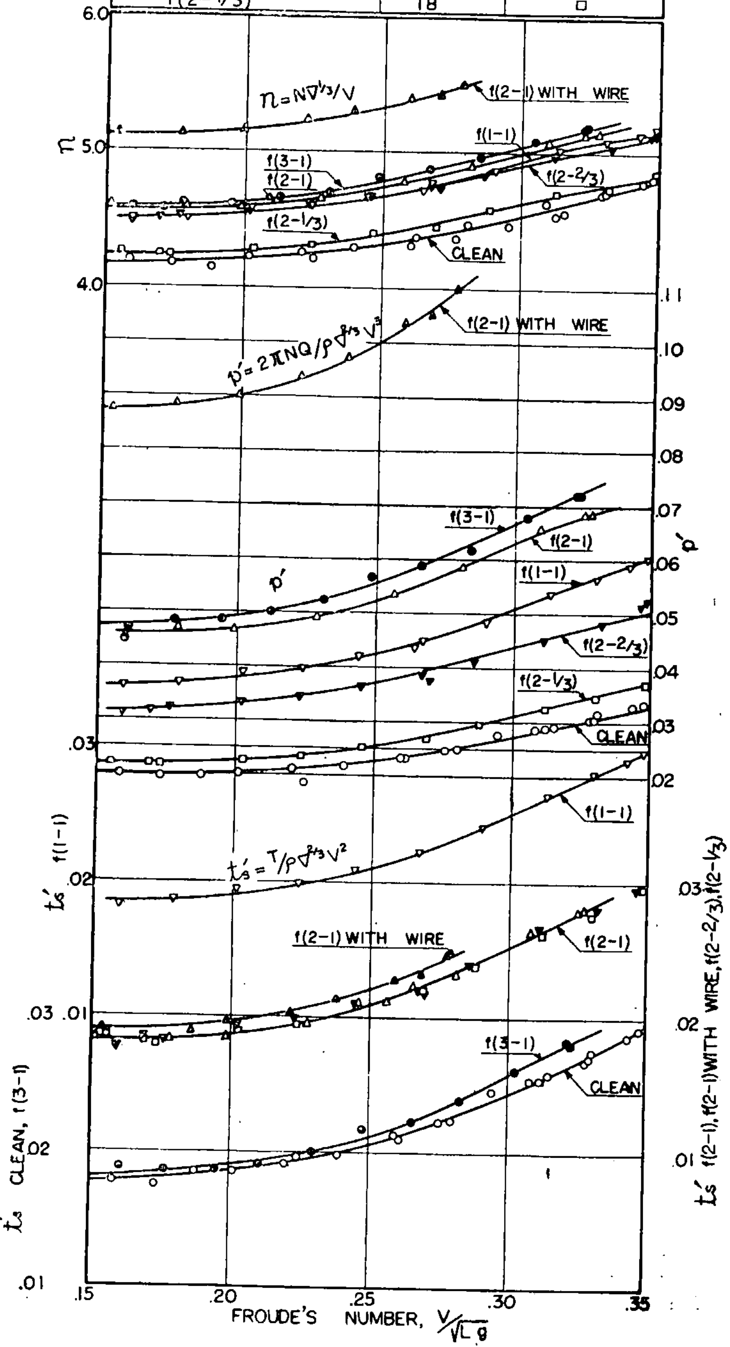
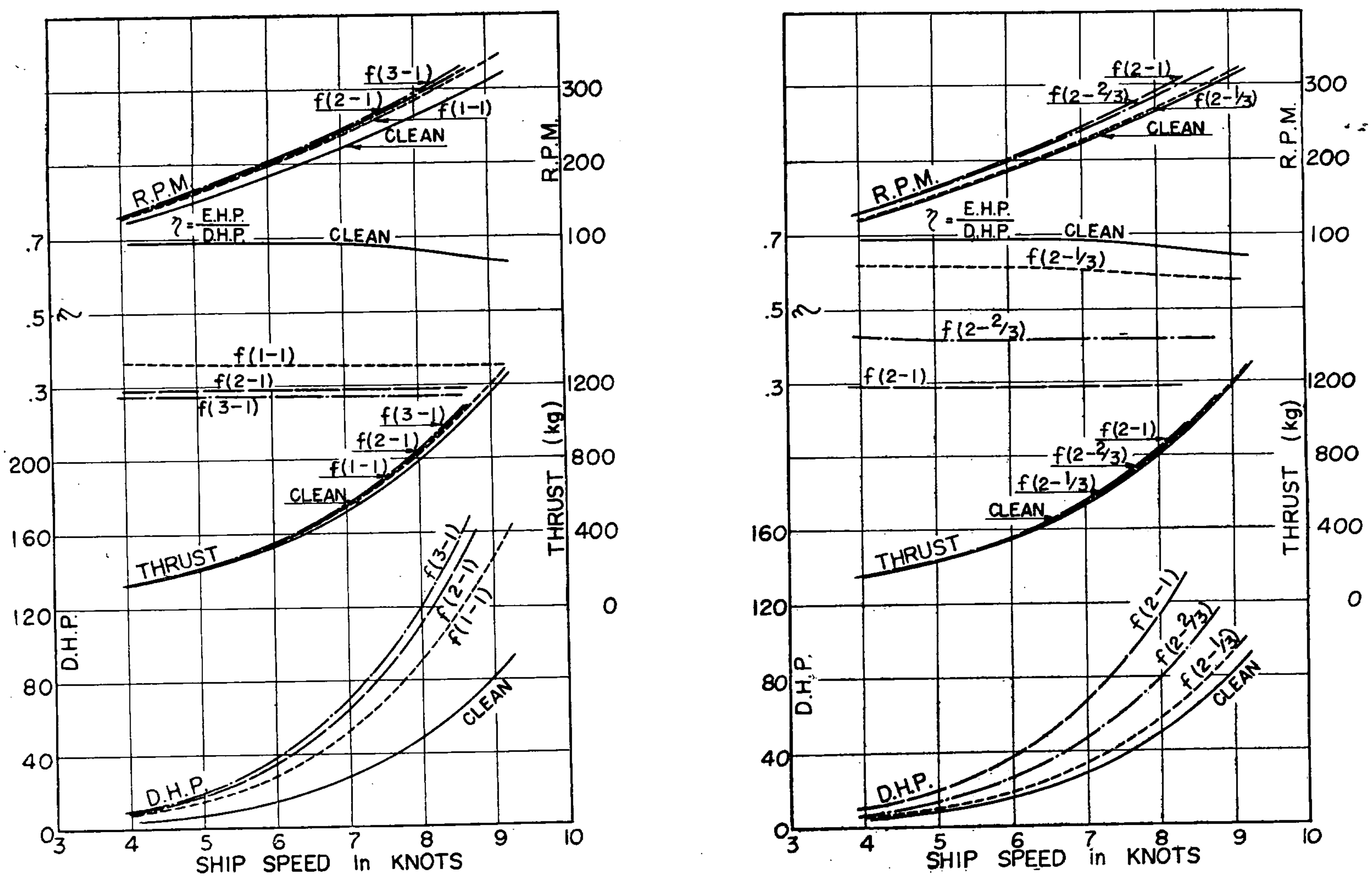


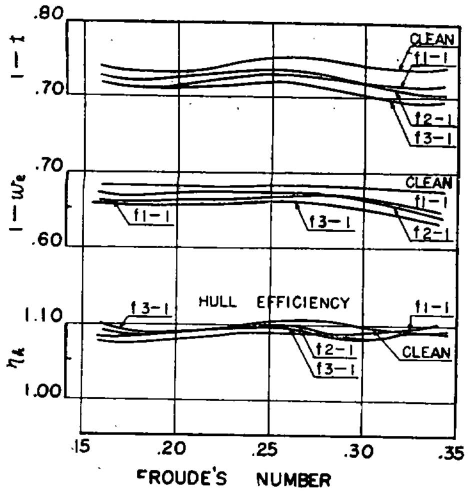
Fig. 5-6. Results of Self-Propulsion Tests with Roughened Model Propeller —Hull Clean—



