1-16 (昭和 47 年 5 月日本造船学会春季講演会において講演)

Study on Flow Pattern around the Stern of Full Ship Form by Use of the Geosims

Kyoji Watanabe*, *Member* Koichi Yokoo**, *Member*
Takashi Fujita*, *Member* Hiromitsu Kitagawa**, *Membr*

Summary

In order to study the scaling law for resistance and self-propulsion factors on an extremely full ship form, on which the state of flow pattern around the stern is of type "F" or "S", tests of the geosims composed of 9, 6 and 4 meters in length were carried out as a joint study by the Ship Research Institute and the Nagasaki Experimental Tank of Mitsubishi Heavy Industries, Ltd..

Conclusions obtained from the geosim tests are as follows,

(1) Two types of flow "F" and "S" were observed on 9 meter model as well as 6 meter model.

(2) The state of flow around the stern on full ship form seems to depend on the ship form and not to be affected by the scale of model in the tested range.

(3) Unusual characteristics were not found of the scaling for the resistance in the range of model scale 4 to 9 meters.

1 Introduction

As the size and fullness of tanker becomes greater, the unstable phenomenon due to separation of flow has been experienced in model tests.

The studies on unstable phenomenon in model tests have been continued in the Nagasaki Experimental Tank, and the results of these studies including the repeated self-propulsion tests for the typical full ship form, i.e. M. 1592, which is the parent model of SR 61 (Research Committee No. 61 of the Shipbuilding Research Association of Japan), were already reported to the Society of Naval Architects of Japan in 1969, etc[1)~3)]. From the studies described above the three types of flow patterns around the stern of ship model were named type "N", "F" and "S", after Taniguchi[4)], where N, F and S mean "Normal", "Fickle" and "Separated" flow, respectively.

The characteristics of each type of flow are as follows. Type "N": -The flow pattern of not so full ship form, where the velocity distribution around the stern in self-propelled condition will be almost approximated by the superposition of the induced velocity field due to propeller upon the velocity field in towing condition.

Type "F": -The flow pattern of full ship form, where the separation of the flow around the stern tends to be so unstable that it is changed considerably by the effect of propeller suction.

Type "S": -The flow pattern of very full ship form, where the separation is so stable that the state of flow is unaffected by the propeller suction.

The ordinary tanker models of 6-7 meters in length, having C_B of about 0.80 and L/B over 6.0, have usually the flow pattern of type "F", and the models in the same range of size with extremely blunt run of C_B over 0.83 and L/B below 6.0, have commonly that of type "S".

The previous studies have shown that the type of the flow can be distinguished experimentally in

* Nagasaki Technical Institute, Mitsubishi Heavy Industries, Ltd.
** Ship Research Institute.

the comparison of the effective wake obtained by ordinary self-propulsion test (w_m) with the effective wake obtained by the propeller test behind the model at zero propeller thrust (w_0). Namely, in the case of flow type "S", w_m nearly coincides with w_0 as in the case of flow type "N", but in the case of flow type "F", w_m is considerably smaller than w_0.

Furthermore, the nominal wake (w_n), obtained from the wake measurements at the propeller position is nearly equal to w_0, and the ratio of w_n to w_m gives a guidance in distinguishing the type of flow.

Consequently, in the case of the flow type "F", the thrust deduction factor derived from the self-propulsion test loses its common meaning originally defined for flow type "N".

The existence of the three types of flow in self-propelled condition naturally arouses a question how the type of flow at the stern of actual ship is. At present, however, there has been little known the state of flow around the stern of actual ship. From the studies by Taniguchi et al. etc[5)~8)]. it has been supposed that the flow type on actual ship would be "N" except the special one having an extremely blunt stern.

Thus the matter becomes very serious, because in the model test carried out with the hull form on which the flow type at the stern is "S" and "F", the flow field does not simulate that on the actual ship. In this case the thrust deduction factor measured is false and the wake fraction does not reflect on the true picture of the flow field around the stern. Moreover the resistance measured in the towed condition is also doubtful as to its scaling up.

