Repeated Self Propulsion Test on a Tanker Model

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Summary

In Mitsubishi Experimental Tank (Nagasaki), investigations have been made into the repeatability of self-propulsion tests on full ship forms by repeating the resistance tests, the self-propulsion tests and the propeller open-water tests for a 7m wooden model of a typical tanker.

The self-propulsion factors deduced properly from the self-propulsion tests are scarcely affected by water temperature, and the standard deviations of the self-propulsion factors from their mean values are about 0.006 for e_r, about 0.005 for w_m and about 0.01 for t, and the estimated standard deviation of SHP of the actual ship due to the dispersion of the self-populsion factors is about 1.5%.

1. Introduction

Along with the progress in the tank test technique and facilities, the accuracy and the reliability of the tank test results have been improved. The prediction of the propulsive performance of actual ships is, however, dependent on the accuracy and the reliability of each propulsive element—resistance, self-propulsion factors, characteristics of propeller and model-ship correlation method.

In Mitsubishi Experimental Tank (Nagasaki) investigations have been made into the repeatability of self-propulsion tests on full ship forms, by repeating the resistance tests, the self-propulsion tests and the propeller open-water tests for a 7m wooden model of a typical tanker.

The self-propulsion tests were repeated 21 times, and the propeller open-water tests were repeated 14 times, for the period of a year. The results of these tests were reduced to the self-propulsion factors, and the dispersion of these factors were investigated.

2. Model and test procedure

2.1 Models

The particulars of the ship model used for the repeated tests and those of the corresponding actual ship (45,000 DWT tanker) are given in Table 1. All the tests were carried out for the same condition (the same displacement and trim) corresponding to the full load condition of the actual ship.

The propeller model is geometrically similar to the actual propeller and its particulars are given in Table 2.

2.2 Schedule of the test

At first we intended to caarry out the tests (self-propulsion tests, resistance tests and propeller open-water tests) with the interval of about 2 weeks in the period of a year. But on account of the tight schedule of the tank experiments the tests could not be carried out as had been planned, and we conducted 21 self-propulsion tests and resistance tests and 14 propeller open-water tests in the period from July 1964 to August 1965.

The dates and the water temperatures of the tests are presented in Table 3.

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Table 1 Particulars of Model Ship and Actual Ship

	Model Ship	Actual Ship
L_{PP}	7.000m	213.0m
L_{WL}	7.142m	217.3m
B	1004.5mm (inc. skin)	30.50m (mld)
d	373.0mm (inc. skin)	11.32m (from BL)
Δa	2095kg	60.500t
Sa	10.38m^2	9,612m^2
C_{bpp}	0.7984	
C_{ppp}	0.8050	
C_m	0.9918	
C_{Bpp}	48.265%	

Table 2 Particulars of Model Propeller (p. 1281)

Diameter	216.9mm
Pitch	159.4mm
Pitch Ratio	0.7348
Boss Ratio	0.1818
Expanded Area/Disc Area	0.5600
Thickness-Chord ratio (0.7R)	0.0737
Number of Blades	5
Blade Section	Aerofoil

Table 3 List of the Self-Propulsion Tests and the Propeller Open-Water Tests

Self-Propulsion Test				Propeller Open-Water Test				
Test No.	Date of Experiment	No. of Measuring Run	Water Temperature	Test No.	Date of Experiment	Water Temperature	$\frac{nD^2}{\nu}$	$Re\ (K)$
1	1964- 7-13	19	20.1 °C	1	1964- 7-10	19.7 °C	4.65×10^5	2.57×10^5
2	,, 7-25	14	20.3	2	,, 7-23	21.0	4.81 ,,	2.65 ,,
3	,, 8-10	15	23.2	3	,, 8- 4	21.8	4.89 ,,	2.70 ,,
4	,, 8-22	14	24.6	4	,, 8-24	25.1	5.28 ,,	2.91 ,,
5	,, 9- 4	16	26.1	5	,, 9- 7	26.6	5.47 ,,	3.02 ,,
6	,, 9-17	15	26.3					
7	,, 10- 3	17	22.9	6	,, 10- 6	22.9	5.06 ,,	2.79 ,,
8	,, 10-20	16	21.6					
9	,, 11- 6	16	20.0	7	,, 11- 5	20.1	4.70 ,,	2.59 ,,
10	,, 11-22	16	17.9					
11	,, 12- 7	17	16.6	8	,, 11-24	17.2	4.37 ,,	2.41 ,,
12	,, 12-16	17	15.6	9	,, 12-12	15.8	4.22 ,,	2.33 ,,
13	1965- 1-.5	15	14.8					
14	,, 1-21	17	13.2					
15	,, 3-24	15	12.6	10	1965- 3- 9	12.1	3.82 ,,	2.11 ,,
16	,, 4- 3	16	12.6	11	,, 4- 6	12.4	3.85 ,,	2.13 ,,
17	,, 5- 7	15	14.8	12	,, 4-29	14.1	4.03 ,,	2.23 ,,
18	,, 5-26	16	17.7	13	,, 5-18	16.4	4.28 ,,	2.36 ,,
19	,, 6-22	10	19.6					
20	,, 7-31	15	25.6	14	,, 8- 3	25.4	5.32 ,,	2.93 ,,
21	,, 8-19	15	25.8					