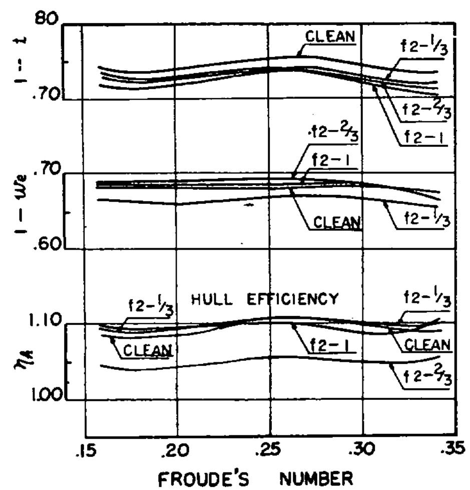
(a) Wholly Roughened Propeller

(b) Partially Roughened Propeller

Fig. 5-7. DHP, etc., estimated from the Model Tests, Clean Hull



(a) Wholly Roughened Propeller



(b) Partially Roughened Propeller

Fig. 5–8. Self-Propulsion Factors for Model with Roughened Propeller

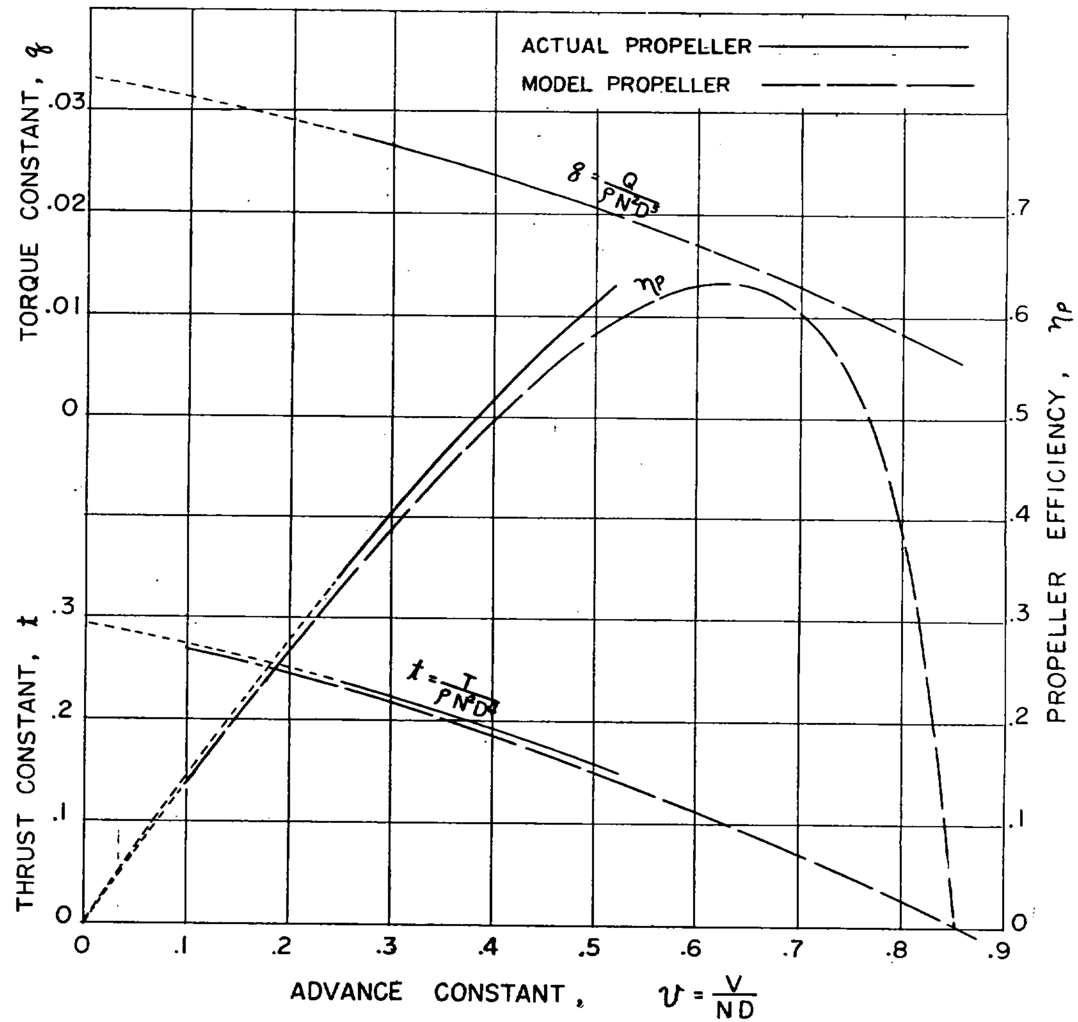


Fig. 6–1. Characteristic Curves for Model and Actual Propeller —Clean Propeller—

PART III. EFFECTS OF FOULING BOTH OF SHIP'S HULL AND PROPELLER

Chapter 7

Full-Scale Measurements

In the 6th, 7th and 8th experiments on fouling of the ship's hull, full-scale measurements with the propeller fouled with barnacles were also carried out. Aspects of the fouled propeller are shown in Fig. 7-1 (a, b, c). The test conditions and measured values of these experiments are shown in Table 7-1 and 7-2, respectively. Corrections for the wind force and the displacement of the ship were made. Their calculations and results are shown in Table 7-3 and Fig. 7-2, respectively.

The degree of fouling in each test cannot be described quantitatively. The fouling in each test was caused by growth of barnacles during the mooring since the last test. The degree of fouling was the least in the 8th test and the most in the 7th test. According to the observation after the experiments, it was noticed that about one third of the blade surfaces near the root was covered with living marine growths, mainly barnacles, and that the middle part was covered with only the shells

Table 7-1. Test Conditions

Experiment No.		6	7	8
Date		1953, July 5	1953, Sep. 14	1953, Oct. 19
Weather		Cloudy	Blue sky	Blue sky
Wind Direction & Force		ENE 1	SSW 3	NNE3∼NE2
Wave Scale		Calm	Calm	Calm
Temp. of Sea Water (deg. C)		22.3	26.0	21.9
Specific Gravity of Sea Water		1.017	1.019	1.022
Draft (m)	Fore	1.828	1.805	1.798
	Aft	1.993	2.030	2.035
	Mean	1.911	1.918	1.917
Displacement (tons)		77.2	77.8	77.8

of barnacles, while the part near the tip was clean. Barnacles near the tip of the propeller were torn off by the force due to high revolution of the propeller. The condition in the 7th experiment is considered to be in the neighbourhood of F 2-2. For reference, the results with clean propeller are also shown in Fig. 7-2.

Chapter 8

Model Experiments

Self-propulsion tests were performed with the propeller roughened with sands (Fig. 8-1) for each condition of roughness of the hull surface. Their results are shown in Fig. 8-2. Fig. 8-3 shows DHP, etc., obtained from the results shown in Fig. 8-2. For reference, the results with clean propeller for each roughened hull surface are also shown, from which it will be seen how great the effect of fouling of the propeller is.

Thrust deduction coefficient, effective wake fraction and hull efficiency are shown in Figs. 8-4, 8-5 and 8-6, respectively.

Acknowledgement

At the conclusion of this report, a word of thanks is due to all those who have lent their assistance during the experiments. We desire to express thanks in particular to the following institutions:—

The Ministry of Transportation for their subsidy which expedited the realization of this research.

The Shimizu Shipyard, Nippon Steel Tube Co., Ltd., for meeting the high charges entailed in fitting the measuring apparatus.

The Shimizu Harbour Office, Ministry of Transportation, for cooperation in the full-scale measurements by making the tug boat "Hakuryu-maru" available to us.

The University of Mercantile Marine for cooperation in the full-scale measurements.

The Transportation Technical Research Institute for cooperation in the full-scale and model experiments.

Table 7-2. Measured Values in Self-Propulsion Tests with Fouled Hull and Propeller

Exp. No.	Date	Number of Run	Engine Load	Direction of Run	Time at Inning	Time on Course	Ship Speed (knots) Over Ground	Ship Speed (knots) Through Water V_s*1	Relative Wind Direction (deg.)	Relative Wind Speed (knots)	Helm Angle (deg.) Mean	Helm Angle Maximum Port	Helm Angle Maximum Starboard	RPM Engine Room	RPM Shaft Tunnel	Thrust (kg)	DHP
6	July 5 1953	605	Slow	W→E	12h-07m	1m-59.2s	5.31	5.07	P 4	8.1	P2.1	6.5	0	206	207	581	32.1
		606	〃	E→W	12-14	1-57.9	5.37	5.65	P 1	4.5	P3.0	4.5	−2.5	212	213	602	34.2
		608	1/4	E→W	12-32	1-39.9	6.34	6.67	S 21	5.2	P4.0	4.5	−3.5	254	255	877	56.1
		609	〃	W→E	12-37	1-39.2	6.38	6.27	P 6	8.3	P3.3	6.0	−2.5	255	256	897	57.5
		611	1/2	E→W	15-35	1-26.6	7.31	7.37	P 3	8.0	P3.6	5.0	−2.0	295	297	1235	89.0
		612	〃	W→E	15-41	1-27.5	7.25	7.34	S 7	8.1	P2.8	7.0	0	294	297	1222	87.7
		613	3/4	E→W	15-49	1-17.7	8.15	8.25	P 20	9.5	P3.6	4.5	−3.0	335	338	1611	132.7
		614	〃	W→E	15-55	1-18.8	8.03	8.03	S 36	8.3	P3.5	7.0	−2.0	335	338	1594	131.2
		615	4/4	W→E	16-02	—	—	—	P 19	10.5	P3.1	4.0	−2.5	—	372		
		616	〃	E→W	16-08	1-11.8	8.82	—	S 14	8.0	P2.3	3.0	−1.0	369	371	1960	176.9
		617	〃	W→E	16-25	1-11.3	8.88	8.84	P 15	12.0	P2.9	3.5	−2.5	368	369	1957	176.0
		618	〃	E→W	16-32	1-12.8	8.70	8.57	S 12	6.8	P2.5	4.0	−1.5	364	368	1926	172.0
7	Sep. 14 1953	703	D.Slow	W→E	16-00	2-34.1	4.41	4.24	S 96	14.2				166	166	404	26.9
		704	〃	E→W	16-22	2-49.8	3.73	3.87	P 59	13.9				168	167	415	28.9
		705	Slow	W→E	16-34	2-07.6	4.96	4.91	S 102	14.6				205	204	570	47.8
		706	〃	E→W	16-45	2-17.8	4.60	4.86	P 59	14.7				207	207	593	50.8
		707	1/4	W→E	16-54	1-46.1	5.97	5.96	S 81	13.9				250	251	829	84.8
		708	〃	E→W	17-02	1-53.0	5.60	5.70	P 49	15.7				253	254	860	88.7
		709	2/4	W→E	17-09	1-31.6	6.92	6.92	S 79	12.4				295	296	1176	136.3
		710	〃	E→W	17-14	1-35.6	6.63	6.96	P 51	14.4				299	299	1238	142.2
		711	3/4	W→E	17-26	1-31.8	7.74	7.81	S 69	13.3				342	338	1599	200.4
		712	〃	E→W	17-33	1-26.0	7.36	7.59	P 43	14.8				335	337	1616	200.1
8	Oct. 19 1953	804	D.Slow	W→E	10-46	2-37.6	4.02	4.08	P 47	17.8	P3.0	4.0	−2.5	168	164	440	19.6
		805	〃	E→W	10-54	2-29.1	4.25	4.21	S 126	8.0	P4.2	4.5	−3.5	163	163	423	18.0
		806	Slow	W→E	11-05	2-05.4	5.05	5.10	P 21	14.3	P3.7	6.0	−1.0	207	207	695	35.5
		807	〃	E→W	11-12	2-00.9	5.24	5.29	S 124	7.6	P5.2	6.5	−4.0	204	204	660	31.6
		808	1/4	W→E	11-19	1-45.4	6.01	6.17	P 26	14.9	P5.0	6.0	−2.5	249	247	990	53.6
		809	〃	E→W	11-26	1-43.5	6.12	6.27	S 110	8.4	P4.2	5.5	−4.0	245	247	967	51.7
		812	2/4	W→E	11-54	1-30.2	7.02	7.17	P 29	17.8	P4.0	6.0	−2.5	293	295	1425	83.5
		813	〃	E→W	12-00	1-27.1	7.27	7.46	S 109	7.9	P4.0	5.5	−2.5	290	295	1392	82.9
		814	3/4	W→E	12-07	1-17.8	8.14	8.20	P 18	16.9	P4.5	5.5	−3.0	346	348	2063	143.8
		815	〃	E→W	12-12	1-15.1	8.44	8.38	S 98	4.7	P4.0	5.0	−2.2	349	352	2074	147.1
		816	4/4	W→E	12-17	1-13.9	8.57	8.67	P 14	21.9	P2.9	3.5	−2.0	378	371	2426	180.3
		817	〃	E→W	12-22	1-11.4	8.87	8.86	S 61		P1.8	3.7	−1.5	368	372	2389	