These different types of flow have been observed through many model tests at the Nagasaki Experimental Tank. The repeated self-propulsion test on M. 1592 gives the following results. The flow pattern around the stern is changed by load condition. In 65% load condition, the states of flow type "S" or "F" are unstable and sometimes alternate with each other during a test run. Variation of propeller loading or propeller position effects a chang of the flow state.

From the above consideration, it was suggested that the geosim tests of M. 1592 would be useful for studying the effect of the model scale on the state of the flow or on the separation of flow at the stern of model.

Geosim tests of M. 1592, up to large model of 9 meters in length, were then planned and carried out as a joint study at the Ship Research Institute and the Nagasaki Experimental Tank.

2 Test Scheme and the Model Used

As mentioned before, the ship models used in the tests are geometrically similar to M. 1592. At the Nagasaki Experimental Tank many kinds of tests in regard to unstable phenomenon have been carried out with the model of 6 meters in length.

The principal items and the lines of model are shown in Table 1 and Fig. 1 respectively.

Four geosim models were tested. The two of them, M. 0111 and M. 0112 of 6 and 9 meters in

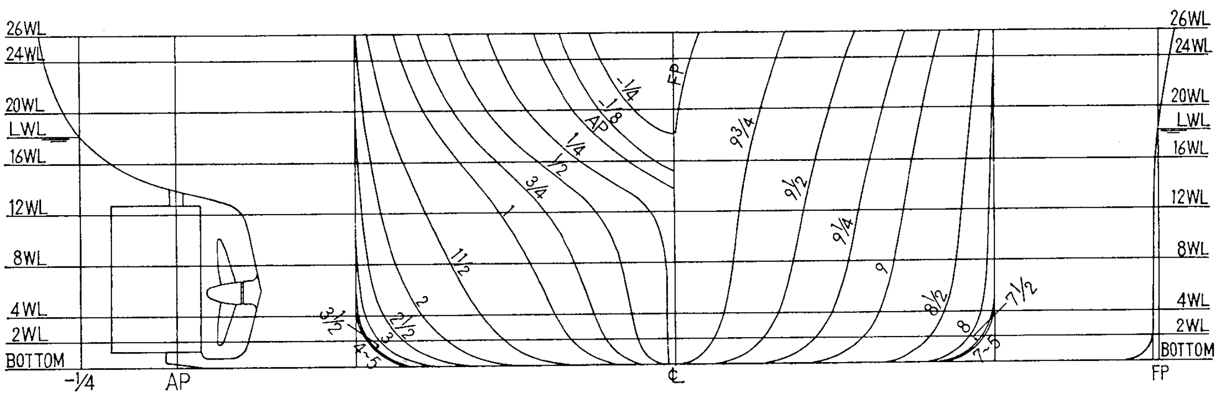

Fig. 1 Body Plant of Model

Table 1 Principal Items of Tests

Load Condition		Full Load Condition				65% Load Condition				44% Load Condition			
Model No.		M. 2043	M. 2023	M. 0111	M. 0112	M. 2043	M. 2023	M. 0111	M. 0112	M. 2043	M. 2023	M. 0111	M. 0112
L_{pp} (m)		2. 000	6. 000	6. 000	9. 000	4. 000	6. 000	6. 000	9. 000	4. 000	6. 000	6. 000	9. 000
Binc. skin (m)		0. 6667	1. 000	1. 000	1. 500	0. 6667	1. 000	1. 000	1. 500	0. 6667	1. 000	1. 000	1. 500
Draught	d_f					141. 80	212. 70	212. 70	319. 05	71. 87	107. 80	107. 80	161. 78
	d_m (mm)	241. 55	362. 32	362. 32	543. 48	161. 80	242. 70	242. 70	364. 05	111. 87	167. 80	167. 80	251. 78
	d_a					181. 80	272. 70	272. 70	409. 05	151. 87	227. 80	227. 80	341. 78
Trim (mm)		0	0	0	0	40. 00	60. 00	60. 00	90. 00	80. 00	120. 00	120. 00	180. 00
Displacement (kg)		516. 42	1742. 9	1743. 1	5883. 1	335. 73	1133. 1	1130. 1	3814. 1	127. 31	767. 16	757. 9	2558. 0
Wetted Suface Area (m^2)		3. 872	8. 711	8. 703	19. 583	3. 183	7. 162	7. 176	16. 167	2. 780	6. 257	6. 268	14. 103
Coefficient	C_m	0. 990				0. 986				0. 979			
	C_{bpp}	0. 802				0. 778				0. 762			
	C_{ppp}	0. 809				0. 789				0. 778			
B/d		2. 760				4. 120				5. 959			
