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The Resistance Tests on the I. T. T. C. Standard Model

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The Resistance Tests on the I. T. T. C. Standard Model

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As the joint study of the I. T. T. C. Resistance Committee, the standard model made of laminated fibre-glass was tested in the Mitsubishi Experimental Tank (Nagasaki) and also in the T. T. R. I. and Japan Defence Agency Tanks.

Fairly good agreement between the resistance curve obtained in the N. L. P. Tank and that in the Mitsubishi Tank is obtained, if the blockage effect is corrected appropriately. No storm phenomenon has not been seen during the test period of two years. It seems that there is no relation between the variations of resistance and the time of experiment, water temperature and the depthwise distribution of the water temperature. The standard variation of the measured resistance coefficient for these two years is about 1 %.

Symbols

R resistance
v speed of model
S skin area of model
L waterline length of model
Δ displacement of model
ρ mass density of water, kg.s²/m⁴
ν kinematic coefficient of viscosity, m²/s
R_n Reynolds number, vL/ν
Ct resistance coefficient (corrected to 15 °C), $R/\rho/_2 v^2 S$
Ct_0 datum resistance coefficient obtained from the tests in N. P. L. No. 2 Tank
Ct_{0M} datum resistance coefficient obtained from the tests in the Mitsubishi Experimental Tank (see Fig. 3)
$\underline{Ct/Ct_0}$ daily mean value of Ct/Ct_0 for each speed group
$\overline{Ct/Ct_0}$ yearly mean value of Ct/Ct_0 for each speed group
σ daily standard deviation of Ct/Ct_0 for each speed group, i.e.

$$\sigma=\sqrt{\frac{\Sigma(Ct/Ct_0-\underline{Ct/Ct_0})^2}{n}}$$

n=number of runs per day

$\bar{\sigma}$ arithmetic mean of σ for one year
σ^* yearly standard deviation of Ct/Ct_0 for each speed group, i.e.

$$\sigma^*=\sqrt{\frac{\Sigma(Ct/Ct_0-\overline{Ct/Ct_0})^2}{N}}$$

N=number of total runs per year

Table I PRINCIPAL PARTICULARS OF THE STANDARD MODEL

Design	B. S. R. A.
Length	4.8265m
Breadth	0.6637m
Draught	0.3137m
Midship section area	0.2043m²
Displacement	652.9kg
Skin area	4.600m²
Block coefficient	0.65
Maximum section coefficient	0.981
Prismatic coefficient	0.663
L.B.C. from midship	0.5% L. B. P. aft
Half angle of entrance	12.3 degree
Length/breadth	7.27
Breadth/draught	2.12
Bilge radius/breadth	0.109
Trim	Level

1 Model and Test Procedure

The model is made of laminated fibre-glass from the same mould as used for the original standard models as supplied to four British tanks. From the maker's shop the model was sent to N. P. L., Teddington, where beams were fitted, approximate water lines marked and the bow fitted with studs, then shipped to Japan. The model was delivered to our experimental tank on May 22, 1960.

The standard model is of the B. S. R. A. 0.65 block coefficient form[1] and 4.8265 meter in length. The principal particulars and a photograph of the model are shown in **Table I** and **Fig. 1** respectively.

The offsets of the standard model were measured by using our model shaping machine and were checked with its designed offsets. The results of the first measurement conducted in August 1960 showed that both the stern and bow of the model were bent 1-2 mm to the port side in the horizontal plane. The comparisons between the measured offsets and the designed ones at 173 measuring points showed the standard deviation of 1.1 mm (0.3% of the half breadth) and the maximum deviation of 3.1 mm (1% of the half breadth). The second measurement was made in September, 1961, about a year after the first measurement. The comparisons of the centerline offsets of the typical water lines are shown in Fig. 2, on which we see no remarkable growth of deformation. Therefore, it is considered that the small

Fig. 1 *A photograph of the Standard Model*

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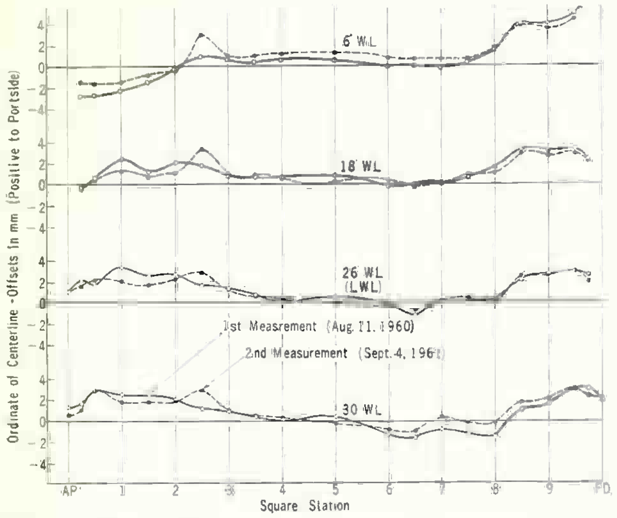