Remarks: *1. by Shiba speed meter

Table 7–3. Analysis of the Results of Self-Propulsion Tests with Fouled Hull and Propeller

Process of Analysis

1. θ and V_w are the values corrected from the wind tunnel tests.
2. k was read from Fig. I–7.
3. $q'=\frac{Q}{\rho N^2 D^5}=\alpha\frac{\text{DHP}}{(\text{RPM})^3}$, $\alpha=\frac{75\times 60^3}{2\pi\rho D^5}$
4. $q=q_a'-(q_a'-q_w')\frac{kV_{wa}^2-V_s^2}{kV_{wa}^2-kV_{ww}^2}$

   Suffixes a and w indicate the runs against wind and with wind, respectively. The values of q in this table are those read from the fair curve of q plotted on a base of RPM.
5. Corrected DHP$=\frac{(\text{RPM})^3}{\alpha}q$
6. Corrected speed $V_s'=V_s+\Delta V_s$

   $\Delta V_s=\frac{N}{\beta}(q-q')$

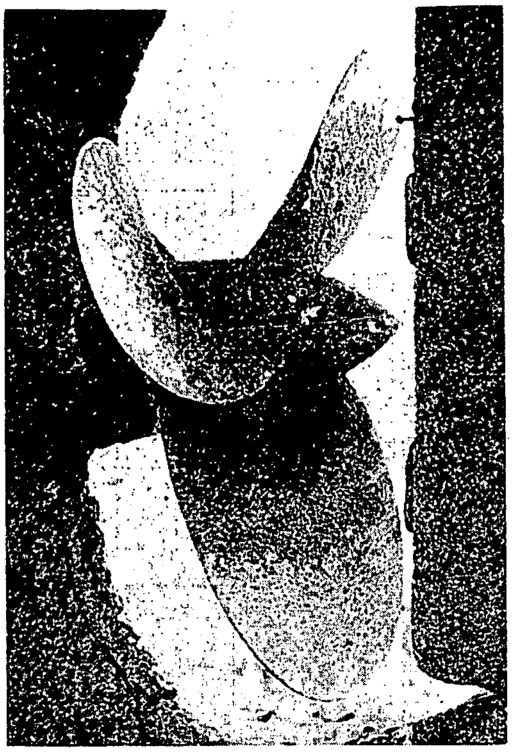
   $\beta=\frac{\Delta q}{\Delta v}$ and it was calculated from the characteristic curves of model propeller.
7. $t'=\frac{T}{\rho N^2 D^4}=\delta\frac{T}{(\text{RPM})^2}$, $\delta=\frac{60^2}{\rho D^4}$
8. $t=t_a'-(t_a'-t_w')\frac{kV_{wa}^2-V_s^2}{kV_{wa}^2-kV_{ww}^2}$
9. Corrected thrust $T=\frac{(\text{RPM})^2}{\delta}t$
10. DHP and T were corrected for the displacement. Standard displacement is 78.7 tons.

Exp. No.	Date	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	Measured Data: RPM (Shaft Tunnel)	Measured Data: Thrust (kg)	Measured Data: DHP	Relative Wind*: Direction θ (deg.)		Relative Wind*: Speed V_w (knots)	Wind Direction Effect Coeff. k	Correction for Wind Force: Torque Constant q'	Corrected Torque Constant q	Corrected DHP	Corrected Speed V_s' (knots)	Thrust Constant t'	Corrected Thrust Constant t	Corrected Thrsut T (kg)	Correction for Displacement: DHP	Thrust T (kg)
6	July 5 1953	605	Slow	5.07	207	606	32.1	P	4	7.4	0.98	0.0277	0.0274	31.8	5.17	0.191	0.180	570	32.2	604
		606	〃	5.65	213	622	34.2	P	1	4.0	1.00	0.0271	0.0272	34.4	5.63	0.185	0.181	608	34.8	637
		608	1/4	6.67	255	877	56.1	S	23	5.4	0.83	0.0259	0.0260	56.4	6.62	0.182	0.185	891	57.1	902
		609	〃	6.27	256	897	57.5	P	7	7.7	0.96	0.0262	0.0260	57.0	6.35	0.185	0.185	897	57.7	908
		611	2/4	7.37	297	1229	89.0	P	3	7.3	0.99	0.0260	0.0258	88.4	7.49	0.188	0.187	1229	89.5	1244
		612	〃	7.34	297	1215	87.7	S	8	7.6	0.94	0.0256	0.0258	88.4	7.25	0.186	0.187	1215	89.5	1230
		613	3/4	8.25	338	1611	132.7	P	22	9.7	0.83	0.0263	0.0261	131.7	8.35	0.191	0.190	1602	133.3	1621
		614	〃	8.03	338	1594	131.2	S	39	8.6	0.88	0.0260	0.0261	131.7	7.96	0.189	0.190	1602	133.3	1621
		615	4/4		372															
		616	〃	8.89	371	1960	176.9	S	16	7.8	0.83	0.0265	0.0267	178.2	8.74	0.193	0.194	1971	180.3	1995
		617	〃	8.84	369	1957	176.0	P	16	11.9	0.83	0.0268	0.0267	175.3	8.88	0.194	0.193	1946	177.4	1970
		618	〃	8.57	368	1926	172.0	S	13	6.6	0.85	0.0264	0.0266	173.3	8.46	0.192	0.193	1936	175.4	1959

Remarks: * Values corrected from the wind tunnel

Table 7–3. (Continued)

