ON VISCOUS RESISTANCE OF A LARGE SCALE TANKER MODEL

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ABSTRACT

A large scale model ship (L_{PP}=25m) "DAIOH" was constructed for the sake of filling up the gap between the tank test results and the full-scale ship trial data. In this report, the resistance test of DAIOH and her *geosims* are treated. The viscous resistance component, represented by a form factor k and a ΔC_f, is examined.

Recently in Japan, a number of manoeuvring tests of large scale model ships have been carried out on the sea [1][2][3]. But as to the resistance and propulsion test, any report is not seen because of various difficulties encountered on the sea. And then for further atempts on this kind of experiment, some details of DAIOH experiment are described, especially as to the countermeasures to natural disturbances.

In the Appendix, self-propulsion test results and propeller open test results of DAIOH and her *geosims* are shown with brief comments.

INTRODUCTION

The growth in size and fullness of oil tankers and ore carriers has come to a standstill for the time, but no one will ever think it has reached its final limit. In contrast to this growth, the prediction of full scale performance of ships from model test results seems to have been losing its accuracy and reliability. The reason for it may be considered as follows:

1) The size of model ships tested in a towing tank is remained constant, whereas the size of real ships have been one-sidedly grown larger. Consequently, the tank test results in a lower Reynolds number have to be extrapolated to a very high Reynolds number with the aid of a similarity law. And here the accuracy of the prediction depends upon both the accuracy of tank test results and the extrapolation method used.

2) The tendency adopting a fuller stern form makes the stern flow very complicated, and gives rise to 3-dimensional flow separation phenomena. This causes not only decreasing the accuracy of tank test results but also threatening the validity of similarity law widely accepted hitherto.

To overcome these difficult situations, various efforts have been made by many researchers. Some tried to improve the measuring instruments and the test techniques in a towing tank, some carried out *geosim* tests, and some attacked to full-scale ship experiments. In spite of many efforts, we are not yet given any sufficient solution for practical purposes.

Under these circumstances an experimental research project using a large scale model ship DAIOH was planned in order to fill up the gap between the test results in a towing tank and the performances of a real ship. The project contained many kinds of tests and experiments as shown in Table 1, but here we confine ourselves to pick up the parts relating to the resistance and propulsion tests only.

In section 1. of this report, the model ship DAIOH is introduced in detail. In section 2. the resistance test results of DAIOH together with her *geosims* are reported. And in section 3. the viscous resistance and the ΔC_F are discussed. In section 4. the test methods, especially the countermeasures to the natural disturbances are stated and also measuring instruments are described. In the appendix, the self-propulsion test results of DAIOH and her *geosims* are presented briefly.

Table. 1 Summary of DAIOH series models & experiments

	SHIP	DAIOH	DM120	DM070	DM047	DM035
Scale Ratio	1/1	1/15.38	1/31.67	1/55	1/81.6	1/110
Lpp (m)	385.0	25.025	12.000	7.000	4.714	3.500
B (m)	70.0	4.550	2.182	1.273	0.857	0.636
d (m)	23.27	1.513	0.7254	0.4231	0.285	0.2116
Proportions and Coefficients	L/B = 5.50 B/d = 3.01 $\nabla/(0.1L)^3 = 9.20$		$C_b = 0.837$ $C_p = 0.839$ $C_M = 0.997$		$C_w = 0.890$ $l_{cb} = -3.28$ % Lpp	
Vol. of Disp. (m³)	524,941	144.20	15.895	3.155	0.9633	0.3944
W.S.A. (m²)	39,597	167.30	38.47	13.09	5.935	3.273
Kind of Tests Conducted and Test Places.	I	RT, SPT, WS (TSU) POT (SRI) TT. Z, YRZetc (TSU) ACT (TSU)	RT, SPT, POT, WS (SRI)	RT, SPT, POT, WS (SRI)	RT (UO) TT. Z, YRZetc (UO)	RT (UO) RT (UH) POT ACT (UH)

NOTE : Kind of Test···RT = Resistance test. SPT = Self-propulsion Test. POT = Prop. Open test. WS = Wake survey.
TT = Turning test. Z = Z-test. YRZ = Yaw-rate Z-test. ACT = Accel./Decel. test.
Place···TSU = NKK Tsu Shipyard. SRI = Ship Research Insitute,
UH = University of HIROSHIMA. UO = University of OSAKA.

1. LARGE SCALE MODEL SHIP DAIOH AND SEA AREA

DAIOH is a 1/15 scale model of a 460,000 DWT. VLCC, whose construction is unfortunately suspended due to the 'oil shock.' The paticulars of DAIOH are summarized in Table 2, and the general arrangement, the lines, and her photograph are shown in Fig. 1, Fig. 2, and in Fig. 3 respectively. The length (L_{PP}) of it is decided to 25 m, taking into account of the maritime regulations, building and maintenance costs, the width and the water depth of the sea area, and the size of *geosims* tested in a towing tank. For the sake of securing the stability and the working space for the crew, the freeboad and the bridge of DAIOH are comparatively large and not similar to those of the real ship.

The main propeller is driven by an electric motor which is easy to be controlled and excites scarce vibration. As shown in Fig. 4, motor driven outboard thrusters are equipped on both sides of the stern and they are used in the resistance and propulsion test. Otherwise in an ordinary run, the outboard thrusters are pulled up and folded under the truss. The main propeller which is similar to that of the real ship and thruster propellers are tested in a towing tank previously.

The selected sea area for DAIOH experiments is a harbour situated near the Nippon Kokan Tsu shipyard. The water depth in the harbour is about 8 m, and the tidal difference is 2 m in maximum and 0.8 m in minimum. Early morning in June, wind seldom blows, so the experiments were carried out in those times. Usually DAIOH is moored to a landing stage at the west corner of the harbour but, if necessary, lifted and put on the keel blocks by a crane.

2. RESISTANCE TEST OF DAIOH AND HER *GEOSIMS*

2.1 Resistance Test of DAIOH

Resistance and propulsion tests of DAIOH were carried out first time in July and August 1975, but the expecced fine data were scarcely obtained. The main reasons of the failure were considered as follows:

1) The effects of natural disturbances on the tests were more severer than previously expected and, especially, the irregular current in the harbour made the measured results much scatter.

2) Fouling effects of hull surface by sea plants or micro-sea-lives were so

TABLE 2

PARTICULARS OF "DAIOH"

1. GENERAL

SHIP TYPE : Flush decker
G.T./L.W. : 77.25 GT/49.2 tons
YEAR BLT. : JUNE, 1974
M..ENGINE : Diesel-Electric(AC~AC)
FLAG/OWNER : JAPAN/NIPPON KOKAN CO.

