SKIN FRICTION AND TURBULENCE STIMULATION

Committee Members

Prof. **C. W. Prohaska** (Chairman).
Capt. **M. L. Acevedo.**
Dr. **G. Hugues** (Secretary).
Dr. **M. Kinoshita.**
Prof. **L. Landweber.**
Ir. **A. J. W. Lap.**
Prof. **K. Wieghardt.**

COMMITTEE REPORT

INTRODUCTION

The main decisions of the 1957 Conference as regards Subjects 2 and 4 were:

"The Conference decides that the line given by the formula

$$C_F = \frac{0{,}075}{(\log_{10} R_n - 2)^2}$$

is adopted as the "ITTC 1957 model-ship correlation line", it being clearly understood that this is to be regarded only as an interim solution to this problem for practical engineering purposes."

"The Conference recommends that work should continue on all relevant problems:

(*a*) to improve the model and ship correlation,
(*b*) to determine roughness allowances,
(*c*) to explain the effect of form and
(*d*) to discuss and improve measuring techniques, including the effect of turbulence stimulation and tank boundary interference."

MEETING OF THE COMMITTEE, SEPTEMBER 1958

A meeting of the Committee was held in Copenhagen in September 1958, at which all the members were present except Dr. Landweber. The three main topics discussed at this meeting were:

1. Model-ship correlation allowances.
2. Form effect.
3. Standard models.

1. The question of allowances to be used for the prediction of ship trial results in relation to the 1957 model-ship correlation line was discussed very fully by the Committee. It was agreed that the Committee could not directly suggest values of these allowances, at least not at present but that it would be useful to obtain the views of the various tanks as to what values they think appropriate in this connection. The comprehensive questionnaire already sent out by the Propulsion Committee was noted, but it was felt that it would be of advantage to have overall correlation allowances, inclusive of scale effect on the propulsion factors, for use until such time that the latter can be decided. A circular to this effect was therefore prepared and sent out to all tanks (App. 1 (i)).

2. Some discussion took place on form effect in general, and it was agreed that every effort should be made to improve our knowledge of the effect of form

in relation to model-ship correlation. Reports were given of further work at low values of Froude Number at NPL, at NSMB, and in Japan, and it was suggested that all tanks should be asked to send to the Committee the results of any similar work A circular as set out in App. 2 (i) was prepared and sent out to all tanks.

3. The Committee was informed of the work on standard models which had been started in British tanks and welcomed the possibility of other tanks being able to obtain for their own use "identical" models. It was agreed that all tanks should be informed of this work and that such models could be available to them, if they so wished. For this purpose the circular as set out in App. 3 (i) was prepared and sent out to all tanks.

RESPONSE TO THE CIRCULARS

1. *Model-ship correlation allowances.*

This circular asked for the *views* of tank superintendents as to the values of the correlation allowances which they consider appropriate for use with the ITTC 1957 line to give accurate *predictions* of ship power. In response to this direct request the Committee has received some suggested values in replies from the following establishments: SSPA, Göteborg, NSMB, Wageningen, VDB, Duisburg, and SVA, Wien (see App. 1 (ii)). In addition a few tanks have stated that they are presently unable to furnish the requested information, including a joint reply from the British tanks saying that they are not yet in a position to make any recommendation.

In addition to these replies some *data* have been received from different sources giving the *deduced* values of the correlation allowances from a number of trial analyses. These are from the Japanese tanks (JTTC), the Paris tank, the Rome tank and SVA, Berlin-Karlshorst. These data have been carefully considered by the Committee together with other similar data available (listed in App. 1 (iii)), but in view of the large scatter of the deduced correlation allowances shown by these results the Committee as such does not consider itself able to make any further analysis of these data nor to make any recommendations of specific values of the correlation allowances for prediction work.

2. *Form effect.*

In reply to this circular the Committee received data from six sources (see App. 2 (ii)). These results are also shown plotted in App. 2, in relation to the ITTC 1957 line, and the main hull characteristics are tabulated also. These data support other published data in showing the desirability of ultimately introducing an allowance for form effect in model-ship correlation work, but the Committee has not felt itself able to undertake any detailed analysis to attempt to relate this form effect to the hull characteristics.

3. *Standard models.*

In response to this circular a number of tanks expressed the wish to obtain a similar model and to date 15 tanks now possess one of these standard models. These tanks are:

JOHN BROWN & CO., Clydebank.
WILLIAM DENNY & BROTHERS LTD., Dumbarton.
NATIONAL PHYSICAL LABORATORY, Teddington.
VICKERS-ARMSTRONGS, St. Albans.
HYDRO-OG AERODYNAMISK LABORATORIUM, Copenhagen.
STATENS SKEPPSPROVNINGSANSTALT, Gothenburg.
SHIPBUILDING RESEARCH INSTITUTE, Brodarski Institut, Zagreb.
ISTITUTO VASCA NAVALE, Rome.
SCHIFFBAUTECHNISCHE VERSUCHSANSTALT, Vienna.
CANAL DE EXPERIENCIAS HIDRODINAMICAS, El Pardo.
JAPANESE TOWING TANK CONFERENCE, Japan.
KRYLOFF SHIPBUILDING RESEARCH INSTITUTE, Leningrad.
NED. SCHEEPSBOUWKUNDING PROEFSTATION, Wageningen (*).
NATIONAL RESEARCH COUNCIL, Ottawa.
BASSIN D'ESSAIS DES CARÈNES, Paris.

A note giving details of the design of the standard model, the conditions of test adopted in the British tanks and a suggested procedure for the analysis and correlation of the results was prepared for the Committee, and a copy has been sent to each tank possessing one of these models. This note is reproduced in App. 3 (ii).

Most of the above tanks have had their models for a relatively short period so that at the time of preparation of this report it has not been possible in most cases to carry out many tests. To date the Committee has not received any results, but it is hoped that in due course the very great interest already shown in this work will lead to the accumulation of data of consi-

---

(*) It has been agreed between NSMB, Wageningen, HSVA, Hamburg and VWS, Berlin, to use this model at each tank in turn.

derable value in relation to the "erratic variation of model resistance" and the "techniques of measuring model resistance" as well as providing useful information on inter-tank comparisons.

MEETING OF THE COMMITTEE, MARCH 1960

A second meeting of the Committee was held in Copenhagen in March 1960. Capt. Acevedo and Dr. Kinoshita were not able to attend this meeting. After consideration of the responses to the questionnaires, the following additional topics were discussed at this meeting:

4. Tank boundary interference.
5. Correlation between resistances of large and small models.
6. Resistance of rough surfaces.
7. Transition from laminar to turbulent flow.
8. Techniques for boundary-layer investigations.

4. On this subject the Committee noted the considerable amount of work which has been done in recent years (see App. 4), and was informed of other work which is in hand. It is felt that there is enough information available in the small Froude-number range for tanks to correct for blockage effects, if they so wish, and the Committee does not think it necessary to state a preference for any one system. In the moderate to high Froude-number range there are also various suggested methods of correction but the Committee feels that more experimental evidence is required for this range in particular.

5. The Committee has been informed that SVA, Berlin, as well as the American towing tanks using small models have found somewhat poorer correlation with the results of larger geosims with the ITTC 1957 line than with the ATTC 1947 line (see App. 5). It would be desirable to obtain comments on the slope of the correlation line at small Reynolds numbers from other small towing tanks.

6. Recent studies of the boundary layer and resistance of rough surfaces apparently confirm the boundary-layer laws previously assumed on the basis of experiments in channels, and the exploitation of these laws has yielded methods of predicting the resistance of roughened surfaces at ship's Reynolds numbers from the results of tests of roughened plates in a towing tank, (see App. 6).

7. Explorations with hot wire anemometers of the nature of flow in the transition region where flow is changing from laminar to turbulent have led to an increasingly clear physical picture of the phenomena of formation of turbulence (see App. 7, refs. 1-4). On the basis of this understanding a new type of turbulence stimulator, consisting of an array of triangular wedges, has been suggested (see App. 7, refs. 5-6). Recent work on turbulence stimulation emphasizes the difficulty of the problem (see App. 7, refs. 7-8-9-10).

8. The Committee has noted the increasing interest in investigations of the fundamental characteristics of turbulent flows about ship models using hot wires and films in water. Work of this nature has been undertaken in several laboratories (App. 8, refs. 1-3).

The technique of measuring shear stress by means of a total head tube in contact with a boundary has also received considerable attention in the last few years. Although this method may now be considered a convenient one for measuring the shear stress on a flat plate, its application in the three-dimensional boundary layer on a ship model remains to be justified. If this can be accomplished it would finally become possible to separate skin friction drag from total drag (App. 8, refs. 4-12). In this connection it may be noted that a method of separating viscous from wave drag employing wake measurements has also been studied in some laboratories (see App. 8, ref. 12).

RECOMMENDATIONS CONCERNING MODEL-SHIP CORRELATION

In view of the scarcity of the replies to the circular on this subject the Committee has no definite values to suggest of correlation allowances for use with the ITTC 1957 line. The Committee considers that tanks should continue to investigate the use of this line and to inform the Committee of the values of the correlation allowances which they find from their own experience are necessary. It would also be of value if tanks at the same time would investigate the influence of form effect on these correlation allowances. If the Conference agrees to the continuation of this work, the Committee would appreciate discussion on these points.

APPENDIX I

(i) : CIRCULAR TO TANK SUPERINTENDENTS REGARDING CORRELATION FACTORS AND ALLOWANCES

The 8th ITTC held in Madrid in September 1957 adopted the formula :

$$C_f = \frac{0{,}075}{(\log_{10}R_n - 2)^2}$$

as the "ITTC 1957 model-ship correlation line".

The Conference requested that it should be clearly understood that this line is to be regarded only as an interim solution to this problem for practical engineering purposes. These purposes comprise mostly the prediction of ship power from model experiment results, and doubtless many tanks are attempting to apply the new line to such work. Associated with any such application it is necessary to use correlation allowances or factors to take account of other effects which cannot yet be assessed accurately.

These questions were discussed at a meeting of the Skin Friction Committee in 1958. It was agreed that it would be useful if the views of tank superintendents could be obtained and put collectively before the next Conference in 1960 as to the values of the correlation factors or allowances which they consider to be appropriate for use with the above line to give accurate predictions of ship power. The collection of these views will enable the Conference to see what measure of agreement exists on this matter. It will not be prejudicial to any future change in the correlation line which may be decided upon as the result of further research and in fact will form a basis for any corresponding adjustment of the correlation factors or allowances which would be necessary in such event.

The Skin Friction Committee therefore invites you to co-operate in this matter by replying to the enquiry set out below. For the sake of uniformity it has been necessary to set out a specific method of predicting the ship power. It is appreciated that your usual method may differ from the one chosen for this enquiry, but it is hoped, nevertheless, that you will be able to supply the information requested in accordance with the chosen method. This, of course, in no way implies adoption of this method for future use unless there is a general desire for this to be done.

It will also be noted that it is suggested that the correlation be expressed in terms of either a correlation factor Z or a correlation allowance ΔC_f. This is done to allow for a possible preference in method of approach, but the Committee would be pleased to have your views as to appropriate values of either or both Z and ΔC_f. If you give both, please state which method you prefer.

To give the Committee time to prepare its report for the next Conference it will be appreciated if you send me your replies not later than September 30th, 1959.

C. W. Prohaska.

Chairman ITTC Skin Friction Committee

Correlation allowances or correlation factors for the prediction of ship power from the model results.

For the present enquiry it is assumed:

A. *Trial conditions.*

Smooth sea, no wind, deep water. Hull surface good, i.e. adequate preparation followed by careful painting to produce a smooth finish; no subsequent fouling, or if so, adequate cleaning before the trial. The surfaces of the propeller blades are also assumed to be smooth and clean.

B. *Prediction from model test results.*

This is expressed as:

$$dhp = \frac{(ehp) \times Z}{\eta}$$

where

dhp = estimated delivered horse power absorbed at the ship propeller.

ehp = estimated ship tow-rope horse power corresponding to the resistance test of the model when fitted with appendages except those in the screw race (it is suggested that bilge keels are also excluded). The scaling to ship is made by the ITTC 1957 model-ship correlation line applied to the *total* surface area including that of the appendages fitted. The temperature is taken as 15° C or 59° F.

η = actual propulsive efficiency obtained in the model test at the propeller loading corresponding directly to the ship propeller power, i.e. at the resistance loading corresponding to (ehp) × Z.

Z = a correlation *factor* designed to bridge the gap between the value $\frac{ehp}{\eta_t}$ estimated from the model experiment data and the estimated value of *dhp* for the ship trial.

It will be seen that in the above no correction is applied directly for possible propulsive scale effect, the correlation factor Z being an overall factor to allow for such propulsive scale effect as well as for possible error in the resistance scaling.

On the other hand it may be preferred that the correlation should be made by means of an *allowance* ΔC_t on the estimated total ship resistance coefficient C_t. If the same value of η_t is used as above, it follows that $Z = 1 + \frac{\Delta C_t}{C_t}$ if the two methods are to give the same value of the predicted ship horse power. Therefore there is no constant relation between Z and ΔC_t, but the conversion of average values of the one to average values of the other is a simple matter in relation to average values of C_t.

The values of Z or ΔC_t will vary with the hull structural roughness and probably with the absolute length of the ship. It may also vary with the length/displacement ratio, the block coefficient, or similar ratios and coefficients, and further with the size of the model and with model conditions. The effect of the absolute ship speed is considered as secondary to the above mentioned effects and may be neglected.

It is suggested that values of Z or of ΔC_t should be given for the combinations set out in this table:

SHELL PLATING	LENGTH OF SHIP (ft.)			
	200	400	600	800
All welded				
75% welded				
50% welded				
25% welded				
All riveted				

The data should be given for *single-screw* ships, and adjustments (if any) for twin-screw ships stated separately. In case the figures given are related to limited values of for instance length/displacement ratio or block coefficient, the limits should be stated, and if possible corrections for departures.

The average size of model and the average value of blockage (model midship section area ÷ tank section area) associated with these assessments should also be given.

(ii) : REPLIES TO THE ABOVE CIRCULAR

1. *Reply from SSPA, Gothenburg;*

Allowances for use with the ITTC 1957 *model-ship correlation line*

Our answer to the questionnaire of 15th April 1959 reads as follows:

It is impossible to give simple correlation factors or allowances for *dhp*—or *rpm*—predictions, primarily due to the fact that scale effects on the propulsive factors seem to be of great importance. Research work is going on at SSPA on these problems, and we hope to be able to present a paper on this early in 1960.

As a guidance the following figures, approximately applicable to normally shaped, all welded, single screw merchant vessels, can be given

LENGTH OF SHIP (ft) (ft)	ΔC_t
200	0.00085
400	0.00055
600	0.00020
800	0.00010

2. *Reply from NSMB, Wageningen;*

Trial trip allowances.

Description of the method of correlating ships and model data which has been in use many years at the N.S.M.B.

Proposed allowances for use with the ITTC-1957 extrapolation method.

At the N.S.M.B. self-propulsion tests are carried out according to the "Continental" method, *i.e.* for progressive speeds at self-propulsion point of ship in tank condition. The self-propulsion point is determined on base of the Froude skin friction coefficients, which means that a certain roughness allowance is comprehended in the calculations.

On the values of tank-DHP, derived from the tests, which are conducted as circumscribed above, allowances are given to obtain the value of BHP for the trial condition.

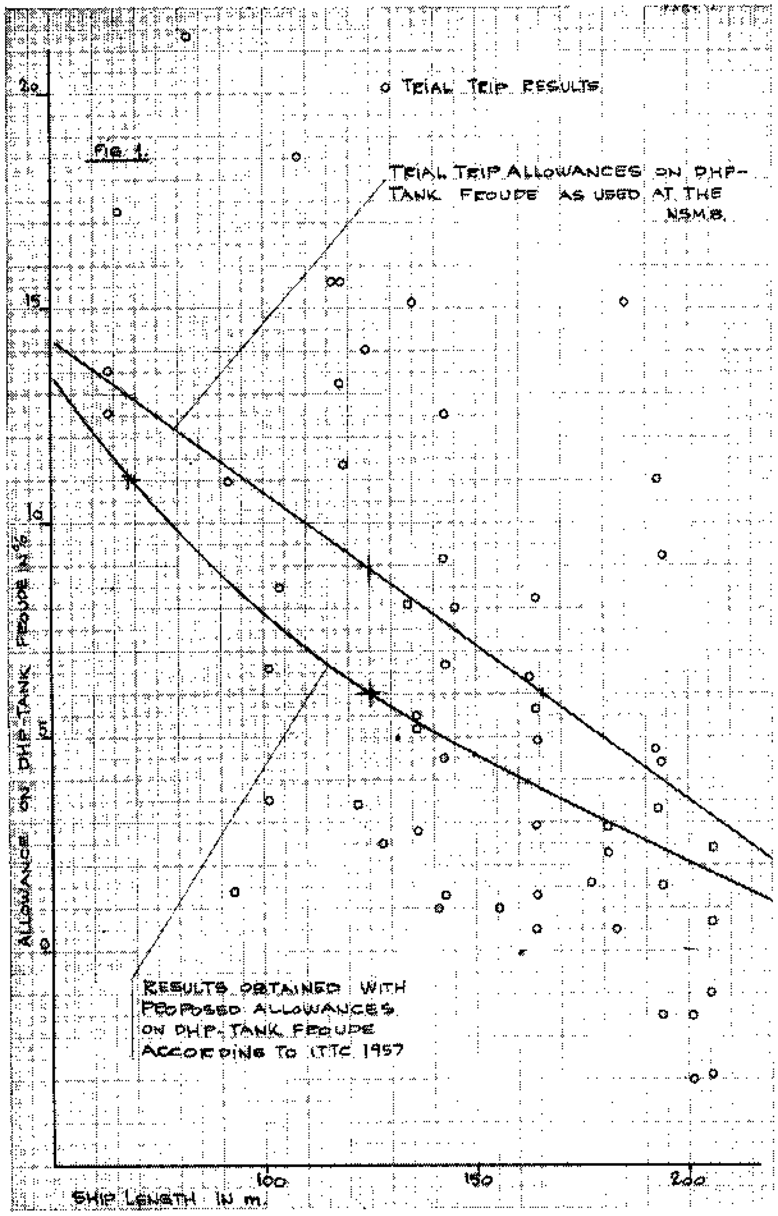


FIG. 1.

TABLE 1.
Differences between various extrapolation methods.

Extrapolation method	$C_{tot} \times 10^5$ for ship	Difference between C_{tot} and C_{tot} according to Froude $\Delta C_{tot} \times 10^5$	C_{tot} in percentages of C_{tot} according to Froude
200 ft ship			
ATTC - 1947	2802	— 269	91.2
ITTC - 1957	2728	— 343	88.8
Froude	3071	—	100.0
400 ft ship			
ATTC — 1947	2569	— 345	88.2
ITTC — 1957	2496	— 418	85.7
Froude	2914	—	100.0
600 ft ship			
ATTC — 1947	2454	— 366	87.0
ITTC — 1957	2381	— 439	84.4
Froude	2820	—	100.0
800 ft ship			
ATTC — 1947	2380	— 369	86.6
ITTC — 1957	2305	— 444	83.8
Froude	2749	—	100.0

These allowances amount to:

0 % for ships having a length of 250 m (820 ft)
5 % for ships having a length of 180 m (590 ft) (1)
10 % for ships having a length of 110 m (360 ft)
15 % for ships having a length of 40 m (130 ft)

They are represented in Figure 1 and are considered to comprehend amongst others the following average allowances:

3 % for shaft friction losses
½ % for loss in propeller efficiency due to the higher propeller loading as a result of the allowance (2)

The allowances on EHP as used by the N.S.M.B. are therefore

— 3 ½ % for ships having a length of 250 m (820 ft)
+ 1 ½ % for ships having a length of 180 m (590 ft)
+ 6 ½ % for ships having a length of 110 m (360 ft) (3)
+ 11 ½ % for ships having a length of 40 m (130 ft)

These allowances are represented in Figure 2.

In order to be able to convert the total allowances now in use at the N.S.M.B. into an allowance system to be applied on base of the ITTC-1957 method, the following calculations were made :

1. For five models with block coefficients of 0.60—0.65—0.70—0.75 and 0.80, all having a length-breadth-draught ratio of 7.0 and a breadth-draught ratio of 2.4, the total specific resistance C_{tot} at a water temperature of 15^0 C was calculated on base of the N.S.M.B. statistics.

2. For each model the frictional and residuary resistance coefficients were calculated at the economical speed, using the following methods

a) A.T.T.C.-1947 (Schoenherr)
b) I.T.T.C.-1957
c) Froude.

3. For each model the results were converted to ships having lengths of 200 ft, 400 ft, 600 ft and 800 ft using each of the three above-mentioned methods, without applying any allowance.

The ship results are represented in Figure 3 as average lines of total specific resistance on base of log R_n. The differences in the resistance predictions according to the three methods are given in Table 1, both as differences in total specific resistance and as percentages of the values predicted according to Froude.

The latter percentages can be used for a direct comparison with the present allowances on the Froude resistance or EHP-prediction. To this end they are plotted in Figure 2 for the ITTC-1957 method. From this figure it appears, that the differences between resistance or EHP-predictions according to Froude including the allowances and the resistance or EHP-predictions according to ITTC-1957 without any allowance amount to the following percentages of the Froude resistance or EHP-prediction:

16.6 % for ships having a length of 250 m (820 ft)
16.9 % for ships having a length of 180 m (590 ft)
19.9 % for ships having a length of 110 m (360 ft) (4)
21.2 % for ships having a length of 40 m (130 ft)

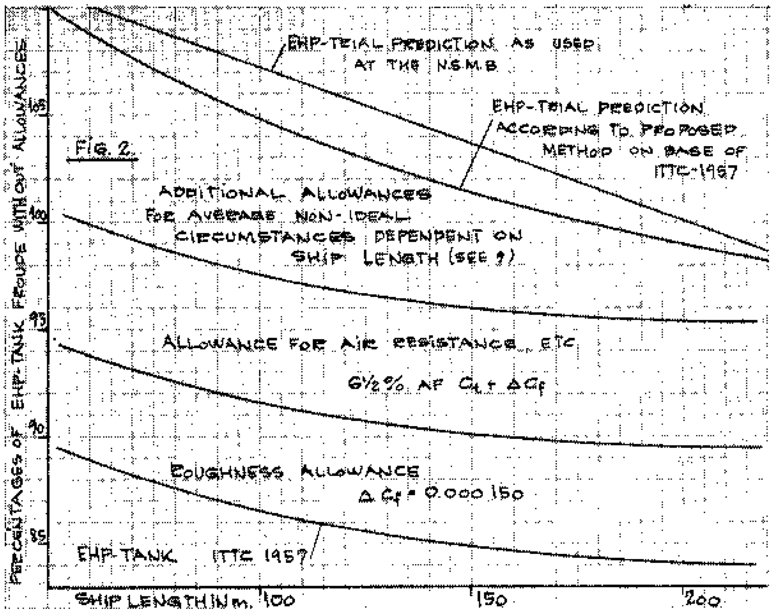


FIG. 2.

Allowances of this magnitude would therefore have to be applied to the ITTC-1957 smooth ship resistance or EHP-prediction. These allowances must be considered to consist of (as an average):

3 % for air resistance
1 % for increase in resistance due to steering
2 ½ % for resistance of bilge keels, which are usually not present during tank tests.

An allowance for surface roughness.

An allowance for differences between average trial conditions and ideal trial conditions, consisting of:

1° an allowance for fouling
2° an allowance for paint deterioration
3° an allowance for wind resistance
4° an allowance for rough water resistance } (5)

From a publication by the B.S.R.A. it has appeared, that the average roughness allowance for a clean newly painted ship is of the order of $\Delta C_f = 0.000150$. About the same value was found from a careful analysis by AEW at Haslar of trial trip data of a single screw ship.

It appears also from the trial results of long ships, represented in Figure 1 that, taking into account the allowances mentioned under *2* and *5*, the roughness allowance cannot be much greater than $\Delta C_f = 0.000150$.

If this value could be assumed to be the best possible average roughness allowance for trial trips under ideal circumstances, it could be suggested to accept this allowance as a standard roughness allowance.

This standard roughness allowance could then be used for the calculation of the self-propulsion point of ship and for the calculation of the skin friction correction. It is represented in Figure 2 in percentages of EHP-Froude without allowance.