Resistance Test Exp. Date		1970. 5. 18	1970. 4. 1	1970. 9. 16	1970. 9. 28	1970. (5. 19 / 6. 17)	1970. 3. 30	1970. 9. 17	1970. 9. 29	1970. (5. 20 / 6. 18)	1970. 4. 2	1970. 9. 17	1970. 9. 29
W. T.		17. 0	13. 7	23. 7	21. 7	(17. 2 / 18. 7)	13. 6	23. 7	21. 7	(17. 4 / 18. 8)	13. 7	23. 7	21. 7
Self-propulsion Test Exp. Date		1970. 5. 18	1970. 4. 1	1970. 9. 18	1970. 10. 2	1970. (1. 19 / 6. 17)	1970. (3. 30 / 3. 31)	1970. (9. 21 / 9. 24)	1970. (10. 1 / 10. 5)	1970. (5. 20 / 6. 18)	1970. 4. 2	1970. 9. 22	1970. 9. 30
W. T.		17. 0	13. 7	23. 5	21. 3	(17. 2 / 18. 7)	13. 6	22. 7	(21. 4 / 20. 7)	(17. 4 / 18. 8)	13. 7	23. 0	21. 7
Wake Measurement Exp. Date		1970. 6. 10	1970. 5. 21	1970. 9. 25	1970. 10. 8	1970. 6. 9	1970. 5. 22	1970. 9. 26	1970. 10. 9	1970. 6. 8	1970. 5. 23	1970. 9. 26	1970. 10. 12
W. T.		19. 8	17. 0	22. 5	20. 2	19. 6	17. 0	22. 5	20. 2	19. 4	17. 2	22. 5	20. 2

length respectively, were tested at the Ship Research Institute. Another two models, M. 2023 and M. 2043 of 6 and 4 meters in length respectively, were tested at the Nagasaki Experimental Tank. Resistance test, self-propulsion test and wake measurements at propeller center plane were carried out in the three load conditions, viz. full load, 65% load, and 44% load conditions were chosen for each model.

The resistance test and the self-propulsion test were carried out in accordance with the routine test method in each experimental tank. In addition to usual self-propulsion test, the effect of propeller loading on the flow pattern around the stern was examined by changing the propeller loading to a large extent from the model point of self-propulsion to nearly zero thrust. Besides these tests, self-propulsion tests with various propeller positions were also carried out in 65% load condition on 6 and 9 meter models, where the propeller was shifted aft and forward by 0.085 D of its standard position (C- and B-position, respectively ; D is the diameter of the propeller). The wake distributions were measured by a five hole pitot tube at both of the experimental tanks.

3 Tests Results

3.1 Resistance tests

To present the results of resistance test, we shall introduce the following non-dimensional expression.

$$C_t=C_v+C_w'=C_{fH}(1+k)+C_w' \qquad (1)$$

where

$C_t=R\Big/\frac{\rho}{2}v^2S$; total resistance coefficient

$C_v=R_v\Big/\frac{\rho}{2}v^2S$; viscous resistance coefficient

$C_w'=R_w\Big/\frac{\rho}{2}v^2S$; wave-making resistance coefficient

C_{fH} ; Hughes'basic frictional resistance coefficient.

k ; form factor.

