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Effect of Sinkage and Trim on Form Factor of Resistance

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Summary

In order to investigate the effect of sinkage and trim on form factor, resistance tests were conducted on two sets of geometrically similar models with keeping their trim and sinkage constant. The results of these experiments show that sinkage and trim have important effects on form factor of resistance and that form factor is nearly constant independent of ship's speed if the trim and sinkage in her runs were kept constant.

1. Introduction

Although Hughes[1] assumed that form factor of resistance was constant for a certain ship form independent of ship's speed, form factor varies certainly with ship's speed according to Cedric Ridgely-Nevitt[2] and the author.[3] Principal reason for the variation of form factor due to ship's speed or Froude No. is considered to be in the variation of trim and sinkage of a ship in her running.

In order to investigate the effect of trim and sinkage on form factor, resistance tests on similar models for both a tanker and an experiment boat "Musashino" were conducted with keeping their trim and sinkage constant during their runs.

Also, ordinary resistance tests were performed to be compared with the results above mentioned.

2. Models employed and test conditions

Two sets of geometrically similar models were made, one of which is a set of tanker models and the other of experiment boat models. The body plan and contours of the tanker model are shown in Fig. 1 together with the principal particulars of the prototype, and those of the experiment boat model in Fig. 2. Model no. and length are shown in Tables 1 and 2 for the tanker models and experiment boat models respectively.

Test conditions for both families of models are shown in Tables 3 and 4, respectively. Studs were used as turbulence stimulation for all the experiments.

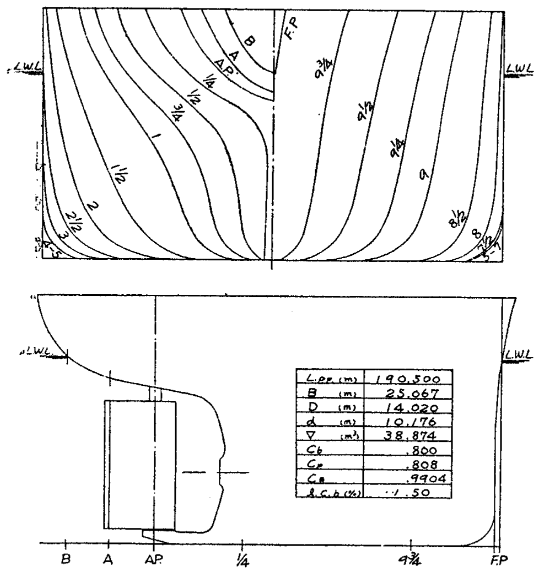

Fig. 1 Body Plan and Contours of the Tanker Model

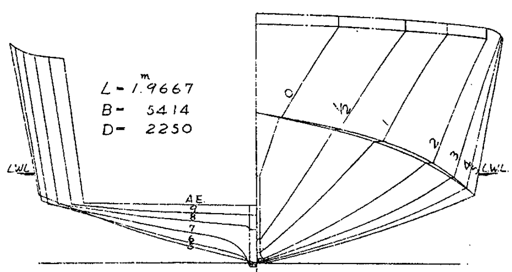

Fig. 2 Body Plan of the Experiment Boat Model

Table 1 Model No. and Length of The Tanker Models

M.S.No.	Length(m)	Scale Ratio
1319	4.50	1/42.33
1190	6.00	1/31.75

Table 2 Model No. and Length of The Experiment Boat Models

M.S.No.	Length(m)	Scale Ratio
1315	2.00	1/6
1316	4.00	1/3

Table 3 Test Conditions of the Tanker Models

M.S.No. 1319

Condition		I	II	III	IV	V	VI	VII	VIII
Trim, % of L_{WL}		0	−1%	−2%	+1%	0	−2%	0	−2%
	A.P.		.2182	.1954	.2631		.2071		.2190
Draft(m)	M.S.	.2404	.2407	.2404	.2406	.2516	.2521	.2628	.2640
	F.P.		.2632	.2854	.2181		.2971		.3090
Displacement(m³)		.5124				.5398		.5670	
Wetted Surface(m²)		4.131	4.104	4.079	4.148	4.242	4.193	4.355	4.309