Fig. 2 *Plot of the centerline-offsets of typical waterline of the Standard Model*

deformation of our standard model is inherent and that there has been no growth of it.

The test procedures of our standard model as shown below are essentially the same as British ones but are slightly modified to suit more our own tank.

(1) Experiment

(1.1) The height of the towing point should be in the load water plane within a tolerance of 5 mm.

(1.2) Before each test the model surface will be rubbed down carefully with a sponge.
A note will be made of any surface deterioration.

(1.3) The temperature of the water will be measured at the mid-length of the test section, at 0.3 meter below the surface and at mid-depth and bottom of the tank, both before the first run and after the last run. The mean measured temperature of the water at the point 0.3 meter below the surface will be used for the analysis.

(1.4) The model will be ballasted to $\Delta=652.9\pm0.05$ kg without trim.
The length and the skin area of the model at this condition are taken as $L=4.8265$ m and $S=4.600$ m^2.

(1.5) The test runs will be made in the order 1.893, 1.655, 1.420, 1.183 and 0.945 m/s (within a tolerance of 0.005 m/s) and this sequence will be repeated 4 times, making 20 runs in all.

(1.6) The interval between runs will be 8 minutes.

(1.7) The wave absorbers on the both side walls and the current-meter will be used as usual but the speed relative to ground will be used for analysis.

(2) Analysis

(2.1) The test results are represented as the total resistance coefficient, $Ct=R/\frac{\rho}{2}v^2S$ versus Reynolds No. R_n.

(2.2) The resistance test results will be corrected to 15°C using the I.T.T.C. 1957 modelship correlation line and the A.T.T.C. 1939 values of ρ and ν will be used.

(2.3) The actual difference of each experiment spot from the datum line (**Fig. 3**) is expressed as a percentage of the datum value.
The arithmetic mean of these percentage is then taken for each speed group.
This is called the day mean value for the group.

(2.4) For each group the cumulative mean value is also calculated. This is the arithmetic mean of all the day mean values previous to and including the date of test.

(2.5) For each group a plot is made on a base of date of test of the following:
(a) the day mean value
(b) the upper and lower limits of the individual results
(c) the cumulative mean value.