On the results of resistance tests calculated on base of the ITTC-1957 line an allowance would have to be made of

$\Delta C_f = 0.000150$ for surface roughness

$6\frac{1}{2}\%$ of $C_t + \Delta C_f$ for air resistance, steering resistance, resistance of bilge keels } (6)

On the results of self-propulsion tests carried out on this base the following percentage allowance would have to be made:

10 % on DHP tank for air resistance, steering resistance, resistance of bilge keels, decrease in propeller efficiency due to overload, shaft friction losses. } (7)

Moreover an additional allowance has to be made both on $C_t - \Delta C_f$ and on DHP-tank for differences between the average actual trial trip conditions and the ideal trial trip conditions. This additional differ-

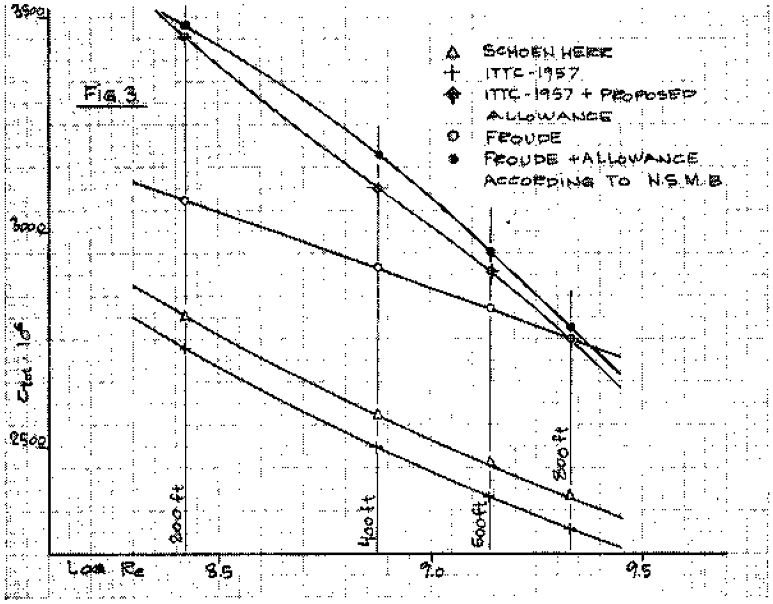


FIG. 3.

ence can easely be determined from Figure 2 in percentage of EHP tank according to Froude.

For the N.S.M.B. this percentage would amount to

− 10.2 % for ships having a length of 200 ft
8.9 % for ships having a length of 400 ft
5.7 % for ships having a length of 600 ft
1.8 % for ships having a length of 800 ft
(8)

In this way trial predictions of EHP and BHP would be obtained, which are practically equal to those on base of the presently used Froude method. It is the opinion of the N.S.M.B. that this is necessarry in order to maintain a certain continuity in the predictions. The latter percentages could be standardized, however, approximately as follows (percentages of $C_t + \Delta C_f$ or DHP tank)

10 % for a ship having a length of 50 m (164 ft)
9 % for a ship having a length of 75 m (246 ft)
8 % for a ship having a length of 100 m (328 ft)
7 % for a ship having a length of 125 m (410 ft)
6 % for a ship having a length of 150 m (492 ft)
5 % for a ship having a length of 175 m (574 ft)
4 % for a ship having a length of 200 m (656 ft)
3 % for a ship having a length of 225 m (738 ft)
2 % for a ship having a length of 250 m (820 ft)
1 % for a ship having a length of 275 m (902 ft)
0 % for a ship having a length of 300 m (984 ft) and more
(9)

They apply to the model size as used in the N.S.M.B. (20-22 ft) and average trial conditions at the North Sea and may in principle be different for other tanks.

Summarizing the method to be applied to derive BHP_{ship} from model tests becomes now :

1. Conduct self-propulsion tests on base of ITTC-1957 line with standard roughness allowance of $\Delta C_f = 0.000150$.
2. Convert results to full scale DHP.
3. Apply standard allowance for air resistance, etc. to full scale DHP. A value of 10 % is suggested by the N.S.M.B. for this allowance.
4. Apply extra allowance according to 9 in order to obtain the values of BHP to be expected under average trial conditions.

By way of example allowances on EHP for the smooth ship in tank condition as predicted on base of the ITTC-1957 method were calculated for the average ship of which the resistance prediction is represented in Figure 3.

The allowances used are:

6 ½ % + 2.2 % for the 800 ft ship
6 ½ % + 4.7 % for the 600 ft ship
6 ½ % + 7.1 % for the 400 ft ship
6 ½ % + 9.6 % for the 200 ft ship
$+ (\Delta C_f = 0.000150)$.

The results obtained in this way are plotted in Figure 2 as a percentage of the Froude prediction without any allowance for the same ship. The comparative total allowances on DHP were plotted in Figure 1 for a direct comparison with the present method, together with a number of actual allowances found by the N.S.M.B. on trials in recent years. The results were also plotted in Figure 3.

All the trial results of Figure 1 were obtained with the aid of a torsion meter and the trials took place under average good weather conditions for the North Sea (Beaufort 0-4). By far the majority of the results apply to all welded hull conditions.

In Figure 1 it can be seen, that the differences between the BHP predictions for trial condition according to Froude and according to the proposed method are only small. Furthermore it can be seen that the trial predictions according to the presently used Froude system are a little on the high side, especially for the longer ships. The proposed allowances for use with the ITTC-1957 method give, however, slightly lower results than according to the old system.

Wageningen, March 1960.

3. *Extract of reply from VDB, Duisburg :*

The ΔC_r for normal shallow water ships (i.e.about the 200′-ship) when using the ITTC Skin Friction Formula are given as follows:

Shell plating	ΔC_r
All welded	0.0003
50% welded	0.0004
All riveted	0.0005

4. *Extract of reply from SVA, Wien :*

For the prediction of the *dhp* we scale up the results of the propulsion tests with the models. For calculating the friction correction force we take the ITTC 1957 model ship correlation line and give a roughness allowance of 0.25×10^{-3} for the ship. For trial condition we give an allowance of 7 % to the power and 1½ % to the revolutions for all welded ships. For all riveted ships is the allowance about 12 % for power and 2 % for revolutions. So we can say the correlation factor Z varies between 1.07 and 1.12. The temperature is taken as 15° C, the average size of the models is a length of about 6 m. The blockage varies between 0.004 and 0.006.

5. *Reply from the British Tanks :*

National Physical Laboratory, Ship Division

We held a meeting of the British Towing Tank Panel here on the 26th January, at which the question of a reply to your letter on ship-model correlation was discussed.

This problem has been under consideration by the British delegates to the ITTC for some time now, and a few months ago we set up a small group consisting of Mr. Moor as Chairman, with Clements from Ship Division and Canham from B.S.R.A., to study the available data with a view to recommending a set of ΔC_f values, which would be acceptable to all five British commercial tanks for use in conjunction with the existing standard procedure. At the meeting on 26th January, Mr. Moor reported that his groupe were not yet in a position to make any recommendations, and I would ask you to accept this letter as an official intimation from the British tanks to this effect. We still hope to be able to come to some agreement before the Paris meetings, and will keep you informed of any progress to this end.

(iii): DATA RECEIVED PERTAINING TO THE ABOVE CIRCULAR

1. *Data from Japanese Tanks :*

(*a*) *Masao Kinoshita; ΔC_f values for several vessels using the ITTC 1957 M-S correlation line*, Sept. 1, 1958. Technical Research Laboratory, Hitachi Shipbuilding & Engineering Co. Ltd., Osaka Japan, 1 page, giving ΔC_f values deduced from 10 trial trips and ranging from —0.00008 to + 0.00055.

(*b*) *Kaname Taniguchi, Kinya Tamura : Comparison of ΔC_f analysis* Report No. 308, August 10, 1958, Experimental Tank (Nagasaki) Laboratory Mitsubishi Shipbuilding & Engineering Co. Ltd., 5 pages, giving ΔC_f values deduced from 9 trial trips and ranging from —0.00038 to + 0.00005.

(c) *ΔC_f values for several vessels using the ITTC 1957 M-S correlation line.* Data Sheet No. 1, May 1959, Transportation Technical Research Institute, Ministry of Transportation, Tokyo Japan, 4 pages giving ΔC_f values deduced from trial trips with 28 cargo ships and ranging from + 0.00004 to 0.00054, and ΔC_f values deduced from trial trips with 23 tankers and ranging from —0.00027 to + 0.00028.

(*d*) *Kaname Taniguchi : ΔC_f values for several vessels using the ITTC 1957 M-S correlation line*, Data Sheet No. 2, May 1959. Experimental Tank of Laboratory Mitsubishi Shipbuilding & Engineering Co. Ltd., Nagasaki Japan, 1 page, giving ΔC_f values deduced from 40 trial trips and ranging from —0.00052 to + 0.00040.

(*e*) *Masao Kinoshita : ΔC_f values for several vessels using the ITTC 1957 M-S correlation line*, Data Sheet No. 3, May 8, 1959, Technical Research Laboratory, Hitachi Shipbuilding & Engineering Co. Ltd., Osaka Japan, 2 pages giving ΔC_f values deduced from trial trips with 12 cargo vessels and ranging from +0.00017 to +0.00067, and ΔC_f values deduced from trial trips with 10 tankers and ranging from —0.00032 to+ 0.00004.

(*f*) *Masao Kinoshita : ΔC_f values for several vessels using the ITTC 1957 M-S correlation line and form factor* K'. Data Sheet No. 6, Aug. 15, 1959. Technical Research Laboratory Hitachi Shipbuilding & Engineering Co. Ltd., Osaka Japan, 2 pages giving ΔC_f values deduced from trial trips with 16 tankers and ranging from —0.00019 to +0.00030, and ΔC_f values deduced from trial trips with 12 cargo vessels and ranging from +0.00001 to 0.00063.

(*g*) *Note on standard method of estimation ΔC_f from the results of sea trial.* Data Sheet No. 7, Sept. 22, 1959, JTTC.

The general trend of the ΔC_f curves given in the above mentioned publications a-f is very similar to that found by R. E. Clements (see (iv)).

2. *Data from Paris Tank*

(*a*) Extract of data sheets prepared by the Paris Tank giving Z-values for 4 tankers, 2 liners and 6 cargo vessels. For the tankers the Z-values vary from 1.02 to 1.22, for the liners from 1.09 to 1.22 and for the cargo vessels from 1.00 to 1.36. See table on the opposite page.

ESTABLISHMENT		BASSIN D'ESSAIS DES CARÈNES, PARIS.							
Reference	Type	Length WL	Prop. number	Displ.	Welded joint	Speed	$\frac{v}{\sqrt{gl}}$	R*n*	*z*
		m		tons	%	knots		$\cdot 10^9$	
1134	tanker	196,5	1	42430	80	16,25	0,191	1,42	1,03
						17,48	0,205	1,53	1,02
						17	0,199	1,48	1,03
						17,61	0,206	1,54	1,03
						16,31	0,191	1,42	1,10
						17,19	0,201	1,50	1,06
						17,48	0,205	1,53	1,07
						16,77	0,196	1,46	1,04
1147	tanker	173,98	1	28626	80	16,1	0,200	1,24	1,04
						16,6	0,207	1,28	1,09
						17,2	0,214	1,33	1,09
1152	tanker	205,36	1	49016	80	17,77	0,204	1,62	1,06
1219	tanker	186	1	36580	80	15,3	0,184	1,27	1,22
						16,1	0,194	1,33	1,17
1009	liner	94	2	2214	20	21,99	0,373	0,781	1,22
						23,05	0,391	0,819	1,19
						15,16	0,427	0,893	1,09
1052	liner	176,91	2	18410	20	23,8	0,294	1,87	1,10
						25	0,309	1,96	1,10
1046	cargo	142,89	2	13548	30	18,62	0,256	1,18	1,06
						18,78	0,258	1,19	1,09
1144	cargo	136	1	12658	90	16,49	0,232	0,848	1,18
						15,97	0,225	0,821	1,13
						16,62	0,234	0,855	1,14
1227	cargo	82	1	2977	90	14,45	0,262	0,448	1,14
						15,27	0,277	0,472	1,10
						15,66	0,284	0,484	1,11
1228	cargo	90	1	4157	90	15,82	0,274	0,630	1,00
						16,56	0,287	0,660	1,02
		88	1	3539		15,92	0,278	0,624	1,04
						16,68	0,292	0,654	1,04
1237	cargo	140	1	14213	90	14,30	0,198	1,02	1,20
						15,25	0,211	1,09	1,24
						16,45	0,228	1,17	1,23
		134	1	10300		15,71	0,223	0,98	1,36
						16,38	0,232	1,02	1,30
						17,41	0,247	1,09	1,17
		140	1	14923		14,21	0,197	0,92	1,16
						15,26	0,212	0,99	1,16
						16,53	0,230	1,07	1,12
1307	cargo	14	1	15161	90	18,33	0,248	1,25	1,00
						18,50	0,250	1,38	1,03
						19,66	0,267	1,47	1,02

Data from Rome Tank :

b Extract of letter from Istituto Vasca Navale, Rome
The Rome Tank has made a certain number of comparisons between model and ship using the ITTC 1957 Line in order to obtain the ΔC_f allowances. The results obtained up to the present are:

(*a*) Tanker 36,000 t.dw L = 200 m (3 sister ships)
Δ = 47,500 t. V = 14 & 18 knots, ΔC_f mean = 0
Δ = 29,500 t. V = 18 knots, ΔC_f mean = 0.0001
(*b*) Tanker 35,400 t.dw L = 200 m (7 sister ships)
Δ = 48,200 t. V = 14 & 18 knots, ΔC_f mean = 0.00005
Δ = 30,500 t. V = 17,5 knots, ΔC_f mean = 0.0001
(*c*) Passenger ship L = 167 m
Δ = 23,000 t. V = 18 & 21 knots, ΔC_f = 0.00025
(*d*) Passenger ship L = 96 m (3 sister ships)
Δ = 4,300 t. V = 14 & 18.5 knots, ΔC_f mean = 0.0003
(*e*) Trawler L = 36 m
Δ = 430 t. V = 13 knots, ΔC_f = 0.0002

The ships *a*, *b* and *e* have fully welded shells, the ships *c* and *d* have partially welded shells.

The resistances found at the trials have been reduced by 5% (air resistance and shaft losses).

Extract of reply from SVA, Berlin-Karlshorst :

We can furnish comparison values only for an inland cargo vessel fitted out with two rudder nozzles.

After reducing the shaft power by 2% to allow for wind influence, the ITTC-Line + $\Delta C_t = 0.1\ 10^{-3}$ gave good agreement between the trial results in the speed range from 7.6 to 9.3 knots and the values $\left(\text{EPS} + \Delta C_t \frac{\frac{1}{2} V^3 S}{75}\right)$ obtained from the model measurements.

The model scale was 1:10, giving the blockage of 0.0044. The allowance $\Delta C_t = 0.1\ 10^{-3}$ corresponds to a value $Z = 1.0225$.

References

[1] Clements R. E.: *An Analysis of Ship-Model Correlation Data using the* 1957 *ITTC Line,* Trans. INA 1959.

APPENDIX II

(i): Circular to tank superintendents

Form Effect

At a meeting of the Skin Friction Committee held in Copenhagen in September, 1958, it was agreed that every effort should be made to improve our knowledge of the effect of form in relation to model-ship correlation. To this end it was also agreed that all tanks should be asked to send to the Committee the results of any new work on form effect, such as obtained in tests at low Froude number.

The Committee would therefore be glad to receive from time to time any new data relevant to this problem which you are willing to allow the Committee to use in any communication to the Conference.

It would be convenient if data on resistance at low Froude number could be given in accordance with the specimen table given below.

Specimen Table for Data at low Froude Number.

Tank . . . .
Tank breadth . . . .
Tank depth . . . .
Tank cross-section area . . . .
Type of hull (e.g. tanker, etc.). . . . .
Model length b.p. (l) . . . .
Model length on water line . . . .
Model breadth. . . . .
Model draught. . . . .
Model trim . . . .
Model displacement . . . .
Model wetted surface area (S). . . . .
Block coefficient . . . .
Midship section coefficient. . . . .
Water-line coefficient . . . .
Longitudinal Position of centre of buoyancy .
½ angle of entrance at L.W.L. . . . .
Type of stern (single or twin screw) . . . . .
Turbulence stimulator fitted to model . . . .

Experiment results

Temperature of water . . . .
Kinematic viscosity of water (ν). . . . . . .

Speed (v)	Resistance (R)	$R_n = \frac{v\,l}{\nu}$	$C_t = \frac{R}{\frac{1}{2}\rho s v^2}$

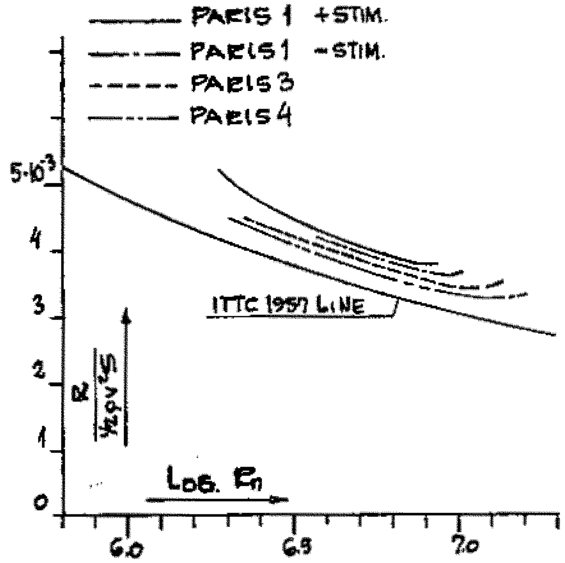
Establishment		William Denny & Bros. Ltd., Dumbarton					Istituto Vasca Navale, Rome				
Tank breadth		22.33 ft					12.50 m				
Tank depth		8,31 ft					6.30 m				
Tank cross section area		186 ft^2					72.5 m^2				
Model		A	B	C	D	E	UNITS	C 881	C 888	C 901	C 906
Type		Bulk carr.	Tanker	Pass. carg.	Vehicle fer.	Trawler		Submarine	Rev. body	Cargo	Submarine
Length b. p.	ft	17.0	14.0	15.667	14.0	11.5	m	4.16		6.240	
Length on WL	ft	17.4	14.39	15.76	14.0	12.14	m	4.189*	3.627*	6.434	4.331*
Breadth	ft	2.326	1.9514	2.843	2.544	2.755	m	$0.\overline{4}$	3.363	0.872	0.341
Draught aft	ft	0.946	0.778	0.929	0.709	1.424	m	$2,\overline{4}$	1.281	0.388	0.875
Draught forw.	ft	0.946	0,778	0.813	0.618	0.766	m	$2.\overline{4}$	12.81	0.388	0.875
Trim	ft	0	0	0.116	0.091	0	m	0	0	0	0
Displacement lbs	F.W.	1737	101.8	1336	774	1276	kg	494.00	261.80	1382.40	262.69
Wetted surface area	ft^2	58.53	40.20	47.64	34.74	41.24	m^2	5.7462	3.2488	7.7332	4.2110
Water plane area	ft^2	32.68	23.58	32.19	24.94	26.82	m^2	0.1650	0,1035	0.3263	0.0937
Midsh. section area	ft^2	2.192	1.505	2.30	1.549	2.696					
Block coefficient		0.7438	0.768	0.5520	0.525	0.590		0.5286	0.5478	0.6550	0.4804
Midsh. sect. coefficient		0.9959	0.991	0.9292	0.918	0.894		0.7395	0.7855	0.9644	0.7504
C. O. B. from mid Lbp	%	1.606 f	1,393 f.	0.408 a	0,427 a	3.52 a					
C. O. F. from mid Lbp	%	0.494 a	0.357 a	1,37 a	2.88 a	4.32 a					
2 angle of entrance	LWL	23.8°	28.4°	16.8°	12.7°	21.5°		20°32′	23°17′	14°30′	13°30′
Type of stern (No. of screws)		1	1	1	2	1		1	1	1	1
Turbulence stimulator		studs	studs	studs	studs	studs		none	studs	studs	studs
								*max. length			

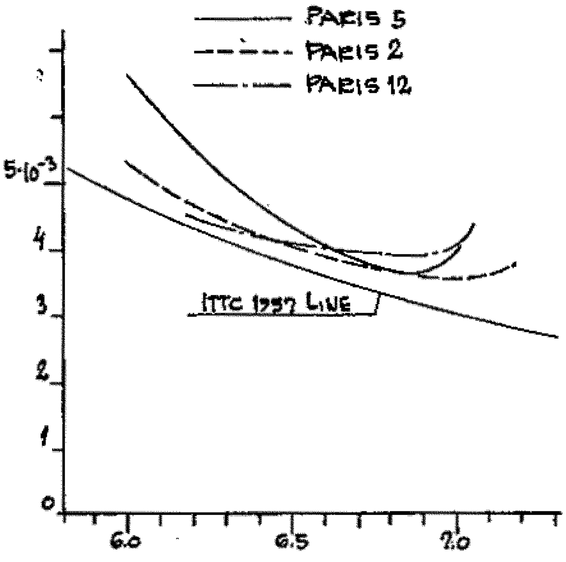
Establishment	Bassin d'Essais des Carènes, Paris.									
Tank breadth	13 m									
Tank depth	4 m									
Cross section area	52 m²									
Model	1	2	3	4	5	6	7	8	9	10
Reference	1012	1127	1155	1181	1272	1272	1278	1278	1329	1338
Length b. p.	5.718	6.960	7.810	8.602	7.486	7.486	7.569	7.569	7.178	3.88
Length on WL m	5.718	6.960	7.818	8.876	7.486	7.138	7.719	7.534	7.294	3.88
Breadth m	0.588	0.780	0.962	0.998	0.994	0.994	1.092	1.092	0.957	0.90
Draught m	0.181	0.231	0.261	0.297	0.411	0.243	0.404	0,262	0.411	0.390
Trim m	0.038	0.048	0	0	0	0.074	0	0.093	0	0.130
Displacement kg	320.39	607.49	1025.64	1388.48	2451.10	1380.93	2703.42	1692.97	2229.74	542.60
Wetted surface area m²	3.525	5.971	8.142	9.943	11.49	8.924	12.251	9.932	10.868	4.085
Water plane area m²	2.612	3.826	5.29	6.043	6.471		7.184		5.856	2.622
Midship section area m²	0.085	0.1471	0.226	0.2851	0.4052	0.2489	0.4391	0.2996	0.3902	0.2452
Block coefficient	0.523	0.491	0.523	0.522	0.8020	0.801	0.793	0.786	0.777	0.395
Midsh. sect, coefficient	0.8016	0.818	0.902	0.963	0.992	0.978	0.994	0.980	0.993	0.699
C. O. B. from mid Lbp %	1.2 a		1.8 a	0.6 a	2.9 f		3.0 f		2.6 f	0.3 a
C. O. F. from mid Lbp %		6.5 a	5.7 a	4.1 a	1.1 f		1.0 a		0.3 a	5.6 a
½ angle of entrance LWL	11°7′	6°34′	6°30′	6°	36°		34°		25 °	17°45′
Type of stern	2	2	2	4	1	1	1	1	1	1
Turbulence stimulation.	none/studs	none	none	none	none	none/studs	none	none	none	none

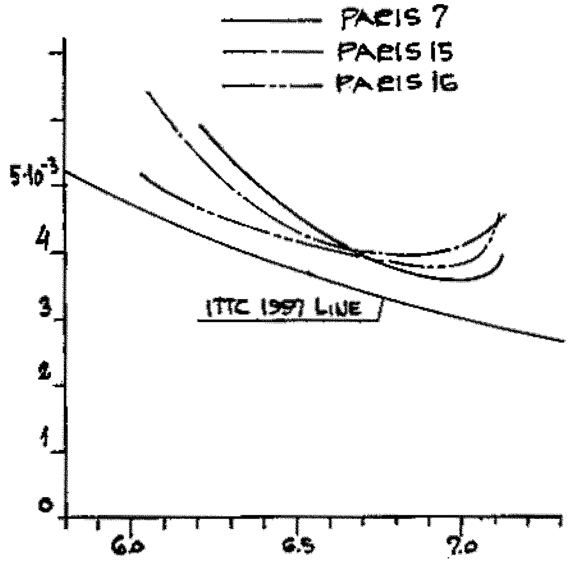
Establishment	Bassins d'Essais des Carènes, Paris									
Tank breadth	13 m									
Tank depth	4 m									
Tank cross section area	52 m^2									
Model	11	12	13	14	15	16				
Reference	1350	1351	1356	1357	1357	1359				
Length b. p.	6.735	6.500	4.20	6.885	6.885	6.173				
Length on WL m	6.816	6.404	4.515	7.053	6.852	6.410				
Breadth m	0.943	0.940	0.894	0.969	0.969	0.919				
Draught m	0.347	0.3475	0.385	0.401	0.2331	0.371				
Trim m	0	0	0.030	0	0.189	0				
Displacement kg	1467,5	1458.1	820.68	2055.5	1133.03	1405.0				
Wetted surface area m^2	8.3016	8.230	5.109	9.9961	7.6308	7.8964				
Water plane area m^2	2.6360	4.685	3.173	5.6230		3.8048				
Midsh. section area m^2	0.3212	0.3224	0,2967	0.3840	0.2216	0.2762				
Block coefficient	0.658	0.697	0.528	0.751	0.732	0.648				
Midsh. section coefficient	0.982	0.987	0.862	0.989	0.981	0.967				
C.O.B. from mid Lbp %	0.4 a	0.8 f	0.4 a	1.8 a		0.8 f				
C.O.F. from mid Lbp %	2.3 a	2.6 a	0.5 a	5.7 a		1.8 a				
½ angle of entrance LWL	14°	13°30′	26°30′	25°		13°30′				
Type of stern (No. of screws)	1	1	1	1	1	2				
Turbulence stimulator	none	none	none	none	none	none				