M.S.No. 1190

Condition		I	II	III	IV	V	VI	VII	VIII
Trim, % of L_{WL}		0	−1%	−2%	+1%	0	−2%	0	−2%
	A.P.		.2910	.2605	.3508		.2762		.2920
Draft(m)	M.S.	.3205	.3210	.3205	.3208	.3355	.3362	.3505	.3520
	F.P.		.3510	.3805	.2908		.3962		.4120
Displacement(m³)		1.2146				1.2795		1.3440	
Wetted Surface(m²)		7.264	7.214	7.170	7.292	7.458	7.372	7.658	7.578

Remarks; 1) Positive and negative trims mean trim by the stern and stem respectively
2) Condition I corresponds to the designed condition.

Table 4 Test Conditions of the Experiment Boat Models

M.S.No. 1315

Condition		I	II	III	IV	V	VI	VII	VIII
Trimangle		0	1°57′	3°33′	−1°33′	0	1°57′	3°33′	−1°33′
	A.E.		.1307	.1531	.0782		.1574	.1809	.1035
Draft(m)	M.S.	.1027	.0977	.0931	.1042	.1277	.1244	.1209	.1295
	F.P.		.0647	.0331	.1302		.0914	.0609	.1555
Displacement(m³)		.04396				.06499			
Wetted Surface(m²)		.9230	.9036	.8870	.9342	1.0472	1.0250	.9896	1.0528

M.S.No. 1316

Condition		I	II	III	IV	V	VI	VII	VIII
Trim Angle		0	1°57′	3°33′	−1°33′	0	1°57′	3°33′	−1°33′
	A.E,		.2614	.3062	.1564		.3148	.3618	.2070
Draft(m)	M.S.	.2054	,1954	.1862	.2084	.2554	.2488	.2418	.2590
	F.P.		.1294	.0662	.2604		.1828	.1218	.3110
Displacement(m³)		.35168				.51990			
Wetted Surface(m²)		3.692	3.614	3.548	3.737	4.189	4.100	3.958	4.211

Remarks; 1) Positive and negative trims mean trim by the stern and stem respectively
2) Condition I corresponds to the designed condition.

3. Resistance experiments under the condition sinkage and trim kept constant

Resistance tests on the tanker models were conducted under the eight conditions as shown in Table 3. Total resistance coefficients c_t are shown in Figs. 3 and 4. Where, as the wetted surface area to calculate c_t for all the conditions is used S_0, wetted surface area of Condition I. Values of c_t below $F=.14$ are very scattered, which shows that values of form factor obtained by Hughes' method are likely to contain considerable amounts of errors.