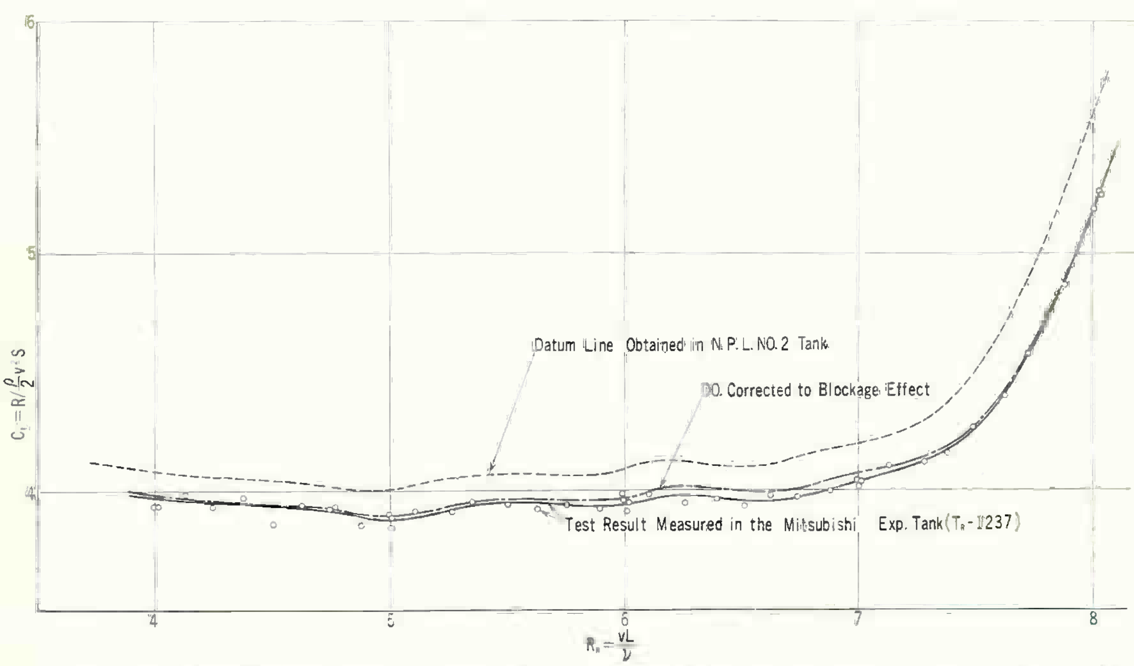

Fig. 3 *Comparison of the resistance coefficient curves between the N. P. L. No. 2 Tank and the Mitsubishi Experimental Tank*

The water temperature is also plotted in each figure.

2 Blockage Effect

In order to make a reasonable comparison of the test results obtained in the various tanks of different blockage ratios, it is necessary to make an appropriate blockage effect correction. For this purpose, the blockage effect of the standard model was investigated in our tank by towing the model through both the large section and the small section of tank in each run. The tests were conducted twice, i. e. on May 27 and on October 21, 1960. The blockage ratios and the related particulars of these tests are as follows;

	the large section (165 m in length)		the small section (120 m in length)	
Test	1st	2nd	1st	2nd
Temp. (surf.)°C	17.8	22.0	17.6	22.0
Tank sectional area, m²	78.11	77.935	21.53	21.45
Tank width, m	12.5	12.5	6.1	6.1
Blockage ratio	0.00261	0.00262	0.00948	0.00951

The test results were analyzed by the author's method[2] and the correction factor k for speed-increment due to the blockage effect was found to be 1.43 for the 1st test and 1.41 for the 2nd test. These values are somewhat larger than the mean value (1.10) of those we obtained previously for other ship models. But, by taking a rounded mean as $k=1.4$, the blockage effect correction for the standard model may be calculated by the next equation:

$$\frac{\Delta v}{v}=1.4\, m\, (L/B)^{\frac{3}{4}}$$

where Δv is the speed-increment due to the blockage effect, m is the blockage ratio, L is the length of the model and B is the breadth of the tank. By this method of correction, the datum resistance curve obtained from the tests in N.P.L. No. 2 tank was corrected to the same blockage ratio as our experimental tank (large section) and was compared with the test results in our tank (Test No. Tr-1237). The comparison is shown in Fig. 3 which shows the fairly good agreement between the both tests. The mean deviation of these two resistance curves at the five standard test speeds is 0.46% and the maximum deviation is less than 1%. The datum resistance curve was obtained by taking the mean of the four British standard models tested twice each in N. P. L. No. 2 tank. From the comparison shown in Fig. 3, we may conclude that the author's method of blockage effect correction and the measured resistance in our tank are both accurate enough for the purpose of the standard model test.

3 Comparisons of the Test Results among the Four Japanese Experimental Tanks

In accordance with the decision of Japan Towing Tank Committee, the standard model was circulated to the T. T. R. I. Tank and the Japan Defence Agency Tank and tested by the same test procedure as that of the Mitsubishi Tank. After No. 3 test in the Mitsubishi Tank, the model was sent to T. T. R. I. and tested on June 13 and 14 in No. 2 Tank and on June 18 and 20 in No. 1 Tank. Then the model was shifted to the Japan Defence Agency Tank and tested on July 24 and 27, 1960.

The test results obtained in these three Tanks were corrected to the same blockage ratio as that of the Mitsubishi Tank (large section) and were compared with the test results of the Mitsubishi Tank.

In **Table II** the mean deviations of the resistance coefficient for the five speed groups in each Tank are shown, taking the resistance coefficient curve (Fig. 3) measured in the Mitsubishi Tank as datum. The discrepancies of the resistance obtained in these four tanks are not so small and reach as high as 3.3%. But in the mean, for each speed group or for each Tank, the deviation is almost less than 1%. From these comparisons it may be said that the present situation of the accuracy