(1) To analyze a self-propulsion test, the result of the propeller-water test on the same line was used.
(2) $Re\ (K) = (C_{0.7}/\nu)\ \sqrt{V^2+(0.7\pi nD)^2}$
where V is the speed of advance of propeller at 30% of slip ratio

2.3 Test method

The tests and the analysis of the test results were conducted in accordance with the standard procedure of our experimental tank. Our practice of the self-propulsion tests is summarized as follows:

(1) The resistance tests and the self-propulsion tests are carried out on the same day for the same displacement and trim.

(2) The water speed is measured by a current meter which is mounted on the towing carriage about a ship length forward of the fore end of the model. The current meter is calibrated before and after the tests every day.

(3) The self-propulsion tests are conducted at the "ship point". The skin friction correction is calculated from the difference of the frictional resistance coefficients of the ship model and actual ship. The frictional resistance coefficients are given by

$$C_{fm}=\frac{0.455}{\left(\log\dfrac{vL_{WLm}}{\nu_m}\right)^{2.58}}$$

$$C_{fs}=\frac{0.490}{\left(\log\dfrac{vL_{WLs}}{\nu_s}\right)^{2.58}}$$

(Suffixes m and s refer to model and actual ship, respectively)

where 0.490 is an empirical factor adopted in our experimental tank and does not necessarily agree with the factor to be used for the actual powering-calculation of an individual ship (The reason is described in 4).

3. Analysis of the results of self-propulsion tests

The results of the self-propulsion tests were reduced to the self-propulsion factors—relative rotative efficiency e_r, wake fraction w_m and thrust deduction fraction t.

In the course of the analysis the open-water characteristics of propeller are needed. They were obtained from the results of the open-water tests carried out on the nearest date to the self-propulsion tests. The number of revolutions of the propeller was 10 rps, which corresponds to the number of revolutions at the design speed.

w_m and e_r were obtained on the basis of the thrust identity method. t was calculated by the following formula

$$t=\frac{T+SFC-R}{T}$$

where T is the thrust of the propeller,

R is the resistance obtained from the resistance test at the same load condition and the same speed, and

SFC is the towing force called the skin friction correction.

4. Method of estimating DHP of actual ship

In estimating DHP of an actual ship, we do not scale up directly the DHP of the model measured in the self-propulsion tests, but it is our practice to calculate DHP of the ship, as described in detail in ref. (2), based on EHP and the self-propulsion factors of the actual ship which can be estimated from the results of the resistance tests and the self-propulsion tests respectively. The purpose of the self-propulsion tests in our experimental tank is, therefore, to obtain the self-propulsion factors as analyzed from the test results. For this purpose the accuracy of SFC is not a substantial problem, because, as recognized in general, the propeller loading affects scarcely the self-propulsion factors.

According to our practice, EHP of such a full ship form is estimated by the method of Hughes, which has been proved to be reasonable method by the systematic investigation on the geosim models[1].

5. Effects of water temperature

The variation of the water temperature through the repeated tests was considered as one of the causes of the dispersion of the test results. So the effect of the water temerature on the test results was investigated first.

The power coefficient k_p and the residual resistance coefficient C_{ra} decrease with the increase of the water temperature as shown in Figs. 1 and 2. With the increase of 14°C in water temperature the power coefficient k_p decreases by 3% and the total resistance of the model decreases by 1.5–2.0%.