Fig. 2 shows an example of the total resistance coefficients of the geosims in 65% load condition plotted on the basis of C_{fH}, after making the blockage correction[9]. In Fig. 2, $(1+k)$ is determined by the slope of $C_t \sim C_{fH}$ curves and C_w' by the ordinate at $C_{fH}=0$. The results of the tests in the range of low Froude numbers below 0.10 could not exclude the experimental errors perfectly, but the results in the range of Froude number over 0.10 give an almost constant value of form factor.

$(1+k)$ and C_w thus analyzed are plotted in Fig. 3 for every load condition. Those C_w curves are compared in Fig. 4 with the measured values of C_w derived from the following relations ;

$$C_w=\frac{S}{\nabla^{2/3}}C_w'=\frac{S}{\nabla^{2/3}}\{C_t-C_{fH}(1+k)\} \qquad (2)$$

In the figure, there are some fluctuations in measured values in the lower speed range, especially under full load condition. Except those points the analyzed C_w curves fit the measured points reasonably. It is then concluded that the relation (1) holds well and the analyzed C_w involves no scale effect.

In Fig. 3 the values of form factor in full

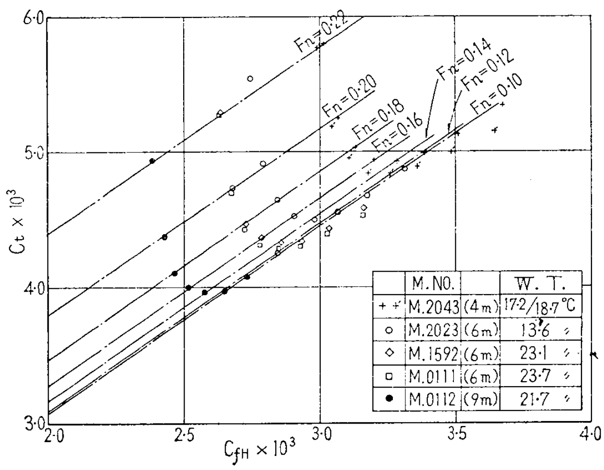

Fig. 2 Plot of C_t on the Basis of C_{fH} (65% Load Cond.)