2. DIMENSIONS etc.

L_{OA} 26.335m	$C_B = 0.837$	$C_P = 0.839$	
L_{BP} 25.025m	$C_M = 0.890$	$l_{CB} = -3.28\%$	
B 4.550m	L/B = 5.5	B/d = 3.01	
D 2.300m	Displacement	147.8 ton	
d_{ext} 1.313m	Wet. S. Area	167.3 m^2	

3. PROPULSION MACHINERY

MAIN DIESEL······53ps × 180vrpm × 1set
GENERATOR ······AC3ϕ × 60Hz, 40kVA × 220V
MAIN PROPULSION MOTOR(Induction)
······3ϕ, 11kW × 220V × 1740rpm
PROP. MOTOR FOR O. B. THRUSTER
(Induction) ······3ϕ, 7.5kW × 220V × 1740rpm × 2
RPM CONTROLLER······Induction Kluch
RPM REDUCTION ······R. GEAR AND I. K.
RANGE OF RPM : MAIN PROP. 0~480rpm
O. B. PROP. 0~800rpm

4. PROPELLERS

	MAIN	O. BOARD
BLADE NO.	5	3
DIAMETER	627 mm	360 mm
PITCH	386 mm	360 mm
E.A. RATIO	0.605	0.600
BOSS RATIO	0.1606	0.124
BLADE SECTION	MAU	OGIVAL

5. RUDDER & STEERING GEAR

TYPE Balanced Rectangular Rudder × 1
AREA, /AREA/L. d 0.744m^2 / 1/49
ASP. RATIO/BAL. RATIO 1.32 / 0.249
STEERING GEAR······HYDRAULIC-MOTOR
DRIVEN, Max. Torque 0.5ton·m
NAVIGATION INSTRUMENT······JYRO-
COMPASS AND AUTO PILOT SYSTEM

6. MISCELLANEOUS

DIMENSION OF BRIDGE HOUSE:
L × B × H = 3.2m × 3.0m × 2.0m
BALLAST TANKS AND CAPACITY:
FORE PEAK TANK 15.4m^3
NO. 1 BWT(P. S) 2 × 25.0m^3
NO. 2. 3 BWT(P. S) 4 × 25.2m^3
ELECTRICITY FOR MEASURING
INSTRUMENT: 3ϕ, AC, 60Hz 100V × 20A

7. OUT-BOARD THRUSTER APPARATUS

BRIDGE STRUCTURE : STEEL-TRUSS
BRIDGE DIMENSION : L0.9m × B9.6m × H1.5m
TOTAL WEIGHT : about 4 tons
PROPELLER IMMERSION(DESIGN) 1.280m
MAXIMUM THRUST(at 4 kt) 100kg/Shaft

remarkable. In Fig. 5 the examples of resistance increase due to fouling are shown. During the period of experiments, the hull surface was washed on the keel block twice on July 9 and 19. It is found from the figure that the total resistance increased about 30 percent in a week, but the rate of increasing seemed to be rather irregular.

3) Because of improper mechanism, the outboard thrusters often troubled.

In the next June (1976), the tests were again carried out after very careful preparations which were learned from the valuable experiences of the previous year. The details of countermeasures applied will be explained later.

Now, all the results of resistance tests in full loaded condition are shown in Fig. 6. The resistance values plotted in the figure have already been corrected according to the methods to be described later. The resistance of DAIOH was obtained in two ways, one is directly measured with thrustmeters installed in the outboard thrusters, and another is indirectly calculated using the open characteristic curves of the outboard propellers. The measured results in two ways are in good coincidence as shown in the figure. From Fig. 6, it is said that the test results seem to be reliable and repeatable and also seem to be almost excluded the effects of various disturbances.

During the period of tests, comparatively fine weather and calm sea condition continued and the high tide came on June 10, and the low tide on June 22.

2.2 Resistance Test of the *geosims*

In order to investigate the form factor and the scale effect of self-propulsion factors of the ship form, *geosims* of four sizes (L_{PP}=3.5 m, 4.7 m, 7.0 m, 12.0 m) were tested in the three towing tanks. The principal dimensions of them, the kinds of tests carried out, and the towing tanks used are listed in Table 1.

In Fig. 7, the total resistance curves of *geosims* are drawn together with the schöenherr's friction line. In Fig. 8, the residual resistances, by substructing the Schöenherr's C_{F0} from total resistance C_T, are shown. All of the results are in the full loaded condition. At a first sight of Fig. 7, it is found that the discrepancy among the resistance curves of each model are very serious and one may think they contain some errors. Of course, staffs of each towing tank eagerly pursued the causes by re-analysing the measured data or by repeating the towing tests. But the situations did not take a turn for the better.

Examining detail data and discussing many times, the following reasons were deduced.

1) Originally the resistance of this ship seems to be changeable, because the measured records with a special resistance dynamometer show considerable fluctuation of resistance as shown in Fig. 9. The range of the fluctuation is about ±10 percent of the total resistance.

2) Examining in details of resistance tests, the recorded curves of trim and sinkage are found to be not the same in different days, in spite of the same running speed and the same water temperature. And this means the pressure distributions around the hull and accordingly the resistance are not the same in the two tests.

3) Because of low test speed, fairly large area of laminar flow remains on the bow part of the model, even if the turbulent stimulators (studs) are fitted. Furthermore, the laminar part may change its area sensitively with the surrounding water condition.

In this connection, the difference of turbulent stimulation methods also cause to scatter the test results. However, each method was allowed to follow the practices of each towing tank.

3. VISCOUS RESISTANCE AND ΔC_F OF DAIOH

After all, the form factor of the *geosims* were not be able to be determined by making use of the diagram of $C_{F0} \sim C_T$ relation as usually done. So the form factor was simply determined as k≑0.38 (based on the Schöenherr friction line), making much account of the data of 12_m model (DM120) in Fig. 7. It is considered the largest model might supply more accurate result. The mean resistance curve of DAIOH is also shown in Fig. 7. Assuming the above mentioned form factor k≑0.38 is correct, the ΔC_F of DAIOH is estimated at 0.0003 in Fig. 7.

Now, let us inquire the ΔC_F, roughness effect of hull surface, from another point of view. Fig. 10 shows three examples of painted DAIOH hull surface.

Photograph (a) in the figure represents a quite smooth part of the hull and it is said to be a standard surface condition of newly built ships in Japan. The roughness is wavy type and height of roughness is 50∿70μ by eye measurement. The area occupied with this roughness is estimated about 10∿15 percent by eye inspection. From reference [4], corresponding ΔC_F is estimated at the order of 0.0001.

Photograph(b) of Fig. 10 shows a normal smooth part of the hull surface and the roughness type is also wavy in general, but the deteriorations are found in several places. The mean height of this roughness is estimated about 100μ by eye and photograph inspection. This roughness may occupy about 80 percent of the total wetted surface area. It is very difficult to estimate the ΔC_F of this degree of roughness. Referring to the experimental report of NSRDC[5], the report of PENELOPE[6] and also the reference [4], ΔC_F of this type of roughness is estimated about 0.0003.