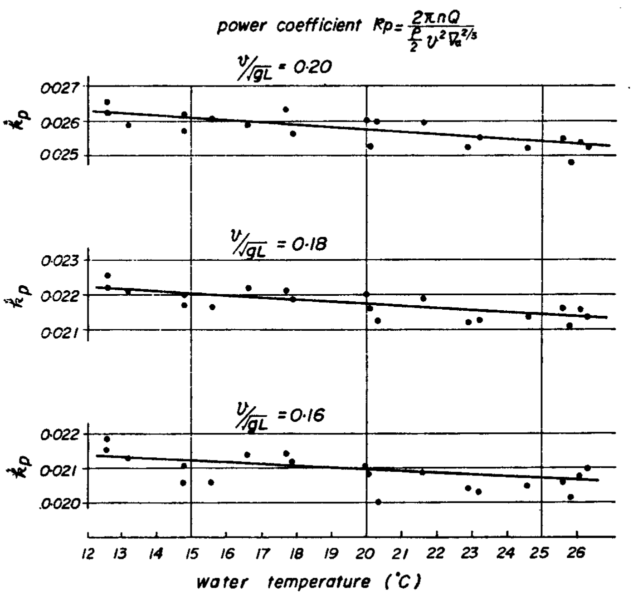


Fig. 1. Effect of water temperature on power coefficient.

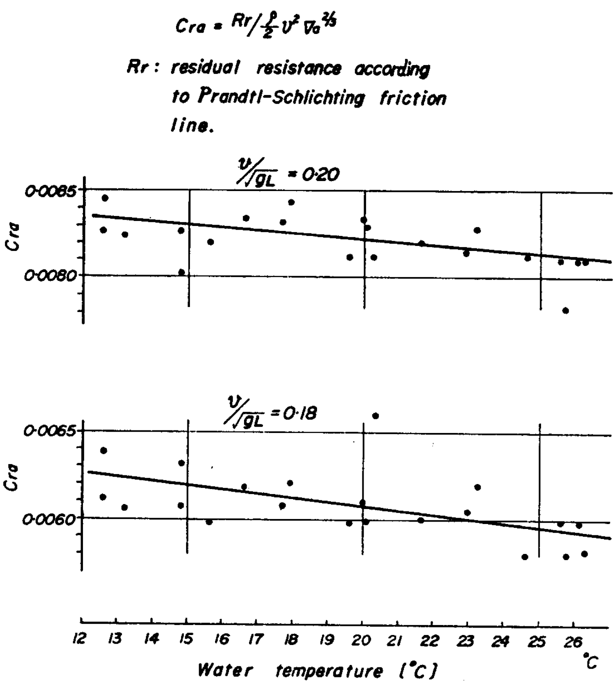


Fig. 2. Effect of water temperature on C_{ra}.

The effect of water temperature on propeller open-water characteristics is shown in Fig. 3. These characteristics are obtained from the open-water tests carried out with 10rps, so that Reynolds number nD^2/ν varies between 3.8×10^5 and 5.4×10^5 with the variation of water temperature between 12°C and 26°C. For this range of variation, e_p changes by about 2% (in relative percentage), K_T about 1% and K_Q about 2%.

The variation of power coefficient k_p with water temperature may be explained as the sum of the variation of the residual resistance coefficient and the variation of the propeller efficiency.

It is to be noted that, in contrast with the variation of the power coefficient and the residual resistance coefficient, the self-propulsion factors are scarcely affected by water temperature (Fig. 4). From such results, it is presumed that the effect of the water temperature on the characteristics of propeller under self-propulsion condition is almost the same as the effect on the propeller open-water characteristics. It will be reasonable, therefore, to use the propeller open-water characteristics obtained by the propeller open-water test carried out on the possible nearest date of the self-propulsion test to deduce the self-propulsion factors from the results of the self-propulsion test.