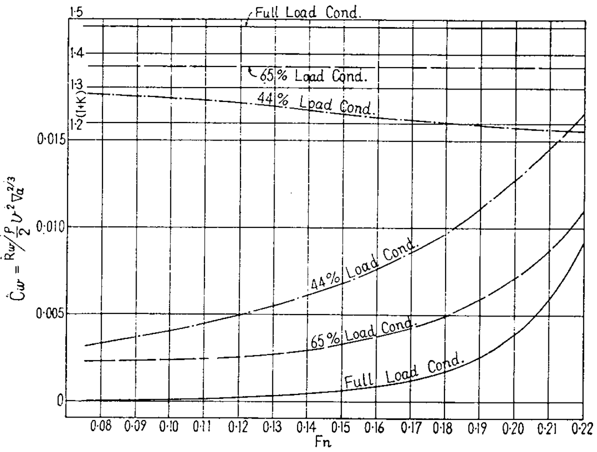

Fig. 3 Analyzed C_w and $(1+k)$

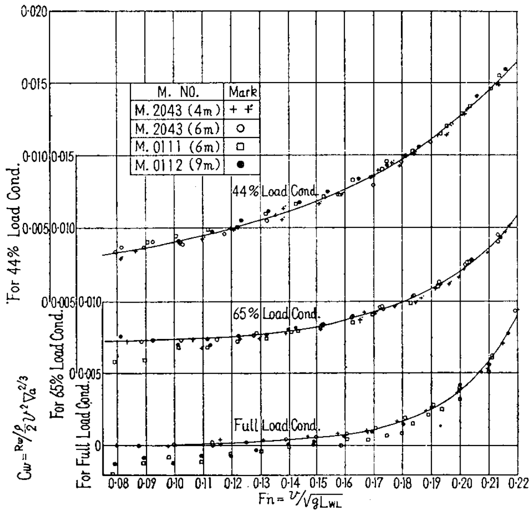

Fig. 4 Plot of Wave-making Resistance Coefficient

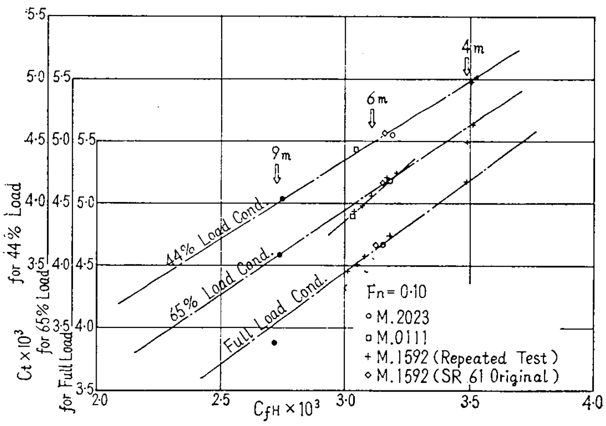

Fig. 5 Plot of C_t on the Basis of C_{fH}

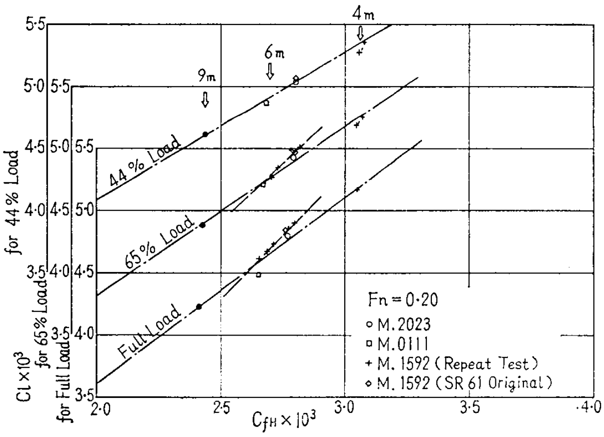

Fig. 6 Plot of C_t on the Basis of C_{fH}

load and 65% load conditions are almost constant, but in 44% load condition they show a slight decrease with increase of Froude number. It is also noticed in the figure that C_w at low Froude number in light condition is not zero. The non-zero C_w can be deduced theoretically as well for a ship form with remarkable blunt stem and raises a question about the Hughes method which assumes C_w being zero at very low Froude number.

Figs. 5 and 6 show another example of the total resistance coefficient of the geosims in three load conditions as Froude number 0.1 and 0.2 respectively, including the results of the repeated test of the 6 meter model M. 1592, plotted on the basis of C_{fH}.

It may be concluded that there is no remarkable difference in the scale effect of the viscouse resistance between of such full ship form, where the state of the flow around the stern is of type "S" or "F", and that of the ordinary full ship forms.

From these figures it appears that the variation of C_t against C_{fH} in geosim test is rather smaller than that of repeated tests except in full load condition at Froude number 0.1. The above tendency in the repeated tests agrees with the fact that the value of form factor decreases with the increase of water temperature. It may be suggested, however, that the effect of water temperature on viscous resistance has a diffrent quality to that of model scale on viscouse resistance for very full ship model.

3. 2 Self-Propulsion Tests

Fig. 7 shows the values of w_m, w_0 and w_n of the geosims plotted on the basis of C_{fH}. The spots marked with (●), (△) and (○) indicate the values of w_m, w_0 and w_n respectively, the meaning of which were mentioned before.

The relationship between the nominal wake (w_n) and the effective wake (w_n), shows a remarkable dependence on load condition.

In 65% load condition, the value of w_m for the standard position of propeller nearly coincides with the values of w_0 and w_n, while in the full load condition, the values of w_m are considerably smaller than those of w_0 and w_n.