A comparatively deteriorated part of hull surface is shown in Photograph(c) of Fig. 10, but it exists only in very small portion of the hull surface. The height of roughness is estimated about 200∿300μ and the type of roughness is not perfectly wavy. The ΔC_F of this roughness is supposed to be not small but owing to smallness of its occupied area, its ΔC_F is ignored here. From the above mentioned facts, eventually the ΔC_F of DAIOH is estimated at 0.0003. The augmentation of resistance due to the most smooth part of roughness and that of the most rough part seemed to be cancelled each other, and only normal smooth part is responsible to the ΔC_F.

Now the ΔC_F the estimated in two ways and the results of them are coincident with each other, so this value of ΔC_F is perhaps very close to the true value.

4. DETAIL OF DAIOH EXPERIMENTS

4.1 Countermeasures for Distrubances

Experiments of DAIOH were carried out in selecting a calm sea condition, but the complete exclusion of the natural disturbances could not be realized.

In steady running, a low Froude number ship such as DAIOH is easy to be disturbed by currents, winds etc. And to measure the forces acting on the hull is very difficult, because the forces to be measured are very small quantities in comparison with her own displacement. The small disturbances in running velocity causes the large fluctuation of measuring forces. Therefore, the countermeasures to disturbances are indispensable to these experiments.

a) Current

The currents in the harbour were investigated by buoys and the outline of measured results is shown in Fig. 11. Avoiding the area of complex currents, the trial course was selected so as to be along the direction of the current. In fact, when DAIOH crossed the circulating current, her speed or the heading angles were changed abruptly. The current speed is nearly proportional to the tide range, and sometimes it reaches to 0.15 m/sec. As the current changes its direction after two or three hours later from the high tide, the favourable time for experiment is close to that time at the neap.

b) Ship Speed Relative to Water

Current speed varies with the water depth and accordingly the ship speed relative to water also. Fig. 12 shows examples of them. The left two figures are recorded at a spring tide and the right two are at a neap tide.

The speed of DAIOH was measured by JIS-type of pitot tubes. Two of them were fitted at the caps of the outboard thrusters. The other three were arranged in the virtical plane, aside 3.4 m from ship center line, and each position of setting was 0.3, 0.9, and 1.5 m below water surface respectively.

From the speed data of each water depth, the "representative speed" was defined. It was the speed of a certain water depth which was the vertical centroid of the wetted surface area of the hull. In the DAIOH's case it was 1.1 m below the water surface. In many cases, the centroid of wetted surface area almost coincides with that of skin friction resistance. Hereafter the representative speed is used as the ship speed.

c) Wind Pressure Resistance

As the projected lateral area of DAIOH is relatively large, the wind pressure resistance must be considered.

Providing a 1/15 scale model of DAIOH, a wind tunnel test was carried out and offered the directional wind pressure resistance as shown in Fig. 13. Measuring the relative wind velocity and direction and with the aid of Fig. 13, the wind pressure resistance was estimated. The relative wind velocities and directions recorded during the trial are shown in Fig. 14.

d) Other Distrubances

This time, the effects of the following disturbances were not considered; small waves without accompanying ship motions, swell and seiche, the slope of water surface etc. Because the proper methods of correction were unknown.

4.2 Comments on Apparatus and Instruments

The propeller shaft arrangement of DAIOH is shown in Fig. 15. As seen in the figure, a self-propulsion dynamo-meter is installed in the intermediate shaft. Merits of connecting the induction cluch is easy to control the propeller in wide range of revolutions and also easy to keep the revolution constant. The maximum range of the self-propulsion dynamometer is 250 kg for thrust and 30 kg-m for torque respectively, and the error range is both ±0.1 percent of the full scale. A caution was needed that the output of magnetic strain type pick-up was changed by its setting direction, and it was found due to terrestrial magnetism.

The outboard thruster is hung from both sides of board by a rudder-like sword. The thruster propellers are selected as of rather small diameter and large pitch because of stable operation in a certain range of its loading. Preventing the thruster propellers from air drawing, they are set in the water depth of 1.28 m.

Concerning to the other instruments, it seems to need no special explanations.

4.3 Procedures of Tests and Analyses

The test course of DAIOH is shown in Fig. 11. The measurement was carried out after a sufficient approach run and when the ship speed became constant. After two ways of resistance test, two ways of self-propulsion test were followed alternatively. It makes possible to obtain more accurate self-propulsion factors.

The measured thrust, torque, ship speed relative to water, propeller revolutions etc. were continuously recorded on pen-recorders. As far as possible, a simplified calibration and a zero point checking of main instruments were carried out in every two test runs, but their characteristics were found almost constant.

In the resistance test, when DAIOH is running steady, the forces acting on the hull are balancing as follows (Fig. 16),

$$R_T = (T_R + T_L) - (R_W + R_{SW}) + T(1 - t) - \Delta R \quad (1)$$

where R_T: total resistance, T_L and T_R: thrust of outboard propeller in right and left hand side respectively, R_W: wind pressure resistance, R_{SW}: resistance of swords hanging from outboard thrusters, t: thrust deduction fraction, T: thrust of main propeller, ΔR: some small unknown disturbance forces, unmeasurable and assumed zero.

The main propeller was not removed during the resistance tests, and it was kept rotating at a certain small revolutions so as to produce no thrust and no resistance. But in the actual condition, it produced a certain thrust so the term T(1-t) is added in the equation (1).

In the self-propulsion test, the balancing forces acting on the hull are written as follows,

$$T(1 - t) = R_T - (T_R + T_L) + (R_W + R_{SW}) + \Delta R = R^* \quad (2)$$

In this case, the second and the following terms correspond to a skin friction correction (SFC), and R* corresponds to a real ship resistance. On the sea, R_W and ΔR are not able to be controled, so to give a correct value of SFC is quite difficult.

Equation (1) and (2) were used in the analyses of measured data.

It is notable that the unknown disturbance force ΔR gives severer effect to the self-propulsion test than to the resistance test, because the quantity of R* is about a half of R_T.

5. CONCLUDING REMARKS

In order to fill up the gap between tank tests and real ship performances, a large scale model ship DAIOH was built and various kinds of tests on the sea were carried out.

A part of results concerning to viscous resistance was reported here together with that of her *geosims*.

From the experimental point of view, the resistance test of DAIOH on the sea was successful and provides a fairly good resistance curve. But in obtaining the viscous resistance of DAIOH from her total resistance, two difficulties arose as to the form factor k and the ΔC_F.