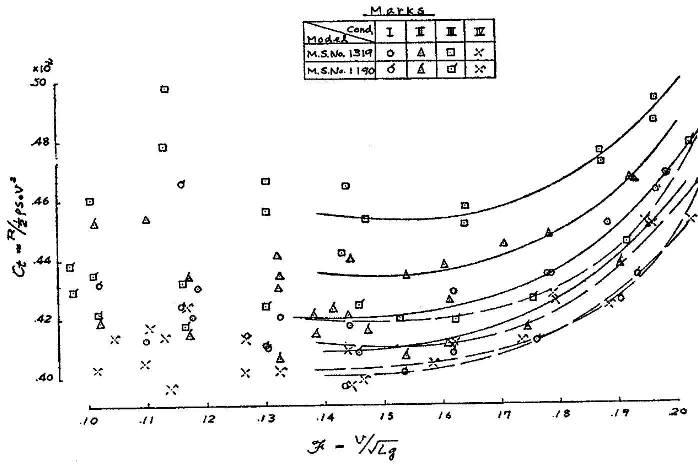

Fig. 3 Total Resistance Coefficients of the Tanker Models at the Designed Draft

Resistance tests on the experiment boat models were performed under the eight conditions as shown in Table 4, in two ranges of model speed. Test results are shown, in a form of c_t, in Figs 5,6,7 and 8. Figs 7 and 8 express very peculiar aspect that c_t of the bigger model is larger than that of the smaller model except the condition under which the models have the largest positive trim. Since the blockage effect will be negligible even for the largest model at the increased draft, this phenomena are considered to be based upon the seperation of the flow around the model. Different from the ordinary resistance tests at which all the motions in the vertical plane are free, such kinds of tests as trim and sinkage are kept constant during ship's running restrict the ship's motion, and therefore seperation is likely to take place. Under the condition, where seperation takes place, seperation field must be increased with the increase of Reynolds No. Since the more seperation gives the greater resistance, c_t of the bigger model could be larger than that of the smaller model.

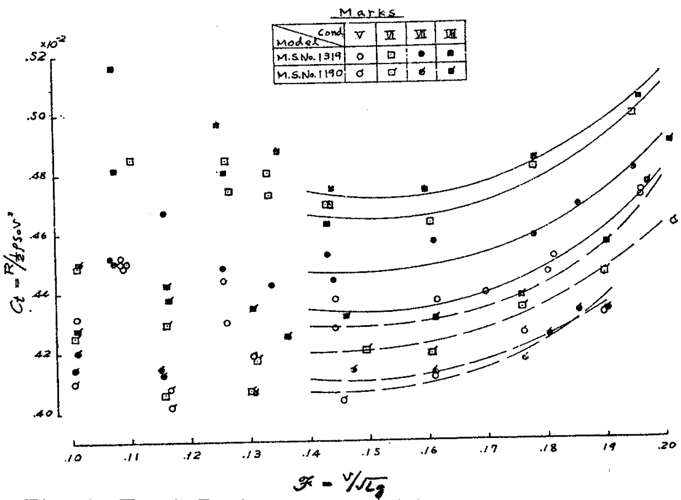

Fig. 4 Total Resistance Coefficients of the Tanker Models at the Increased Drafts

4. Form factors in various conditions

Form factors at various Froude No. are obtained by using the test results abovementioned and the method given in the paper "Scale Effect Experiments on Some Ship Forms". $(1+k)$ is shown in Figs. 9,10 and 11. From these figures it will be seen that form factor is nearly constant independent of Froude No. or ship's speed. Although Figs. 10 and 11 in the previous paper show that form factor varies remarkably with Froude No., it will now be understood that variation of form factor is not based upon ship's speed itself but upon variation of trim and sinkage of a ship due to change of ship's speed. As is supposed easily from the results of resistance experiments, almost all the values of $(1+k)$ in the higher speed range of the experiment boat models are negative. Figs. 12 and 13 were obtained

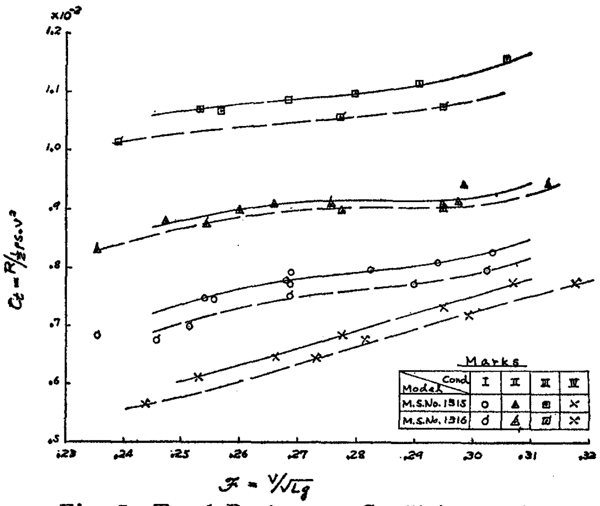

Fig. 5 Total Resistance Coefficients of the Experiment Boat Models at the Designed Draft in the Lower speed Range