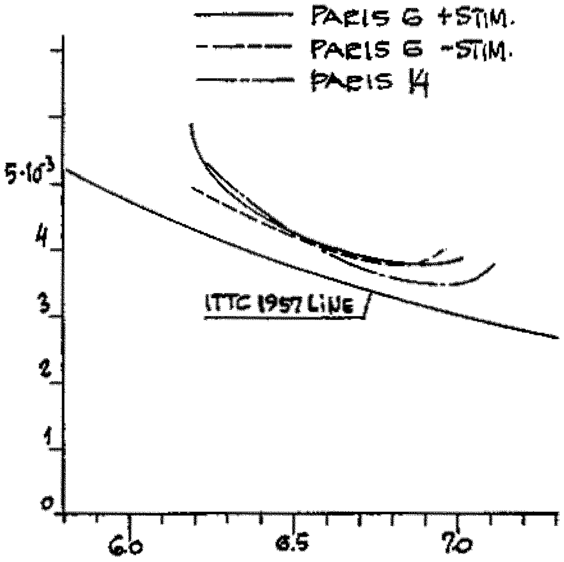
Establishment		Ship Laboratory — National Research Council, Canada									
Tank breadth		25 ft									
Tank depth		10 ft									
Tank cross section area		250 ft^2									
Model		141/892	141/893	146/1208	146/1196	146/1207	153/1373	87/185	87/196		
Type		Coastal	Patrol	Fishing			Coastal	Icebreaker			
Lenght b. p.	ft	14.333	14.333	7.3	7.3	7.3	13.333	8.333	8.333		
Lenght on LWL	ft	14.333	14.333	6.958			13.333	8.333	8.333		
Breadth	in.	28.94	28.96	27.36	27.68	28.03	39.86	24.8	24.8		
Draught aft	in.	9	9.5	8.646	10.2	12.6	11.50	10.3	10.3		
Draught forw.	in.	9	9.5	6.617	9.0	11.4	7.50	10.3	10.3		
Trim % LWL		0	0	2.37	1.37	1.37	2.5	0	0		
Displacement lbs		828.99	895.95	262.1	392.6	565.93	892.18	432.33	427.52		
Wetted surf. area	ft^2	34.766	36.239	17.365	20.458	23.868	38.644	18.613	17.316		
Waterplane area	ft^2	25.825	25.930	12.306	13.25	14.55	29.692	12.590	12.590		
Block coefficient		0.513	0.524	0.416	0.454	0.506	0.408	0.469	0.463		
Midsh. sect. coefficient		0.867	0.875	0.701	0.755	0.799	0.757	0.754	0.754		
C.O.B.		7.245	7.282	3.595	3.646	3.784	6.821	4.263	4.230		
C.O.F.		7.854	7.836	3.868	4.158	4.092	7.144				
½ angle of entrance LWL											
Type of stern (No. of screws)											
Turbulence stimulator		Tripwire	Tripwire	Tripwire	Tripwire	Tripwire	Tripwire	Tripwire	Tripwire		

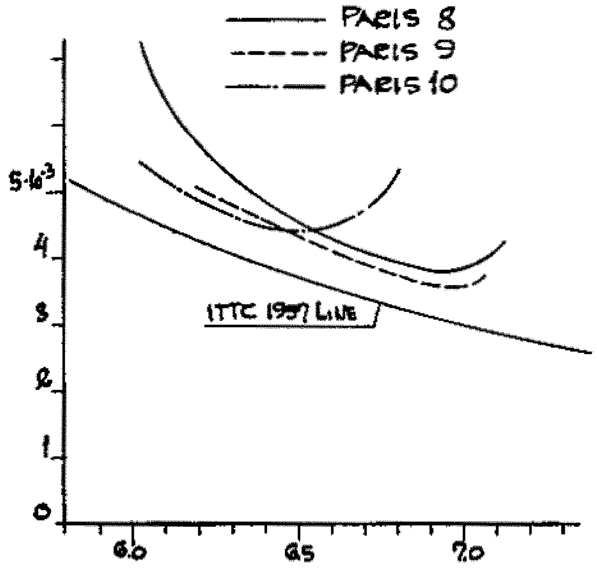
Establishment		Schiffbautechnische Versuchsanstalt in Wien							Mitsubishi Nagasaki		
Tank breadth		10 m							12.5 m		
Tank depth		5 m							6.5 m		
Tank cross section		50 m^2							ab. 80 m^2		
Model		615	685	697	699 A	708	717	726		1179	1263
Type		Cargo	Cargo	Riverboat	Tanker	Riverboat	Cargo	Cargo			
Length b. p.	m	6.08	5.708	6.000	6.604	6.000	6.0	5.321			
Length WL	m	6.152	5.708	6.000	6.664	6.005	6.106	5.448			
Breadth	m	0.88	0.725	0,822	0.894	0.822	0.846	0.893	Lpp/B :	7.1561	7.0766
Draught	m	0.184	0.150	0.089	0.290	0.088	0.342	0.297	B/d :	2.279	2.634
Trim		0	0	0	0	0	0	0			
Displacement	m^3	0.8112	0.5208	0.2936	1.2904	0.2936	1.1791	0.9329	$10^2 \nabla LWL^3$:	0.5831	0.5785
Wetted surf. area	m^2	6.568	5.215	4.716	7.825	4.827	6.927	5.873			
Water plane area	m^2	4.81	3.79	3.745	4.945	4.007	3.98	3.674			
Midsh. section area	m^2	0.1613	0.1086	0.0726	0.2570	0.0726	0.2845	0.2606			
Block coefficient		0.8345	0.838	0.67	0.7547	0.67	0.682	0.662		0.7150	0.7897
Midsh. sect. coefficient		0.996	0.992	0.994	0.993	0.994	0.985	0.984			
C.O.B. from mid Lbp	%	2.52 f	2.00 f	0.435 f	1.74 f	0.41 f	0.12 a	0.73 f			
C.O.F. from mid Lbp	%	1.30 f	0.58 a	4.19 a	5.95 f	4.26 a	0.21 a	1.15 a			
½ angle of entrance	LWL	46°	39°	13°	27°	13°	13°	20°			
Type of stern (No. of screws)		2	1	2	1	2	1	1			
Turbulence stimulator		Tripwire	Tripwire	none	studs	none	Tripwire	studs			

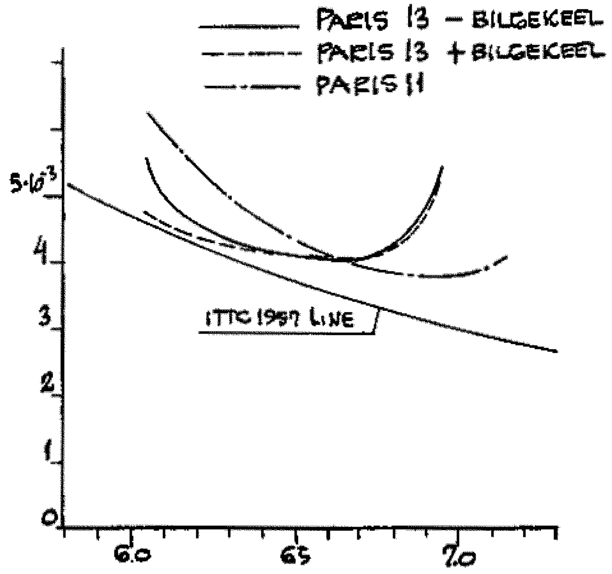

PARIS 1 +STIM.
PARIS 1 -STIM.
PARIS 3
PARIS 4
5·10⁻³
4
3
2
1
0
ITTC 1957 LINE
R / ½ρv²S
LOG. Rn
6.0
6.5
7.0

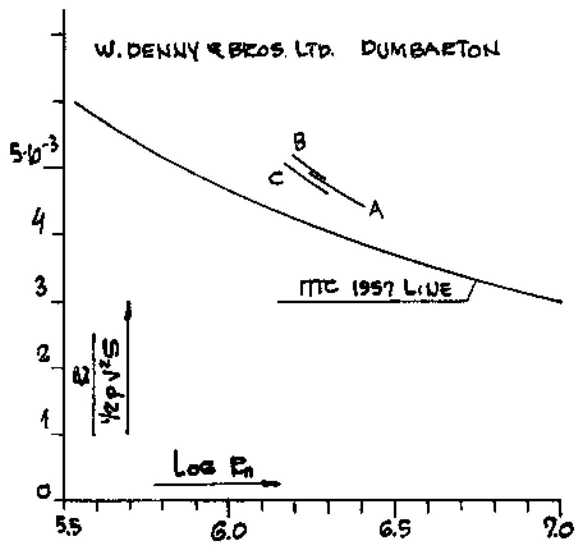

PARIS 5
PARIS 2
PARIS 12
5·10⁻³
4
3
2
1
0
ITTC 1957 LINE
6.0
6.5
7.0

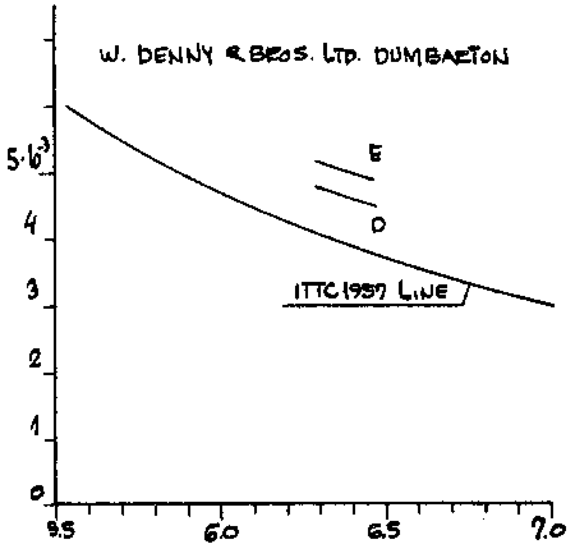

PARIS 7
PARIS 15
PARIS 16
5·10⁻³
4
3
2
1
0
ITTC 1957 LINE
6.0
6.5
7.0

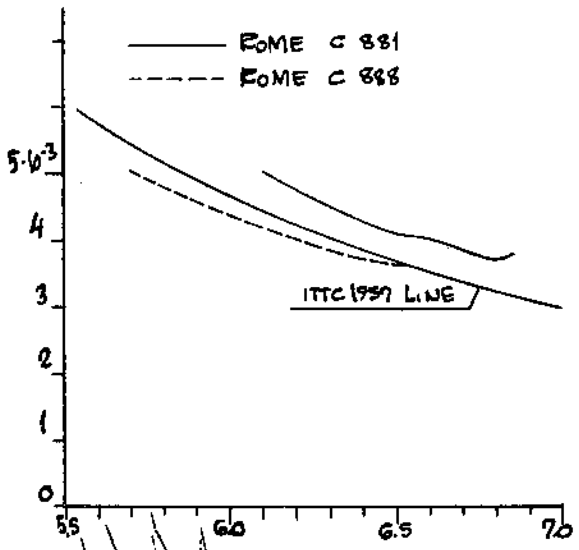

PARIS 6 +STIM.
PARIS 6 -STIM.
PARIS 14
5·10⁻³
4
3
2
1
0
ITTC 1957 LINE
6.0
6.5
7.0

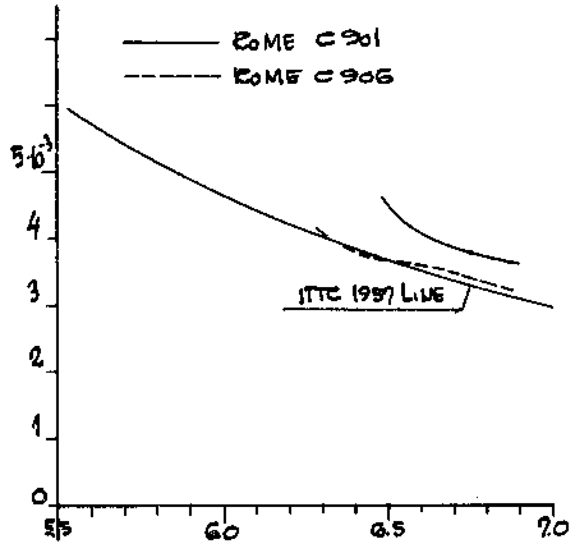

PARIS 8
PARIS 9
PARIS 10
5·10⁻³
4
3
2
1
0
ITTC 1957 LINE
6.0
6.5
7.0

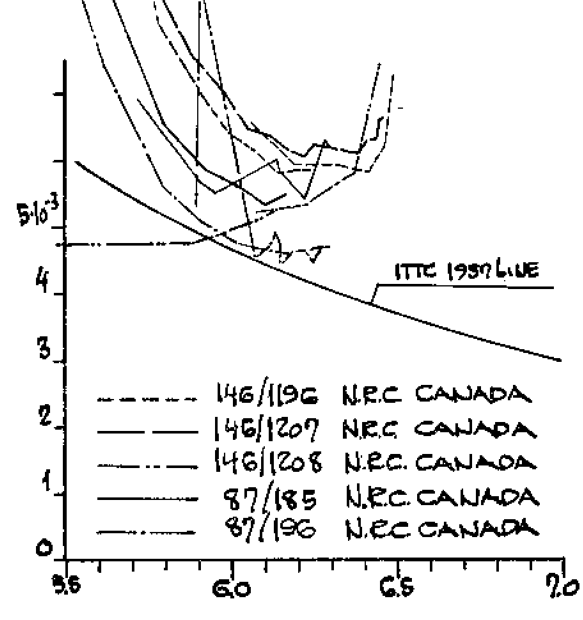

PARIS 13 - BILGEKEEL
PARIS 13 + BILGEKEEL
PARIS 11
5·10⁻³
4
3
2
1
0
ITTC 1957 LINE
6.0
6.5
7.0

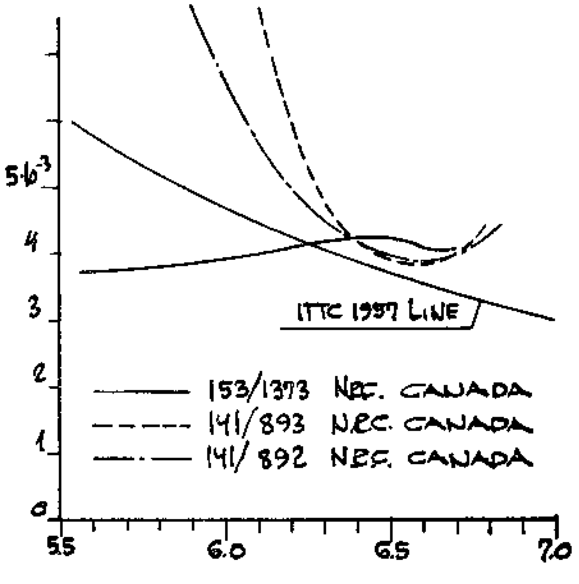

W. DENNY & BROS. LTD. DUMBARTON
B
C
A
ITTC 1957 LINE
5·10⁻³
4
3
2
1
0
R / ½ρV²S
Log Rn
5.5
6.0
6.5
7.0

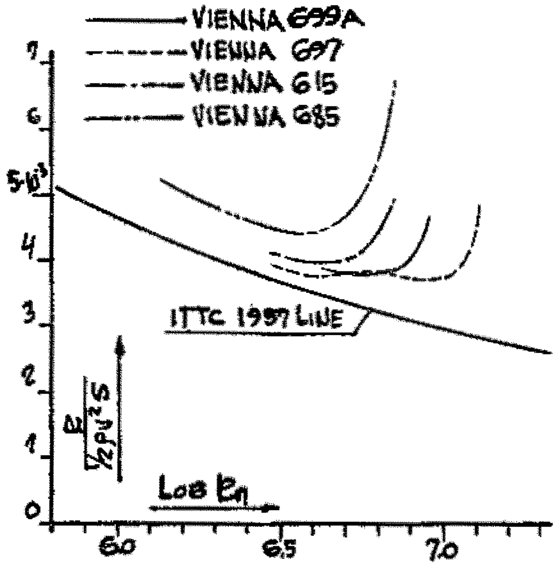

W. DENNY & BROS. LTD. DUMBARTON
E
D
ITTC 1957 LINE
5·10⁻³
4
3
2
1
0
5.5
6.0
6.5
7.0

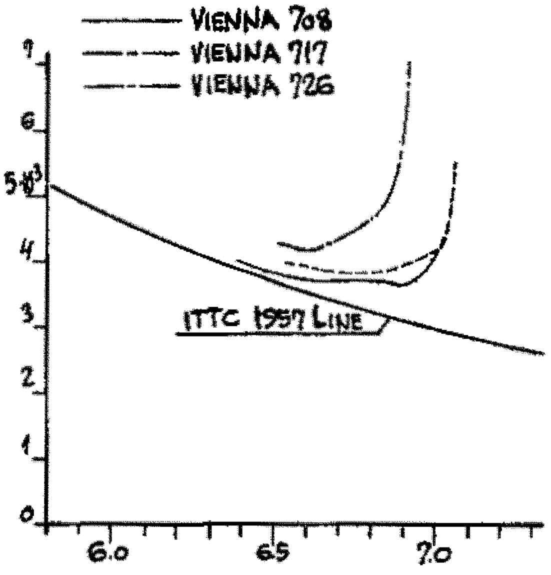

ROME C 881
ROME C 888
ITTC 1957 LINE
5·10⁻³
4
3
2
1
0
5.5
6.0
6.5
7.0

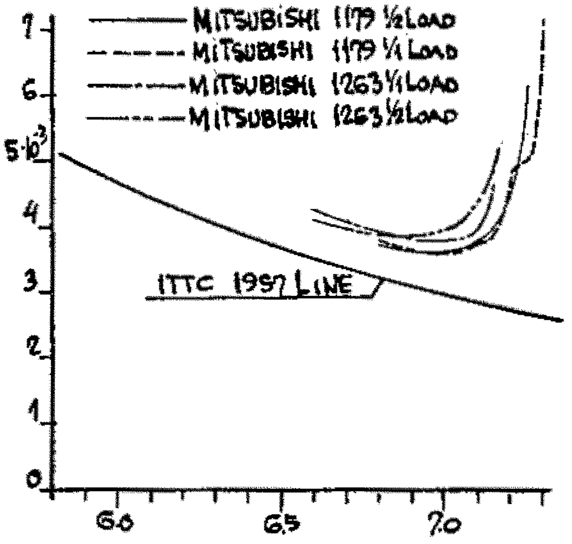

ROME C 901
ROME C 906
ITTC 1957 LINE
5·10⁻³
4
3
2
1
0
5.5
6.0
6.5
7.0

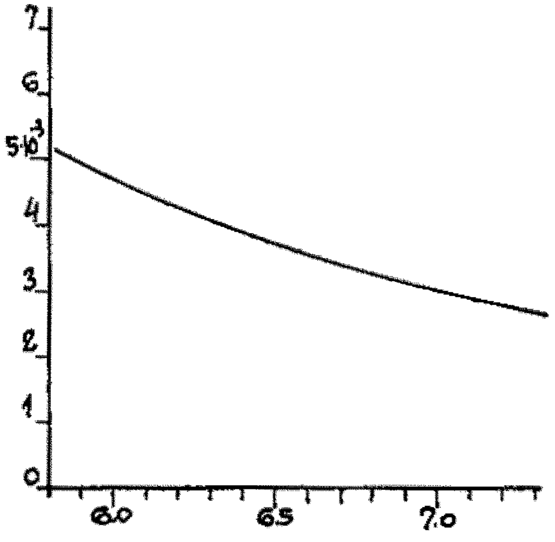

ITTC 1957 LINE
146/1196 N.R.C CANADA
146/1207 N.R.C CANADA
146/1208 N.R.C. CANADA
87/185 N.R.C CANADA
87/196 N.R.C CANADA
5·10⁻³
4
3
2
1
0
5.5
6.0
6.5
7.0

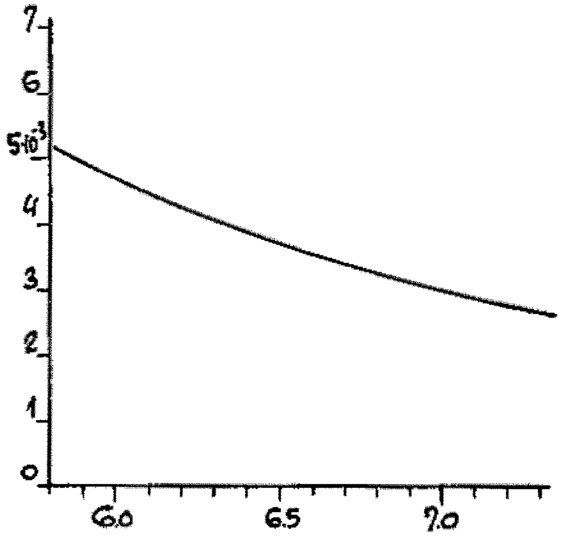

ITTC 1957 LINE
153/1373 N.R.C. CANADA
141/893 N.R.C. CANADA
141/892 N.R.C. CANADA
5·10⁻³
4
3
2
1
0
5.5
6.0
6.5
7.0

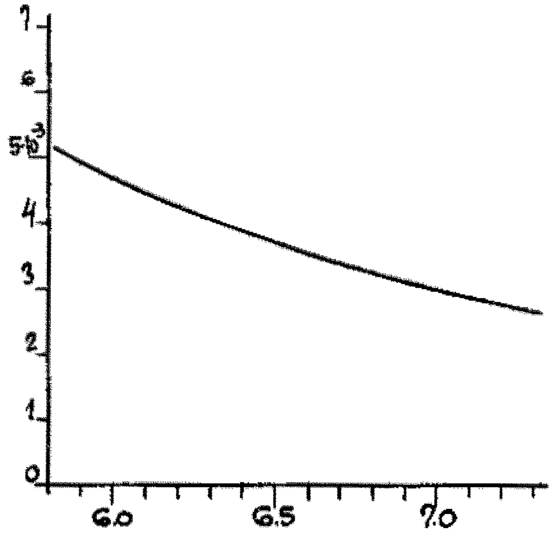

VIENNA 699A
VIENNA 697
VIENNA 615
VIENNA 685
ITTC 1957 LINE
R / ½ρv²S
Log Rn
7
6
5·10⁻³
4
3
2
1
0
6.0
6.5
7.0


VIENNA 708
VIENNA 717
VIENNA 726
ITTC 1957 LINE
7
6
5·10⁻³
4
3
2
1
0
6.0
6.5
7.0


MITSUBISHI 1179 ½ LOAD
MITSUBISHI 1179 ¼ LOAD
MITSUBISHI 1263 ¼ LOAD
MITSUBISHI 1263 ½ LOAD
ITTC 1957 LINE
7
6
5·10⁻³
4
3
2
1
0
6.0
6.5
7.0


7
6
5·10⁻³
4
3
2
1
0
6.0
6.5
7.0


7
6
5·10⁻³
4
3
2
1
0
6.0
6.5
7.0


7
6
5·10⁻³
4
3
2
1
0
6.0
6.5
7.0

(ii): Replies to the Above Circular

Direct replies (*) have been received from the following tanks:

1. Bassin d'Essais des Carènes, Paris.
2. William Denny & Bros. Ltd., Dumbarton.
3. Experimental Tank of Laboratory, Mitsubishi Shipbuilding & Engineering Co. Ltd., Nagasaki.
4. Istituto Vasca Navale, Rome.
5. National Research Council, Ottawa.
6. Schiffbautechnische Versuchsanstalt in Wien

For comparison all C_f-curves are reproduced appended, together with pertinent data regarding the models tested.