Initially, the form factor k had been expected to determine easily from the *gesim* tests, and then the ΔC_F was expected to be determined definitely with that form factor. But as stated in section 2.2, the *geosim* test itself had many problems to be solved.

The ΔC_F in section 3. was treated in a pure sense of roughness effect on skin friction and it was slightly different from the ΔC_F so called the ship model correlation factor.

The ΔC_F estimated by inspection was a reasonable value, even if the methed was somewhat rough. The roughness effect on skin frictional resistance is another very important problem to be investigated.

The details of experiments on the sea were discussed in section 4. As the test conditions on the sea were severer than had expected, various countermeasures to the natural disturbances were indispensable.

In the appendix, the results of self-propulsion tests of DAIOH and her *geosims* are presented.

Also the propeller open test results of DAIOH and her *geosims* are shown in the appendix.

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APPENDIX

The self propulsion factors of DAIOH and her *geosims* are shown in Fig. 17. They are analysed with the open characteristics of each propeller shown in Fig. 18. In the figure, η_R indicates relative rotative efficiency, η_O: open efficiency, $1-w_T$: wake factor obtained by thrust identity method, $P'=2\pi nQ/\rho v^3 \nabla^{2/3}$: torque coefficient, $t'=T/\rho v^2 \nabla^{2/3}$: thrust coefficient.

From Fig. 17, the scattering of analysed points of DAIOH is nearly the same as that of her *geosims*, and it suggests from the fact that the measuring accuracy in the sea experiment is almost sufficient. But as to the thrust deduction factor, the plotted points are considerably scattering by the reason stated at the end of section 4.

The open test results of DAIOH series propellers are shown in Fig. 18. The smallest propeller of DM035 was tested at a certain Reynolds number less than critical one, so its characteristics differs a little from the others.

The scale effect of the self-propulsion factors and the open characteristics of propellers can be seen in Fig. 17 and Fig. 18, but further discussions on these problems are left in the future.

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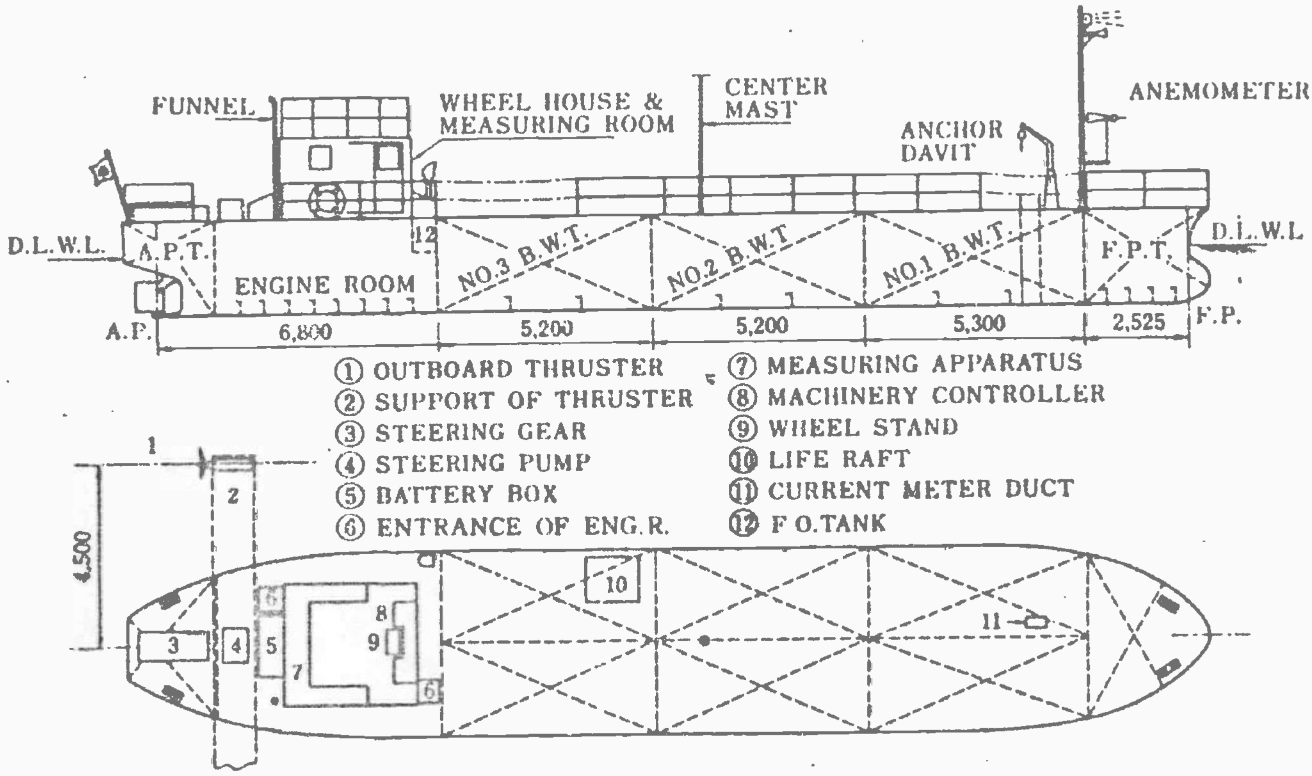