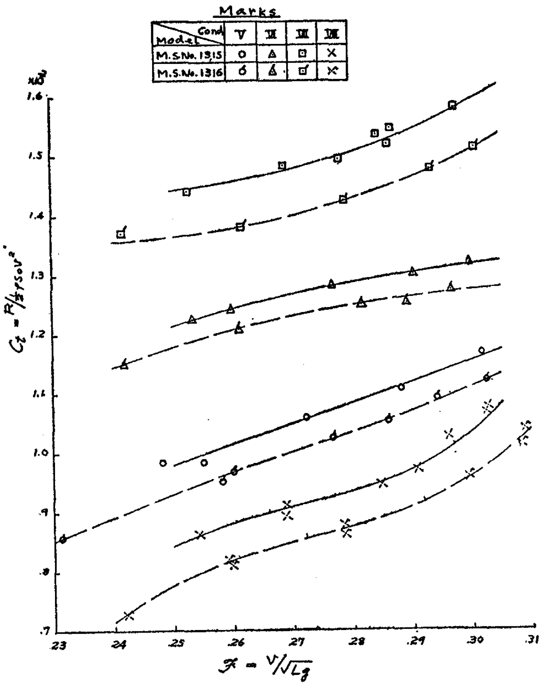

Fig. 6 Total Resistance Coefficient of the Experiment Boat Models at the Increased Draft in the Lower Speed Range

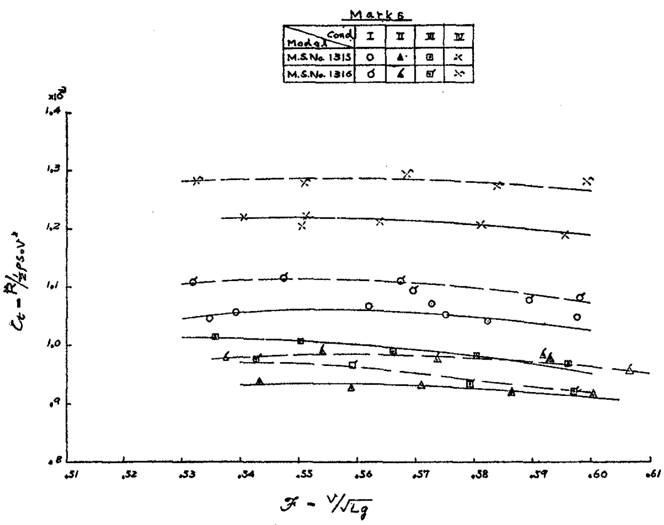

Fig. 7 Total resistance Coefficients of the Experiment Boat Models at the Designed Draft in the Higher Speed Range

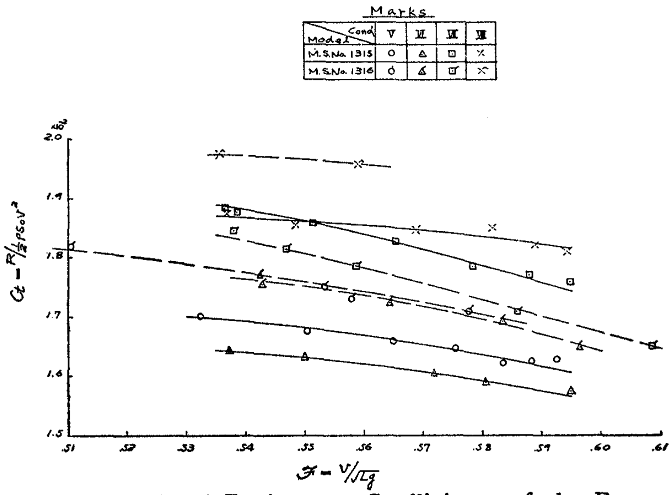

Fig. 8 Total Resistance Coefficients of the Experiment Boat Models at the Increased Draft in the Higher Speed Range