In each load condition the values of w_0 and w_n nearly coincide with each other, in spite of the difference in the scale of the models. Moreover, the values of w_n and w_0 in three load conditions coincide rather well with each other, in spite of the considerable difference in the effective wake w_m.

The spots marked with (×) and (+) in 65% load condition indicate the effective wake obtained by the additional self-propulsion test with propeller position B and C. As mentioned before, in the full load condition, such small change of propeller position does not affect the results of self-propulsion tests and the spots are omitted.

At the propeller position C considerably smaller values of w_m are obtained than at the standard position, while the relation of w_m to w_0

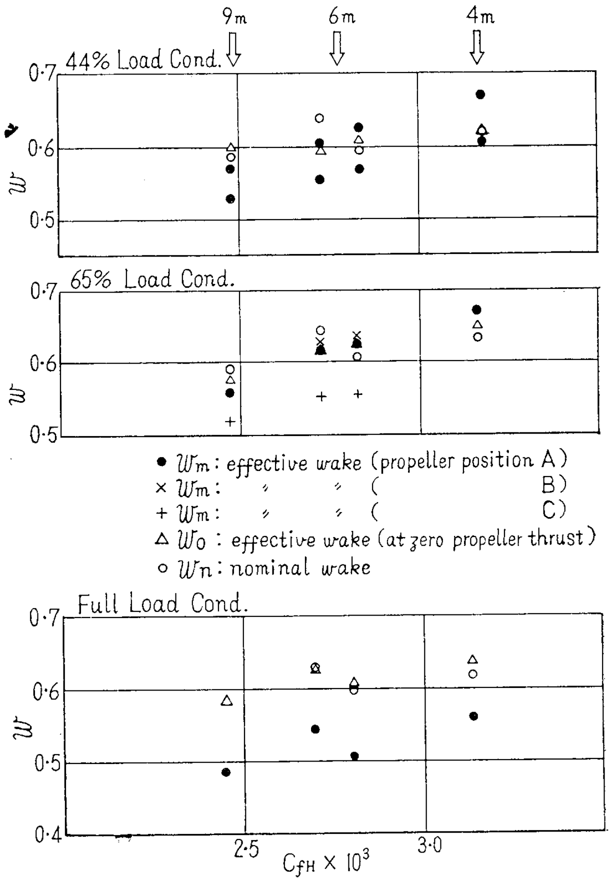

Fig. 7 Plot of Wake Fraction Factors on the Basis of C_{fH}

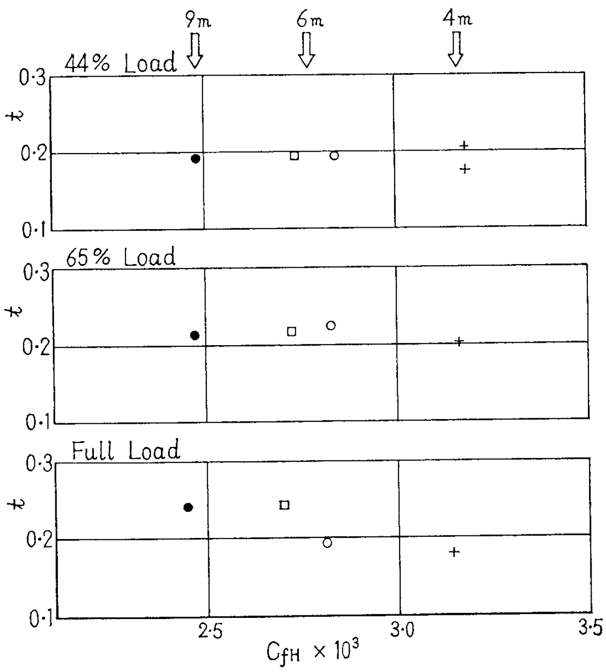

Fig. 8 Plot of t on the Basis of C_{fH}

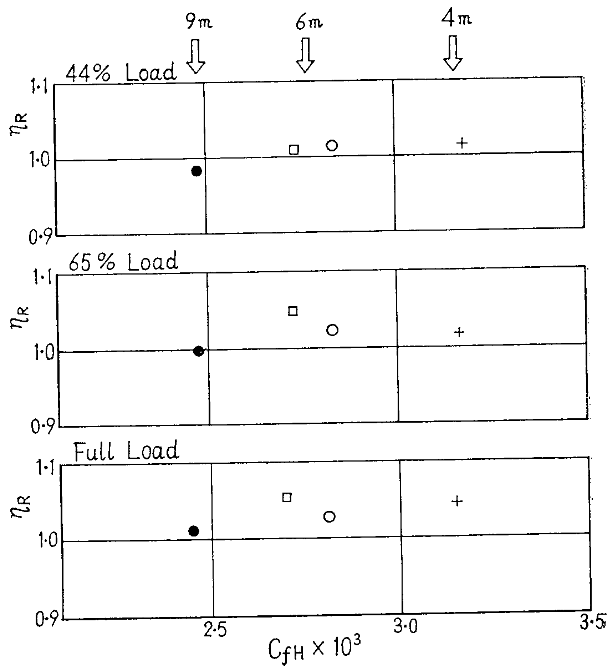

Fig. 9 Plot of η_R on the Basis of C_{fH}

or w_n becomes nearly the same as that in the full load condition.

On the other hand, at the propeller position B, the values of w_m scarcely differ from the values at the standard position of propeller, except of 9 meter model, on which there can be seen a linear relationship between w_m and the position of the propeller.

From these results of geosim tests, it may be concluded that the state of flow in full ship form, such as of type "F" or "S", depends on the ship form and that it is not affected by the scale of the model, in the range of the length of models from 4 to 9 meters.

Figs. 8 and 9 show the values of thrust deduction t and relative rotative efficiency η_R of the geosims plotted on the basis of C_{fH}.

As for t, no appreciable scale effect can be noticed except in the case of full load condition. As for η_R, no definite trend can be found but somewhat a similar tendency as in w_m may be noticed.

No remarkable trend of the scale effect in t and η_R on very full ship form will be found.

3.3 Wake Measurements

Figs. 10 and 11 show the comparison of the measured distribution of the axial component of wake and velocity vector projected to a section normal to model base line.