Fig. 1 General arrangement of DAIOH

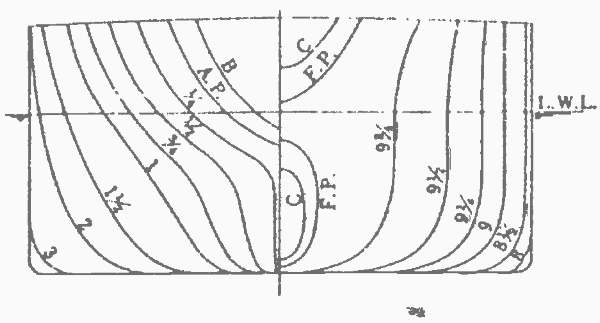


Fig. 2 Lines of DAIOH

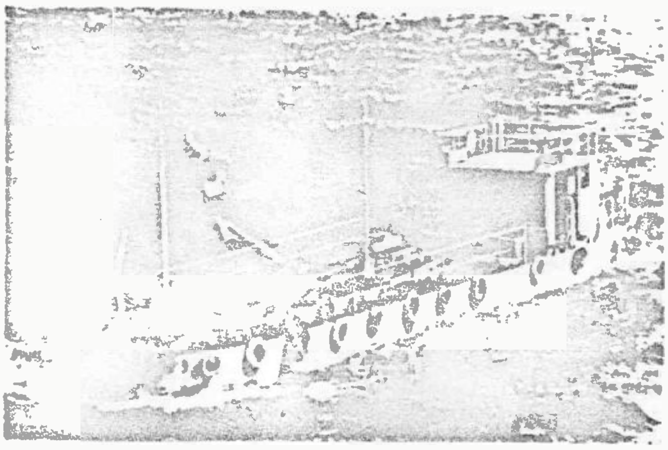


Fig. 3 DAIOH

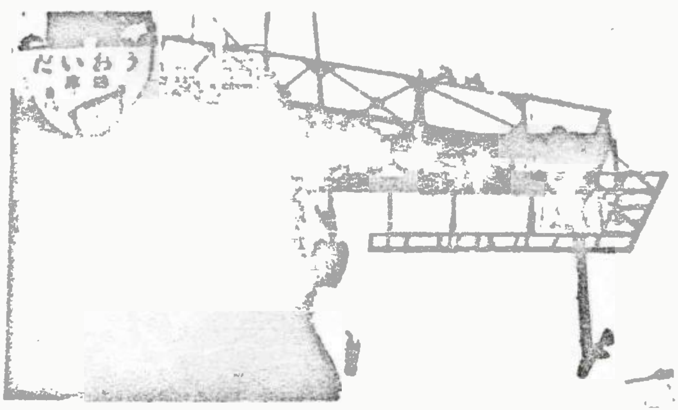


Fig. 4 Outboard thruster

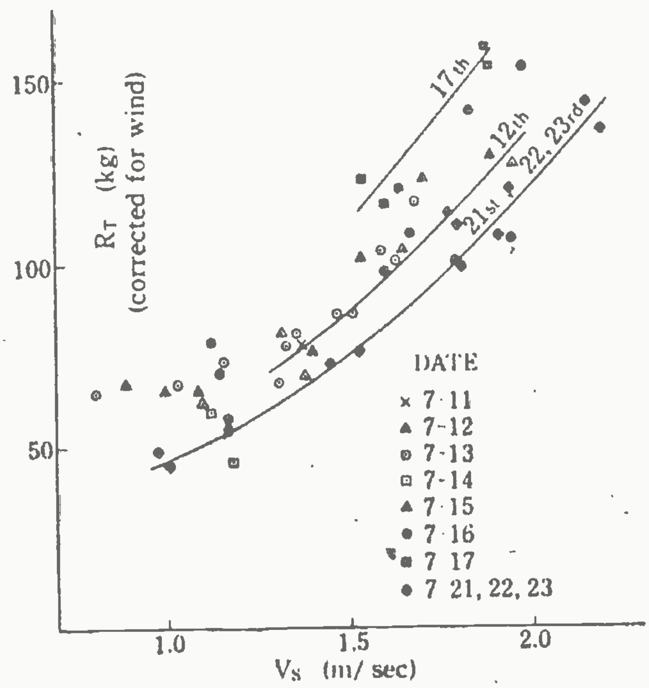
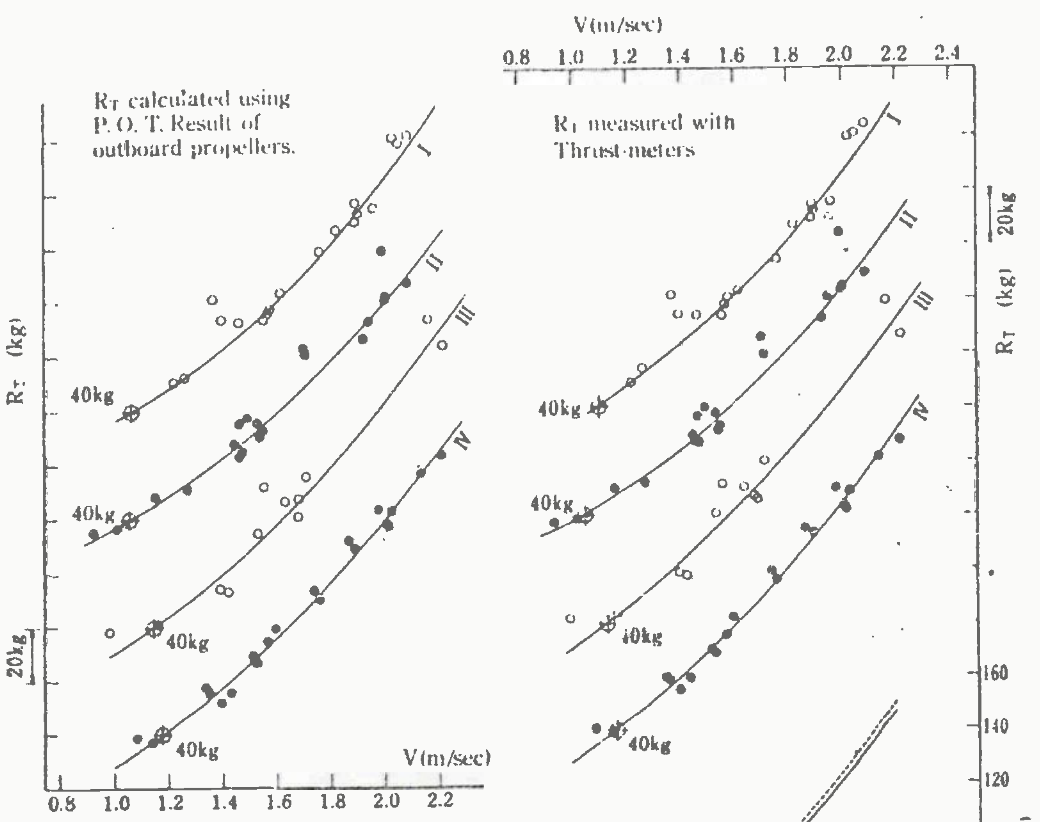
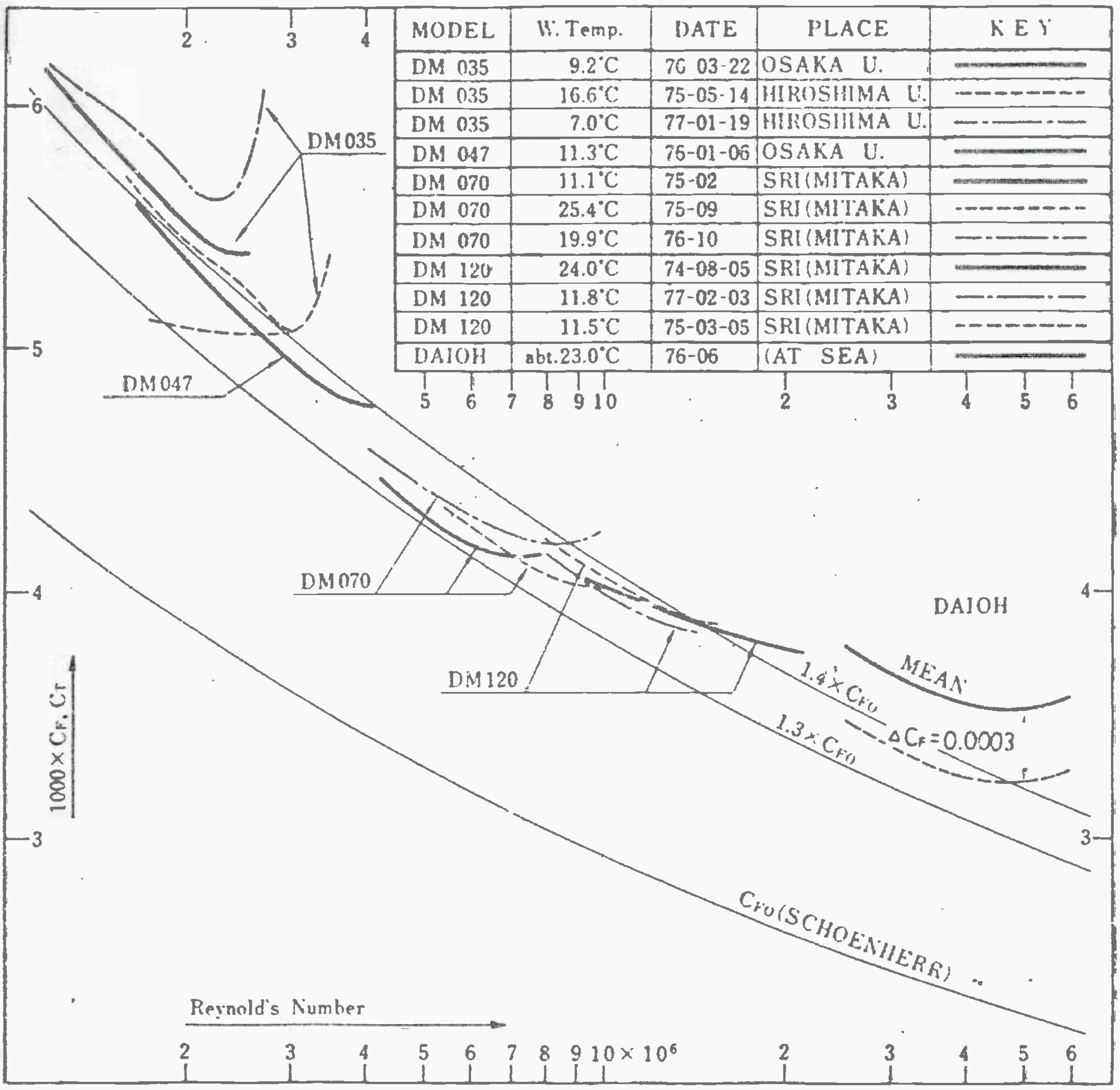