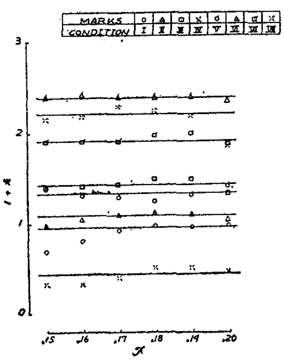

Fig. 9 Form Factors of the Tanker

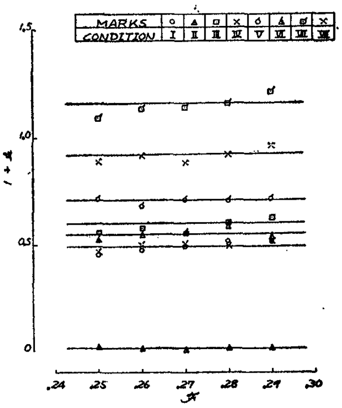

Fig. 10 Form Factors of the Experiment Boat (Lower speed Range)

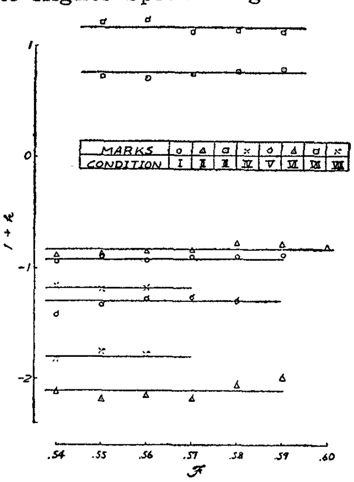

Fig. 11 Form Factors of the Experiment Boat (Higher Speed Range)

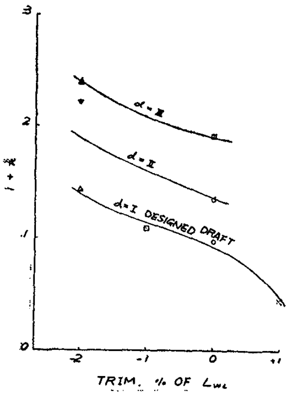

Fig. 12 Effect of Trim and Sinkage on Form Factor (Oil Tanker)

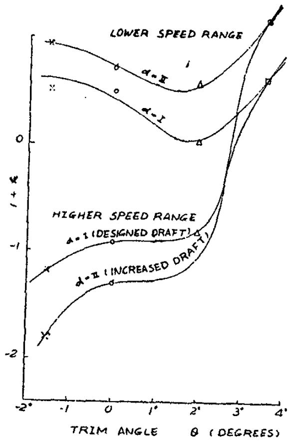

Fig. 13 Effect of Trim and Sinkage on Form Factor (Experiment)

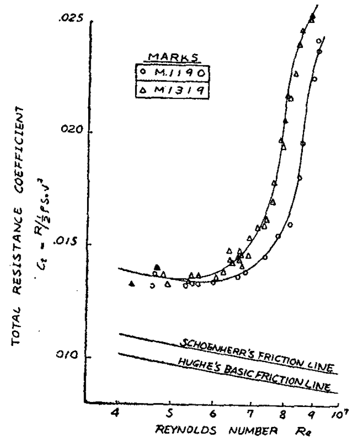

Fig. 14 Total Resistance Coefficients of the Oil Tanker Models

from Figs 9, 10 and 11. These figures give a better idea of the effect of sinkage and trim on form factor. The fact that $(1+k)$ of the experiment boat Models in the higher speed range coincides well with that in tne lower speed range at about 3.5 degrees of trim angle suggests that there will not be any seperation in this range of trim.

5. Results of the ordinary resistance experiments

The ordinary resistance experiments were carried out under the condition I for the both similar models of the tanker and experiment boat. In these tests, trim, sinkage and wetted surface area were measured.