Table II COMPARISONS OF THE TEST RESULTS AMONG THE FOUR JAPANESE EXPERIMENTAL TANKS

Items	Expt. Tank (Test No.)		Speed group					Mean
			1	2	3	4	5	
Mean of $\frac{C_t-C_{toM}}{C_{toM}}$ in %	T.T.R.I. No. 2	(U-1)	+0.43	+0.36	+1.37	+0.23	+0.50	+0.58
	do.	(U-2)	−0.24	+0.58	+0.73	+0.13	+0.13	+0.27
	T.T.R.I. No. 1	(U-3)	−0.27	−2.33	−1.22	−0.82	−1.12	−1.15
	do.	(U-4)	−1.45	−1.77	+0.14	−0.06	−0.28	−0.68
	J.D.A.	(B-1)	−0.82	−0.47	+0.60	−0.10	+2.34	+0.31
	do.	(B-2)	−1.72	−0.76	+1.32	+0.76	+3.34	+0.59
	Mean		−0.68	−0.73	+0.49	+0.02	+0.82	−0.02
	N.P.L. No. 2 Tank*		+0.25	+0.52	+0.68	+0.87	0.00	+0.46
Standard deviation of C_t/C_{toM} in %	T.T.R.I. No. 2	(U-1)	1.02	0.69	0.33	0.75	0.91	0.74
	do.	(U-2)	0.16	0.79	0.18	0.23	0.23	0.32
	T.T.R.I. No. 1	(U-3)	2.12	0.83	0.60	0.73	2.08	1.27
	do.	(U-4)	0.53	0.64	0.34	0.69	1.51	0.74
	J.D.A.	(B-1)	0.64	0.43	1.12	0.98	0.36	0.71
	do.	(B-2)	1.15	0.41	0.55	0.40	0.45	0.59
	Mean		0.94	0.63	0.52	0.63	0.92	0.73
Mean of σ (Apr. '60-Apr. '62)			0.62	0.60	0.54	0.51	0.86	0.62

Expt. Tank	B	A	m	$\Delta v/v$ **
Mitsubishi	12.50m	77.78m	0.00262	0.00180
T.T.R.I. No. 1	10.00	53.00	0.00385	0.00312
T.T.R.I. No. 2	8.00	32.96	0.006[illegible]9	0.00593
J.D.A.	12.50	89.50	0.00228	0.00156

** $\Delta v/v=1.4m\ (L/B)^{3/4}$

* corrected to blockage

of resistance test is not satisfactory even for the practical purpose and the improvement of accuracy of resistance test has to be pursued strongly.

4 Analysis of the Test Results in the Mitsubishi Experimental Tank

4.1 Analysis of Ct/Ct_0

In the Mitsubishi Experimental Tank, 15 tests were conducted in the first year beginning from April 1960 and 24 tests were made in the second year in a regular pitch of about two weeks. All these test results were analyzed in accordance with the standard procedure described in Chap. 1 and are shown in **Fig. 4**. The mean difference from the datum line is about −5 % for the speed groups 1-4 and −7 % for the speed group 5. These differences are due to the difference in the blockage ratio in the two tanks as already stated in Chap. 2. The mean difference between the daily upper and lower limits is about 1.5 %, and the maximum difference is 6 %. Also no storm phenomenon[3] is seen in **Fig. 4**.

To make these points clearer, the standard deviation of Ct/Ct_0 for 4 runs of one day was calculated for each speed group and is plotted in **Fig. 5** with the daily mean value of Ct/Ct_0 and the water temperature. From the figure we can see clearly the independency of the standard deviation of each speed group. There is no case in which the standard deviations for all speed groups are very small or very large at the same time. So we may conclude that the deviation of resistance does not depend on the time of experiment.

The one year mean of the daily standard deviation, the one year mean of Ct/Ct_0, and the standard deviation of the whole measurements for one year for each speed group were also calculated and are shown in the tables in **Fig. 5**.

$\bar{\sigma}$ and σ^* in the first year are about 0.6-1.0 % and 1-2 % respectively, but in the second year they are reduced to 0.4-0.8 % and 0.5-1 % respectively, i. e. to about 80 % and 60 % of those of the first year. And the magnitude of σ^* is about twice $\bar{\sigma}$.