Fig. 5 Resistance increase due to fouling



Wk.	DATE	W. T.	γ	ν × 10⁶
I	6 - 2	22.0	1.016	0.9914
	3	22.0	1.019	0.9969
II	9	21.5	1.018	1.0063
	10	23.0	1.017	0.9716
	11	22.0	1.012	0.9839
III	15	21.5	1.019	1.0082
	16	22.0	1.012	0.9453
	17	22.0	1.012	0.9453
IV	22	22.5	1.017	0.9823
	23	24.0	1.016	0.9489
	24	23.0	1.017	0.9716

Fig. 6 Total resistance of DAIOH vs. speed



MODEL	W. Temp.	DATE	PLACE	KEY
DM 035	9.2°C	76 03-22	OSAKA U.	
DM 035	16.6°C	75-05-14	HIROSHIMA U.	
DM 035	7.0°C	77-01-19	HIROSHIMA U.	
DM 047	11.3°C	76-01-06	OSAKA U.	
DM 070	11.1°C	75-02	SRI(MITAKA)	
DM 070	25.4°C	75-09	SRI(MITAKA)	
DM 070	19.9°C	76-10	SRI(MITAKA)	
DM 120	24.0°C	74-08-05	SRI(MITAKA)	
DM 120	11.8°C	77-02-03	SRI(MITAKA)	
DM 120	11.5°C	75-03-05	SRI(MITAKA)	
DAIOH	abt.23.0°C	76-06	(AT SEA)	