Total resistance coefficients of the tanker models are shown in Fig. 14. Trim angle θ, sinkage

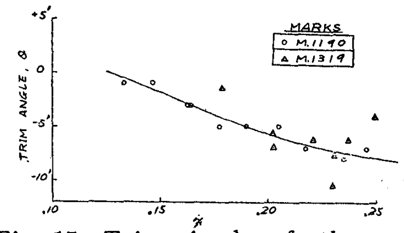

Fig. 15 Trim Angle of the Tanker Models in Their Runs

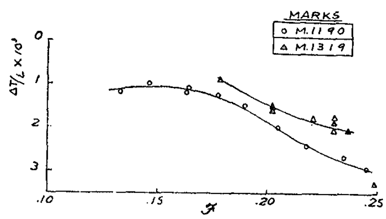

Fig. 16 Sinkage of the Tanker Models in Their Runs

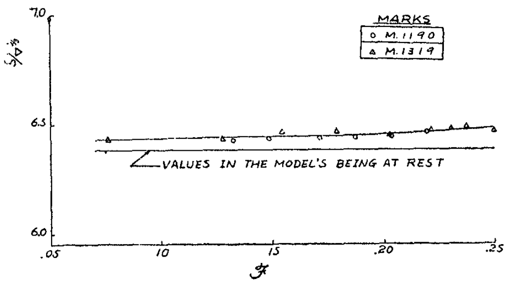

Fig. 17 Wetted surface Area of the Tanker Models in Their Run

parameter $\Delta T/L$ and wetted surface parameter $'S/\nabla^{2/3}$ of the tanker models in their runs are shown in Figs. 15, 16 and 17 respectively. Since the data for Model 1319 in Figs. 15 and 16 were measured by the trim recorder for the tests in waves, accuracy is comparatively lower than the values for Model 1190. Taking the agreement of the results between Model 1190 and 1319 in Figs. 15 and 17 into consideration, the results in Fig. 16 should also be coincided with each other. Therefore, for such a low speed ship as an oil tanker, sinkage, trim and wetted surface area of the similar models must be the same independent of model size. Fig. 18 is given as another proof for this idea. Wave profile of the actual ship is not the same as that of the model, but wetted surface area shows a good coincidence between the ship and model as shown in the table in this figure.

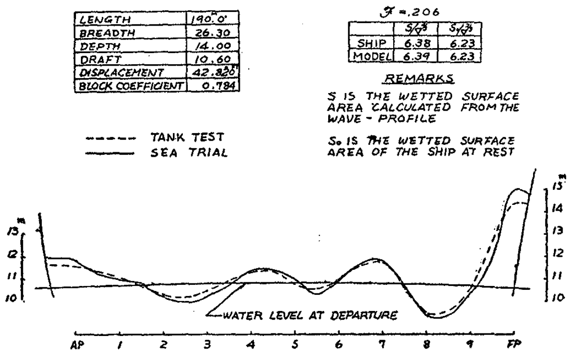

Fig. 18 (a) Comparison of WaveProfiles between Ship and Model

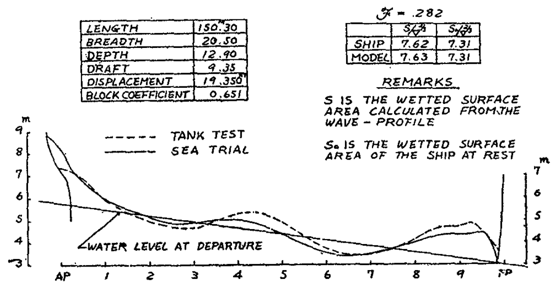

Fig. 18 (b) Comparison of Wave Profiles between Ship and Model

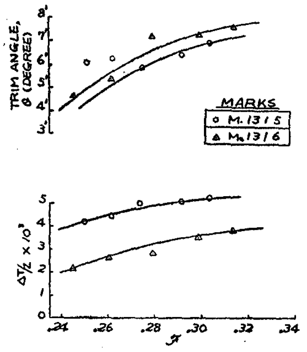

Fig. 19 Trim Angle and Sinkage of the Experiment Boat Models in the Lower Speed Range