(iii): Recent References

[1] Sasajima H. Yoshida E., Tanaka J. and Nakato M.: *Form Effects on Frictional Resistance of Ship and Power Prediction of Large Tankers Journ. Soc. Nav. Arch.*, Japan, 103, 1958.

[2] Tamiya S.: *Form Coefficients, Institute of Industrial Science*, Tokyo University.

[3] Inui T.: *On a Resistance Dynamometer for a Submerged Body — Its Details and Applications to Form Drag Measurements*, Journ. Soc. Nav. Arch. Japan, Vol. 99, 1956.

[4] Hughes G.: *The Prediction of Smooth Ship Resistance from Model Data*, TINA, 1958.

[5] Lap, A.J.W.: *Some Applications of the Threedimensional Extrapolation of Ship Frictional Resistance.* Trans. Inst. Eng. & Shipb. in Scotland, 1958.

[6] Henschke W.: *Die Drahtschleppmethode und Masstabuntersuchungen mit Fischkuttermodellen.* Bericht Nr. 224, Schiffbau Versuchsanstalt, Berlin-Potsdam.

[7] Ridgely-Nevitt C.: *Geometrically Similar Models.* An Investigation of Some Problems Resulting from Their Resistance Values. Int. Shipbuilding Progress, July 1959.

[8] Inui T.: *Study on Wave-Making Resistance of Ships.* Soc.-Nav. Arch. Japan 60th Anniversary Series, vol. 2.

[9] Masataschi Bessho: *On a Wave Theory of a Submerged Body*, Soc. Nav. Arch. Japan, 60 Anniversary Series, vol. 2.

[10] Amtsberg H., Schwanecke H.: *Uber Widerstands- und Druckmessungen an getauchten Rotations körpern* Schiffstechnik, Sept. 1958.

[11] Wieghardt K.: *Betrachtungen zum Zähigkeitwiederstand von Schiffen*, Jahrbuch der S.T.G., 1958.

[12] Petersohn E.G.M.: *The Pressure Drag due to Turbulent Separation on Bodies of Revolution with varying Boundary Layer Thickness*, Report 75, The Aeronautical Research Institute of Sweden, 1957.

(*) They are given above.

APPENDIX III

(i): Circular to Tank Superintendents

Standard models for resistance testing.

At the 8th ITTC held in Madrid in September, 1957, a paper on "Introductory Remarks on Techniques of Measuring Model Resistance" by Dr. G. Kempf was included in the formal contributions prepared for the session on Subjects 2 and 4 — Skin Friction and Turbulence Stimulation, and the Conference at its general session decided that "Techniques of Measuring Model Resistance" should be included in the programme for the next Conference under these same subjects.

The questions raised in Dr. Kempf's paper did not receive any attention because the session was devoted exclusively to consideration of the model-ship correlation line, but it is well known that these questions are a matter of concern to many tanks. In particular this paper drew attention to the uncertainties which exist concerning the measurement of model resistance and the comparison of results obtained in different tanks and at different times in the same tank. To help resolve these uncertainties the original proposal of General Barrillon was strongly endorsed by Dr. Kempf, that "every tank... should procure a standard model or two of a material which will retain its shape and its smooth surface".

At a meeting of the Skin Friction Committee held in Copenhagen in September, 1958, the Committee was informed that work of the kind proposed in Dr. Kempf's paper had, in fact, been started in 1956/57 in four of the British tanks (John Brown, Denny, Vickers and NPL), and a joint programme of testing and comparison of the results is now in continuous operation, each tank possessing "identical" models made in laminated fibre glass. This work began as an attempt to find the reasons for and, if possible, to eliminate erratic changes in model resistance, but has naturally led to inter-tank comparisons. The Committee was shown the preliminary results of this work and expressed great interest. The possibility of other tanks being able to participate was discussed and it was agreed that all tanks should be informed.

Details concerning the British standard models are given in the attached note. It is possible that other tanks at not too great a distance from Great Britain may wish to avail themselves of the opportunity of obtaining an "identical" model from the same mould. Alternatively, any tank may wish to have a model of the same form and size made of suitable material in its own country. In either case the Skin Friction Committee would support the extension of this investigation to as many tanks as possible. It has also been informed that the British tanks hope to present a joint statement to the next Conference of the results obtained up to that time.

As indicated in the attached note the mould for the British standard models is being retained at Ship Division, NPL, for the time being. While any enquiry for the supply of a similar model should be made direct to Messrs. Halmatic, the Superintendent of Ship Division would like to be informed if you are interested so that it will be known if there is any demand for the mould to be retained. The Skin Friction Committee is also interested to know whether you wish to participate in any joint research on the subject. You are requested therefore to kindly fill in and return the attached forms.

(ii): CIRCULAR TO TANKS POSSESSING STANDARD MODELS

Standard Models.

A number of member tanks of the ITTC have acquired a standard model made of laminated fibreglass from the same mould as used for the original standard models as supplied to four British tanks; others may be acquiring similar models or making their own to the same design.

All of these models so far have been sent first of all to NPL, Teddington where beams were fitted, approximate water lines marked and the bow fitted with studs.

The four British tanks concerned are Messrs. John Brown (Clydebank), William Denny (Dumbarton), NPL (Teddington), and Vickers-Armstrongs (St. Albans). These tanks have been making tests at regular intervals with their standard models for the past 18 months. They are working to an agreed programme, and the results, after the initial analysis has been made, are being sent to NPL for a further correlating analysis to be made.

It is felt that the other tanks who have acquired one of these models or intend to do so may like to have details of the design, and of the test procedure being followed in the British tanks and at NPL for the correlating analysis. These details are given on the attached sheets.

The uniform test conditions set out on Sheet 3 are intended as a guide, and tanks may have their own preferences regarding such items as number of runs and the spacing of these runs in relation to speed. Some tanks may prefer to adopt these conditions and to make other tests in addition. Whatever scheme is used it is hoped that the division of the tests into the five groups as set out on Sheet 4 will be adopted for the correlating analysis so that future comparisons may be made quickly and easily. This grouping is equally suitable whether the tests are concentrated at certain speeds as set out on Sheet 3 or uniformly spaced over the whole of the speed range.

The reference datum line of which the ordinates are given on Sheet 5 was obtained from a combined plot of the results of two sets of tests with each of the first four standard models in NPL No. 2 tank. This line should not be regarded necessarily as the best average for this tank but simply as a convenient datum for comparative work.

It is emphasized that NPL cannot undertake the complete correlating analysis for any other tanks. The Resistance Committee will, however, be glad to receive data and to compare results and to report to Conference provided these data are presented in the final form indicated in Figure 4. If the data are presented in other forms the work of comparison will be too onerous for the Committee to undertake.

Experience in the British tanks has shown that it is desirable to make tests at fairly regular intervals. About once every two weeks is a good average. Testing should be continued for a long period if the immediate purpose of investigating "erratic changes in measured resistance" is to be fulfilled, and also if the work is to be of value for the comparison of results between tanks. It is suggested that at least 12 sets of tests in any one tank should be made before sending results to the Committee.

Standard models

Design Details

Design (*)	B.S.R.A.
Block coefficient	0.65

(*) ALMY AND HUGHES : *Model Experiments on a Series of 0.65 Block Coefficient Forms. Part I*, I. N. A. 1954.

Maximum section coefficient	0.981	
Prismatic coefficient	0.663	
L.C.B. from midships	0.5 per cent L.B.P. aft	
Half angle of entrance	12.3 degrees	
Length/breadth	7.27	
Breadth/draught	2.12	
Bilge radius	6 ft	
Breadth	55 ft	for ship 400 ft L.B.P.
Draught	26 ft	
Midship section area	1403 ft²	
Displacement	10,623 tons salt water	
Scale of model to 400 ft ship	1/25.26	

Model length b.p.	15.835 ft
Model surface area	49.51 ft²
Model midship section area	2.20 ft²
Model displacement	1439.5 lbs fresh water
Trim	Level

Measurement (by hook gauge) between tops of wood beams and the water surface, as trimmed at NPL } .... model ...... ins.

NOTE : A wood model was first made from which to form the fibreglass mould. Due to shrinkage of the wood during the preparation of this model it became necessary to re-cut to a slightly smaller scale than at first intended. This accounts for the odd scale as seen in Sheet 1. Despite the second cutting some further shrinkage took place, leaving a slight taper of the sides of the model at amidships (which should be parallel), the lower levels being narrower than at the waterline. There is also a small longitudinal curvature of the keel due to movement of the wood after finishing.

STANDARD MODELS — Offsets and Area Curve Ordinates.

Station	Draught for 400 ft Ship									
	2 ft	6 ft	10 ft	14 ft	18 ft	22 ft	26 ft	30 lt	34 ft	26 ft
	Waterline Offsets									Area Curve Ordinate
AP 0	—	—	—	—	—	—	17.5	26.7	33.8	1.8
1/4	1.9	2.5	3.0	3.7	5.6	17.0	31.0	40.3	47.5	7.6
1/2	3.2	6.2	9.3	13.0	19.6	31.2	43.7	52.7	59.4	16.2
1	8.4	16.2	23.3	32.0	43.4	55.4	65.5	73.0	78.7	33.0
1 1/2	15.8	29.8	40.0	51.2	63.5	73.9	81.7	87.3	91.3	49.0
2	26.3	45.2	58.0	69.2	78.9	86.6	92.1	95.7	97.8	63.8
2 1/2	40.0	61.4	74.4	83.5	89.9	94.4	97.5	99.3	100.0	76.9
3	56.2	76.3	87.1	93.5	96.9	98.9	99.7	100.0	100.0	87.7
3 1/2	71.1	87.7	95.1	98.6	100.0	100.0	100.0	100.0	100.0	94.1
4	84.0	95.7	99.7	100.0	100.0	100.0	100.0	100.0	100.0	97.9
5	92.9	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
6	89.3	98.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.1
6 1/2	81.7	93.2	97.1	98.5	99.3	99.7	100.0	100.0	100.0	96.6
7	70.0	84.5	90.3	92.9	94.4	95.5	96.3	97.0	97.5	89.6
7 1/2	55.6	71.1	78.1	81.8	84.3	86.1	87.5	88.7	89.9	78.3
8	39.6	54.5	61.9	66.3	69.3	71.9	74.2	76.1	77.6	62.5
8 1/2	24.0	37.2	43.6	47.7	50.9	53.4	56,0	58.7	61.6	44.7
9	9.9	19.8	25.4	29.2	31.6	34.0	36.5	39.1	42.9	2.63
9 1/2	—	5.1	9.2	12.0	13.8	15.6	17.3	20.0	23.3	10.0
9 3/4	—	—	2.2	4.9	6.3	7.5	8.9	11.2	13.8	3.9
FP 10	—	—	—	—	—	—	0	2.4	4.3	0

Standard models

Uniform Test Conditions adopted by the British Tanks.

(1) Anti-drift curtains will *not* be used.

(2) Drift of the water along the tank may be measured if desired by means of a float or otherwise before each run so that any excessive growth of drift may be noted. Normally no correction will be made for drift and the land speed will be used in the analysis.

(3) The interval between runs (start to start) will be 10 minutes.

(4) The tests will be made as nearly as possible at agreed speeds of advance in all tanks so that the values of Froude number are the same regardless of temperature differences. The agreed speeds are 3.10, 3.88, 4.66, 5.43 and 6.21 ft/sec., which correspond to Reynolds number of 4, 5, 6, 7 and 8 million at 59° F.

(5) The tests will be made in the order 6.21, 5.43, 4.66, 3.88 and 3.10 ft/sec., (highest to lowest), and this sequence will be repeated 4 times, making 20 runs in all.

(6) The temperature of the water will be measured at the mid-length of the test section, at 1 ft below the surface and at mid-depth and bottom of the tank, both before the first run and after the last run.

(7) Before each test the model surface will be examined and cleaned if necessary to remove dirt and grease. It will be rubbed down wet such as with a Spontex sponge when being put into the water. A note will be made of any surface deterioration.

(8) The model will be ballasted always to the agreed displacement and the trim checked. Any discrepancy from the original trim will be noted.

(9) While the position of the tow-point may differ a little from one tank to another because of internal arrangements of apparatus, etc., it is desirable that the height of the tow-point should be closely the same for the comparative tests. It is suggested that this height should be within 0.5 in. above and 0.5 in. below the load water plane. Each tank should use the same position for all of its own tests, and in all other respects carry out a uniform procedure.

(10) Measurements of viscosity and sampling of the water for biological content will not generally be continued except as individual tanks may consider to be desirable or necessary.

(11) The resistance test results will be corrected at each tank to 59°F using the ITTC 1957 model-ship correlation line. These results will then be entered on the standard table (*) and sent to NPL for further analysis.

Standard models

Procedure for Correlating Analysis.

1. The results are entered in a standard table as shown in Figure 3.

2. The results as corrected to 59°F are used in the further analysis.

3. These results are analysed in five groups

Group No	1	2	3	4	5
Range of Reynolds number (million)	below 4.5	4.5 to 5.5	5.5 to 6.5	6.5 to 7.5	above 7.5
Mean value of Reynolds number (million)	4	5	6	7	8
Mean value of Froude number	0.137	0.172	0.206	0.241	0.275

4. The actual difference of each experiment spot from the datum line (see Sheet 5) is expressed as a percentage of the datum value. The arithmetic mean of these percentages is then taken for each group. This is called the *day mean value* for the group.

5. 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.

6. 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

The water temperature is also plotted in each figure.

A typical plotting is shown in Figure 4.

(*) See Figure 3.

STANDARD MODELS — Ordinates of Standard Model Datum Resistance Curve at 59° F.

R_n (million)	$10^3 C_t$	R_n (million)	$10^3 C_t$	R_n (million)	$10^3 C_t$	R_n (million)	$10^3 C_t$
3.50	4.168	5.15	4.034	6.80	4.153	7.82	5.108
3.55	4.158	5.20	4.043	6.85	4.166	7.84	5.154
3.60	4.146	5.25	4.051	6.90	4.176	7.86	5.211
3.65	4.136	5.30	4.058	6.95	4.187	7.88	5.264
3.70	4.126	5.35	4.062	7.00	4.197	7.90	5.317
3.75	4.118	5.40	4.066	7.05	4.207	7.92	5.373
3.80	4.109	5.45	4.068	7.10	4.219	7.94	5.428
3.85	4.102	5.50	4.071	7.15	4.236	7.96	5.484
3.90	4.094	5.55	4.072	7.20	4.252	7.98	5.539
3.95	4.088	5.60	4.071	7.25	4.274	8.00	5.595
4.00	4.082	5.65	4.070	7.30	4.302	8.02	5.655
4.05	4.077	5.70	4.069	7.35	4.337	8.04	5.715
4.10	4.072	5.75	4.067	7.40	4.379	8.06	5.776
4.15	4.067	5.80	4.065	7.42	4.399	8.08	5.836
4.20	4.061	5.85	4.067	7.44	4.419	8.10	5.896
4.25	4.059	5.90	4.070	7.46	4.441	8.12	5.958
4.30	4.056	5.95	4.078	7.48	4.465	8.14	6.022
4.35	4.053	6.00	4.091	7.50	4.490	8.16	6.087
4.40	4.050	6.05	4.107	7.52	4.519	8.18	6.154
4.45	4.046	6.10	4.118	7.54	4.548	8.20	6.224
4.50	4.042	6.15	4.121	7.56	4.580	8.22	6.300
4.55	4.040	6.20	4.121	7.58	4.611	8.24	6.376
4.60	4.037	6.25	4.120	7.60	4.644	8.26	6.452
4.65	4.032	6.30	4.115	7.62	4.679	8.28	6.528
4.70	4.025	6.35	4.111	7.64	4.717	8.30	6.604
4.75	4.017	6.40	4.106	7.66	4.755	8.32	6.685
4.80	4.009	6.45	4.102	7.68	4.793	8.34	6.766
4.85	4.004	6.50	4.100	7.70	4.832	8.36	6.847
4.90	4.001	6.55	4.101	7.72	4.877	8.38	6.928
4.95	4.000	6.60	4.105	7.74	4.921	8.40	7.009
5.00	4.004	6.65	4.111	7.76	4.965		
5.05	4.011	6.70	4.122	7.78	5.013		
5.10	4.021	6.75	4.140	7.80	5.061		

As obtained from tests in N. P. L. No.2 tank $a/A = 1.24\,\%$; $\nabla/A^{3/2} = 0{,}97\,\%$.

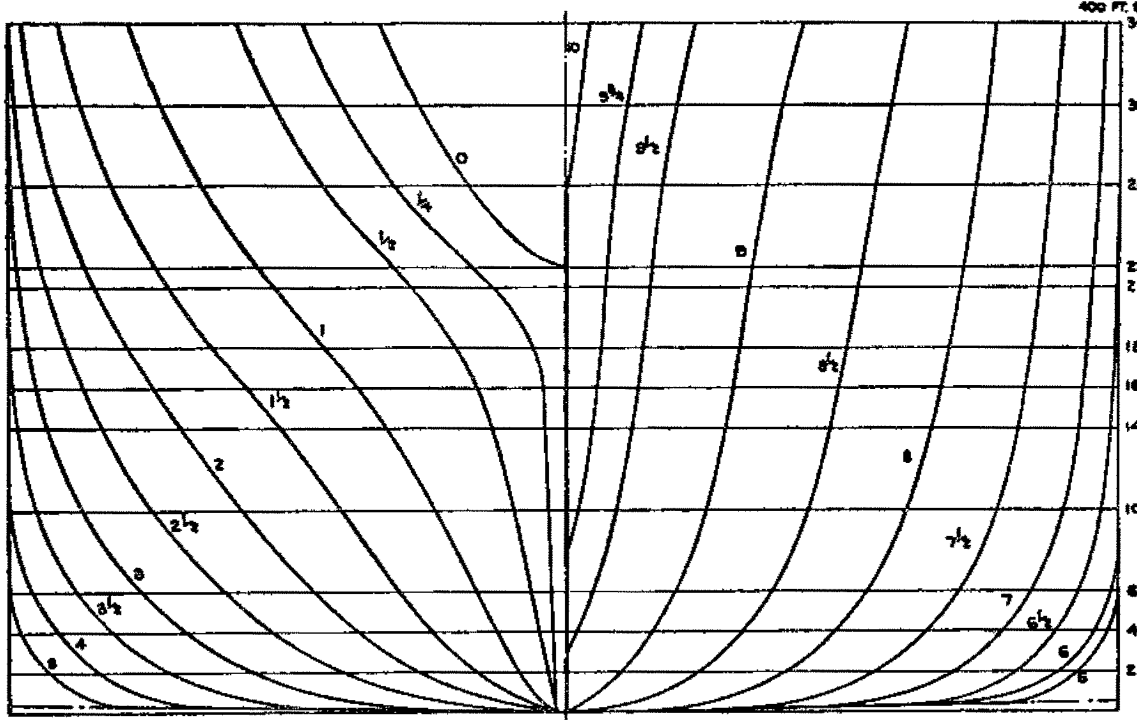


FIG. 1.
Standard model body sections.

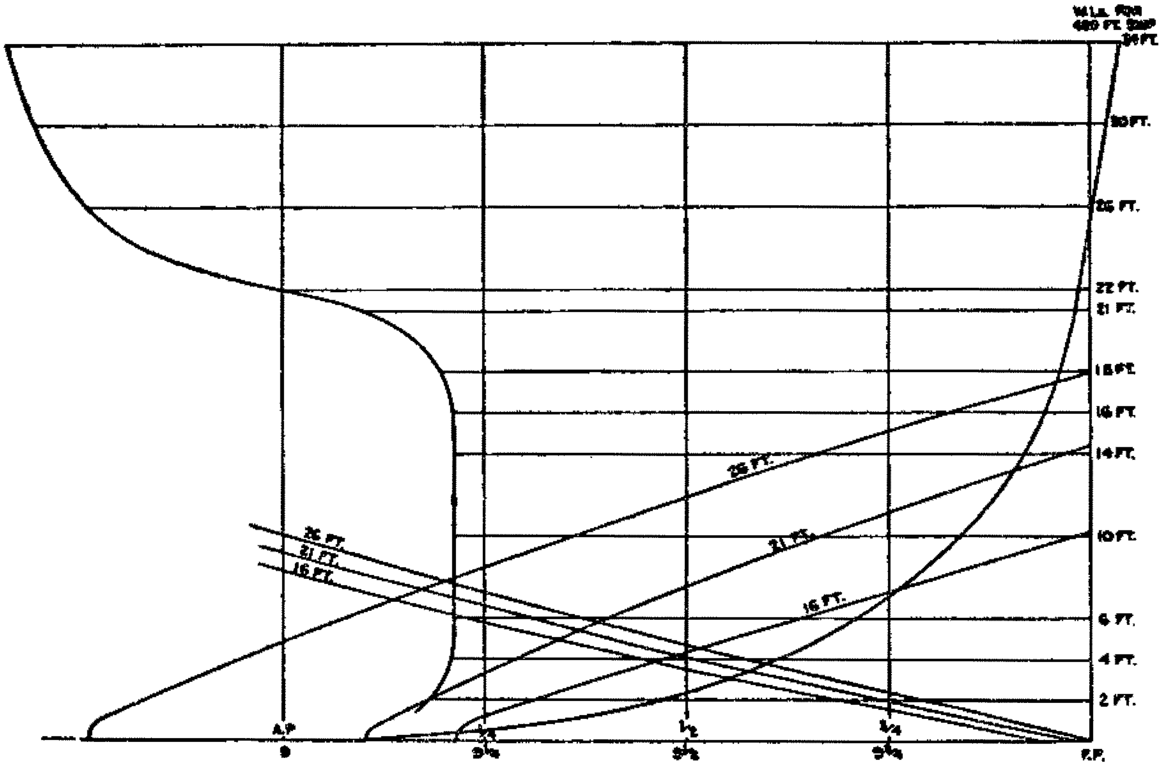


FIG. 2.
Standard model stem and stern contours and water-line endings.