Exp. No.	Date	Number of Run	Engine Load	Measured Data: Ship Speed Through Water V_s (knots)	Measured Data: R P M Shaft tunnel	Measured Data: Thrust (kg)	Measured Data: D H P (Shaft Tunnel)	Relative Wind*: Direction θ (deg.)	Relative Wind*: Speed V_w (knots)	Wind Direction Effect Coeff. k	Correction for Wind Force: Torque Constant q'	Correction for Wind Force: Corrected Torque Constant q	Correction for Wind Force: Corrected D H P	Correction for Wind Force: Corrected Speed V_s' (knots)	Correction for Wind Force: Thrust Constant t'	Correction for Wind Force: Corrected Thrust t	Correction for Wind Force: Corrected Thrust T (kg)	Correction for Displacement: D H P	Correction for Displacement: Thrust T (kg)
7	Sep. 14 1953	703	D.Slow	4.24	166	404	26.9	S 101	13.7	−0.12	0.0450	0.0458	27.4	3.98	0.198	0.199	406	27.6	408
		704	〃	3.87	167	415	28.9	P 65	15.1	0.73	0.0474	0.0454	27.6	4.53	0.201	0.198	409	27.8	411
		705	Slow	4.91	204	570	47.8	S 106	14.2	−0.15	0.0431	0.0433	48.1	4.82	0.185	0.186	572	48.4	575
		706	〃	4.86	207	593	50.8	P 65	16.0	0.73	0.0438	0.0430	49.9	5.19	0.187	0.185	586	50.2	590
		707	1/4	5.96	251	829	84.8	S 87	13.2	0.13	0.0410	0.0411	85.0	5.92	0.176	0.177	826	85.5	831
		708	〃	5.70	254	860	88.7	P 53	16.7	0.85	0.0414	0.0410	87.8	5.90	0.180	0.177	846	88.3	851
		709	2/4	6.92	296	1176	136.3	S 85	11.9	0.21	0.0402	0.0403	136.6	6.91	0.181	0.181	1176	137.4	1183
		710	〃	6.96	299	1238	142.2	P 55	15.5	0.81	0.0407	0.0402	140.5	7.28	0.187	0.182	1205	141.4	1212
		711	3/4	7.81	338	1599	200.4	S 75	13.6	0.57	0.0397	0.0396	199.9	7.78	0.189	0.189	1599	201.1	1609
		712	〃	7.59	337	1616	200.1	P 46	15.3	0.84	0.0400	0.0396	198.1	7.86	0.192	0.189	1591	199.3	1601
8	Oct. 19 1953	804	D.Slow	4.08	164	440	19.9	P 51	17.8	0.90	0.0345	0.0326	18.8	4.70	0.221	0.216	430	18.9	433
		805	〃	4.21	163	423	18.3	S 126	8.0	−0.60	0.0323	0.0328	18.6	4.04	0.215	0.216	425	18.7	428
		806	Slow	5.10	207	695	35.5	P 21	14.3	1.13	0.0289	0.0281	32.6	5.42	0.219	0.214	679	32.8	683
		807	〃	5.29	204	660	31.6	S 125	7.6	−0.56	0.0285	0.0287	31.8	5.20	0.214	0.215	663	32.0	667
		808	1/4	6.17	247	990	53.6	P 29	14.3	1.18	0.0261	0.0254	52.1	6.51	0.219	0.215	972	52.4	978
		809	〃	6.27	247	967	51.7	S 113	8.4	−0.17	0.0252	0.0254	52.1	6.19	0.214	0.215	972	52.4	978
		812	2/4	7.17	295	1425	83.5	P 31	17.8	1.20	0.0249	0.0247	82.9	7.31	0.221	0.217	1399	83.4	1407
		813	〃	7.46	295	1392	82.9	S 112	7.9	−0.16	0.0247	0.0247	82.9	7.46	0.216	0.217	1399	83.4	1407
		814	3/4	8.20	348	2063	143.8	P 20	16.9	1.10	0.0261	0.0258	142.1	8.42	0.230	0.226	2027	142.9	2039
		815	〃	8.38	352	2074	147.1	S 103	4.7	0.08	0.0258	0.0259	147.7	8.34	0.226	0.227	2083	148.6	2096
		816	4/4	8.67	371	2426	180.3	P 16	21.9	1.01	0.0270	0.0268	178.9	8.79	0.238	0.234	2385	180.0	2400
		817	〃	8.86	372	2389					0.0268	0.0269	180.8	8.79	0.233	0.234	2400	181.9	2414