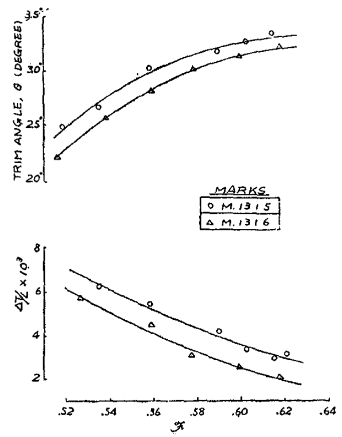

Fig. 20 Trim Angle and Sinkage of the Experiment Boat Models in the Higher speed Range

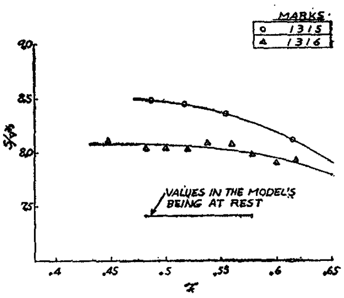

Fig. 21 Wetted Surface Area of the Experiment Boat Models in Their Runs

Trim angle θ, sinkage parameter $\varDelta T/L$ and wetted surface area parameter $S/\nabla^{2/3}$ of the experiment boat models in their runs are shown in Figs. 19, 20 and 21. Different from the results for the oil tanker models, the values of sinkage, trim and wetted surface area do not coincide with between the similar models. Trim angle in the lower speed range can be considered to be the same between the similar models, but except it values of the smaller model are greater than those of larger model. In a case where blockage effect exists, sinkage of the larger model must be greater. The results of these experiments for the experiment boat models show the opposite tendency. Since the test results on the patrol boat models given in the previous paper show the same tendency as the results of the experiment boat models concerning sinkage and trim in models' runs, for such a kind of hull form, sinkage and trim of the smaller model must be larger than those of the larger model, although its reason is not clear. In a hull form as a hydroplane, the larger model gives greater sinkage, trim and wetted surface area (ref. 2 and 3). This fact and the tendency of the difference of the wetted surface area curves between the larger and smaller models, shown in Fig. 21, decreasing with the increase of Froude No., suggest that there must be a cross point between the wetted surface area curves of the similar models at a certain Froude No. In other words, below a certain Froude No. sinkage, trim and wetted surface area of the larger model are less than those of the smaller model, and over that Froude No. those values of the larger model are greater than those of the smaller model.

6. Comparison of the form factors obtained from the free running experiments with those calculated from the results of the draft-fixed experiments

Using the values of sinkage and trim of the models in their runs and the cross curves of the total resistance coefficients obtained in Section 3, total resistance coefficient for a given sinkage and trim

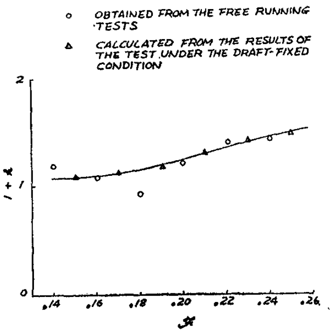

Fig. 22 Comparisons of Form Factors of Tanker Models

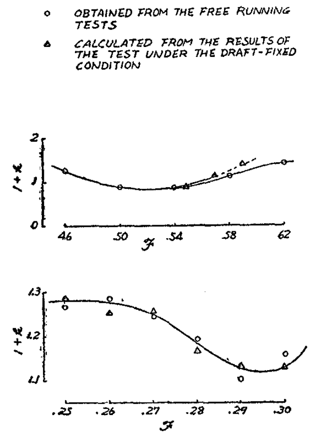

Fig. 22 Comparison of the Form Factors of the Experiment Boat Models

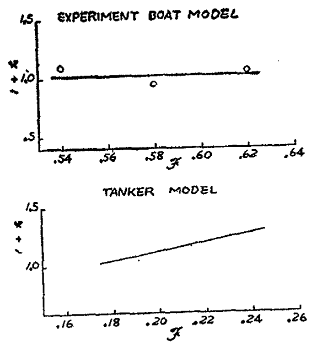

Fig. 24 Form Factors Corrected to Sinkage Trim and Wetted Surface Area

will be obtained for any Froude No., and therefore $(1+k)$ will be calculated for various Froude No. Their results of calculations are shown in Figs. 22 and 23 for the tanker and experiment boat models, together with $(1+k)$ calculated from the results of the free running resistance tests. Both $(1+k)$ obtained from the different sources show a rather good agreement. This implies that both kinds of experiments were performed without a great error, and it may be considered that all the results given here must be relied upon.