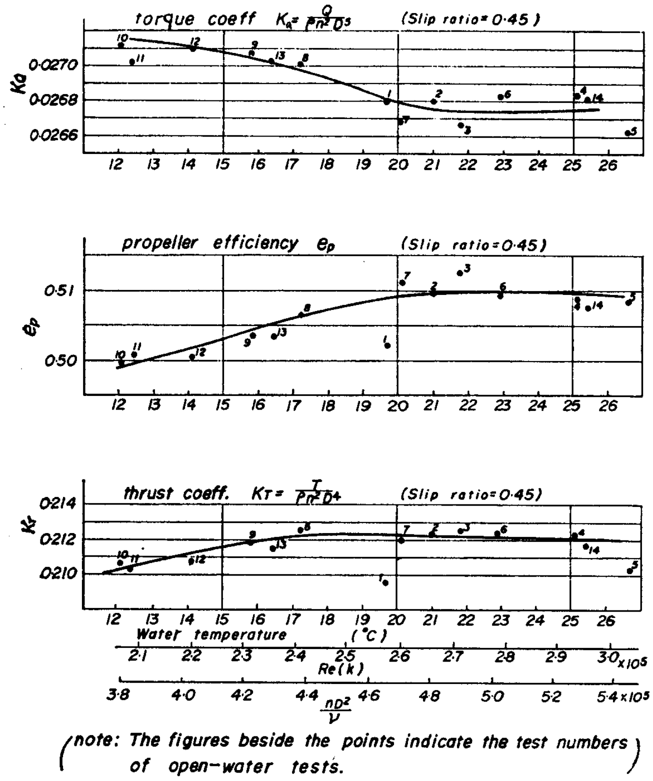


Fig. 3. Effect of water temperature on open-water characteristics of propeller

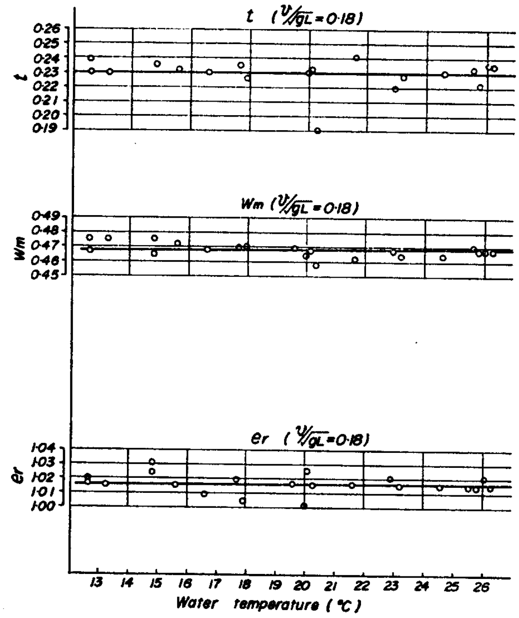


Fig. 4. Effect of water temperature on the self-propulsion factors

6. Scatter of the self-propulsion factors

Each self-propulsion test consisted of 15 to 20 measuring runs covering the range of $v/\sqrt{gL}=0.15-0.22$. The measured thrust, torque etc. at each run were reduced to a set of self-propulsion factors. They were plotted against Froude number and mean curves were drawn through the test points. In this section the deviation of the self-propulsion factors from the mean curves is discussed.

6:1 Mean curves of e_r, w_m and t

Plotting of e_r suggests that the variation of the relative rotative efficiency against Froude number may be expressed by a linear relation. Therefore a straight line was fitted to the plotting of e_r against $v/\sqrt{gL}$ by the method of least squares, and the deviation of each test point from the mean line was calculated.

w_m and t cannot be expressed by a linear relation with respect to Froude number, but plotting of all the test results against Froude number provides us with mean curves of w_m and t (denoted by $\overline{w_m}$ and $\overline{t}$) versus $v/\sqrt{gL}$ as given in Figs. 5 and 6.