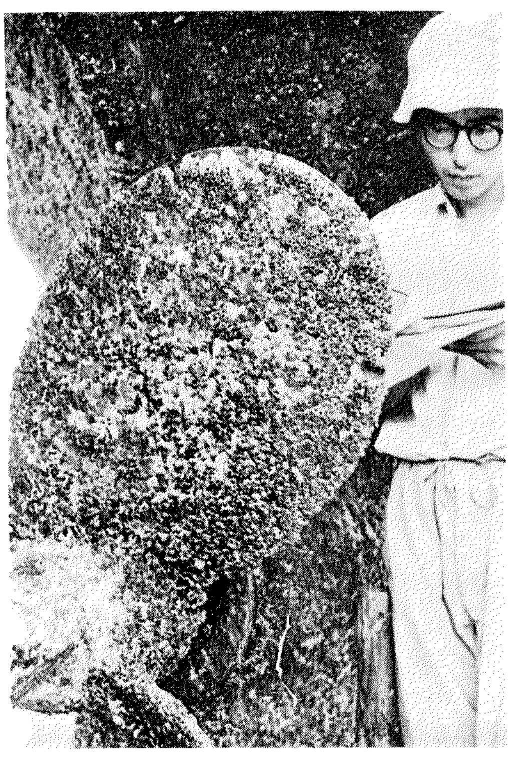
(a) 6th Experiment

(b) 7th Experiment

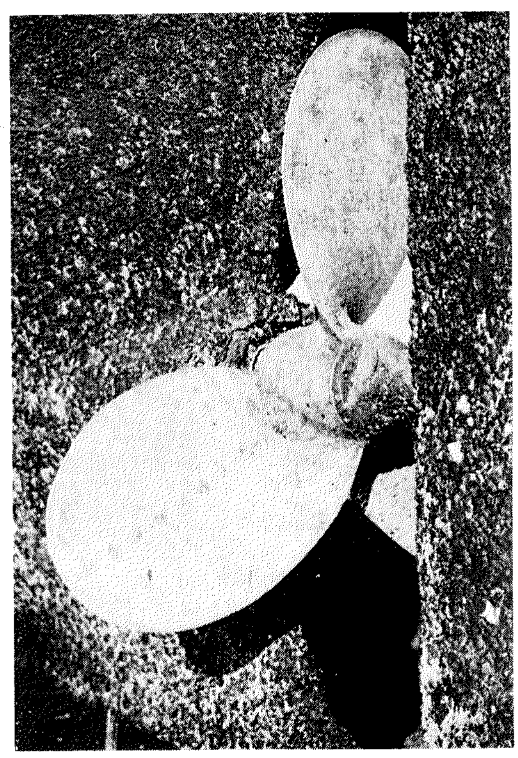
(c) 8th Experiment

Fig. 7-1. Actual Propeller Fouled with Barnacles

(a) 6th Experiment



(b) 7th Experiment



(c) 8th Experiment

Fig. 7-1. Actual Propeller Fouled with Barnacles

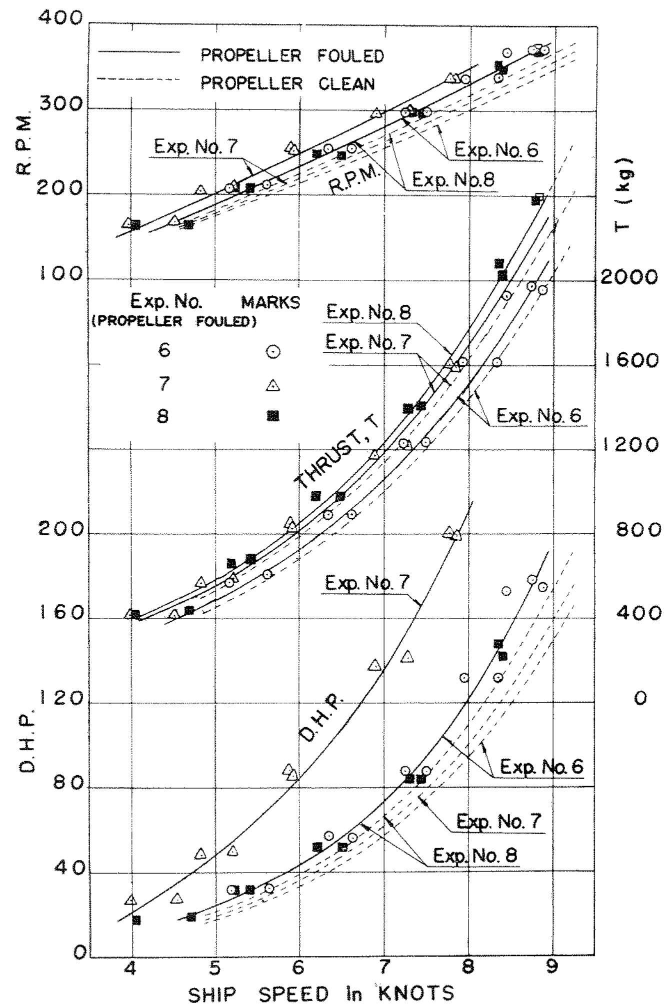


Fig. 7-2. DHP etc. for Ship

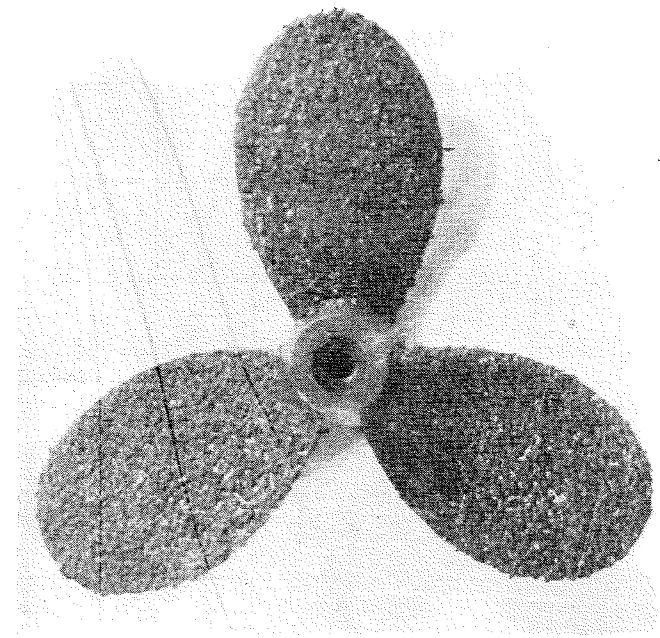


Fig. 8-1. Model Propeller Roughened with Sand

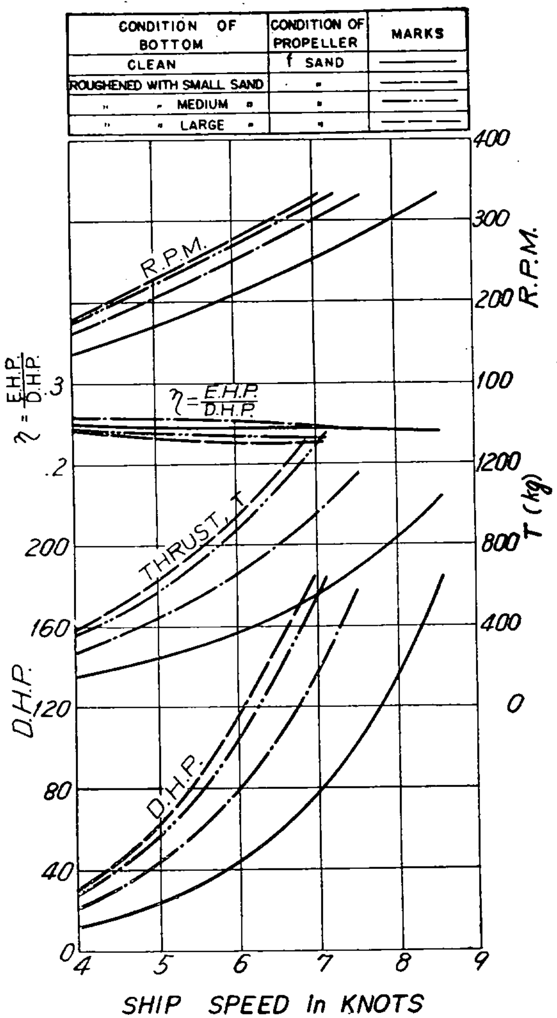


Fig. 8–3. Estimated DHP Curves for Ship, with Roughened Hull and Propeller

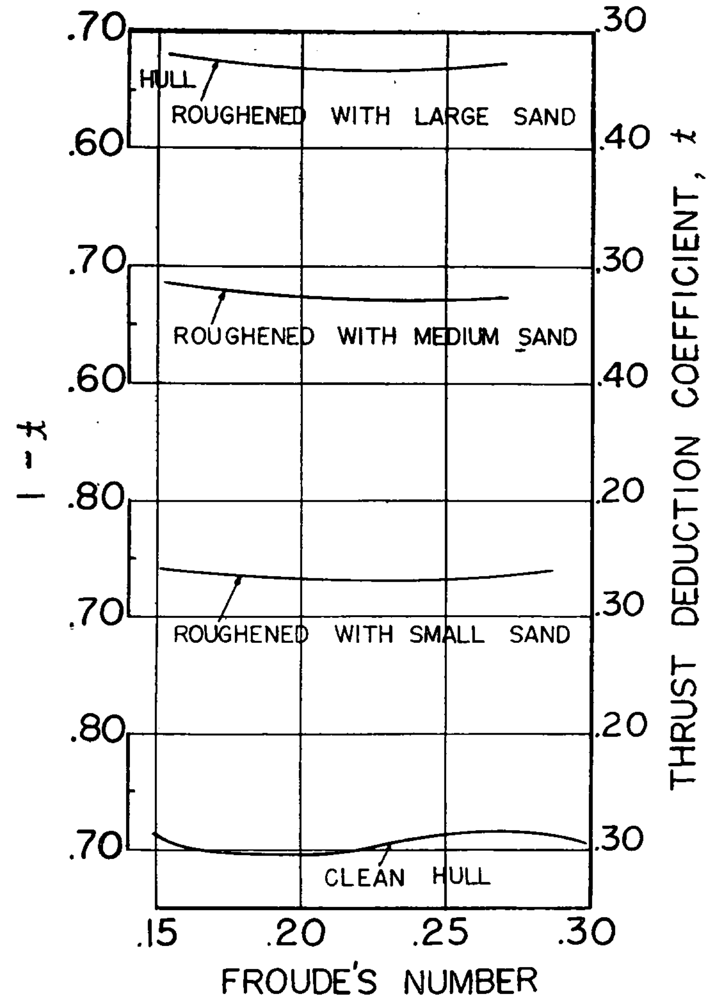


Fig. 8–4. Thrust Deduction Coefficient for Model, Propeller Roughened with Sand

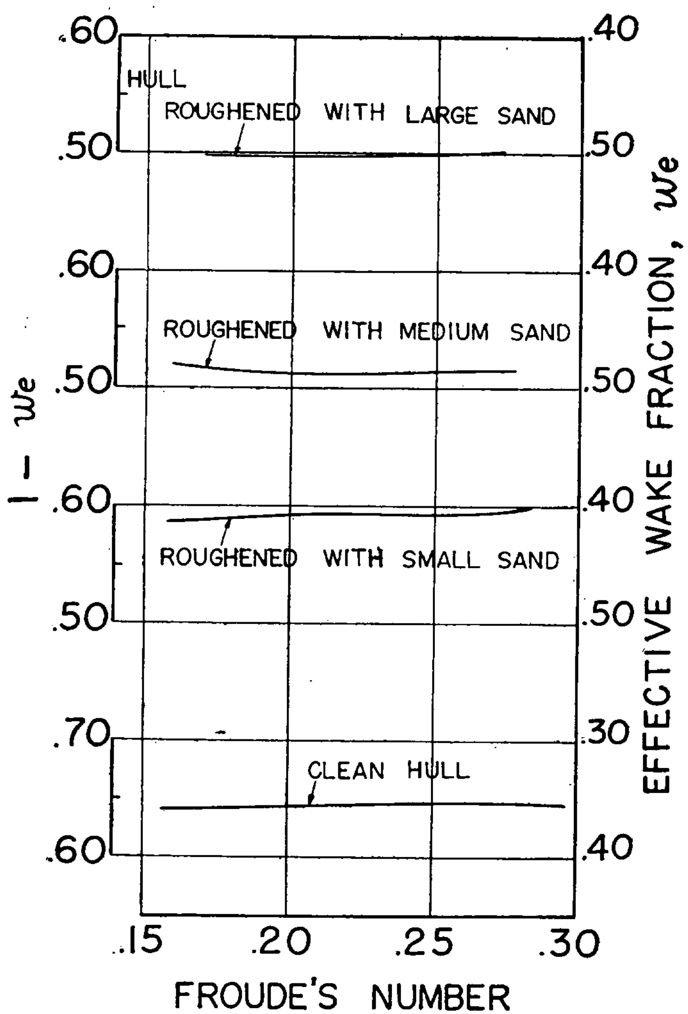


Fig. 8-5. Analysed Wake for Model, Propeller Roughened with Sand

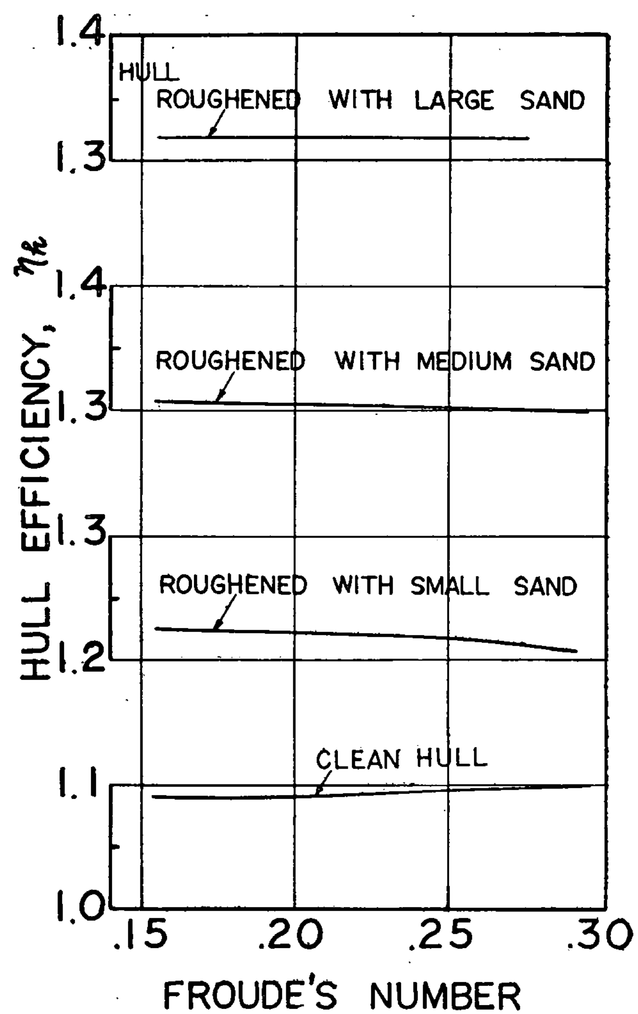


Fig. 8-6. Hull Efficiency for Model, Propeller Roughened with Sand

APPENDIX I. WIND TUNNEL TESTS

1. Method of the tests

Wind tunnel tests were carried out at the Mitaka Branch of the Transportation Technical Research Institute, by using the Göttingen type wind tunnel with an eliptic section (1.5 m × 1.0 m). The model ship was made of lacquered Japanese cypress (hinoki) to a scale of 1/19.866, with all the equipments fitted (Fig. I-1).