7. Effect of sinkage on the form factor

If we use the wetted surface area S_0 of the model at rest for the calculation of the total resistance coefficient c_t, c_t will be expressed by $R/\frac{1}{2}\rho S_0 v^2$. Adding indexes 1 and 2 to c_t and c_f for the smaller and larger models respectively $(1+k)$ is calculated by the following formula ;

$$(1+k)=(c_{t1}-c_{t2})/(c_{f1}-c_{f2})$$

If we use the wetted surface area S changed owing to the model's run instead of S_0,

$$c_t'=R/\frac{1}{2}\rho S v^2$$

This c_t' gives a different value of form factor k'.

$$(1+k')=(c_{t1}'-c_{t2}')/(c_{f1}-c_{f2})$$

Variation of the form factor due to wetted surface area is easily introduced as follows. Expressing $S=S_0(1+x)$,

$$\frac{1+k'}{1+k}=\frac{c_{t1}'-c_{t2}'}{c_{f1}-c_{f2}}\bigg/\frac{c_{t1}-c_{t2}}{c_{f1}-c_{f2}}=1/(1+x)$$

or

$$(1+k)=(1+x)(1+k')$$

If the actual wetted surface area should be used for the calculation of c_t, $(1+k)$ obtained using the wetted surface area of the model at rest will give higher values by x.

On the other hand, when a model runs, the model and water surface around the model sink, which makes water speed around the model increased. Approximate mean values of the increased water speed around the model are given by the following formula[4].

$$v_m=\sqrt{v^2+2g\Delta T}$$

where, v is advance speed of the model and ΔT sinkage of the model.

If the mean water speed was used for the calculation of c_t instead of advance speed v, form factor will have a different value. Denoting the form factor calculated using v_m by k'',

$$(1+k'')=(c_{t1}''-c_{t2}'')/(c_{f1}-c_{f2})=(1+k)v^2/v_m^2$$

Introducing $v_m=v(1+y)$,

$$(1+k'')=(1+k)/(1+y)^2$$

If both variation of wetted surface and increased water speed around the model due to model's sinking are taken into consideration, denoting the new form factor by k''',

$$(1+k''')=(1+k)/(1+x)(1+y)^2$$

It is probable that $(1+k''')$ will be constant independent of Froude No. or Reynolds No. If $(1+k'')$ is assumed to be constant, apparent form factor $(1+k)$ varies proportional to $(1+x)(1+y)^2$.

Fig. 24 shows the form factor corrected to wetted surface, trim and water speed increased due to the ship's sinkage. Form factor of the experiment boat is nearly constant independent of Froude No., but that of the tanker still varies with Froude No. The formula to calculate v_m was obtained, considering only the water speed around the bottom and neglecting that around the side. So, v_m for the tanker model must contain a considearble amount of error.

8. Conclusions

Form factor varies with Froude No. as shown in Fig. 22 and 23. The cause for the variation of form factor, however, is not Froude No. or ship's speed itself, but change of trim and sinkage of a ship due to change of ship's speed.

In order to estimate exactly the resistance of an actual ship, effect of trim and sinkage of the ship in her runs on form factor must be taken into consideration. To do this, resistance tests on the geometrically similar models or at least resistance tests at low Froude No. on the model with several kinds of trim and sinkage must be conducted.

9. Acknowledgement

The author wishes to express his thanks to Kawasaki Heavy Industries Co., Ltd. for the kind supply with valuable data of the wave profiles of the actual ships, and to Mr. Okumoto for his assistance to calculate all the data of this report.

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