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

DATE
MODEL Nº
TANK

TEST Nº
L 15·635 ft
S 49·51 ft²
LARGEST SECTION AREA (a) 2·20 ft²
Δ 1439·5 LB. F.W.
TRIM LEVEL
STIMULATOR STUDS
SURFACE

TOW-POINT :-
FROM LWP in ABOVE / BELOW
FROM ⊠ ft FORWARD / AFT
WIDTH OF TANK ft
DEPTH OF WATER ft
TANK SECTION AREA (A) ft²
a/A (%)
TEMPERATURE (°F):-
AIR
WATER SURFACE
" MID DEPTH
" BOTTOM

	ρ	ν
	(LB.SEC²/FT⁴)	(FT²/SEC)
(a)		
(b)		

(a) FROM SNAME TABLES (AT °F) (USED FOR 'AS MEASURED' CALCULATIONS)

(b) WATER SAMPLE AT TIME OF TEST (AT 59° F)

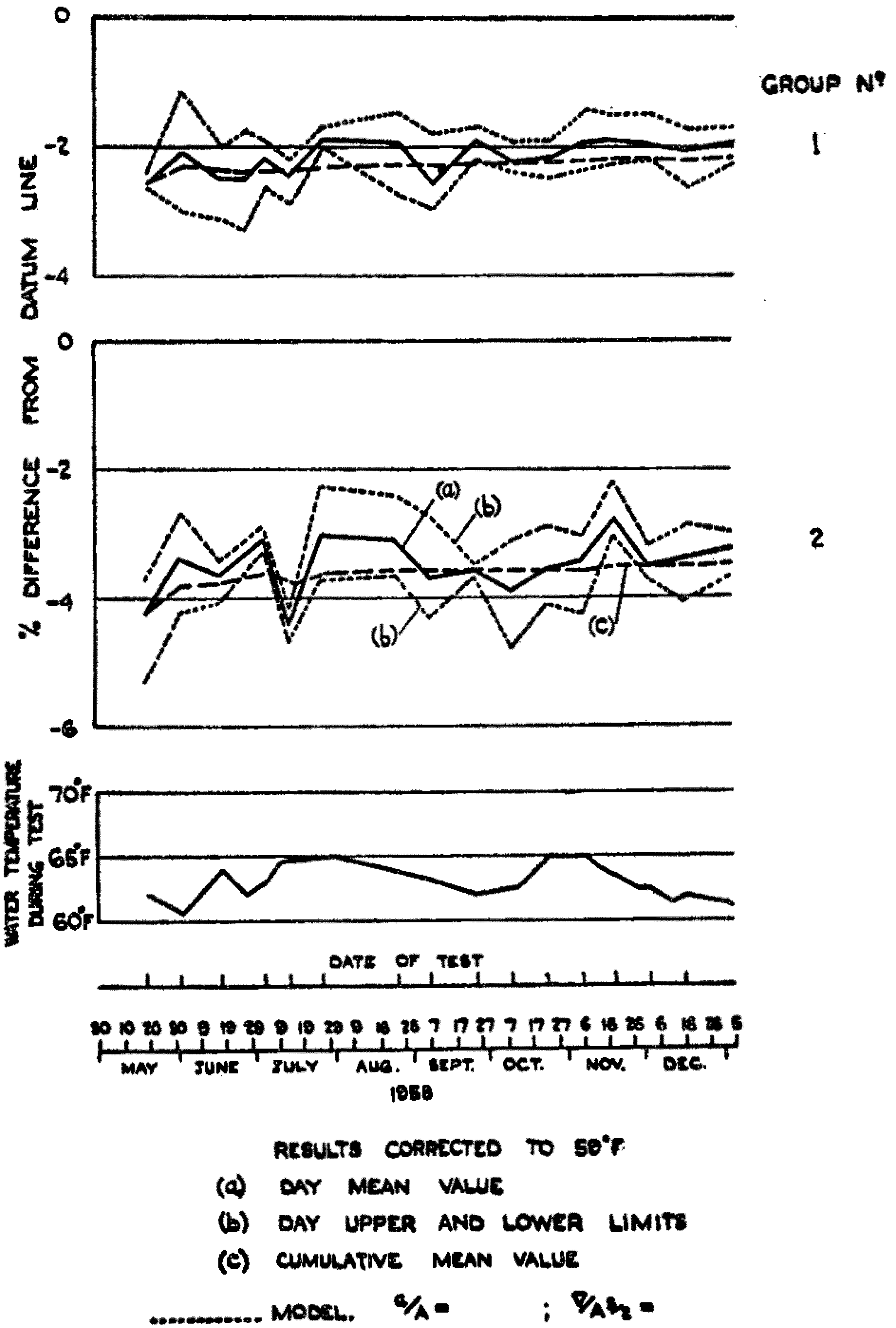
RUN Nº	TIME OF DAY	SPEED V ft/sec	RESISTANCE R LB	AS MEASURED		CORRECTED TO 59°F	
				R_n	C_t	R_n	C_t

$R_n = \frac{VL}{\nu}$ IN UNITS OF 10^6; $C_t = \frac{R}{\frac{1}{2}\rho S V^2}$ IN UNITS OF 10^{-3}

I.T.T.C. 1957 SHIP-MODEL CORRELATION LINE USED FOR CORRECTION TO 59°F

REMARKS :-

Fig. 3.



GROUP Nº
1
2
0
-2
-4
0
-2
-4
-6
% DIFFERENCE FROM DATUM LINE
(a)
(b)
(b)
(c)
WATER TEMPERATURE DURING TEST
70°F
65°F
60°F
DATE OF TEST
30 10 20 30 9 19 29 9 19 29 8 18 28 7 17 27 7 17 27 6 16 26 6 16 26 6
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
1958
RESULTS CORRECTED TO 58°F
(a) DAY MEAN VALUE
(b) DAY UPPER AND LOWER LIMITS
(c) CUMULATIVE MEAN VALUE
MODEL. $c/A =$; $D/Ah_2 =$

FIG. 4.

APPENDIX IV

REFERENCES CONCERNING TANK BOUNDARY INTERFERENCE

[1] Schlichting O.: *Schiffswiderstand auf beschränkter* Wassertiefe, Jahrbuch der S.T.G., 1934

[2] Landweber L.: *Tests of a Model in Restricted Channels* EMB report 460, 1939.

[3] Schuster S.: *Beitrag zur Frage der Kanalkorrektur bei Modelversuchen,* Schiffstechnik Bd. 3, 1955/56.

[4] Emerson A.: *Ship Model Size and Tank Boundary Correction,* Transactions of the North East Coast Institution of Engineers and Shipbuilders, vol. 76, Dec. 1959.

[5] Numata E.: *Effect of Tank Size on Self-Propulsion Tests of a Victory Ship Model,* Report No. 635, Dec. 1956. Davidson Laboratory, Stevens Institute of Technology.

[6] Hughes G.: *The Effect of Model and Tank Size in Two Series of Resistance Tests,* TINA 1956.

[7] Taniguchi K., Tamura K.: *On the Blockage Effect,* Report 307, Experimental Tank (Nagasaki) Laboratory Mitsubishi Shipbuilding and Engineering Co. Ltd., 1958.

[8] Telfer E.V.: *Ship-Model Correlation and Tank Wall Effect,* Transactions of the North East Coast Institution of Engineers and Shipbuilders, 70, Nov. 1953.

[9] Comstock, J. P., Hancock C. H.: *The Effect o Size of Towing Tank on Model Resistance,* SNAME, 1942.

[10] Tupper K. F.: *Contribution to the Question of the Effect of the Basin Walls on Ship Model Tests,* Fifth Int. Congr. for Appl. Mech., 1958.

APPENDIX V

REFERENCES CONCERNING CORRELATION BETWEEN RESISTANCES OF LARGE AND SMALL MODELS

[1] Numata E.: *Correlation Between Resistances of Large and Small Models,* Note No. 537, Davidson Laboratory, Stevens Institute of Technology.

[2] Ridgely-Nevitt C.: *Geometrically Similar Models. An Investigation of Some Problems Resulting from Their Resistance Values,* International Shipbuilding Progress, July 1959.

APPENDIX VI

REFERENCES CONCERNING RESISTANCE OF ROUGH SURFACES

[1] Granville P. S.: *The Frictional Resistance and Turbulent Boundary layer of Rough Surfaces,* DTMB 1024, July 1958.

[2] Hama F. R.: *Boundary-Layer Characteristics for Smooth and Rough Surfaces,* SNAME 1954, vol. 62.

[3] Lap A.J.W.: *Some Applications of the Three-Dimensional Extrapolation of Ship Frictional Resistance.* The Institution of Engineers and Shipbuilders in Scotland, March 1958.

APPENDIX VII

REFERENCES CONCERNING TRANSITION FROM LAMINAR TO TURBUBENT FLOW

[1] Schubauer G. B., Skramstad H. K.: *Laminar Boundary Layer Oscillations and Transition on a Flat Plate.* NACA report No. 909, 1948.

[2] Schubauer G. B., Klebanoff P. S.: *Contributions on the Mechanics of Boundary Layer Transition,* Part of *Boundary Layer Effects in Aerodynamics.* Proceedings of a Symposium held at the N. P. L. on 31st March and 1st April 1955.

[3] Hama, Long and Hegarty: *On Transition from Laminar to Turbulent Flow.* Journal of Applied Physics, 1957.

[4] Klebanoff and Tidstrom: *Evolution of Amplified Waves Leading to Transition in a Boundary Layer with Zero Pressure Gradient.* NASA TN D-195, Sept. 1959.

[5] Hama, F. R.: *An Efficient Tripping Device,* Journal of the Aeronautical Sciences, Mar. 1957.

[6] Takao Inui: *Study on Wave Making Resistance of Ships* Soc. Nav. Arch. Japan, 60th Anniversary Series, vol. 2.

[7] Ridgely-Nevitt C: *Geometrically Similar Models. An Investigation of Some Problems Resulting From Their Resistance Values,* Int. Shipb. Progress, July 1959.

[8] Preston J. H.: *The Determination of Turbulent Skin Friction by Means of Pitot Tubes,* Aeronautical Research Council 15.758 FM 1883, March 1953.

[9] Townsin, R. L.: *Turbulence Detection Results from the use of an Unobstructive Technique during Ship Model Testing,* TINA 1959.

[10] Raghuram T. S.: *A New Technique for use in Ship Model Tanks,* TINA 1958.

APPENDIX VIII

REFERENCES CONCERNING TECHNIQUES FOR BOUNDARY LAYER INVESTIGATIONS

[1] Breslin J. P., Macovsky M. S.: *Effects of Turbulence Stimulators on the Boundary Layer and Resistance of a Ship Model as Detected by Hot-Wires,* DTMB, rep. 724, 1950.

[2] Macovsky M. S., Breslin J. P.: *A Study of Rods as Stimulators of Turbulence in Boundary Layers,* Article in Progress Report in Research in Frictional Resistance, DTMB, rep. No. 726, 1950.

[3] Hasselmann K.: *Decay of Wave-Induced Velocity Fluctuations in the Small HSVA Model Basin* unprinted report from Institut für Schiffbau der Universität Hamburg.

[4] Townsin R. L.: *Turbulence Detection Results from the use of an Unobstructive Technique during Ship Model Testing,* TINA, 1959.

[5] Preston J. H.: *The Determination of Turbulent Skin Friction by Means of Pitot Tubes,* Aeronautical Research Council 15.758 FM 1883, March 1953.

[6] Relf E. F.: *The Use of Pitot Tubes to Measure Skin Friction on a Flat Plate.* Aeronautical Research Council 17.025 FM 2121, Aug. 1954.

[7] Hsu E. Y.: *The Measurement of Local Turbulent Skin Friction by Means of Surface Pitot Tubes,* DTMB, report 957 (Aug. 1955).

[8] Dutton R. A.: *The Accuracy of Measurement of Turbulent Skin Friction by Means of Surface Pitot Tubes and the Distribution of Skin Friction on a Flat Plate,* Aeronautical Research Council, RRM 3058, Sept. 1956.

[9] Smith D. W., Walker J. H.: *Skin-Friction Measurements in Incompressible Flow,* NACA Technical Note 4231 (March 1958).

[10] Bradshaw P., Gregory N.: *Calibration of Preston Tubes on a Flat Plate Using Measurements of Local Skin Friction,* Aeronautical Research Council 20.199 FM 2684, Perf. 1670 (May 1958).

[11] Granville P. S.: *The Determination of the Local Skin Friction and the Thickness of Turbulent Boundary Layers from the Velocity Similarity Laws,* DTMB 1340, Dec. 1950.

[12] Tulin M. P.: *The Separation of Viscous Drag and Wave Drag by Means of the Wake Survey,* DTMB 772, July 1951.

FORMAL DISCUSSION

Dr. W. Henschke.

SCALE MODEL TESTS AND MODEL-SHIP CORRELATION

On the occasion of the opening Symposium of the Brodarski Institute in Zagreb in Sept. 1959, I showed the results of resistance investigations with models of different scales of a fishing cutter [1].

From this time on resistance tests have been carried out with the scale series of a motor coaster. These tests will be completed later on by systematic investigations with models of a medium-sized cargoship and a fast passengership.

All models were made of wood with a varnished surface and had, when tested, trip wires at 1/20 Lpp (looking aft).

Six models of the fishing cutter (fig. 1) of the scales $\alpha = 6, 8, 10, 12, 15$ and 20 were investigated.

All tests were run with a towing winch [1 and 2] with three different displacements according to 110, 135 and 160 t of the full scale ship. As the accuracy of measurement of the winch-cord towing method with very small models was not exact enough, the resistance of the scales of 15 and 20 were measured again by a pendulum. The data obtained were used for the analysis.

The trip wires used had a diameter of 0,5 mm at $\alpha = 20$ and 15 and 0,9 mm at $\alpha = 12, 10, 8$ and 6.

In the case of motor coaster (fig. 5) five models were investigated with the scales of $\alpha = 10, 12, 15, 20$ and 40 with three displacements each, according to 800, 1100 and 1400 m^3 of full scale ship.

All resistance tests of this series were run by a pendulum. The trip wires of all models had a diameter of 1,2 mm.

All the results are summarized in figures 2-4 and 6-8 resp. The parallels to the Schoenherr-line connect with more or less great differences the points of the same Froude number. A somewhat better equalization would be possible by lines with a somewhat lower gradient but by no means however with a higher gradient, as e.g. with the ITTC-line. The present inexplicable scattering is in my opinion within or below the range of the scale investigations, according to the well-known literature.

To clear the question as to if and how the most common conversion methods in these two investigated cases have any effect on the result, the EPS total according to Froude, Schoenherr and ITTC have been lined up in one table, calculated for an equal temperature of 15° C with $\Delta C_f = 0{,}0002$.

The result is that the maximum difference is about $\pm 2\ \%$ for the fishing cutter (table A) in the range of speed from a practical standpoint of about 6-10 knots within the scale of $\alpha = 6$ to $\alpha = 10$ and with different conversion methods. At very low speeds and especially with very small models more scattering of the single data and greater differences take place between the conversion methods.

The same applies to motor coasters (table B-D). Therefore, for the time being, we prefer to calculate the results of the model tests to the full scale ship according to Schoenherr or Froude.

REFERENCES

[1] HENSCHKE W.: *Die Drahtschleppmethode und Maßstabuntersuchungen mit Fischkuttermodellen.* Schiffbau-Versuchsanstalt Berlin Bericht Nr. 224 *Brodarski-Zagreb Symposium,* 1959.

[2] HENSCHKE W.: *Die Tätigkeit der Volkseigenen Schiffbau-Versuchsanstalt,* Schiffbautechnik Berlin 1957, Heft 1.

Schleppleistungen für den 25 m Kutter
Deplacement $\Delta = 135$ t
Reibungszuschlag für
Schoenherr u. ITTC : $\Delta C_F = 0.0002$

V [Kn]	MODELL 144 Modellmaßstad ∝ = 6			MODELL 134 Modellmaßstab ∝ = 8			Modell 91 Modellmaßstab ∝ = 10		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4	3.83	3.82	3.69	3.76	3.69	3.52	3.72	3.59	3.36
5	7.48	7.49	7.28	7.65	7.57	7.27	7.64	7.46	7.09
6	13.7	13.8	13.5	13.5	13.4	12.9	14.1	13.9	13.3
7	24.3	24.5	24.0	23.3	23.3	22.6	24.8	24.6	23.8
7.5	32.7	32.9	32.4	31.9	31.9	31.1	33.0	32.8	31.8
8	44.2	44.6	44.0	43.6	43.7	42.8	44.2	43.9	42.8
8.5	58.8	59.3	58.5	58.4	58.6	57.5	58.5	58.3	57.0
9	75.2	75.9	75.0	76.2	76.5	73.5	75.7	75.6	74.1
9.5	96.1	97.0	96.0	97.9	98.3	96.9	96.7	96.6	94.9
10	126.5	127.5	126.4	125.6	126.1	124.6	124.0	124.0	122.1

V [Kn]	MODELL 146 Modellmaßstab ∝ = 12			MODELL 156 Modellmaßstab ∝ = 15			MODELL 157 Modellmaßstab ∝ = 20		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4	3.81	3.61	3.36	3.46	3.19	2.87	3.66	3.25	2.85
5	8.08	7.80	7.36	6.66	6.22	5.68	7.28	6.59	5.91
6	14.7	14.3	13.6	13.3	12.6	11.8	13.9	12.9	11.8
7	26.3	25.8	24.9	25.3	24.5	23.3	25.7	24.2	22.7
7.5	34.5	34.0	32.9	33.8	32.8	31.4	34.0	32.3	30.5
8	45.7	45.1	43.8	44.9	43.8	42.1	46.0	44.1	41.9
8.5	59.5	58.9	57.3	58.4	57.3	55.4	60.7	58.5	56.1
9	76.4	75.9	74.0	75.1	73.9	71.7	78.5	76.1	73.3
9.5	97.3	96.6	94.6	96.5	95.1	92.6	99.8	97.1	94.0
10	123.5	122.9	120.6	124.9	123.4	120.6	125.7	122.8	119.1
10.5				164.0	162.4	159.2	162.5	159.1	155.1

Schleppleistungen für das Küstenmotorschiff
Verdrängung $\nabla = 800 \text{ m}^3$
Reibungszuschlag für
Schoenherr u. ITTC : $\Delta C_F = 0.0002$.

V [Kn]	MODELL 240 Modellmaßstab $\alpha = 10$			MODELL 270 Modellmaßstab $\alpha = 12$			MODELL 271 Modellmaßstab $\alpha = 15$		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4				9.4	8.8	8.3	11.5	10.8	10.2
5				19.4	18.5	17.6	20.6	19.5	18.4
6	36.8	35.6	34.6	34.2	32.9	31.5	34.8	33.1	31.5
7	59.0	57.5	55.9	56.2	54.3	52.4	56.2	54.0	51.6
8	92.1	90.2	88.1	86.9	84.5	81.9	90.1	87.1	83.8
9	141	139	136	132	130	126	141	138	133
10	216	213	210	207	203	199	220	216	210
10.5	269	266	262	260	257	251	272	267	261
11	340	337	332	328	324	318	341	336	329
11.5	437	434	429	425	421	415	437	431	423
12	574	571	565	558	554	547	571	565	556
12.5	756	752	746	731	727	719	751	745	735
13	984	980	973	951	946	938	979	973	963
13.5	1251	1248	1241	1207	1202	1193	1237	1231	1219
14	1534	1531	1522	1488	1483	1473	1516	1509	1497

V [Kn]	MODELL 272 Modellmaßstab $\alpha = 20$			MODELL 273 Modellmaßstab $\alpha = 40$		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4	8.7	7.7	6.9	12.8	10.8	9.2
5	18.9	17.3	15.8	25.7	22.2	19.5
6	33.8	31.5	29.3	44.0	38.7	34.5
7	56.0	52.8	49.7	68.7	61.2	55.2
8	89.9	85.7	81.3	102	92.2	83.8
9	139	134	128	149	135	124
10	213	206	199	219	202	188
10.5	268	261	253	272	253	237
11	335	327	318	340	319	301
11.5	425	417	406	437	414	393
12	548	539	528	575	549	527
12.5	724	715	702	756	729	704
13	960	950	936	973	943	916
13.5	1222	1212	1196	1231	1198	1168
14	1498	1497	1470	1506	1471	1438

Schleppleistungen für das Küstenmotorschiff
Verdrängung $\nabla = 1100$ m^3
Reibungszuschlag für
Schoenherr u. ITTC : $\Delta C_F = 0.0002$

V [Kn]	MODELL 240 Modellmaßstab ∝ = 10			MODELL 270 Modellmaßstab ∝ = 12			MODELL 271 Modellmaßstab ∝ = 15		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4				14.7	14.0	13.4	13.6	12.8	12.2
5				24.5	23.4	22.4	23.8	22.4	21.3
6	40.9	39.4	38.3	40.5	38.9	37.4	38.9	36.9	35.0
7	63.5	61.7	59.9	62.9	60.7	58.6	62.7	60.0	57.3
8	98.4	96.0	93.6	99.7	96.8	93.9	96.5	93.1	89.4
9	151	148	145	156	152	148	152	148	143
10	233	230	226	235	231	226	233	228	222
10.5	289	286	281	289	284	279	291	286	279
11	362	359	354	359	354	347	365	359	351
11.5	461	457	451	457	452	445	464	458	449
12	605	601	594	599	593	586	602	595	585
12.5	826	822	815	816	811	802	801	794	783
13	1146	1141	1134	1128	1122	1113	1097	1088	1076
13.5	1509	1505	1497	1506	1499	1489	1495	1487	1474
14	1973	1968	1959	1923	1917	1905	1894	1885	1871

V [Kn]	MODELL 272 Modellmaßstab ∝ = 20			MODELL 273 Modellmaßstab ∝ = 40		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4	10.9	9.8	8.8	15.3	13.1	11.3
5	21.5	19.9	18.1	28.1	24.3	21.2
6	37.3	34.6	32.2	50.1	44.2	39.5
7	61.9	58.3	54.7	79.2	70.8	64.0
8	99.2	94.3	89.5	116	105	95.5
9	155	149	142	170	156	143
10	236	228	220	250	231	214
10.5	290	282	272	316	295	277
11	359	350	340	383	360	339
11.5	463	453	441	480	454	432
12	617	606	593	616	588	563
12.5	845	834	820	811	779	752
13	1145	1134	1118	1071	1037	1007
13.5	1517	1505	1488	1407	1370	1337
14	1910	1897	1878	1757	1717	1681

Schleppleistungen für das Küstenmotorschiff
Verdrängung $\nabla = 1400\ \mathrm{m}^3$
Reibungszuschlag für
Schoenherr u. ITTC : $\Delta C_F = 0.0002$

V [Kn]	MODELL 240 Modellmaßstab $\propto = 10$			MODELL 270 Modellmaßstab $\propto = 12$			MODELL 271 Modellmaßstab $\propto = 15$		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4	17.4	16.7	16.2	15.1	14.3	13.7	13.8	13.0	12.2
5	31.7	30.6	29.7	27.8	26.5	25.4	26.3	24.8	23.4
6	51.5	50.0	48.6	46.8	44.9	43.2	44.9	42.6	40.6
7	78.9	76.7	74.8	72.2	69.6	67.2	71.4	68.3	65.4
8	117	114	112	113	110	107	113	109	105
9	174	170	167	167	163	158	171	166	161
10	260	256	251	252	247	241	262	255	249
10.5	319	315	310	310	305	298	327	320	312
11	398	293	388	389	384	376	414	407	398
11.5	505	500	494	497	491	483	531	523	513
12	655	651	644	648	642	633	691	683	673
12.5	886	881	873	877	870	860	917	909	897
13	1244	1239	1231	1223	1215	1205	1258	1249	1236
13.5	1715	1709	1700	1686	1679	1667	1713	1703	1689
14	2211	2206	2196	2176	2168	2156	2203	2193	2177

V [Kn]	MODELL 272 Modellmaßstab $\propto = 20$			MODELL 273 Modellmaßstab $\propto = 40$		
	Froude	Schoe.	ITTC	Froude	Schoe.	ITTC
4	16.9	15.7	14.6	18.7	16.1	14.2
5	29.8	27.7	26.0	35.0	30.7	27.3
6	48.3	45.3	42.6	58.7	52.1	46.8
7	71.8	67.6	63.7	92.6	83.2	75.6
8	108	103	97.5	144	132	121
9	165	158	151	213	196	182
10	249	240	231	313	292	274
10.5	309	300	289	382	358	338
11	385	375	363	467	441	419
11.5	493	482	469	581	553	528
12	644	632	618	733	702	674
12.5	879	866	851	933	898	867
13	1217	1203	1186	1218	1180	1146
13.5	1637	1623	1604	1611	1571	1534
14	2105	2090	2069	2052	2008	1968

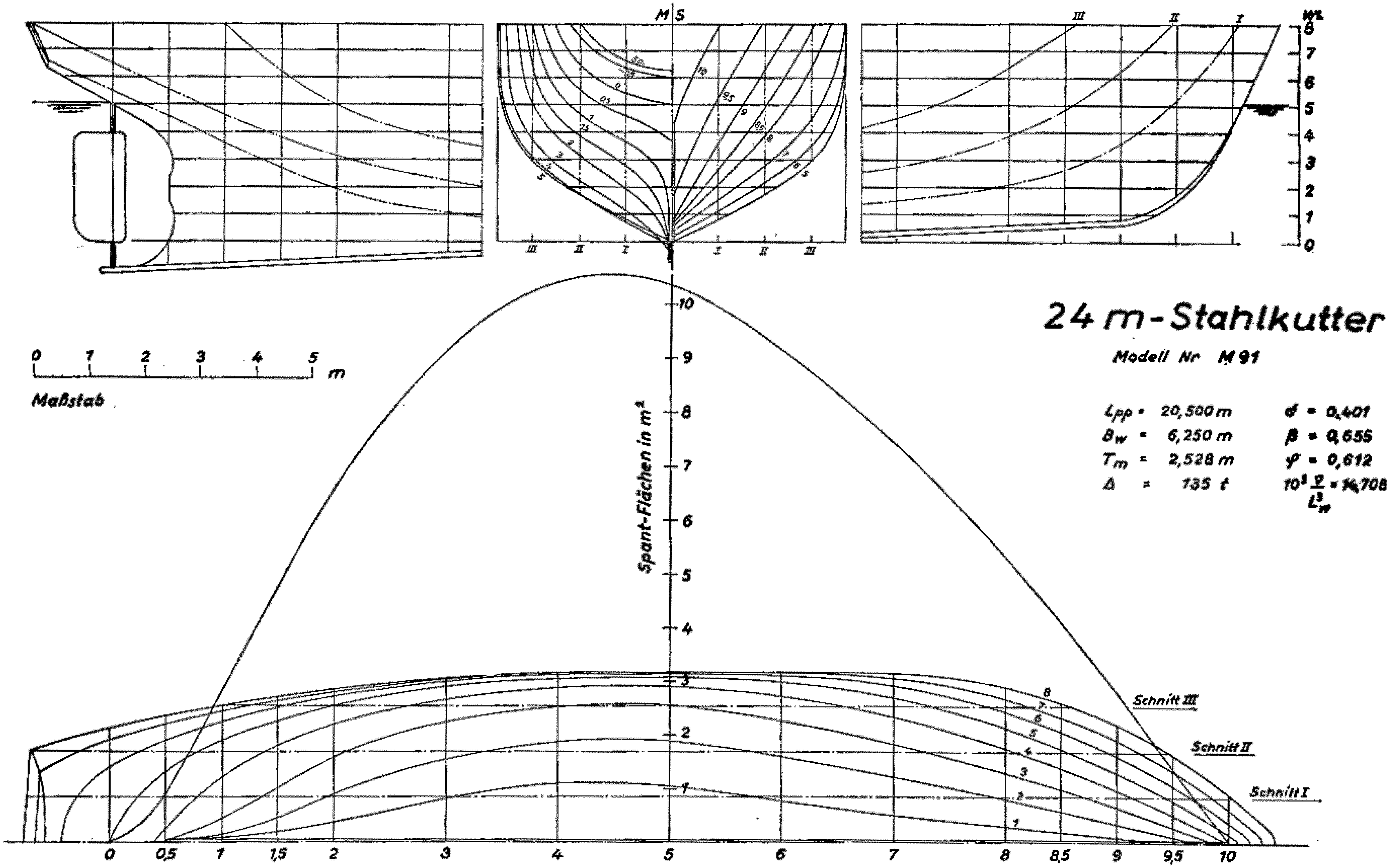

24 m-Stahlkutter
Modell Nr M 91
Lpp = 20,500 m
Bw = 6,250 m
Tm = 2,528 m
Δ = 135 t
δ = 0,401
β = 0,655
φ = 0,612
10³ ∇/L³w = 14,708
Maßstab
0 1 2 3 4 5 m
Spant-Flächen in m²
M S
WL
Schnitt I
Schnitt II
Schnitt III
I
II
III
0 0,5 1 1,5 2 3 4 5 6 7 8 8,5 9 9,5 10

FIG. 1.