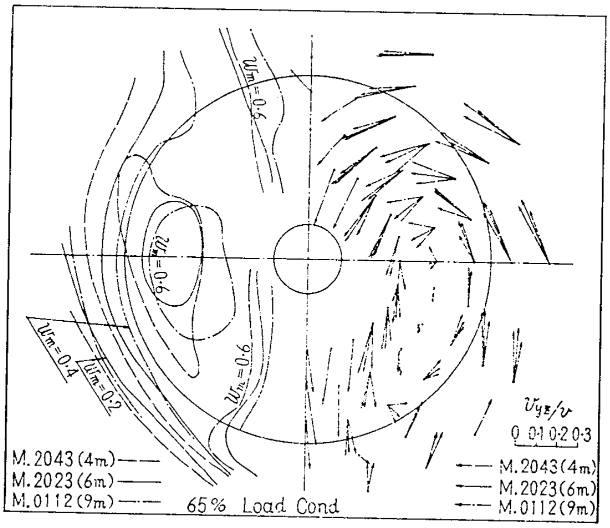

Fig. 10 Comparison of Flow Pattern at the Propeller Position

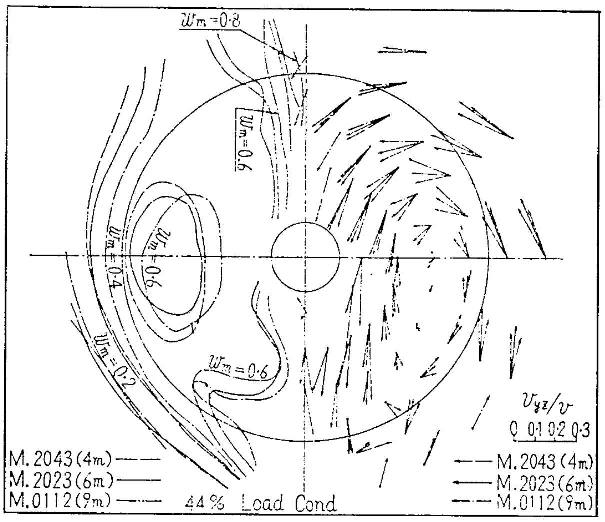

Fig. 11 Comparison of Flow Pattern at the Propeller Position

It appears that the contour curves of the wake fraction shift as a whole towards the model center plane with increasing model scale. Vortices are rather strong and their centers are situated at about 0.7 R of propeller disc slightly under the shaft center line.

There is no remarkable difference between the test results of wake measurement and that of the ordinary full ship form as described in ref. (10).

4 Conclusions

The geosim tests of a very full ship form, on which the flow type "S" is usually seen in 65% load condition, were carried out and following conclusions are obtained.

(1) The difference of the type of flow around the stern between in full load and in 65% load condition is clearly observed even on the 9 meter model by examining the relation of w_m to w_0 or w_n.

(2) The state of flow on the full ship form seems to depend only on the ship form and is not affected by the scale of model in the tested range from 4 to 9 meters in length.

(3) The scale effect of the viscous resistance of such full ship form makes no great difference from that of the ordinary full ship form in the range of model scale from 4 to 9 meters.

(4) It is suggested for very full ship model that the effect of water temperature on viscous resistance has a different quality from that of model scale on.

(5) It is important to make clear the scaling law for the state of flow pattern around the stern, but instructive information to deduce the state of flow at the stern of actual ship was not obtained from this geosim tests.

The study on the effect of the Reynolds number on the viscous resistance of the very full ship should be continued by the geosim tests including larger model than 9 meters or by the water tunnel test with a large model by increasing the water velocity as high as possible.

The authors with to thank the staff of the Ship Research Institute and the Nagasaki Experimental Tank for their cooperations.

References

1) Watanabe, K., "Unstable Phenomenon in the Self-Propulsive Test of Full Ship form Models". The Society of Naval Architects of Japan, Vol. 126, Dec., 1969.
2) Taniguchi, K. and Watanabe, K., "Unstable Phenomenon in the Self-Propulsion Test of Full Ship form Models"., 12th ITTC, Rome, 1969.
3) Taniguchi, K. and Tamura, K., "Study on the Flow Pattern around the Stern of Large Full Ship"., Mitsubishi Heavy Industries Technical Review, Vol. 8, No. 1, Feb., 1971.
4) Taniguchi, K., "Three Types of Flow Pattern at Stern of Ship Model"., Introductory Statement in Group Discussion at 12th ITTC, Rome, 1969.
5) Taniguchi, K. and Fujita, T., "Comparison of Velocity Distribution in the Boundary Layer of Ship and Model"., 12th, ITTC, Rome, 1969.
6) Taniguchi, K. and Fujita, T., "Comparison of Velocity Distribution in the Boundary Layer of Ship and Model"., The Society of Naval Architects of Japan, Vol. 127, June, 1970.
7) Kumai, T. et al., "Measurements of Boundary Layers of Ships, the First Report-Wakasugi Tests". Reports of Research Institute for Applied Mechanics, Kyushu University, No. 28, 1967.
8) Kumai, T. et al., "Measurements of Boundary Layers of Ships, the Second Report-Nansei Maru Tests". Reports of Research Institute for Applied Mechanics, Kjushu University, No. 28, 1967.
9) Taniguchi, K. and Tamura, K., "On the Blockage Effect"., Mitsubishi Experimental Tank Report, No. 307, Aug., 1958.
10) Taniguchi, K., "Study on Scale Effect of Propulsive Performance by Use of Geosims of a Tanker"., Mitsubishi Technical Bulletin, No. 39, 1966.