Fig. 7 C_T vs. R_n curves of DAIOH *geosim* models

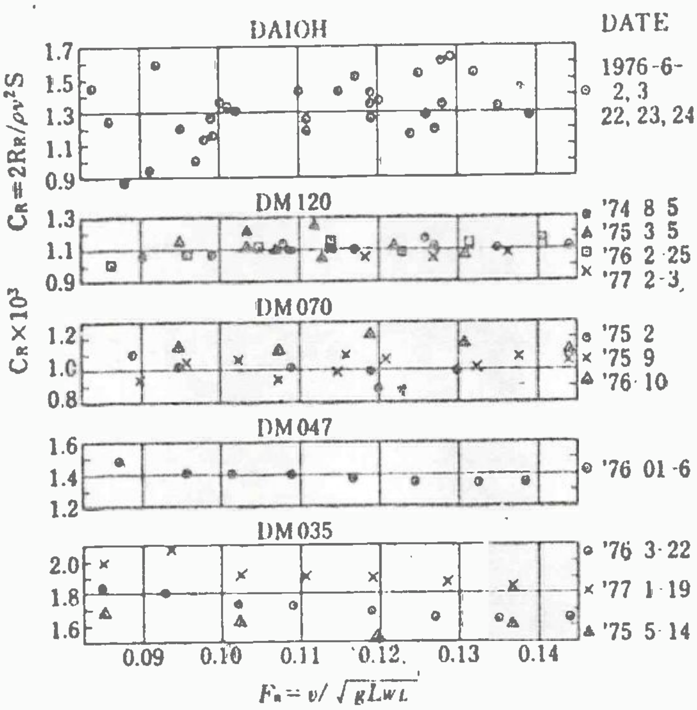


Fig. 8 CR vs. Fn curves of DAIOH *geosim* models

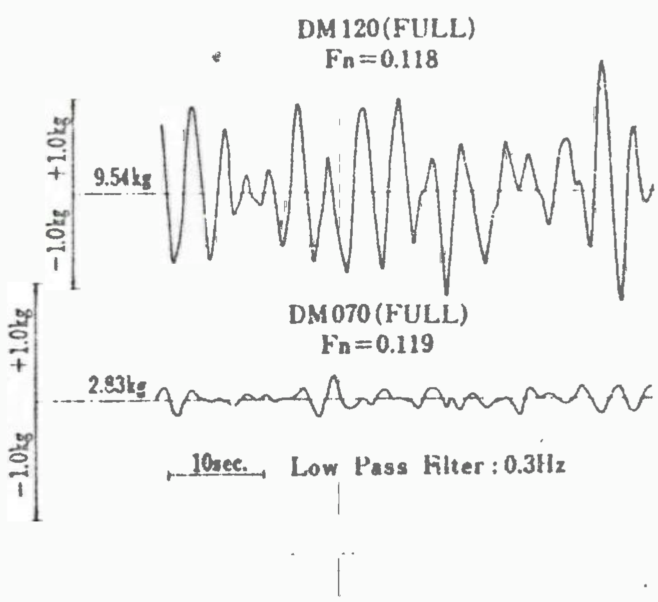


Fig. 9 Fluctuation of resistance observed
on Models DM120 and DM070

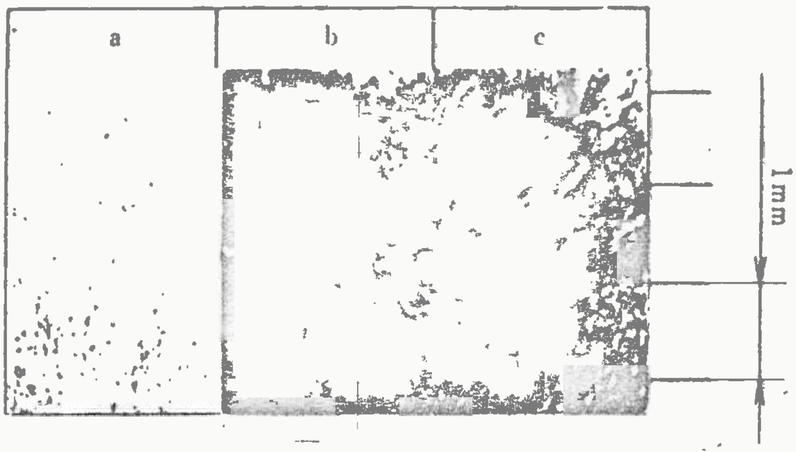


Fig. 10 Examples of painted hull surface

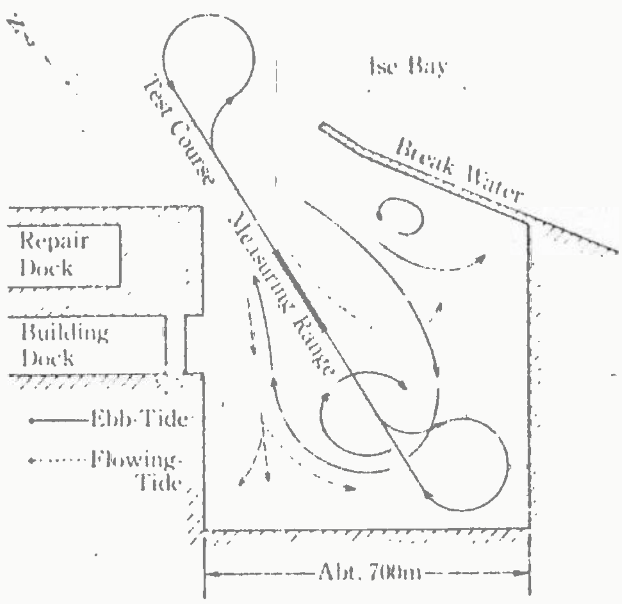


Fig. 11 Test site and current

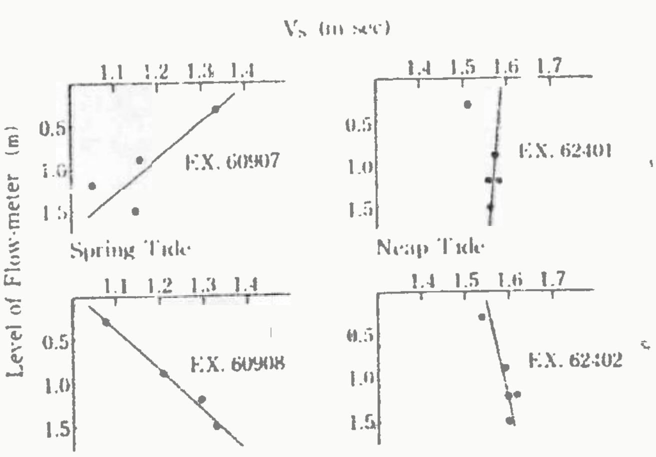


Fig. 12 Examples of ship speed relative to water measured at various depths

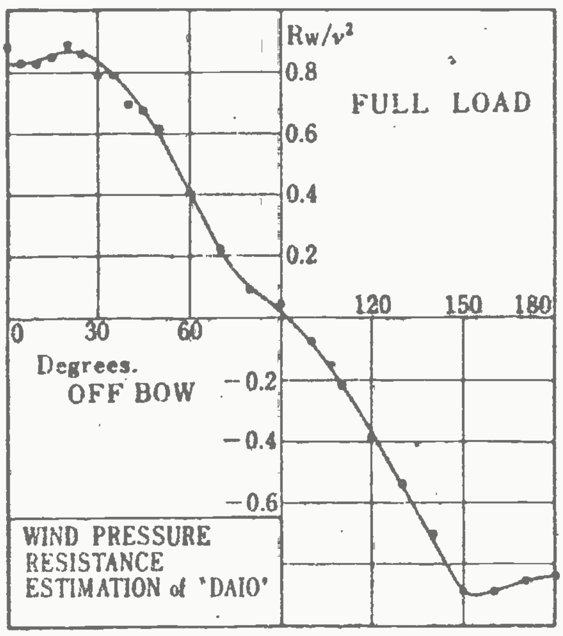


Fig. 13 Wind resistance coefficient of DAIOH