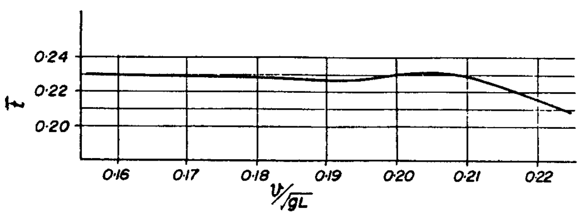


Fig. 5. Mean thrust deduction fraction curve

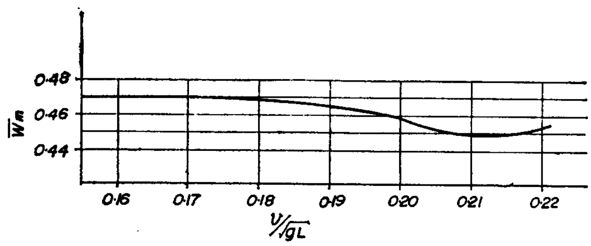


Fig. 6. Mean wake fraction curve

For each test the mean curves of w_m and t were assumed to be expressed by $\overline{w_m}+\overline{\Delta w_m}$ and $\overline{t}+\overline{\Delta t}$, where $\overline{\Delta w_m}$ and $\overline{\Delta t}$ are constant for the respective test, and $\overline{\Delta w_m}$ and $\overline{\Delta t}$ were determined by the method of least squares with reference to $\overline{w_m}$ and $\overline{t}$ curves. The standard deviation of w_m and t was calculated with respect to $(\overline{w_m}+\overline{\Delta w_m})$ and $(\overline{t}+\overline{\Delta t})$ for each test number. $\overline{\Delta w_m}$ and $\overline{\Delta t}$ are plotted in Fig. 7.

6:2 Scatter of e_r, w_m and t

Here the discussion is to be made on the dispersion of the self-propulsion factors in each test. (The 21 self-propulsion tests are numbered No. 1–No. 21 in the order of the date of the tests.)

In Fig. 8 the dispersion of e_r, w_m and t of each test number are expressed in terms of the deviation from their mean curves against Froude number as mentioned in **6.1.** In this figure there can be seen a few test numbers showing large deviation. For example, in the case of e_r, the test number 3 and 4 show large deviations of 1% in σ (standard deviation), but detailed observation of the individual test results reveals that, this is due to only one or two test points having an extraordinary deviation from the mean line. Neglecting these points we may say that the standard deviations are about 0.006 for e_r (0.6% of e_r), 0.005 for w_m (1% of 1-w_m) and 0.01 for t (1.3% of 1-t) throughout the test carried out.

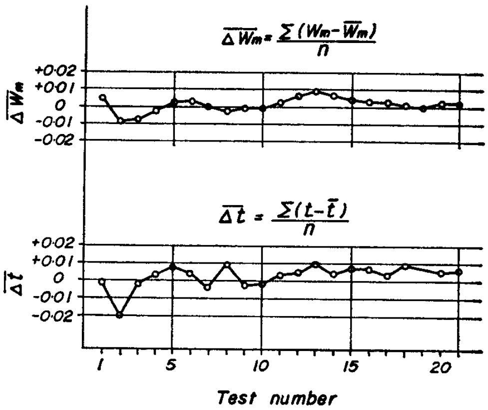


Fig. 7. Δt and Δw_m for each self-propulsion test

Notes for Fig. 7 and Fig 8

e_{ro}---mean line of e_r obtained by the method of least squares for each test.

$\overline{w_m}, \bar{t}$---mean curve of w_m and t, versus Froude number obtained from all tests (see Fig. 5 and 6).

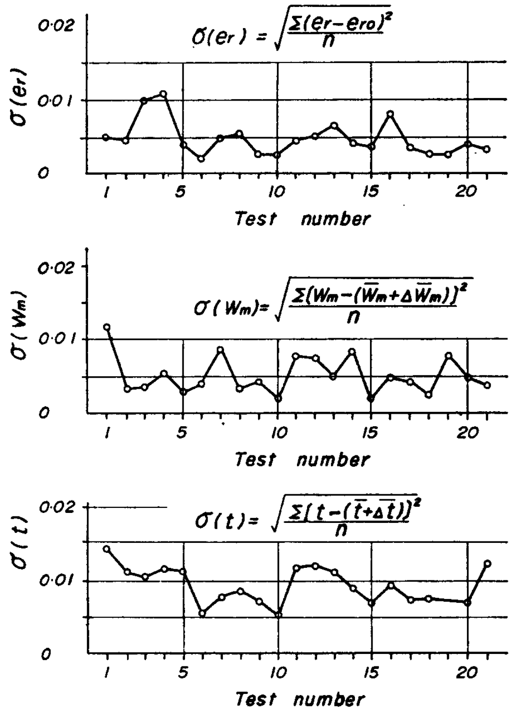
$\overline{\Delta w_m}, \overline{\Delta t}$--average deviation of w_m and t, from $\overline{w_m}$ and $\bar{t}$, for one test

$$\overline{\Delta W_m} = \frac{\Sigma(W_m - \overline{W_m})}{n} \qquad \overline{\Delta t} = \frac{\Sigma(t - \bar{t})}{n}$$