In these two years some modifications were made to the test facilities of our tank. The new type resistance dynamometer has been used from January 19, 1961. During the No. 15 test it was found that there was a need of adjustment of the rail alignment: therefore at

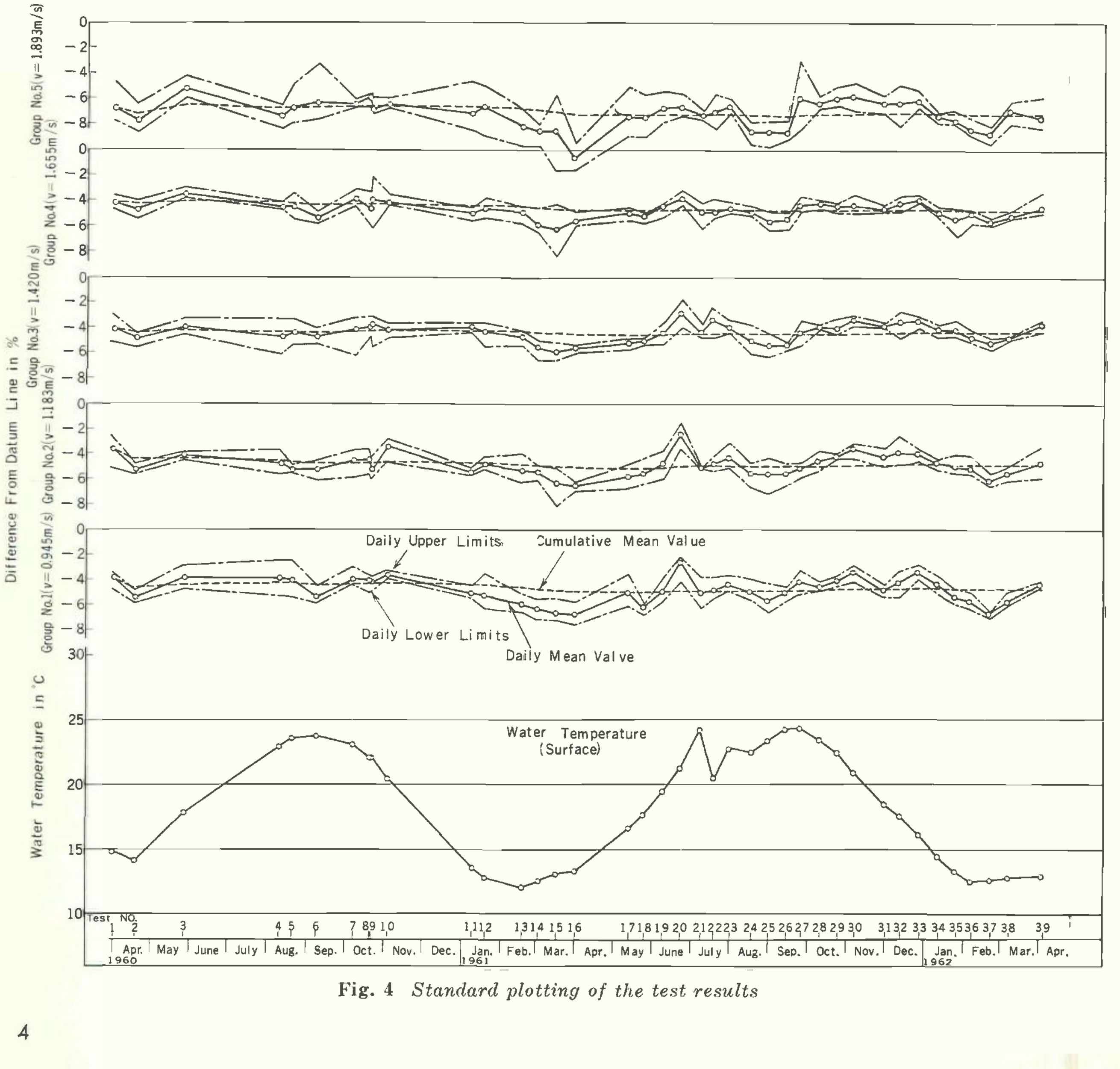

Fig. 4 *Standard plotting of the test results*

the end of March 1961, the rail alignment was adjusted. Also, the joints of the rail were electric-welded in November 1961 to reduce the vibration of towing carriage.

From Fig. 5 it may be seen that the standard deviation of each speed group since December 1961 is relatively smaller than before. The improvements of $\bar{\sigma}$ and σ^* in the second year tests may be due to these modifications.

The magnitude of the standard deviation of Ct/Ct_0 may depend on many causes such as variation of towing speed in run, water temperature distribution, wake distribution, etc. The effect of temperature distribution is investigated in 4.3. To investigate the effect of speed variation in run, the author selected some typical points in **Fig. 5**, i.e. the plots of σ of No. 6, 7, 27 and 28 test for the speed group 5. No. 6 and No. 27 are the examples of large σ, and No. 7 and No. 28 are those of smaller σ. From the records of resistance in these tests, mean deviation of the resistance record around its mean value was calculated and compared with each other as shown in **Table III**. From **Table III**, we can see that there are significant differences in the mean deviation ratio of the resistance record in run between the cases of large σ and those of small σ. But contrary to expectation, σ is small when the deviation of resistance in run is large and vice versa. At present the author can not explain clearly the reason for this, and there seems to remain a room for further studies.