The test condition corresponds to C condition of the actual ship, in which the longitudinal and lateral projected areas of the whole deck elections and hull above water line are 15.79 m^2 and 56.67 m^2, respectively.

The tests were carried out by the so-called 'image model' method in which two models of the above-water portion are joined together symmetrically. To represent the sea surface, a wooden circular plate (1.5 m diameter and 2.3 cm thick) was inserted between the models. The circular plate was suspended and kept horizontal in the test section of the wind tunnel by nine wires, eight of which were attached to the circumferance, and one of which to the center.

The fixing of the 'model' in the wind tunnel is shown in Fig. I-2. The model can be rotated on the circular plate to have any angle of attack of the wind. The mean wind velocity was 30 m/sec. The relative direction of wind off the bow was changed every 10° in the range of 0°~180°. Furthermore, the effect of Reynolds' number was investigated by changing the wind speed. The velocity and the direction of wind were also measured on the mast head and above the wheel house.

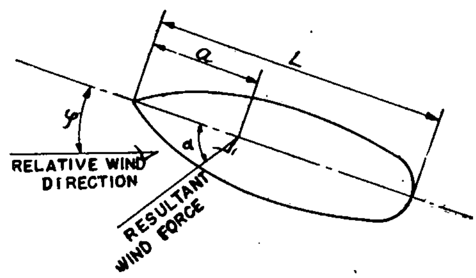
2. Results of the tests

By using the measured results, C_F, α, a/L and k were calculated. Where,

* Members who took share in the wind tunnel tests

Name	Position
Hisamitsu Shiba	Ship Performance Division, Transportation Technical Research Institute
Hiroshi Araki	do.
Tatsuo Hanaoka	〃

$$C_F=\frac{F\cos(\alpha-\varphi)}{1/2\rho V^2(A\cos^2\varphi+B\sin^2\varphi)}$$



F=resultant wind force

V=relative wind velocity

R=wind resistance=$F\cos\alpha$

ρ=density of air

k=wind direction effect coefficient$=\frac{R}{1/2\rho V^2 C_{F_0} A}$

φ=relative direction of wind off the bow

α=direction of resultant wind force off the bow

L=length of model between perpendiculars

a=position of center of pressure of the resultant wind force on the center line from bow

A=transverse projected area of above-water portion of model

B=longitudinal projected area of above-water portion of model

$C_{F_0}=C_F$ at $\varphi=0$

These are shown in Figs. I-3, I-4, I-5 and I-7.

3. Considerations on the tests and their results

In these tests it was necessary to change the relative direction of wind in the range of 0°~180° and, moreover, it was inevitable to hang the model horizontally, because the wind tunnel had an elliptic section with the major axis horizontal.

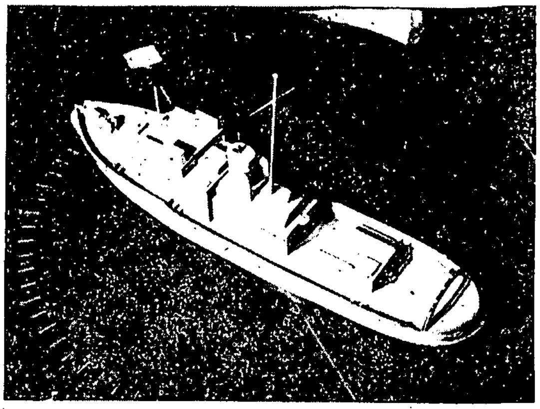
If, therefore, the angle-changing instrument of the balance was used to rotate the model about the vertical axis, it would be very difficult to fix the model. As a consequence the model should be hung by a frame system, and the frame must be strong enough to bear considerably great wind force acting on the model. On the other hand, its air resistance must be small.

A circular disc was used to satisfy the conditions above mentioned. The resistance of the disc and hanging wires was half as large as the minimum resistance of the model. The resistance of the model was obtained by deducting the resistances of circular disc and hanging wires from those of all the attachments, that is, the model, disc and wires.

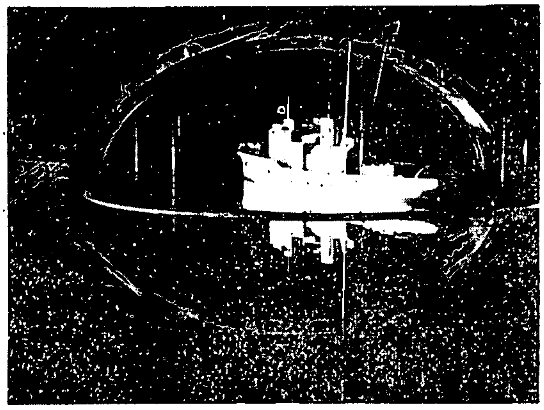
When φ is near 90°, the resistance of disc and wires without model differs from that with model, but this difference can be estimated by calculations. The error of the resistance of the disc at $\varphi=90°$ was 2% of the resistance of the model, assuming that the flow behind the model was at rest. Such a test of a model ship in the wind tunnel for aeroplanes has several defects. For example, the method of correction for the boundary of the wind tunnel has not yet been found, and since a considerable amount of the wake of the model flows out of the wind tunnel, some errors in the resistance due to the difference of the pressure gradients are inevitable.

In Figs. I–3, I–4, I–5 and I–7, the results of the wind tunnel tests of the Yayoi-maru are compared with those of the Nissei-maru. The reason, for which the results of the Nissei-maru were chosen, is that it is a detailed test performed recently by the same method of the image model as in the case of Yayoi-maru, and that the resistance coefficient C_F of the Nissei-maru is the gratest among the results of the tests carried out up to date, while C_F of the Yayoi-maru is the smallest. Fig. I–6 shows a comparison of various resistance coefficients. The value for the Yayoi-maru will be considered to be reasonable, taking into consideration the shape of the deck erections above main hull. Wind direction effect coefficient k has a maximum value at $\varphi=0°$ as shown in Fig. I–7. This is a quite peculiar result compared with the results of other ships.

In Figs. I–8 and I–9 are shown the relative velocity and direction of the wind at the top of the mast and wheelhouse.



(a)



(b)