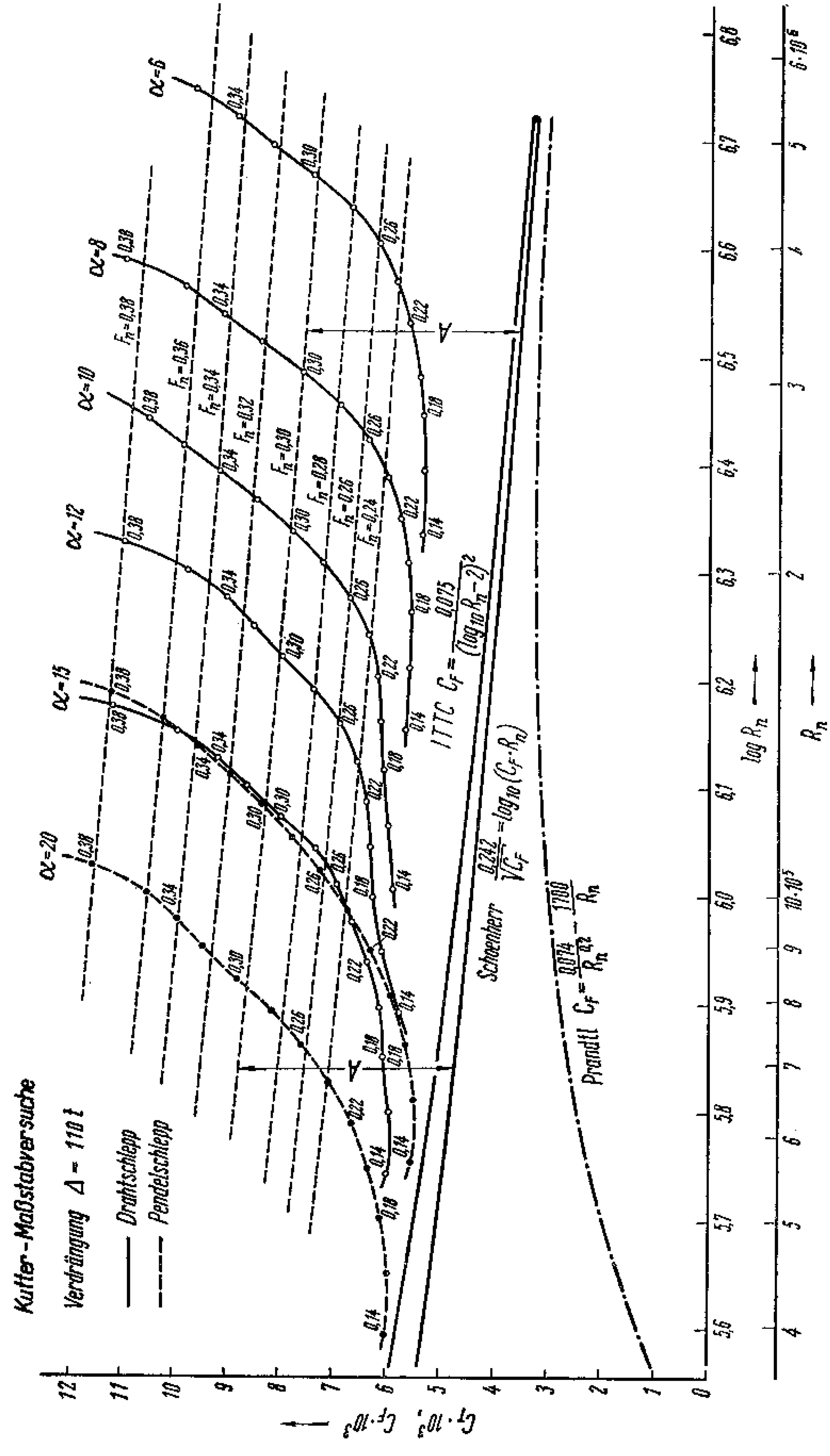

Kutter-Maßstabversuche
Verdrängung Δ = 110 t
Drahtschlepp
Pendelschlepp
α=20
α=15
α=12
α=10
α=8
α=6
Fn=0,38
Fn=0,36
Fn=0,34
Fn=0,32
Fn=0,30
Fn=0,28
Fn=0,26
Fn=0,24
0,14
0,18
0,22
0,26
0,30
0,34
0,38
Δ
ITTC $C_F = \frac{0,075}{(\log_{10} R_n - 2)^2}$
Schoenherr $\frac{0,242}{\sqrt{C_F}} = \log_{10}(C_F \cdot R_n)$
Prandtl $C_F = \frac{0,074}{R_n^{0,2}} - \frac{1700}{R_n}$
$C_F \cdot 10^3$; $C_f \cdot 10^3$
0
1
2
3
4
5
6
7
8
9
10
11
12
log R_n
5,6
5,7
5,8
5,9
6,0
6,1
6,2
6,3
6,4
6,5
6,6
6,7
6,8
R_n
4
5
6
7
8
9
$10 \cdot 10^5$
2
3
4
5
$6 \cdot 10^6$

FIG. 2.

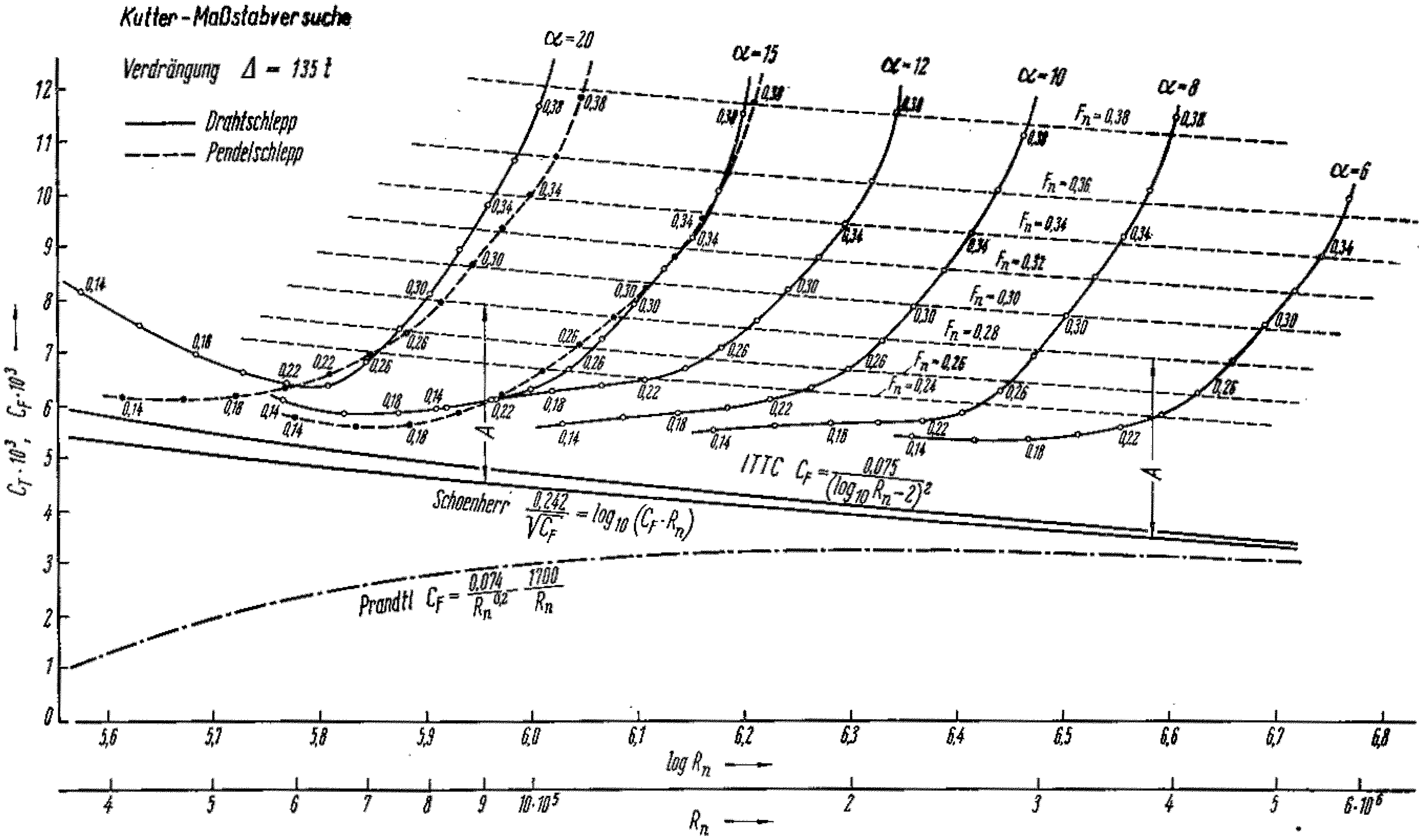

Kutter-Maßstabversuche
Verdrängung Δ = 135 t
Drahtschlepp
Pendelschlepp
α = 20
α = 15
α = 12
α = 10
α = 8
α = 6
Fn = 0,38
Fn = 0,36
Fn = 0,34
Fn = 0,32
Fn = 0,30
Fn = 0,28
Fn = 0,26
Fn = 0,24
0,14
0,18
0,22
0,26
0,30
0,34
0,38
A
ITTC $C_F = \frac{0{,}075}{(\log_{10} R_n - 2)^2}$
Schoenherr $\frac{0{,}242}{\sqrt{C_F}} = \log_{10}(C_F \cdot R_n)$
Prandtl $C_F = \frac{0{,}074}{R_n^{0{,}2}} - \frac{1700}{R_n}$
$C_T \cdot 10^3$, $C_F \cdot 10^3$
0
1
2
3
4
5
6
7
8
9
10
11
12
5,6
5,7
5,8
5,9
6,0
6,1
6,2
6,3
6,4
6,5
6,6
6,7
6,8
log R_n
4
5
6
7
8
9
$10 \cdot 10^5$
2
3
4
5
$6 \cdot 10^6$
R_n

FIG. 3.

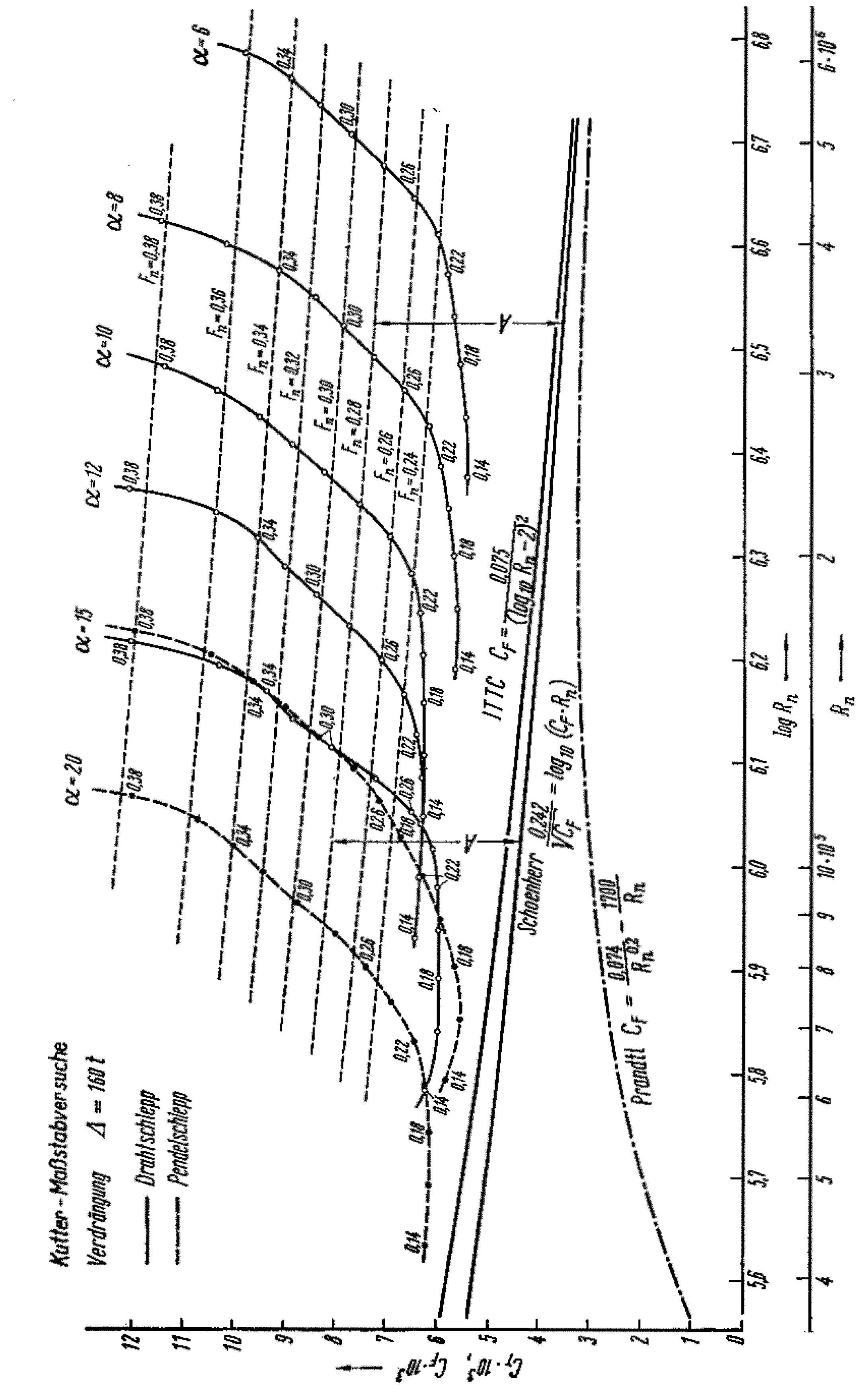
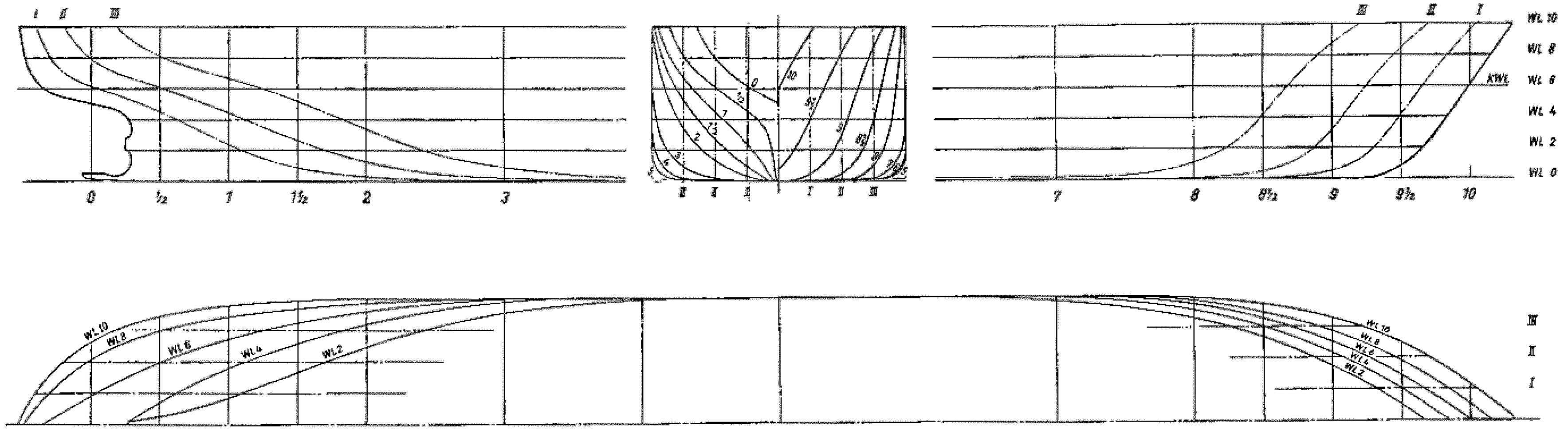

Kutter-Maßstabversuche
Verdrängung Δ = 160 t
Drahtschlepp
Pendelschlepp
α = 6
α = 8
α = 10
α = 12
α = 15
α = 20
Fn = 0,38
Fn = 0,36
Fn = 0,34
Fn = 0,32
Fn = 0,30
Fn = 0,28
Fn = 0,26
Fn = 0,24
0,38
0,34
0,30
0,26
0,22
0,18
0,14
ITTC CF = 0,075/(log10 Rn − 2)²
Schoenherr 0,242/√CF = log10 (CF · Rn)
Prandtl CF = 0,074/Rn^0,2 − 1700/Rn
CT · 10³, CF · 10³
12
11
10
9
8
7
6
5
4
3
2
1
0
5,6
5,7
5,8
5,9
6,0
6,1
6,2
6,3
6,4
6,5
6,6
6,7
6,8
log Rn
4
5
6
7
8
9
10 · 10⁵
2
3
4
5
6 · 10⁶
Rn

FIG. 4.



KÜSTENMOTORSCHIFF

Länge über Alles	59,22 m
Länge zwischen den Loten	53,00 m
Breite auf Spant	9,80 m
Tiefgang	3,60 m
Deplacement (Nordsee)	1350,82 t
δ_μ	0,699
α_μ	0,836
β	0,970

FIG. 5.

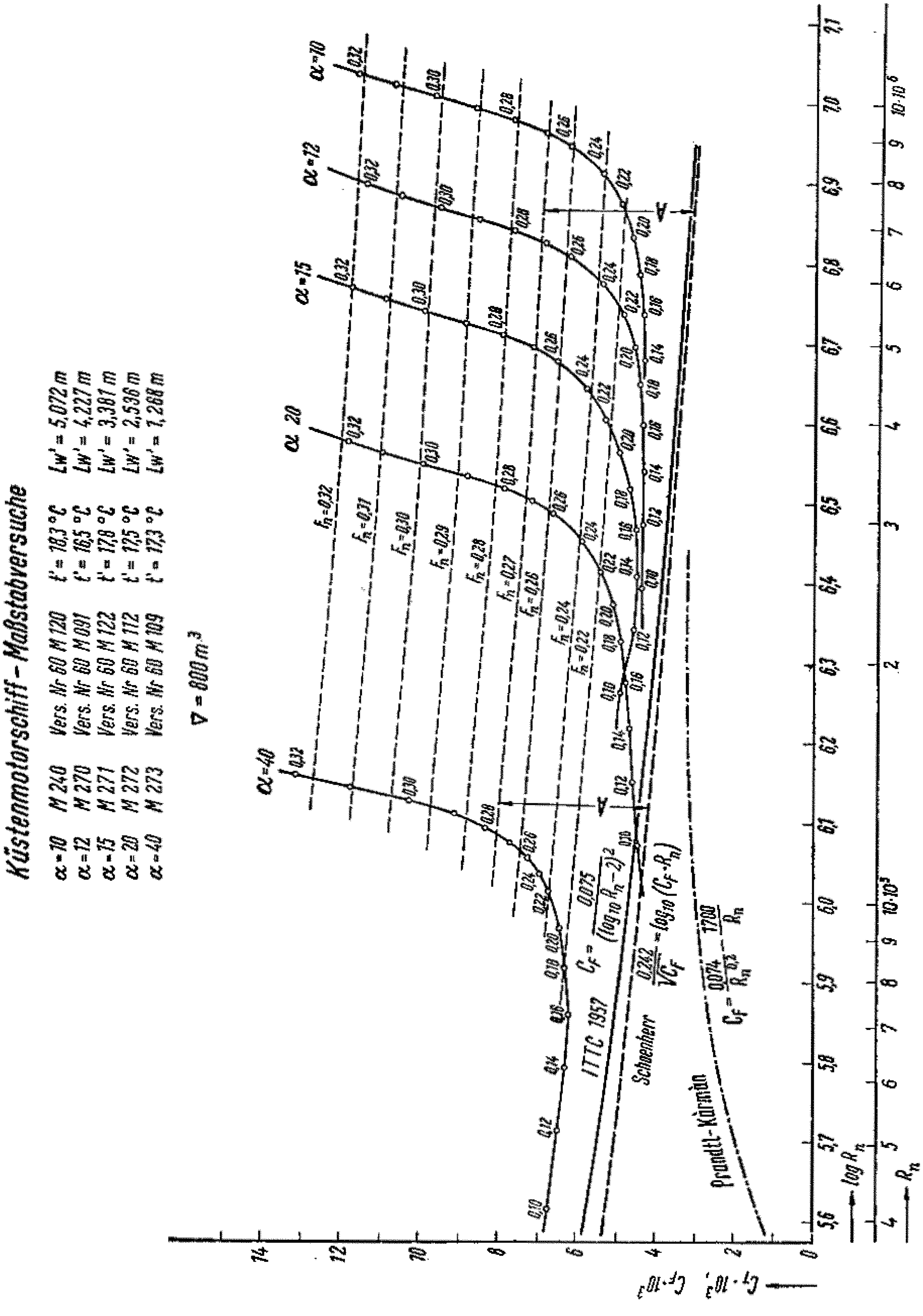

Küstenmotorschiff - Maßstabversuche
α = 10 M 240 Vers. Nr 60 M 120 t' = 18,3 °C Lw' = 5,072 m
α = 12 M 270 Vers. Nr 60 M 091 t' = 16,5 °C Lw' = 4,227 m
α = 15 M 271 Vers. Nr 60 M 122 t' = 17,8 °C Lw' = 3,381 m
α = 20 M 272 Vers. Nr 60 M 112 t' = 17,5 °C Lw' = 2,536 m
α = 40 M 273 Vers. Nr 60 M 109 t' = 17,3 °C Lw' = 1,268 m
∇ = 800 m³
α = 10
α = 12
α = 15
α 20
α = 40
Fn = 0,32
Fn = 0,31
Fn = 0,30
Fn = 0,29
Fn = 0,28
Fn = 0,27
Fn = 0,26
Fn = 0,24
Fn = 0,22
0,10
0,12
0,14
0,16
0,18
0,20
0,22
0,24
0,26
0,28
0,30
0,32
Δ
ITTC 1957
$C_F = \frac{0,075}{(\log_{10} R_n - 2)^2}$
Schoenherr
$\frac{0,242}{\sqrt{C_F}} = \log_{10}(C_F \cdot R_n)$
Prandtl-Kármán
$C_F = \frac{0,074}{R_n^{0,2}} - \frac{1700}{R_n}$
$C_T \cdot 10^3;\ C_F \cdot 10^3$
0
2
4
6
8
10
12
14
log R_n
5,6
5,7
5,8
5,9
6,0
6,1
6,2
6,3
6,4
6,5
6,6
6,7
6,8
6,9
7,0
7,1
R_n
4
5
6
7
8
9
$10 \cdot 10^5$
2
3
4
5
6
7
8
9
$10 \cdot 10^6$

FIG. 6.