4.2 Effect of Water Temperature

The resistance coefficient measured for each run was corrected to the standard temperature (15°C) by using the I. T. T. C. 1957 model-ship correlation line and compared with the datum line of N. P. L. To confirm the validity of this method of temperature correction, the daily mean resistance ratio $\overline{Ct/Ct_0}$ was calculated for each speed group and is plotted in **Fig. 6** against water temperature. From **Fig. 6** we cannot see any significant correlation between Ct/Ct_0 and water temperature for every speed group. Therefore we may say that the temperature correction by the I. T. T. C. 1957 model-ship

Table III COMPARISONS OF THE MEAN DEVIATION RATIO OF THE RESISTANCE RECORD IN RUN (SPEED GROUP 5)

Test No.	σ	Mean deviation ratio of the resistance record in run	No. of run	Difference of mean deviation ratio	$t_{0.05}(\phi)\hat{\sigma}\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}$
6	0.0161	0.0276±0.0032	5	0.0122	0.0118
7	0.0026	0.0398±0.0108	4		
27	0.0195	0.0238±0.0057	4	0.0200	0.0099
28	0.0038	0.0438±0.0058	4		

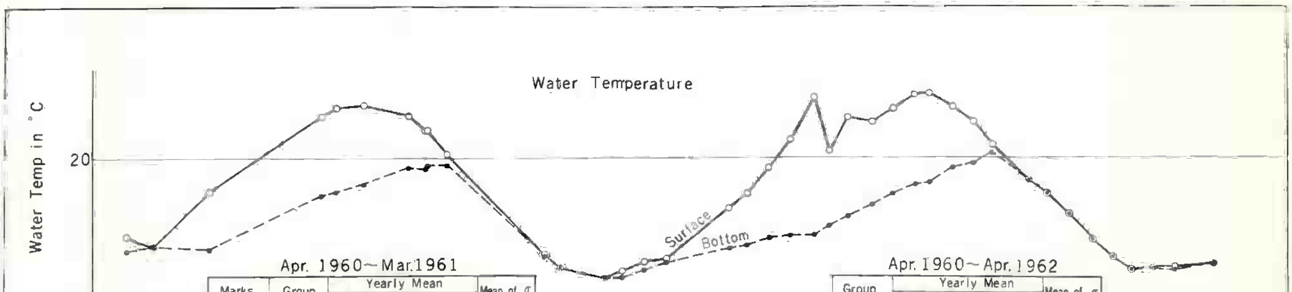

Fig. 5 *Plot of the standard deviation of C_t/C_{t0}, etc.*

correlation line with the A. T. T. C. 1939 values of ρ and ν is accurate enough for our standard model test.

4.3 Effect of Water Temperature Distribution

It has been thought that the depthwise distribution of water temperature might have an effect on the stability or transition of boundary layer, because we often have the bifurcate resistance curve especially on a full model in the early summer when the water temperature increases rapidly and the temperature gradient is large.

To investigate the effect of water temperature distribution on the deviation of resistance, σ is plotted against water temperature difference in **Fig. 7**. But from **Fig. 7** we can find no significant correlation between σ and water temperature difference. Therefore we may say that the temperature gradient in the vertical direction has no significant effect on the deviation of the measured resistance with the accuracy of present studies.

4.4 Analysis based on the Current-meter Speed

So far all the analyses have been made based upon the speed relative to ground. But it is a well known fact that there is a small wake current behind the model and it remains for some considerable time. The deviation of the measured resistance may be affected by this small wake current. To investigate this effect, we have also measured the speed relative to water by a current-meter parallel to the measurement of ground speed. The current-meter was placed 7.66 meter forward of the P. P. of model in the centerline plane in the depth of half draft of the model. Using thus measured speed by the current-meter, the analysis similar to those made upon the basis of the ground speed were made. The comparisons between these two methods of analysis are shown in **Table IV**. From **Table IV** it can be seen that $\overline{Ct/Ct_0}$ with the current-meter speed is smaller than that with ground speed. This is due to the presence of a wake current whose magnitude is in the order of 1 % of the ground speed. But the mean standard deviation is almost the same for both methods of analysis, although a slight improvement may be seen in the analysis based upon the current-meter speed. Therefore it may be said that the wake current has no significant effect on the magnitude of variation of measured resistance.