Fig. I-1. Model Ship for Wind Tunnel Tests

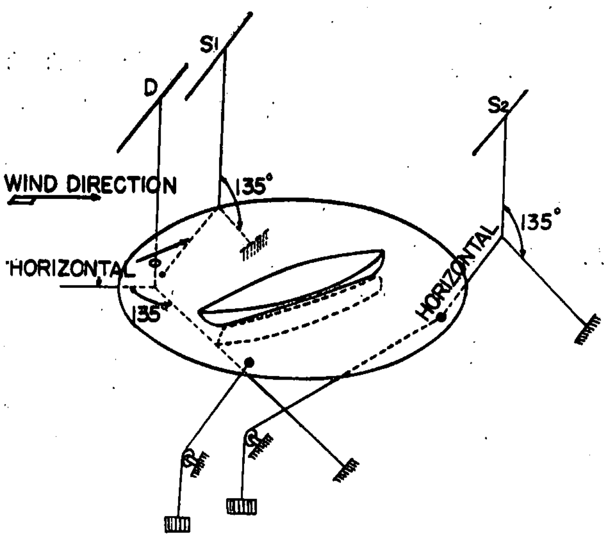


Fig. I-2. Suspension of Model with Circulae Plate

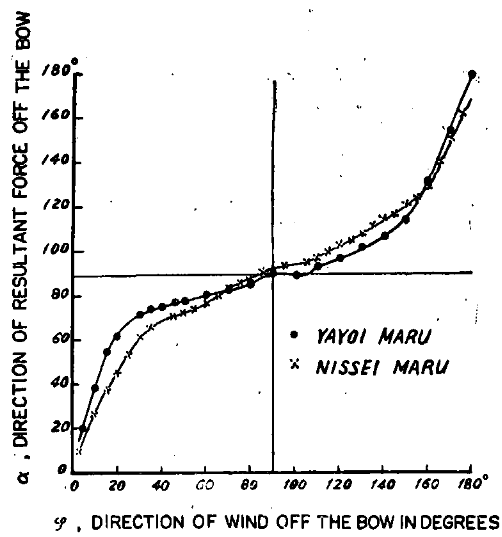


Fig. I-3. Direction of Resultant Force

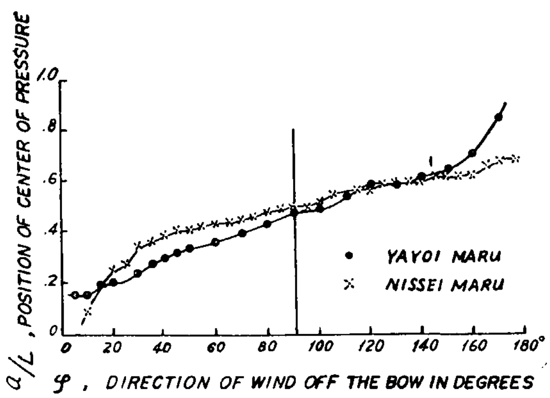
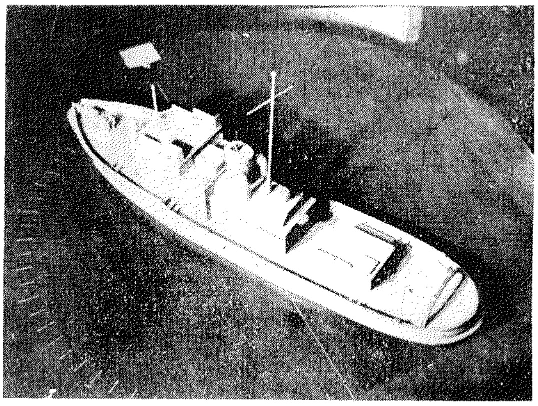
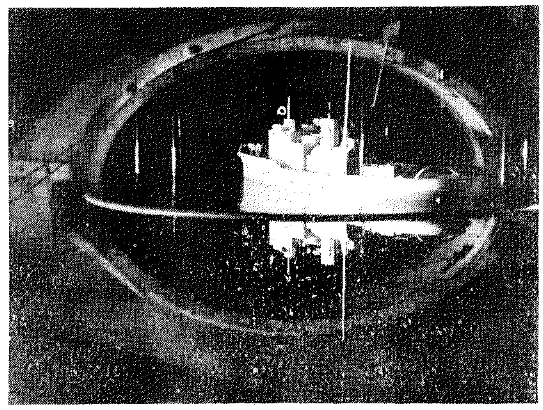


Fig. I-4. Center of Wind Pressure



(a)



(b)

Fig. I-1. Model Ship for Wind Tunnel Tests

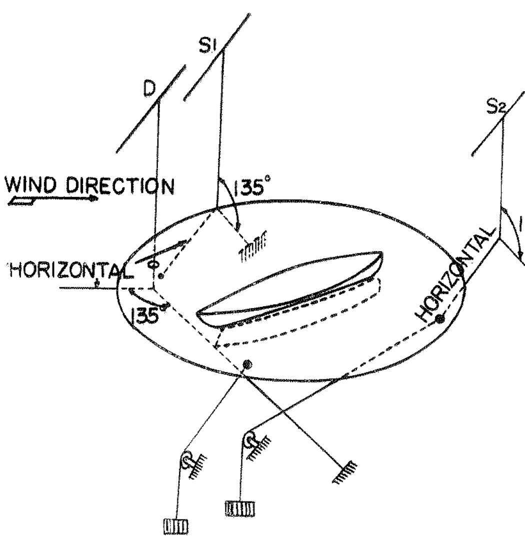


Fig. I-2. Suspension of Model with Circulae Plate

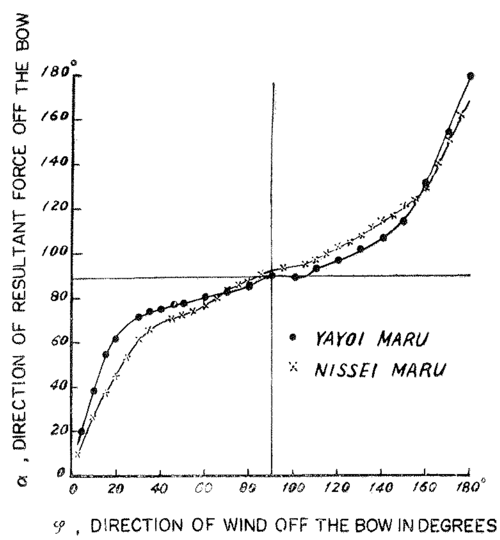


Fig. I-3. Direction of Resultant Force

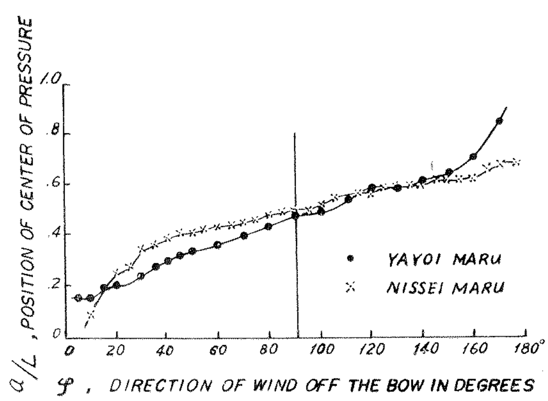


Fig. I-4. Center of Wind Pressure

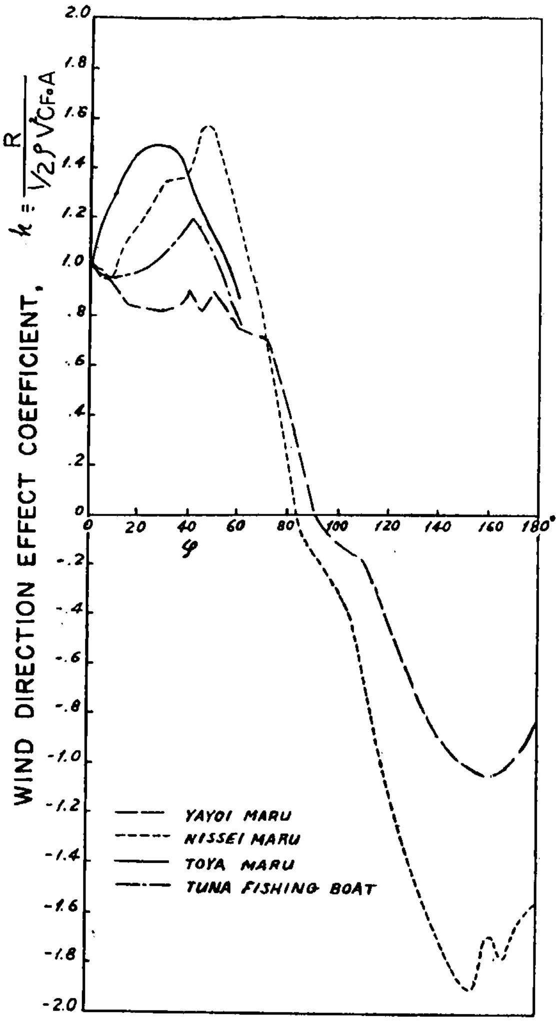


Fig. I-7. Wind Direction Effect Coefficient

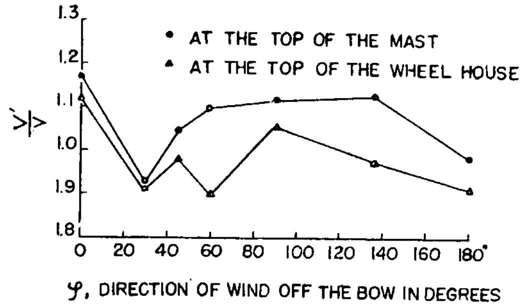


Fig. I-8. Ratio of the Relative Wind speed V' to the General Wind Speed V

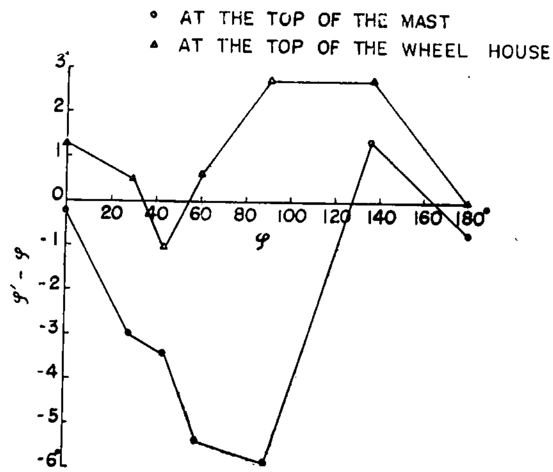


Fig. I-9. Deviation of Relative Wind Direction φ' from the General Wind Direction φ

APPENDIX II. MARINE GROWTHS

1. Kinds of marine growths and their seasonal settlement

Kinds of marine growths on the shell platings were not many. They were Balanus tintinnabulum rosa, Balanus amphitrite communis, Oysters, Serpulids, Bryozoa, Ulva pertuse and so on. The thickest growth among them was barnacles, which covered thickly almost every part of the hull surface except the sides of midship.

In the investigation at the beginning of July, 1952, shortly after repainting, the bottom was kept quite clean. In August of the same year, projections of rust of steel were seen at some places, but no marine growth was found. In October several Bryozoa grew on the bottom, particularly on the bar keel, and a few barnacles on the boot-top near the stem. After that no kind of marine growth was discovered owing to the cold of winter. In May of 1953 barnacles were dotted all over the hull surface except the sides of midship, and other marine growths were dotted everywhere. Oysters grew mainly on the upper side of the bilge keel. In September, barnacles had not increased in number, though they had increased in size remarkably. In October there was found little change in the growth of barnacles. The growing process is shown in Figs. II-1 and II-2.