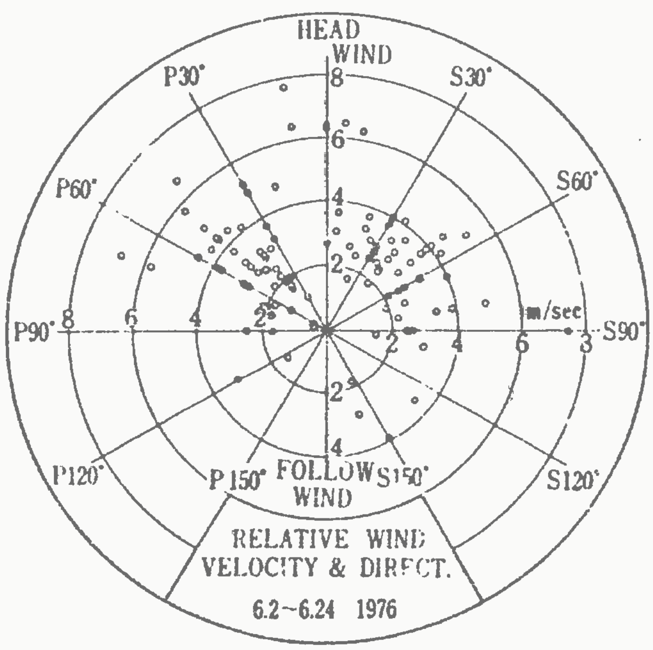


Fig. 14 Observed relative wind velocity and direction

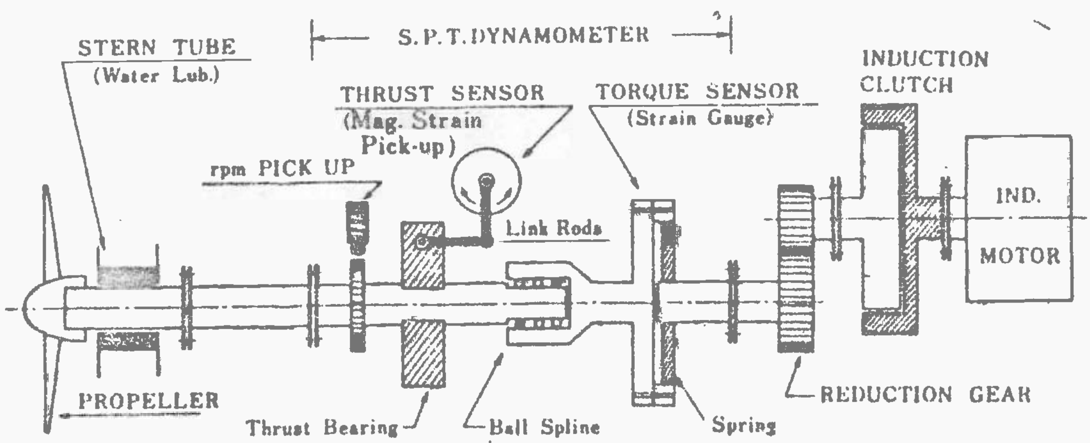
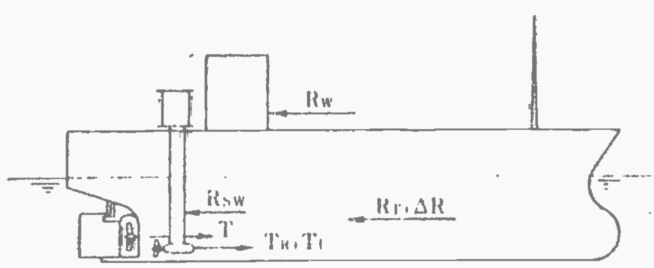


Fig. 15 Propeller shaft arrangement of DAIOH



R_F : Resistance in calm water
ΔR : Resistance due to unknown disturbance
R_W : Resistance due to wind
R_{SW} : Resistance of the swords and flow meter
T : Thrust of main propeller
T_R, T_L : Thrust of outboard propellers

Fig. 16 Forces acting on DAIOH during the test

Fig. 17 Self-propulsion factors of DAIOH *geosim* models

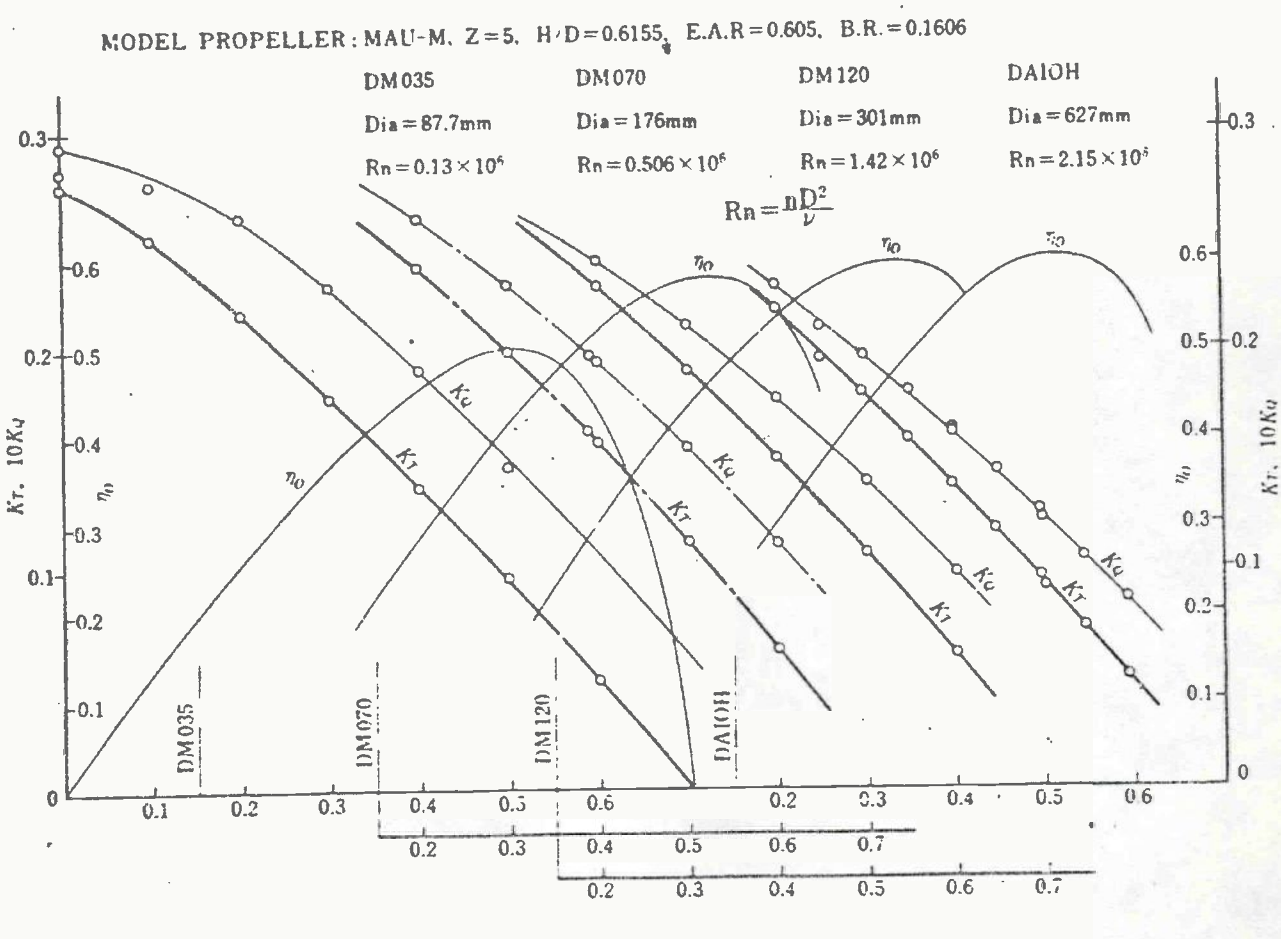


Fig. 18 Open test results of DAIOH *geosim* propellers