5 Conclusions

The main conclusions from the tests conducted during these two years may be summarized as follows:

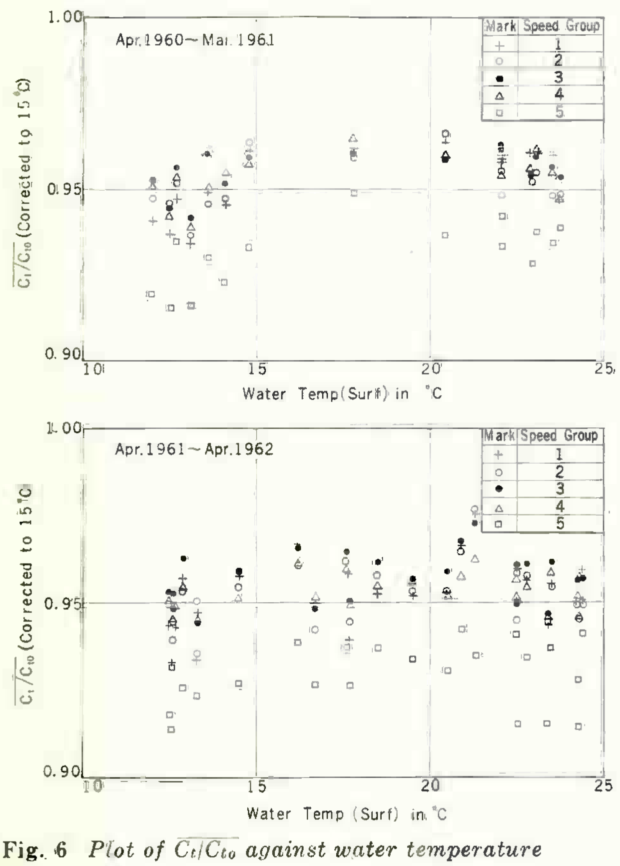

Fig. 6 *Plot of C_t/C_{t0} against water temperature*

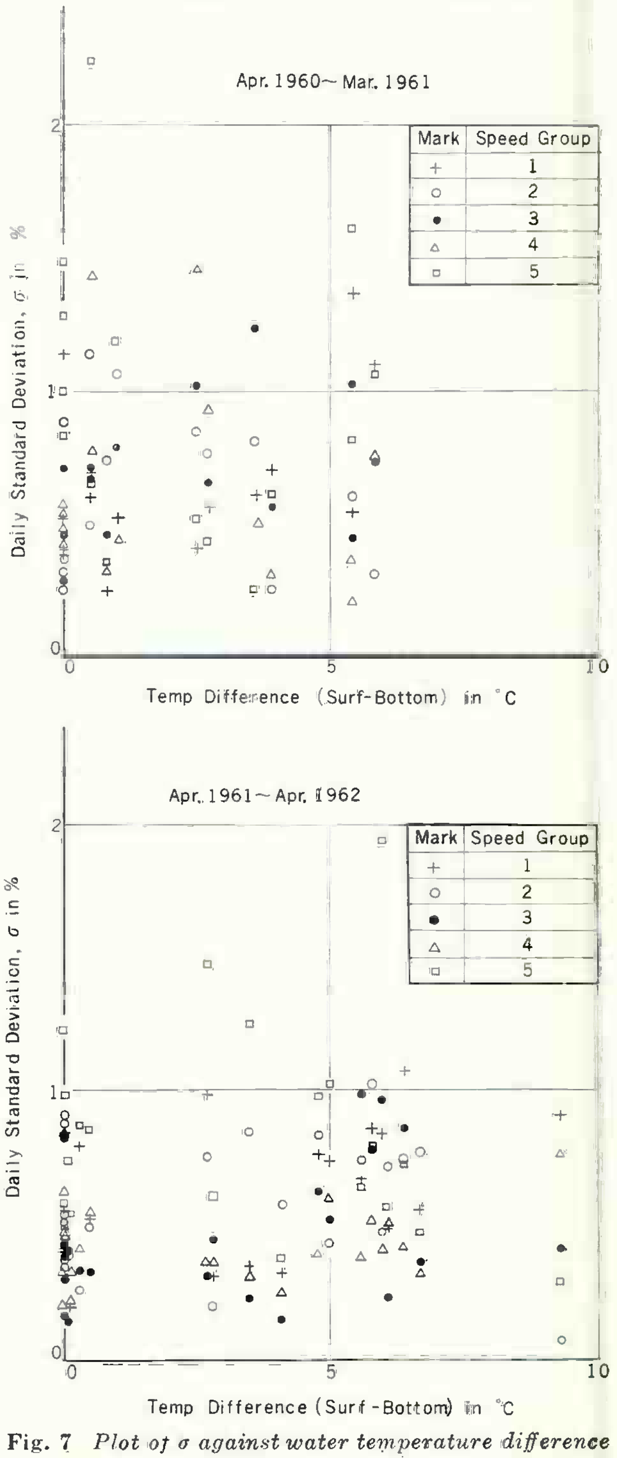

Fig. 7 *Plot of σ against water temperature difference*

Table IV COMPARISONS OF THE ANALYZED RESULTS BETWEEN THE METHOD USING THE GROUND SPEED AND THAT USING THE CURRENT-METER SPEED

	Speed group	The 1st year tests					The 2nd year tests				
		1	2	3	4	5	1	2	3	4	5
$\overline{C_t/C_{to}}$	(G)	95.21	95.12	95.54	95.38	93.11	95.22	95.19	95.68	95.31	92.78
	(C)	97.32	97.13	97.71	97.19	96.71	97.06	96.88	97.54	96.75	95.36
	(C) − (G)	2.11	2.01	2.17	1.81	3.60	1.84	1.69	1.86	1.44	2.58
$\bar{\sigma}$	(G)	0.652	0.625	0.667	0.638	0.960	0.593	0.582	0.460	0.427	0.784
	(C)	0.503	0.557	0.573	0.634	0.675	0.564	0.481	0.474	0.367	0.700
	(G) − (C)	0.149	0.068	0.094	0.004	0.285	0.029	0.101	−0.014	0.060	0.084
σ^*	(G)	1.200	1.557	1.485	1.629	2.454	1.176	1.082	0.891	0.524	1.039
	(C)	1.394	1.267	1.394	1.587	1.676	1.014	0.944	0.908	0.669	1.178
	(G) − (C)	−0.194	0.190	0.091	0.042	0.778	0.162	0.138	−0.017	−0.145	−0.139

(G) Analysis using the speed relative to ground
(C) Do. using the current-meter speed
$\overline{C_t/C_{to}}$, $\bar{\sigma}$, σ^* are expressed in percent

(1) The blockage effect correction of the standard model in the term of equivalent correction to the speed of the model is

$$\Delta v/v = 1.4\,m\,(L/B)^{\frac{3}{4}}$$

(2) Fairly good agreement is obtained between the datum resistance curve obtained in N. P. L. No. 2 tank and that obtained in the Mitsubishi Experimental Tank, provided that the blockage effect is corrected by the above formula (**Fig. 3**).