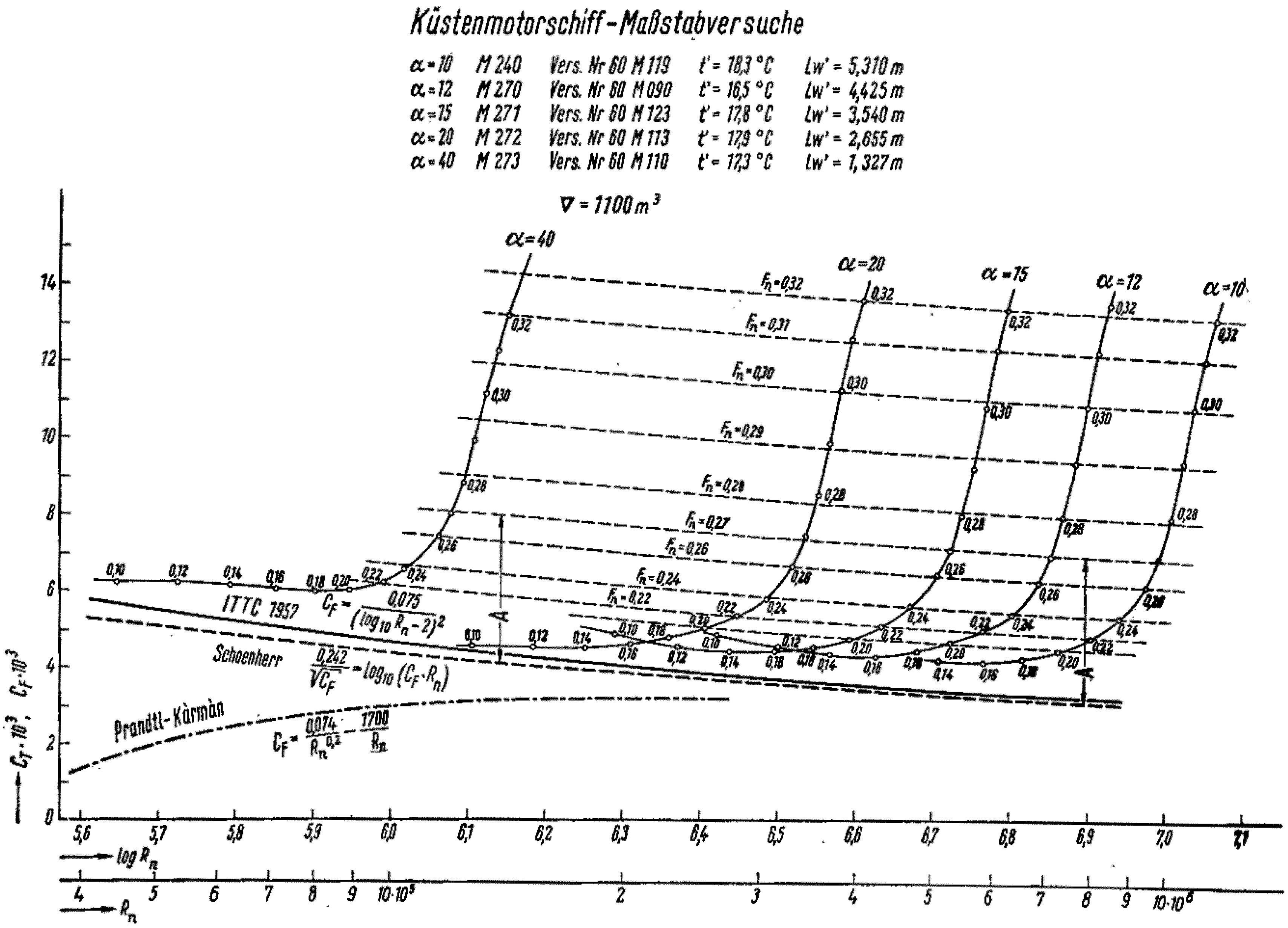

Küstenmotorschiff - Maßstabversuche
α = 10 M 240 Vers. Nr 60 M 119 t' = 18,3 °C Lw' = 5,310 m
α = 12 M 270 Vers. Nr 60 M 090 t' = 16,5 °C Lw' = 4,425 m
α = 15 M 271 Vers. Nr 60 M 123 t' = 17,8 °C Lw' = 3,540 m
α = 20 M 272 Vers. Nr 60 M 113 t' = 17,9 °C Lw' = 2,655 m
α = 40 M 273 Vers. Nr 60 M 110 t' = 17,3 °C Lw' = 1,327 m
∇ = 1100 m³
α = 40
α = 20
α = 15
α = 12
α = 10
Fn = 0,32
Fn = 0,31
Fn = 0,30
Fn = 0,29
Fn = 0,28
Fn = 0,27
Fn = 0,26
Fn = 0,24
Fn = 0,22
0,10
0,12
0,14
0,16
0,18
0,20
0,22
0,24
0,26
0,28
0,30
0,32
A
ITTC 1957 $C_F = \frac{0{,}075}{(\log_{10} R_n - 2)^2}$
Schoenherr $\frac{0{,}242}{\sqrt{C_F}} = \log_{10}(C_F \cdot R_n)$
Prandtl-Kàrmàn $C_F = \frac{0{,}074}{R_n^{0{,}2}} - \frac{1700}{R_n}$
$C_T \cdot 10^3$, $C_F \cdot 10^3$
0
2
4
6
8
10
12
14
log R_n
5,6
5,7
5,8
5,9
6,0
6,1
6,2
6,3
6,4
6,5
6,6
6,7
6,8
6,9
7,0
7,1
R_n
4
5
6
7
8
9
$10 \cdot 10^5$
2
3
4
5
6
7
8
9
$10 \cdot 10^6$

FIG. 7.

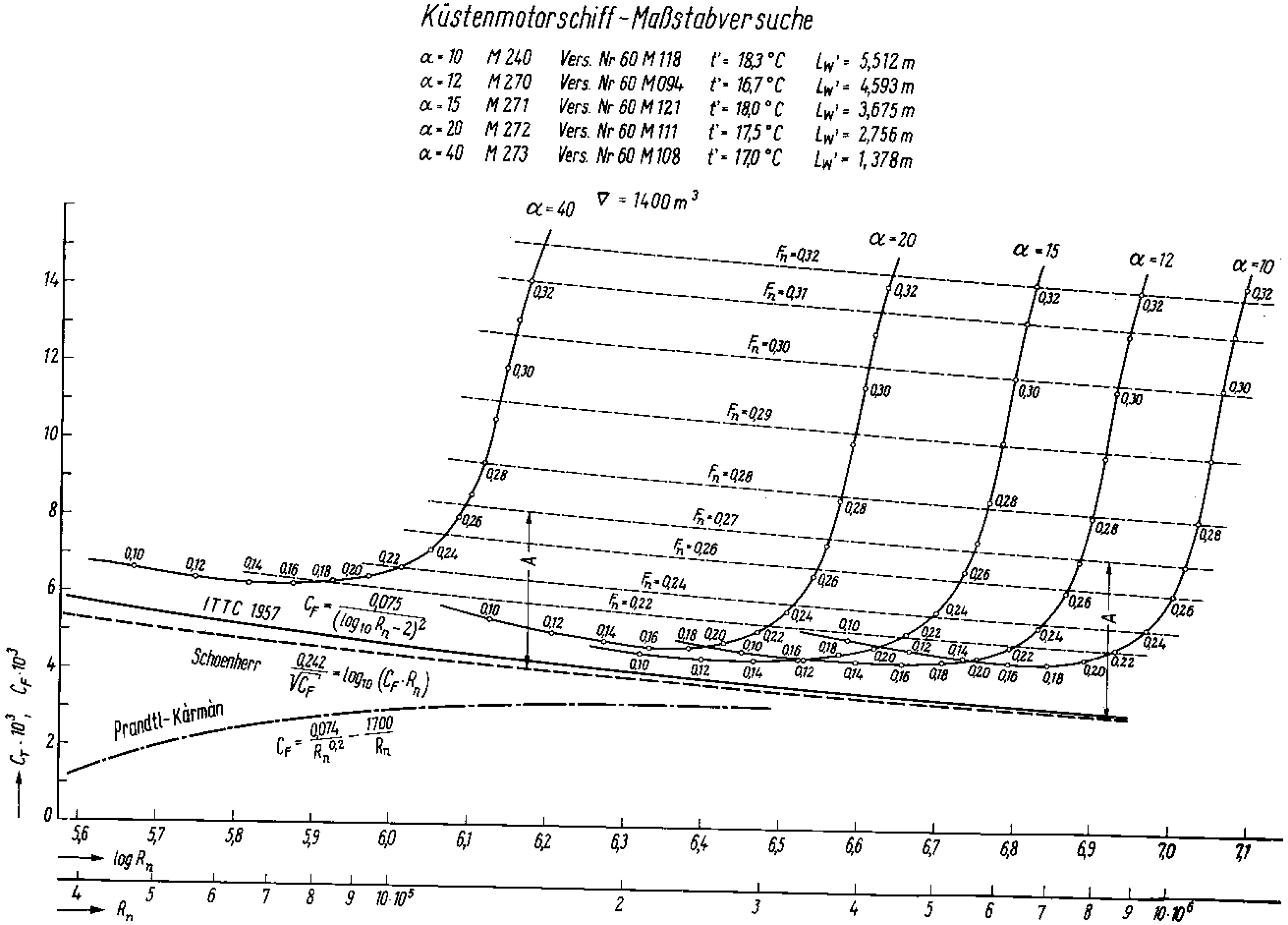

Küstenmotorschiff - Maßstabversuche
α = 10 M 240 Vers. Nr 60 M 118 t' = 18,3 °C Lw' = 5,512 m
α = 12 M 270 Vers. Nr 60 M 094 t' = 16,7 °C Lw' = 4,593 m
α = 15 M 271 Vers. Nr 60 M 121 t' = 18,0 °C Lw' = 3,675 m
α = 20 M 272 Vers. Nr 60 M 111 t' = 17,5 °C Lw' = 2,756 m
α = 40 M 273 Vers. Nr 60 M 108 t' = 17,0 °C Lw' = 1,378 m
∇ = 1400 m³
α = 40
α = 20
α = 15
α = 12
α = 10
Fn = 0,32
Fn = 0,31
Fn = 0,30
Fn = 0,29
Fn = 0,28
Fn = 0,27
Fn = 0,26
Fn = 0,24
Fn = 0,22
0,10
0,12
0,14
0,16
0,18
0,20
0,22
0,24
0,26
0,28
0,30
0,32
A
ITTC 1957 $C_F = \frac{0{,}075}{(\log_{10} R_n - 2)^2}$
Schoenherr $\frac{0{,}242}{\sqrt{C_F}} = \log_{10}(C_F \cdot R_n)$
Prandtl-Kármán $C_F = \frac{0{,}074}{R_n^{0{,}2}} - \frac{1700}{R_n}$
$C_T \cdot 10^3$, $C_F \cdot 10^3$
0
2
4
6
8
10
12
14
log R_n
5,6
5,7
5,8
5,9
6,0
6,1
6,2
6,3
6,4
6,5
6,6
6,7
6,8
6,9
7,0
7,1
R_n
4
5
6
7
8
9
$10 \cdot 10^5$
2
3
4
5
6
7
8
9
$10 \cdot 10^6$

FIG. 8.

Prof. G. Kempf.

RUNNING RESISTANCE-TESTS WITH MODELS OF FULL FORM.

Measurement of resistance with models of full form, i. e. with a blockcoefficient over. 75, give sometimes unsteady results.

The point where the layer leaves the shipform at the rear changes on full forms easily with small alterations of pressure and depends on the initial acceleration of the model.

It is widely unknown what kind of current will appear on the ship, but it is sure that the layer at the rear is fluctuating with the period of yawing.

To insure similarity of model and ship it is therefore advisable to make the model also yaw in the same manner as the ship normally does even at smooth sea.

The registration of the fluctuation of course for three ships shows that it is alternating at least from + 1° to — 1° within a period of about 30 seconds; this means for a model of 6 m length at a scale of 1/25 an amplitude at the rear of about ± 50 mm at a period of about 5 seconds. It may be that already with a smaller amplitude and a shorter period steady and repeatable measurements of resistance for such models of great blockage are obtainable.

The conversion of these resistance-results from a yawing full model to the ship would probably allow a still more reliable prediction for the ship than it can be given today.

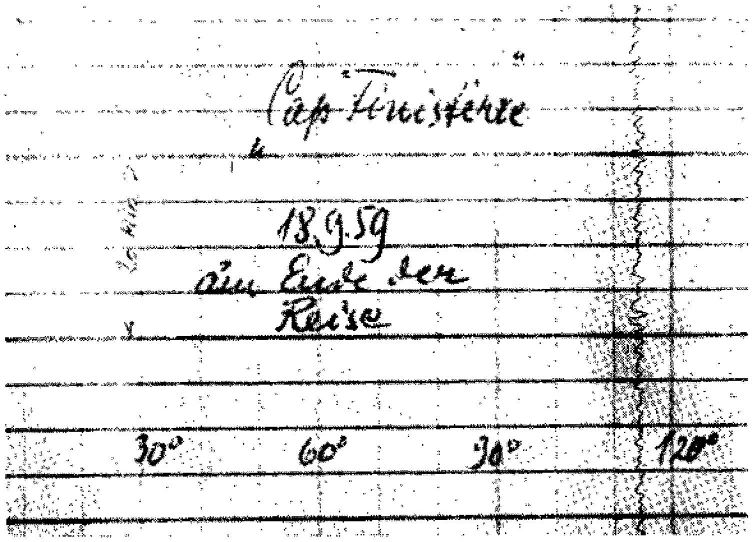


Fig. 1.

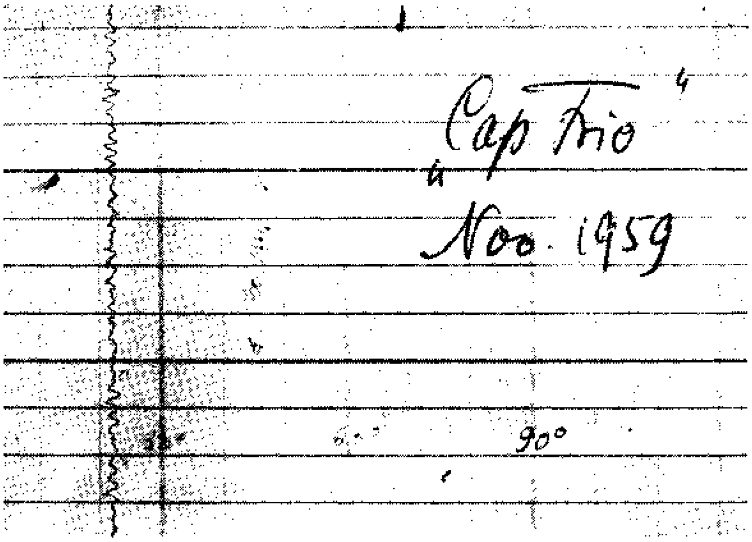

„Cap Frio"
Nov. 1959
90°

FIG. 2.

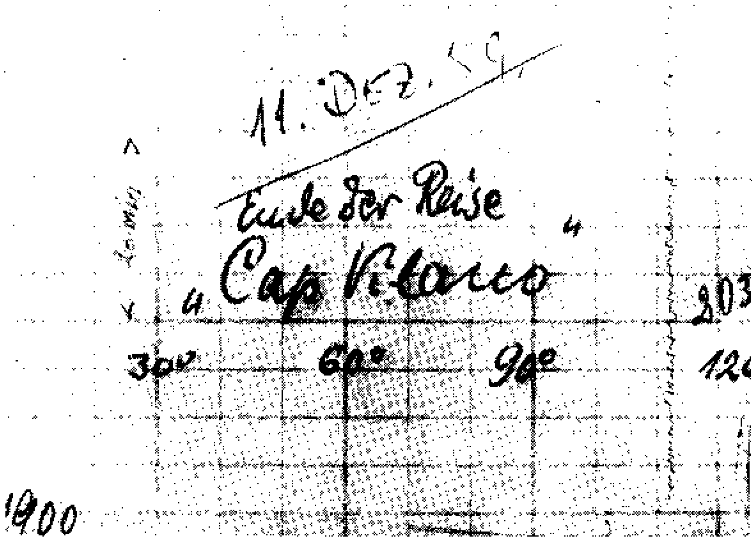

11. Dez. 59
Ende der Reise
„Cap Vilano"
203
30°
60°
90°
120
1900

FIG. 3.

R. N. Newton.

As the Report of the Resistance Committee indicates, one major problem to solve before the model-ship correlation line adopted at the 8th Conference can be used with confidence is the establishment of reliable values for the so called roughness allowance" or Δc_f, which is more correctly described as a model-ship correlation allowance since the difference in roughness between model and ship is only one of many components which together constitute the difference between the resistance calculated from ship trial results and that predicted from model tests.

2. From published data on ship-model correlation using the I.T.T.C. line and particularly that in a paper presented by R.E. Clements, reference 1, two facts emerge clearly. One is that the correlation allowance is frequently large and the other is that the scatter in the results, even for sister ships, is equally large. Mean values as high as 30 per cent of ship E.H.P. and a scatter of as much as 20 per cent in the results of the analysis of 150 ship trials have been found. This result was not surprising and was perhaps to be expected in view of the numerous components of the correlation allowance and the wide variation which many of them can individually possess according to the conditions under which the trials are conducted.

3. One obvious approach to solving the problem of assigning values to the allowance which can be used for reliable prediction of performance is to

(i) Enumerate the components of the allowance so far as possible with existing knowledge.

(ii) Assess the magnitude of as many of these components as may be possible, using existing available data which whilst not perhaps based on sound modern physical concepts has been found reasonable from previous experience.

(iii) Apply the values of these 'assessable' components as corrections in the analysis, leaving a residual correlation allowance embracing those components which cannot yet be assessed because of lack of data.

4. The result of such an approach should be to reduce not only the mean value of the overall allowance but also the scatter between results for ships of a type, so making the prediction of performance in prescribed conditions more consistent and reliable. An attempt to arrive at small, consistent correlation allowances in this manner is currently being made at A.E.W. and the following notes describe the basis of the method.

5. The components of the correlation allowance have been enumerated below. The basis of their assessement is quoted in those cases for which data are available.

(a) *Tank boundary interference or blockage.* Assessed by the method described in Reference 2, Appendix 3.

(b) *Standard model correction to model skin friction resistance.* To eliminate the random variation in model resistance due to "unexplained changes in the quality of the tank water", a standard model is run regularly in both ship tanks at Haslar. Any variation in the standard model resistance is applied as a correction to the measured of the ship model. (Reference 3).

(c) *Effect of viscosity on wavemaking.* When scaling up the residuary resistance from model to ship a correction is made in accordance with the approximate figures quoted in Reference 4, which are broadly confirmed by trial correlation factors of different types of ship.

(d) *Structural roughness due to plate edges, butts, rivet points etc.* Assessed from results of tank tests in which such excrescences were simulated on planks. (Reference 5).

(e) *Surface or paint roughness.* Using information provided in references 2 and 6, a standard value of the increment of resistance due to the roughness of the surface of Admiralty compositions has been evolved and is currently used in the analysis.

(f) *Fouling of ship's hull and propeller.* This is related to the number of days since last undocking — 'a', and the number of days since last complete painting — 'b', by the empirical formula:

$$\text{increase of skin friction resistance} = \left(\frac{a}{500} + \frac{b}{2500}\right) C_f$$

This formula was obtained from the results of trials in temperate waters on ships coated with Admiralty bottom compositions, and is applicable only to new ships on first class trials.

TABLE 1.

Components of Correlation Allowance — Twin Screw Frigate.

All coefficients to be multiplied by 10^{-3}

MODEL

Reynolds' number $\times 10^{-6}$	8.622	10.74	12.23	13.62
Wake % (Taylor)	3.2	3.4	1.7	0
C_T corrected for trial condition, standard model correction and blockage	4.301	4.678	5.670	6.141
C_F	3.079	2.963	2.898	2.845
C_R	1.222	1.715	2.772	3.296
Correction for effect of viscosity on wavemaking	0.167	0.111	0.021	0
Corrected C_R	1.389	1.826	2.793	3.296

SHIP

Reynolds' number $\times 10^{-8}$	7.12	8.86	10.1	11.24
C_F	1.597	1.554	1.529	1.509
C_T naked	2.986	3.380	4.322	4.805
Augment %	8.6	8.5	8.4	7.7
C_T augmented	3.243	3.667	4.685	5.175
Appendage resistance	0.384	0.404	0.434	0.477
Correction for paint roughness	0.120	0.120	0.120	0.120
Correction for structural roughness	0.007	0.007	0.007	0.007
Correction for fouling	0.150	0.146	0.144	0.142
Correction for wind	0.080	0.080	0.080	0.080
Corrected C_T	3.984	4.424	5.470	6.001
Ship C_T augmented as deduced from propellers	4.084	4.653	5.613	6.124
ΔC_T	0.100	0.229	0.143	0.123

$$\text{Mean Value} = \frac{0.595}{4} \times 10^{-3} = 0.149 \times 10^{-3}$$

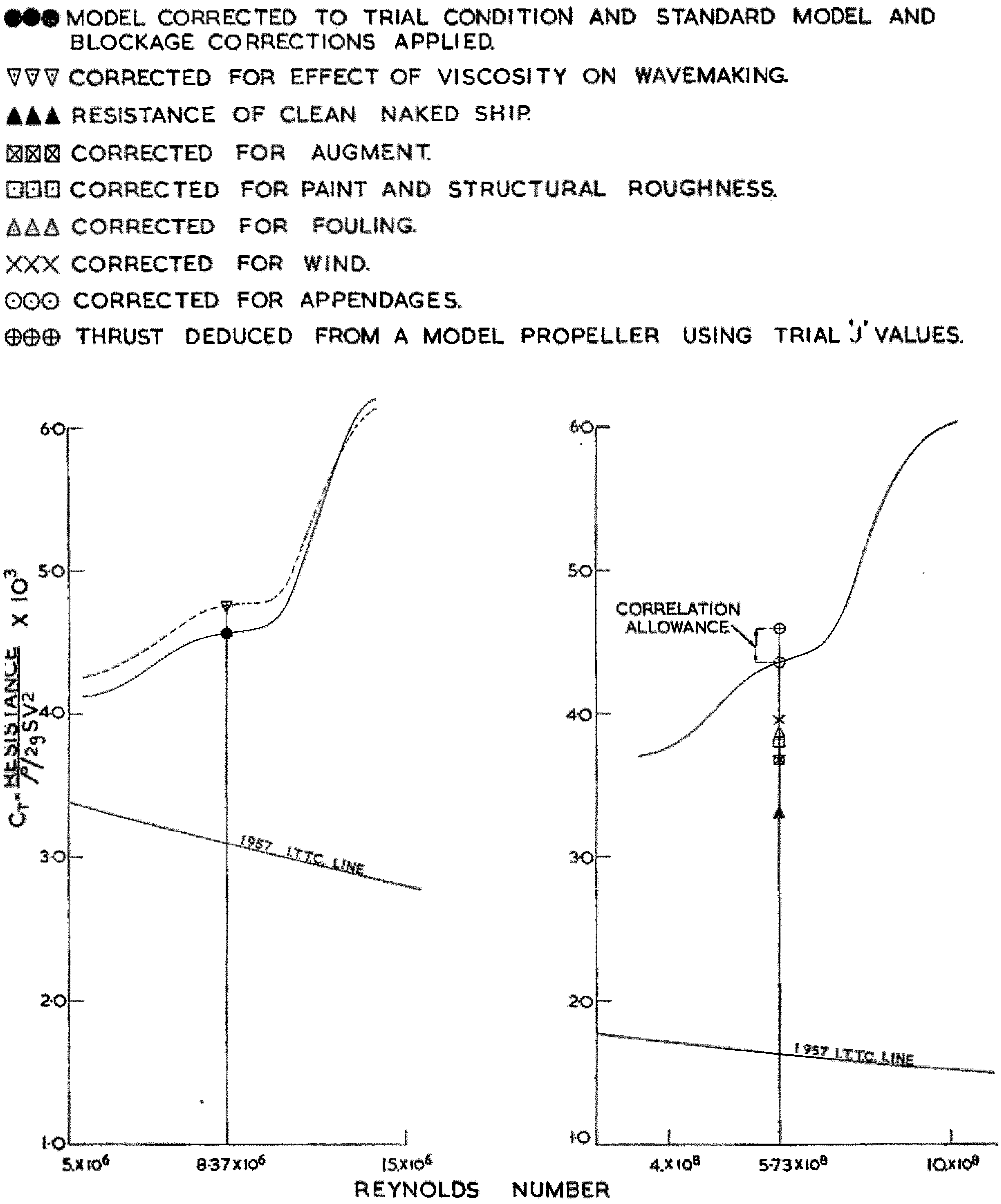


FIG. 1. — Components of correlation allowance.