$\sigma(w_m), \sigma(t)$---scatter of w_m and t, from $\overline{w_m} - \overline{\Delta w_m}$ and $\bar{t} - \overline{\Delta t}$, for one test

$$\sigma(w_m) = \sqrt{\frac{\Sigma(W_m - (\overline{W_m} + \overline{\Delta W_m}))^2}{n}} \qquad \sigma(t) = \sqrt{\frac{\Sigma(t - (\bar{t} - \overline{\Delta t}))^2}{n}}$$

n ---- number of measuring run for one test



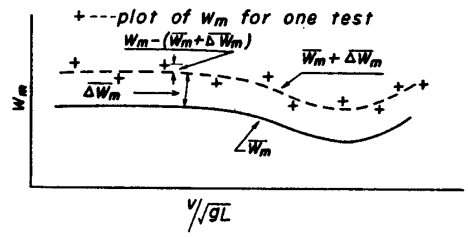


Fig. 8. Standard deviation of e_r, w_m, t from the mean line

For the test number 19, the standard deviation of t was not calculated because of large scattering of thrust deduction fraction. In this test the automatic speed control system of the towing carriage did not work and the test was carried out by the manual control. This suggests the importance of the automatic speed control of the towing carriage in the case of self-propulsion tests.

7 Distribution of t, w_m and e_r of 21 self-propulsion tests

In this section let us discuss the distribution of the self-propulsion factors of 21 self-propulsion tests, choosing $v/\sqrt{gL}$=0.16, 0.18 end 0.20 as the representative Froude numbers.