2. Distribution, quantity and the rate of increase of marine growths

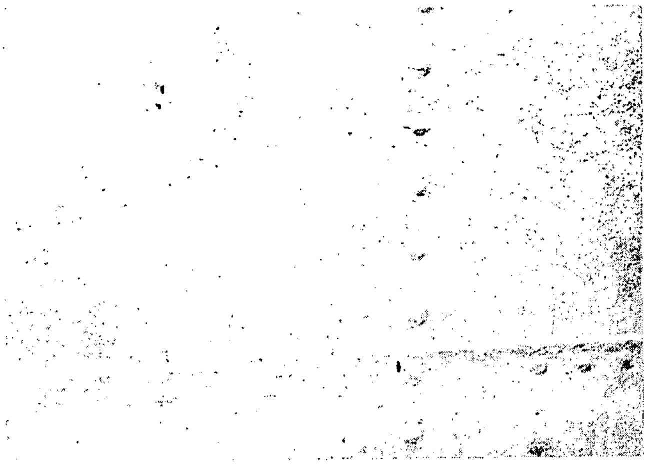
Distribution of the marine growths on the hull surface was investigated on September 14 and October 20, 1953. Three distinct bands of marine growths were noticed along the vertical direction of the hull surface.

Water line part	Covered with thick layers of small barnacles. Thickness was about 10∼20 mm.
Middle part (Portion between 0.7 and 1.4 WL)	Covered with thin layers of barnacles. Least at the midship in number, a little larger in size than those at the water line part.
Bottom part	Covered with thick layers of largest barnacles, mixed with Serpulids, Oysters and other marine growths.

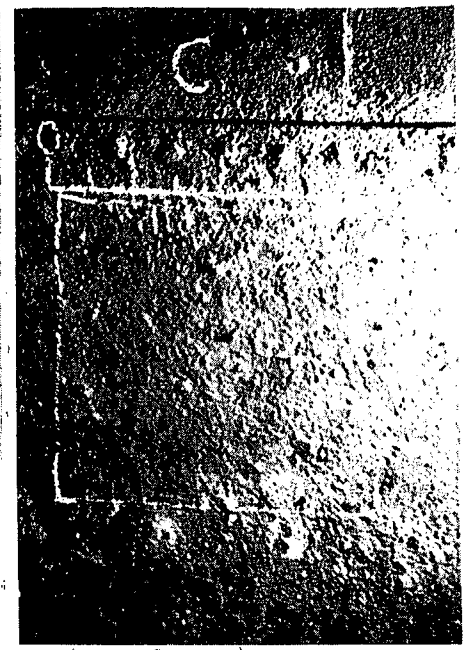
The quantity of the marine growths on the port side was more than that on the starboard side, which is considered to be due to the difference of solar radiation. At the typical parts of the hull surface the number of barnacles in the area of 10 cm × 10 cm was counted in July, September and October of 1953. The results are shown in Table II-1, together with the size. Moreover, in October when the last full-scale measurements of the bottom fouling were performed, the mass of barnacles in the area of 1 m square was measured both at the thickest part (port side of fore body) and the thinnest part (port side of midship). The average weight of them was about 4.2 kg when wet and 2.57 kg when dried. Therefore, the increase of the ship's displacement by them will be considered to be negligible.

Table II-1. Numbers and Size of Barnacles on the Typical Parts of Hull Surface

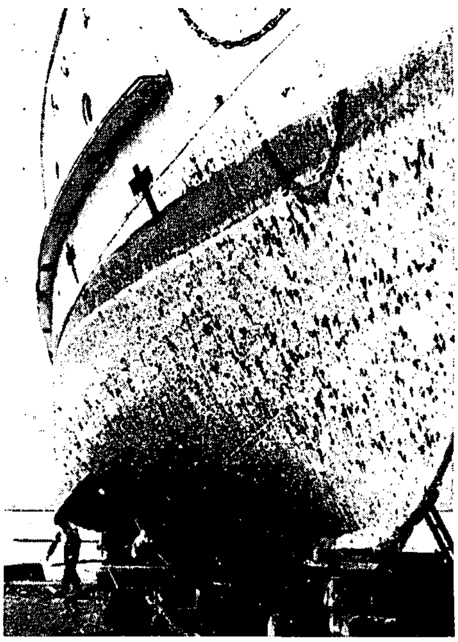
Month	Measured Position	Numbers of Barnacles in 10 cm Square	Average Diameter of Barnacles in mm		Height of Barnacles in mm
			Large	Small	
July	Water Line Part	280∼320	10∼8	2∼3	1∼3
	Middle Part	168	6	1	1∼3
	Bottom Part	325	5		
August	Water Line Part	over 300	6∼5	3	3∼4
	Middle Part	118	10∼11	3	5
	Bottom Part	56∼58	17	10	8
September	Water Line Part	over 300	10	5	7∼10
	Middle Part	188	12	5	8∼10
	Bottom Part	56	14	10	10



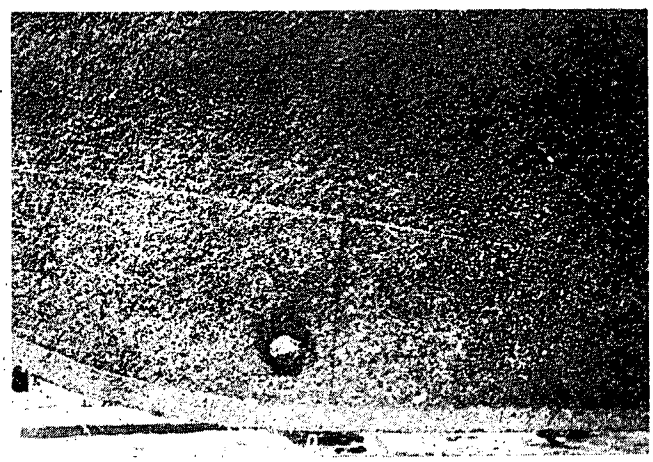
9th Experiment



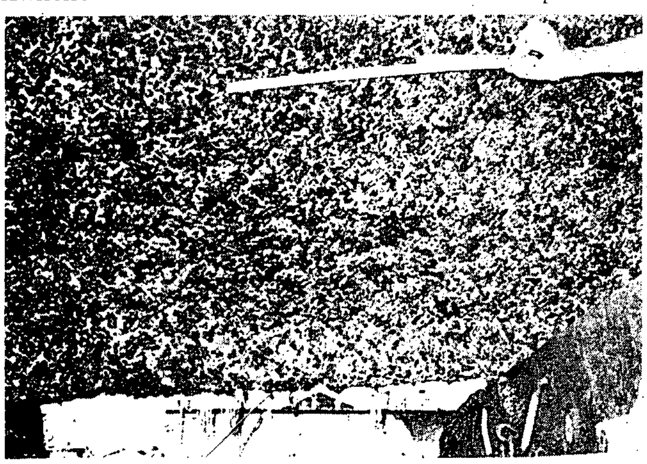
3rd Experiment



5th Experiment



6th Experiment



7th Experiment

Fig. II–1. Growing Process of Marine Growths

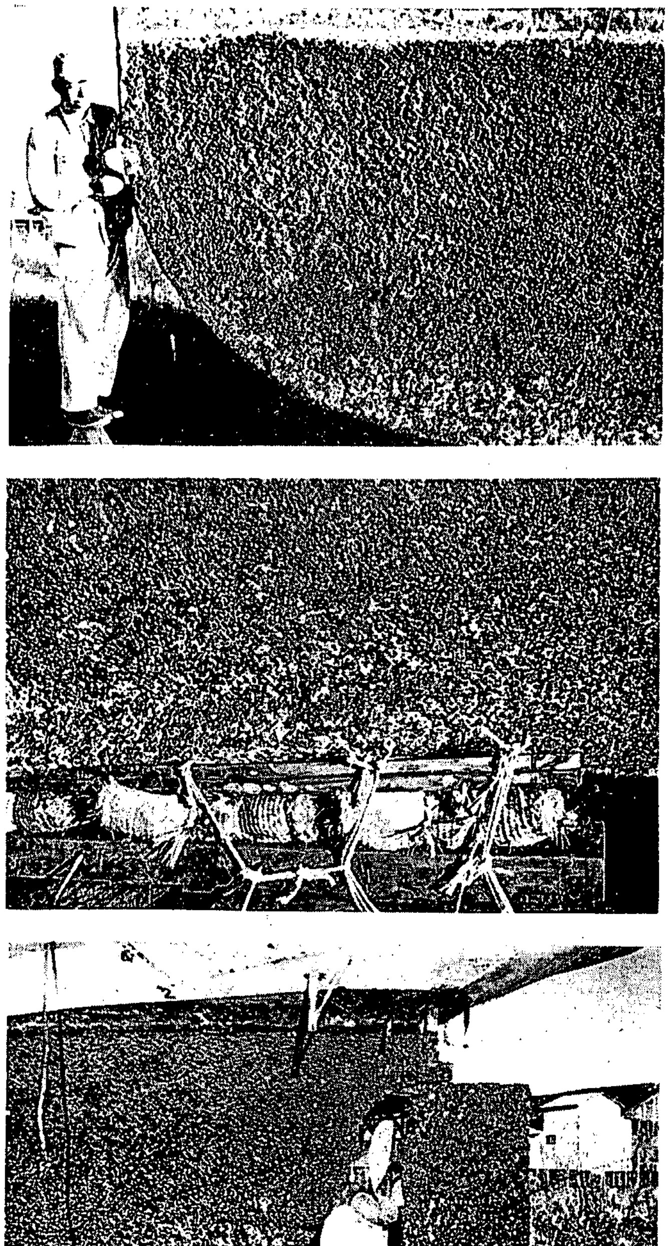


Fig. II-2. Distribution of Marine Growths on the Bottom (8th Experiment)

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電話 (50) 8640, 8641, 9212