(3) From the comparisons of the results of tests conducted by circulating the model among the Mitsubishi Experimental Tank, the T. T. R. I. Tank and the Japan Defence Agency Tank, we see that the agreement of the measured resistance is not so good, i. e. the mean discrepancy of resistance is about 1 %, and the maximum is about 3 % (**Table II**).

(4) From the tests conducted in the Mitsubishi Experimental Tank during these two years, we can see that the mean of the daily standard deviation of Ct/Ct_0 is 0.6–0.7 %, and the yearly standard deviation of Ct/Ct_0 is 1–1.7 %. So-called storm phenomenon has not been seen in our tests (**Figs. 4 & 5**).

(5) Temperature correction of the resistance by the I. T. T. C. 1957 model-ship correlation line is accurate enough for our standard model test (**Fig. 6**).

(6) We cannot see any significant correlation between the variation of Ct/Ct_0 and the temperature distribution of water (**Fig. 7**).

(7) From the similar analysis of the test results based on the current-meter speed measured parallel to the ground speed, we can see that there is a wake current whose magnitude is in the order of 1 % of the ground speed and that the variation of resistance in this analysis is a little smaller than that of the standard analysis based on the ground speed (**Table IV**).

Acknowledgement

The author wishes to thank the directors of the T. T. R. I. Tank and of the Japan Defence Agency Tank for their participations in the present study and to Dr. Kinoshita, the Chairman of the Resistance Sub-committee of J. T. T. C. for his useful co-operation.

The author also wishes to express his appreciation of constant enthusiasm with which the members of Mitsubishi Experimental Tank have carried out this long program of tests.

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