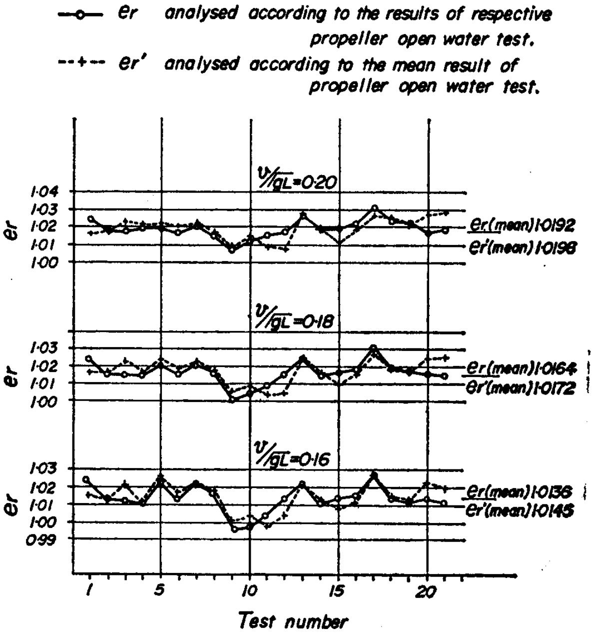


Fig. 9. Comparison of e_r and e_r' 21 self-propulsion tests

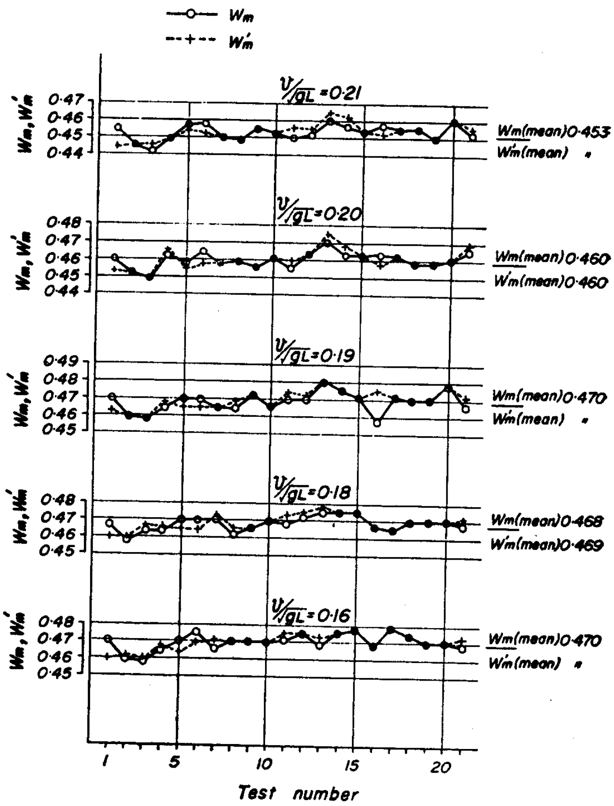


Fig. 10. Comparison of w_m and w_m' for 21 self-propulsion tests

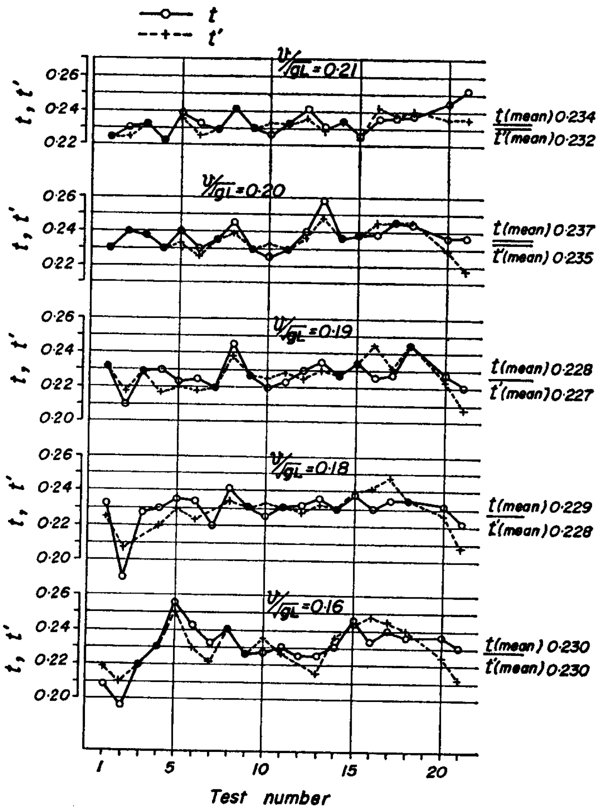


Fig. 11. Comparison of t and t' for 21 self-propulsion tests

The plottings of the self-propulsion factors to the base of the test number are presented in Figs. 9, 10 and 11. e_r, w_m and t plotted with the mark ——○—— were derived from the above-mentioned method of analysis, that is, e_r and w_m were obtained using the results of the open-water test of the propeller carried out on the nearest date to the self-propulsion test and t was obtained from the results of the resistance test carried out on the same day as the self-propulsion test. On the other hand e_r', w_m' and t' with the mark ······+······ were obtained by the analysis using the average propeller characteristics (for the self-propulsion tests No. 1–12, the average open-water characteristics obtained from the tests No. 1–9, and for the self-propulsion tests No. 13–21 the average results of the propeller open-water tests No. 10–14 were used) and the average residual resistance coefficient.

At each Froude number e_r and e_r' were obtained from the straight line against Froude number determined by the method of least squares. But

w_m, w_m' and t, t' were not obtained from the mean curves $\overline{w_m+\Delta w_m}$, etc, mentioned in 6.1, but were read from the mean curves through the plots of w_m, w_m' etc, of all the test points of the respective self-propulsion test.

The standard deviation of e_r, e_r' w_m, w_m', t and t' from their mean values for each Froude number are given in Fig. 12. The standard deviations of the self-propulsion factors from their mean values of the 21 self-propulsion tests are about 0.006 for e_r, about 0.005 for w_m, and about 0.01 for t. The deviations are about the same as those of the test points from the mean line of the respective test. Comparing the standard deviations of e_r, w_m, t and e_r', w_m' t' shown in Fig. 12, it may be said that the standard deviations of e_r and w_m are smaller than those of e_r' and w_m', but in the case of t and t', the standard deviation of t in the lower speed range ($v/\sqrt{gL}=0.16-0.18$) is very large, and the standard deviations of t' (using the average values of resistance coefficients) are rather smaller than those of t. This may be related to large dispersion of the results of the resistance tests of the full tanker ship form.

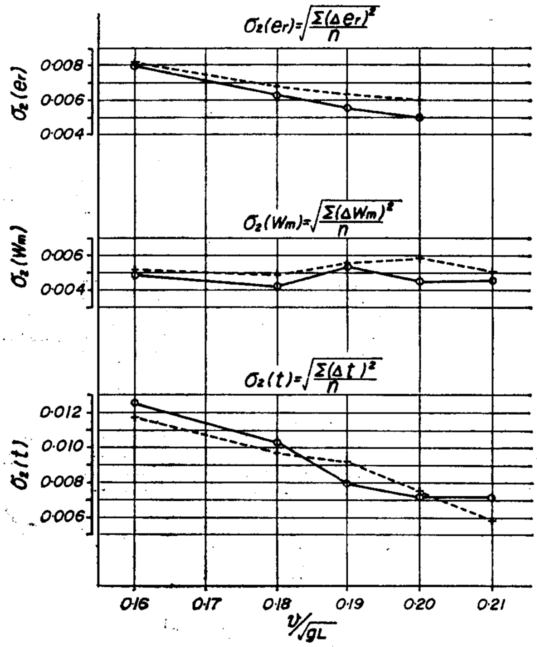


Fig. 12. Standard deviation of t, w_m, e_r, from their mean value

8. Scattering of DHP, estimated from 21 self-propulsion tests

In order to estimate the scatter of DHP obtained by scaling up the self-propulsion test results, the power coefficient $k_p=\dfrac{2\pi nQ}{\frac{1}{2}\rho v^3 \nabla_a{}^{2/3}}$ at the Froude number 0.16, 0.18 and 0.20 are plotted to the base of the test number (Fig. 13). The standard deviations from their mean values are 2.2, 1.7 and 1.7% for Froude number 0.16, 0.18 and 0.20 respectively. As mentioned in 5, water temperature has significant influence on the power coefficient, but the self-propulsion factors deduced from the self-propulsion tests are scarcely affected by the water temperature. Then in order to estimate the effect of the dispersion of the self-propulsion factors on that of the estimated SHP of the actual ship, DHP of the actual ship was calculated according to our method of power estimation(2), using the same EHP and the same propeller charcteristics, together with the respective self-propulsion factors obtained from the 21 self-propulsion tests. The standard deviation of SHP obtained by the above-mentioned method is about 1.5% for the range of Froude number tested.

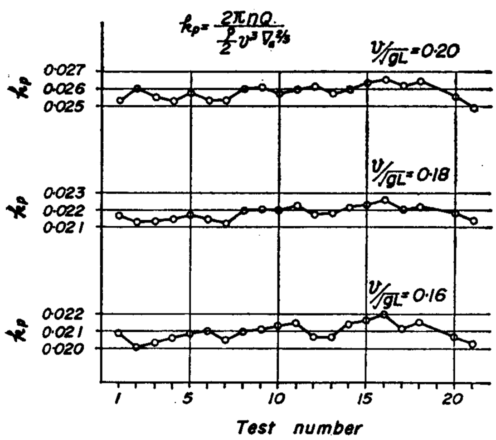


Fig. 13. Power coefficient of repeated self-propulsion test

9. Conclusions

(1) The standard deviations of the self-propulsion factors for each test point from the mean line for the respective self-propulsion test are about 0.006 for e_r (0.6% of e_r), 0.005 for w_m (1% of $1-w_m$) and 0.01 for t (1.3% of $1-t$) through all the repeated tests.

(2) The standard deviations of the self-propulsion factors from their mean values of the 21 self-propulsion tests at representative Froude numbers are about 0.006 for e_r, about 0.005 for w_m and about 0.01 for t. The deviations are about the same as those of the test points from the mean line of the respective tests.

(3) The dispersion of DHP measured by the self-propulsion tests are rather large, and it may be ascribed to the effect of water temperature on the propeller characteristics and the frictional resistance of the model.

(4) The self-propulsion factors obtained according to our testing method are scarcely affected by the water temperature. The author believes that our practice—to derive the self-propulsion factors from the results of the self-propulsion tests, using the results of the resistance tests carried out on the same date of the self-propulsion tests and the results of the propeller open-water tests carried out on the nearest date of the self-propulsion test—is the rigorous method.

(5) The standard deviation of DHP of the actual ship estimated according to our power estimation method (using the respective self-propulsion factors obtained from the 21 self-propulsion tests together with the same EHP and propeller open-water characteristics) is about 1.5% for the range of Froude number tested. This deviation is smaller than that of DHP of actual ship directly scaled up from the model test results.

10. Acknowledgement

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