TABLE 2.
Comparison of Correlation Allowances.

All coefficients to be multiplied by 10^{-3}

	Corrected for Items (a) — (i)		Uncorrected for Items (a) — (i)	
	ΔC_T	Difference from mean value	ΔC_T	Difference from mean value
Destroyer	0.155	—0.019	1.079	0.208
Single Screw Frigate	0.193	0.019	0.728	—0.143
Twin Screw Frigate	0.149	—0.025	0.774	—0.097
Aircraft Carrier	0.198	0.024	0.903	0.032
Mean value	0.174		0.871	

(*g*) *Rough water.* The increase of resistance due to rough water is assessed from model experiments in waves. In the weather conditions in which warship trials are carried out the effect of rough water on resistance has been found to be negligibly small.

(*h*) *Wind resistance of ship on trials.* Assessed by the method described in reference 7.

(*i*) *Correction for appendage resistance.* To eliminate errors due to scale effect on appendages, the measured model appendage resistance is not used to obtain the corresponding ship resistance. Instead, the resistances of the individual appendages are assessed directly for the ship, using empirical formulae based on large scale model tests. A similar procedure is applied to appendages not normally fitted to the model, e.g. bilge keels circulating water inlets and outlets.

(*j*) *"Waviness" of plating.*

(*k*) *Scale effect on wake and augment.*

(*l*) *Cavitation of propeller or appendages.*

(*m*) *Experimental errors.*

(*n*) *Inaccuracy in I.T.T.C. line:* i.e. difference between model or ship skin friction resistance as given by this line and the true values.

(*o*) *Inaccuracies in assessment of allowances* (*a*) *to* (*i*).

Items (*j*) to (*o*) cannot at present be assessed individually because of lack of data. They are, therefore, contained in the gap between ship resistance as predicted from the model and as deduced from trial results i.e. the correlation allowance.

6. The analysis procedure is illustrated for a frigate in Figure 1 and Table 1. The measured model resistance, corrected for blockage, (*a*), and standard model (*b*), is plotted in coefficient form on a Reynolds' number base. At speeds corresponding to each trial speed for the ship, the model residuary resistance, i.e. the intercept of this curve above the I.T.T.C. line, is corrected for the effect of viscosity on wavemaking, (*c*), and the corrected intercept is set up above the I.T.T.C. line at the appropriate ship R_n. This ordinate represents the naked "smooth" ship resistance. To it is added the model augment of resistance and the estimated allowances (*d*) to (*i*), giving the estimated augmented resistance of the "rough" ship complete with appendages. This is compared with the propeller thrust obtained from results of open water experiments on a 20 in. diameter model of the as fitted ship propeller, at a J value given by the trial R.P.M. and the ship speed qualified by model wake. The thrust is obtained by this method for the sake of consistency, since experience has shown that the thrustmeter results where available are not usually sufficiently accurate at low powers.

7. Ideally, the estimated ship resistance and estimated propeller thrust should be equal. In practice, however, they are different by an amount embracing

the components (*j*) to (*o*) above, i.e. by the correlation allowance. This allowance is derived by the method described at each trial speed and since it is found that its variation with speed is usually small and random, the mean value is taken as applicable at all speeds.

8. Correlation allowances for four recent ships calculated in this manner are given in Table 2. It will be seen that the figures derived for the reduced correlation allowance are much smaller than those for the total allowances uncorrected for the components (*a*) to (*i*). Furthermore the scatter in the reduced ΔC_t value over the full range of speed is much smaller. In ships of such fine form as these destroyers and frigates, the total allowance in fact, varies by approximately ± 4 per cent of the total ship resistance at full power; whereas when correction (*a*) to (*i*) are applied, the variation in the allowance is reduced to ± ½ per cent.

9. It will be appreciated that for full form merchant ships the scale effects on wake and augment of resistance (or thrust deduction) are likely to be larger than for the finer forms of warships for which these propulsion factors are generally much smaller. Nevertheless the principle of reducing the overall allowance in the interests of consistency and reliability is considered to be sound and is recommended for the combined consideration of the Resistance and Propulsion Committees since some of the components of the correlation allowance are the concern of the former and others of the latter committee.

10. In conclusion it is pertinent to state that until this or similar approach to the problem of assessing ΔC_t has been proved reliable the prediction of ship performance at A.E.W. Haslar will continue to be made by the procedure described in the 8th I.T.T.C. Transactions, based on the Froude extrapolation method, well established correlation factors for type ships, and the application of some of the corrections described in paragraph 5 of this note.

REFERENCES

[1] CLEMENTS R. E.: *An Analysis of ship model correlation data using the 1957 I.T.T.C. line.* R.I.N.A. 1959.

[2] CONN, LACKENBY & WALKER: *Resistance experiments on Lucy Ashton.* R.I.N.A., 1953.

[3] NEWTON R. N.: *Standard model technique at A.E.W. Haslar* R.I.N.A., 1960.

[4] WIGLEY C.: *Prediction of ship resistance from model results.* Subjects 2 and 4, formal discussion by 8th I.T.T.C., 1957.

[5] ALLAN & CUTLAND.: *Investigation of the resistance of an 18ft. plank.* N.E.C., 1956.

[6] TODD F. H.: *Skin friction resistance and the effects of surface roughness.* S.N.A.M.E., 1951.

[7] DOVE H. L. & FERRIS G. S.: *Development of anchors.* R.I.N.A., 1960.

F. S. Burt.

In the course of drag measurements on bodies of revolution ranging in size from 3 inches to 12 inches diameter and in length diameter ratio from 7 to 8 carried out in a small slotted wall wind tunnel, in the 30 inch slotted wall water tunnel and in a 13 ft. × 9 ft. wind tunnel, numerous wake traverses were made. From these the drag coefficient was worked out by the method of B.M. Jones and was found to be given correctly with an overall scatter of ± 4 %. However, in spite of axial symmetry of the bodies the wake sometimes showed considerable asymmetry to the extent that the drag computed from a traverse from the centre line to port would have a value up to 1.5 times that from the traverse to starboard. Though the amount of asymmetry varied widely with the same model in different positions in one tunnel, in different tunnels and also with geometrically similar models, the average value obtained from a complete diametral traverse was quite consistent. In some of the cases considered here, a large interference drag, up to 100 % of the correct free stream drag, caused by a change in the pressure distribution on the body was present. Nevertheless, the correct free stream values were obtained by a wake traverse. This is an encouraging indication that wake traverses behind towed ship models should give the skin friction drag, provided that the whole area of the wake is covered and symmetry between port and starboard is not relied on.

J. R. Shearer.

THE MEASUREMENT OF THE RESISTANCE OF SHIP MODELS

(Presented by Ship Hydrodynamics Laboratory Feltham. England).

In any attempt to correlate results obtained in different laboratories, the accuracy and stability of measurement of the quantities involved must come into question, and an analysis of the factors influencing these measurements must be made.

The specific aim of the resistance experiment on a model hull is to derive, from a series of experiments, a curve whose ordinates represent a horizontal towing force, while the abscissae represent a state of uniform linear motion which is presumed to have continued for a long time. The distinguishing feature of this field is that the hydrodynamic forces are generally small, while, due to the weight of the model hull, inertia forces may be large. The problem involves three main factors; the performance of the towing vehicle, the measurement of speed and the measurement of the towing force. Although the relation of these factors to each other is important, they will in the first instance, be considered independently.

1. *Performance of the Towing Vehicle.*

It has already been noted that the uniform motion is assumed to have continued for a long time, a state which can never be truly obtained in a towing tank. Very little is known of the stability, in non-uniform motion, of the hydrodynamic phenomena with which we are concerned, and it must be expected that uniform flow conditions will not be established for an interval after uniform velocity is attained, the interval being influenced by the magnitude and pattern of acceleration. It must be assumed that, at any speed during the acceleration of the model, the wave system corresponding to that speed will be at least partially developed, and the steady wave system corresponding to the steady speed will not be developed until all residual wave systems resulting from the acceleration have been shed by the model. With a constant and fairly rapid acceleration, as can be obtained with a well designed automatic speed control system, these components should not be fully developed and should be fairly quickly shed. However, in less refined control systems, and particularly in manual operation, the mode of acceleration could be significant. For example, a manual control system might require the use of a coarse setting control up to a speed slightly below the intended one, followed by a final adjustement on a fine control, resulting in a pause in acceleration during which the wave system corresponding to the lower speed would be fully established. The correct wave system would not then be developed until the model has travelled one model length at the increment of speed. By he same consideration, if in a long tank, incremental changes in speed are made in order to economize in running time, they must be increases only, and the increment must be large enough to ensure rapid shedding of the wave systems corresponding to lower speeds.

Having reached the required speed, the uniformity with which it is maintained is of the utmost importance both the magnitude and the frequency of deviations from the mean value being significant. The relationship of deviation frequency to dynamometer performance will be considered later, but it should be noted that, in general, a low amplitude, short period deviation, is preferable in that the results of such deviations can be averaged over the length of run. A long period deviation on a short run does not provide sufficient information to permit an accurate mean value to be assessed. The limiting case of this would, of course, be a continuous acceleration or deceleration during the run, and this would be a most serious fault. Such a condition could arise due to an inclination of the rails, or to an inadequately compensated thermal effect in the electrical and hydraulic power unit. For example, on a model of 200 lb displacement developing say 5 lb resistance at 5 ft/sec an acceleration of only 1/40 000 g would add a constant 1 % to the towing force. The resultant increase in speed would only be of the order of 0.3 % per 100 ft travel and on a low speed model the resistance would increase about 0.6 %. If, as is not uncommon, only average values of these quantities were recorded an acceleration of this order might well pass undetected unless specially sought.

With these factors in mind, the new carriage in the Ship Hydrodynamics Laboratory was specified to have a controlled acceleration as near linear as possible and a speed which was required to be uniform within ± 0.1 % of any set value within the range 1.0 to 50.0 ft/sec. To achieve a performance of this order requires very great attention to the design, manufacture and alignment of the rails and the mechanical drive units, as well as the speed holding system and to the electrical collectors by which power supplies are transmitted to the carriage.

2. *The Measurement of Carriage Speed.*

The requirement to measure accurately the speed of the towing carriage is easily met by the use of modern pulse counting techniques, and pick-up devices. Not only can high accuracies of time measurement be achieved, but it is easy to subdivide the distance travelled into sufficient fine increments to make it possible to obtain a direct rather than a reciprocal speed scale.

Two systems of speed measurement have been installed at Feltham, one giving a direct printed record of the carriage speed in feet per second as the mean value over any pre-set period from 5 seconds to 200 seconds, and the other being a simple reciprocal system which will be used for calibration purposes and to provide a stand-by record.

Although the measurement of carriage speed is of great importance in assessing carriage performance and in relation to inertia forces, the hydrodynamic forces are, in fact, related to the speed of the hull through the water. Due to thermal convection currents and residual components of the disturbance created by the preceding experiment, the water in the towing tank is never really at rest, the deviation from this condition depending on the nature of the experiments, the size of the model in relation to the tank, the extent and efficiency of disturbance damping devices, and the interval between runs. Since it is not usually economic to wait between runs for a period longer than is required for the main surface wave disturbance to decay, the residual motion of the water is of importance and one must take steps either to reduce this motion to a negligible value, or else to measure it accurately.

Rapid absorption of the wave system developed by the model can be assisted by the use of side beaches or wave suppressers as well as end beaches. The main factor contributing to uncertainty as to the model speed through the water is, however, undoubtedly the drift of the water disturbed by the model as a viscous wake. Immediately after the passage of the model thus usually takes the form of a continuous drift of water along the centre axis of the tank with a return flow along the sides the direction and magnitude of the flow depending to some extent on whether the model is towed or propelled. With time the circulation of water tends to break down along the length of the tank into a series of separate eddies, which slowly die out as a result of internal friction. If large models have been tested in a small tank it is probable that there will be superimposed on the drift, a periodic motion representing the fundamental oscillation period of the water in the tank. Dr. Hughes has previously described how this motion can be successfully minimized by the use of curtains placed transversely across the tank for a period between experiment runs and there is no doubt that this is a powerful technique which considerably improves the stability of the results.

The measurement of the rate of drift, although a neater technique, is by no means easy. The classical method of observing the drift of a float placed in the water before each run is still adopted at Teddington, but it is recognized that this is more of a precaution that excessive motion will be noticed than a precise means of correcting the speed. The obvious approach to this problem is the use of a suitable current meter to give a direct and continuous recording of carriage speed relative to the water through which the model is passing and in fact a solution along these lines is being pursued at Feltham. There are, however, considerable difficulties in obtaining the ultimate and permanent accuracy required, and it must be noted that, at this stage, elimination of the motion is still the best precaution that can be taken.

3. *The Measurement of Model Hull Resistance.*

In the simple resistance experiment the model weight is supported by buoyancy and the model hull is guided in such a way that its axies lies along the axis of motion of the carriage, the model being free to heave, pitch, or surge, but not to yaw. The towing force is applied by the carriage via some form of dynamometer mechanism, the application being made by way of either a roller or a pivoted towing link.

The dynamometer is therefore simply a device for the accurate measurement of a horizontal towing force which is assumed to be derived from the model at a point near its centre of gravity and to be applied to the lower end of some form of weighing lever or pick-up arm. Forces can be measured either in terms of primary standards, i.e. deadweights, or in terms of secondary standards which may be springs. Alternatively, a simulated deadweight system in the form of an electrical, pneumatic or hydraulic force balance could be adopted. Except in the case of gravity towing systems a pure deadweight system is not applicable, since for constant towing speed such a system cannot be stable unless a deliberate unbalance is introduced to give the system a point of stability. The majority of systems in current use take the form of spring balances of some form, in which the applied force is measured in terms of the deflection under load of an elastic element. Such systems are pre-calibrated in terms of known deadweights and the accuracy of the system depends on the stability of the stress-strain relationship of the elastic element. In view of the wide range of forces usually requiring to be covered by a towing dynamometer, it is common practice to fit a fairly sensitive spring element which will measure only a small residual unbalance and to back off the greater part of the resistance by the application of deadweights. In this way the incremental accuracy may be maintained over a fairly wide range. As this is, in one form or another, the standard form of instrument adopted for low speed towing of ship models, certain of its characteristics will now be considered.

The towing system contains the following elements: a carriage, likely to have considerable weight, which is guided along a straight path at a speed which is intended to be uniform but which will, in fact, be subject to such deviations as are permitted by the speed holding system; a dynamometer comprising a system of levers, deadweights and springs, and adding some linear and rotary components to the inertia of the system; and a model hull having a fairly large mass, to which must be added the virtual mass. In its simplest form the performance of such a dynamometer system is equivalent to the behaviour of a mass-spring system in forced oscillation and subjected to a steady superimposed force which is, however, generally backed off by deadweights. In the first instance, the mass-spring system will have a natural frequency controlled by the mass of the model, the moment of inertia of the moving parts of the dynamometer, and by the spring rate. The forcing frequency will derive from the control system of the carriage. In general, any automatic control system will have some hunting frequency representing the maximum response speed of the servo system. In manual control, variations will occur on a more random basis, depending on the operator, the response of the electrical system, and such factors as rail alignment and tracking of wheels. Experience of both manual and automatic systems at Teddington and at Feltham suggests that these forcing frequencies will cover a range of periods of about 1 to 8 seconds, and it is important to consider the best relation of the natural period of the dynamometer to these forcing periods. Obviously resonance is to be avoided, and we are left with the alternative of adopting a stiff spring system in which the natural period of the dynamometer is less than the forcing frequency, or a soft system in which it is greater. Both these arrangements are valid ones and in fact both are in use in towing tanks.

The main characteristics of the stiff spring arrangement are rapid response of the dynamometer to variations in model or carriage behaviour. The model is constrained to follow any speed variation of the carriage fairly closely and any deviation of the mean recorded resistance will mainly derive from inertia forces due to the acceleration of the model mass. Such deviations being of fairly high frequency may be reduced by the introduction of damping. Since the deflection of the system under load is small, a fairly large degree of amplification of the movement will be necessary in order to give a sensitive display.

In the soft spring arrangement, the spring system is not capable of transmitting to the model hull forces sufficiently large to accelerate the model significantly under the influence of carriage speed deviations before these deviations reverse. In such a system, therefore, the model tends, due to its mass, to maintain a more uniform speed than does the carriage and deviations of the recorded resistance represent the displacement of the carriage from the position represented by its intended mean velocity. The introduction of damping in such a system will act against this characteristic, tending to make the model follow the carriage. The deflections of the system under load will be large and amplification of the record therefore small.

The stiff and soft springing systems may be likened respectively to an accelerometer and a vibrograph, the model in the former case being the vibrating mass, and in the latter the datum. There are possible alternative arrangements. Force balance systems, for example, or self-balancing weigh beams will generally have the characteristics of the stiff spring system, tending to maintain the model in step with the carriage. Any spring rate could be used for the dynamometer and the dynamic characteristics of the system determined by a second spring in series with the measuring spring and acting in the linkage between the model and the dynamometer, thus isolating the model from the carriage characteristics. A further possibility is that of balancing the hull mass by a suitable mounted mass on the carriage so that accelerating forces do not act on the dynamometer system. This technique was widely adopted in seaplane work and can have considerable merit in high-speed tests on relatively small and light models, but the masses involved in inertia balancing on large displacement models could be very considerable, and their suspension on friction-free mountings would present special problems.

With a perfect carriage performance, the choice of dynamometer system is of little importance since clearly in uniform conditions either stiff or soft systems will record a uniform force. In practice, deviations in carriage speed must occur, and the view has always been held at NPL that such deviations should not be transmitted to the model. As has already been noted, we are concerned with the measurement of a state which is assumed to be steady, and we have no real knowledge of the effect on the stability of the resistance components of lack of uniformity in speed. In all the resistance dynamometers in current use at NPL for the measurement of the resistance of models of low-speed vessels, i.e. excluding fast motor boats, etc., soft springs are adopted, and damping is not employed except to reduce the effect of initial unbalance of the system at the beginning of the measuring run, the damping being removed before recording beings. The springs used are selected in relation to the mass of the model to give natural periods to the system of the order of 15 to 20 seconds and it should be noted that, provided that this period is significantly greater than the forcing period so that the model is isolated, the spring rate does not affect the absolute magnitude of the deviations recorded on the dynamometer since these do not represent changes in force, but deviations of the carriage in position from that of the constant speed datum represented by the model. An upper limit to the natural period of the dynamometer is imposed by the need to ensure that the true mean position of the resistance record can be detected, and in general the natural period should not exceed half the duration of the measuring run.

The latest dynamometers in use at NPL and SHL take the form of weigh beams in which the main application of deadweight is represented by the position of a weight along the beam, the weight being driven along a lead screw by an electric motor until the force is balanced. Any residual unbalance is taken up by the spring, and the deflection of the beam from the mean position is recorded at NPL mechanically and at SHL electrically. These instruments have load capacities respectively of 50 lb and 100 lb, and the residual spring component is of the order of 1 lb.

The major requirement in making a reliable measurement of resistance is clearly the establishement of the necessary steady conditions for a sufficiently long time, and this requirement will obviously be more difficult to meet, the shorter the tank in relation to model size and speed. The rapid establishement of steady conditions is essential, not only to allow the flow conditions to become stable but also to ensure that a sufficient length of run can be obtained to determine accurate mean values. On these grounds it would seem that an upper limit on the size of model that should be tested in a given tank may be imposed by the conditions of reliable measurement of resistance as well as by the generally accepted condition of freedom from boundary interference.

Sir Victor G. Shepheard.

At the last Conference the principal preoccupation of the Committee on this subject was obtaining international agreement on a rational system of extrapolating model results to the full scale based on Reynolds Number which would replace the empirical Froude friction coefficients. Even though this considerable step forward was achieved in the shape of the '1957 ITTC Model-Ship Correlation Line' it will not come as a surprise to many that in spite of this the Committee has no definite values to suggest for correlation allowances to be used in conjuction with it. As a result of developments in the subject since that time it is quite clear that there is a great deal more in ship-model correlation than Reynolds Number and extrapolator slope and the Committee Report refers to some of the other factors involved.

The major difficulty of course is the scatter of the correlation factors, a substantial proportion of which is unexplained at the moment and it seems unlikely that entirely satisfactory allowances will be developed until we are nearer to a solution of the following:

(*i*) *Consistency of Model Results.*

Possible day to day variations in the results obtained for a given model in a particular tank are involved here and in this connection an interesting account of the way in which the Admiralty tank at Haslar deal with this matter was given by Mr. Newton in his paper to the R.I.N.A. this year [1]. As is well known this involves standard model testing and it is gratifying to see from the Committee Report that no less than 15 tanks throughout the world have now undertaken similar work using models of identical form to those used by the British commercial tanks. It is to be hoped that by the time of the next Conference sufficient data will have been obtained either to enable the cause of these differences to be determined and eliminated or that some method of correcting for them will be developed which will enable model data to be reduced to a standard basis for comparative purposes.

(ii) *Tank Boundary Interference.*

This is doubtless a cause of differences between one tank and another and it is noted with interest that the Committee considers there is now sufficient information available for a satisfactory blockage correction to be made in the lower range of Froude numbers. If this is the case there seems no reason therefore why the various tanks should not try to agree to make such corrections forthwith as the great majority of merchant ships operate in that speed category. If further research shows that some additional correction is required at higher speeds we would surely be no worse off for having eliminated a cause of inter-tank difference over part of the speed range at least.

(iii) *Form Effect on Skin Friction.*

It is agreed that the data adduced by the Committee shows the desirability of introducing an allowance for form effect in this work. It may well be that this would have a significant effect on the extrapolation problem and it is strongly recommended that this matter be investigated with a view to putting forward a definite proposal.

(iv) *Interaction between the Components of Resistance.*

This concerns differences in relative wave damping between model and ship and as has been mentioned elsewhere [2], B.S.R.A. has been responsible for a programme of fundamental work at N.P.L. which is throwing light on these matters and the physics of ship resistance generally. In particular, the real components of resistance are being isolated and their interaction determined. It is interesting to recall that the possibility of certain scale effects arising from variation in the inter-action between the two basic types of resistance at different Reynolds Numbers was suggested by the analysis of the 'LUCY ASHTON' results. It may be remembered that in this investigation there appeared to be a quite definite variation with speed in the differences between the full scale resistance and the smooth ship predictions from the models whatever extrapolation formulation was used [3]. Similar variations with speed are also to be noted in some of the correlation allowances quoted by Clements [4].

(v) *Roughness Effects.*

There is little doubt that variations in hull roughness between one ship and another contribute a great deal to the scatter of correlation factors and the report lists a number of references to recent work in this field. In this connection B.S.R.A. is currently exploring the possibility of making use of total head tubes of the type developed by Prof. Preston. It is proposed to introduce ship type roughnesses into a large diameter pipe, partly with a view to discovering which are the significant roughness parameters and partly in order to develop pitot tubes for measurements adjacent to a rough surface with a view to their eventual use on actual ship hulls.

(vi) *Trials Procedure.*

Although much has been done by the development of standard codes of procedure and improved instrumentation it cannot yet be said that this aspect does not contribute to the scatter of results to at least some extent. Outstanding matters in this connection were discussed in the paper referred to earlier [2].

Finally, of course, there is also the question of propulsion scale effect for which no correction is generally made although there is enough evidence to show that it undoubtedly exists. This of course comes whithin the province of the Propulsion Committee and is discussed in a separate contribution.

When the above matters have been clarified we should be in a better position to break down the allowances into their constituent parts, the ultimate aim being to reduce the unexplained residual to negligible proportions. In this connection it is interesting to note the success which Mr. Newton has already had in the case of warships [5] by using the best available data to make the various corrections.

Statistical methods of analysis involving multiple linear regression have also been used at B.S.R.A. in an attempt to reconcile ship and model results. This work is continuing and more recently a small group has been set up to deal with it consisting of representatives of B.S.R.A., N.L.P. and the St. Albans tank. It is hoped that this type of analysis will produce a useful 'engineering' solution pending the complete solution of the problem by detailed investigation of the various constituent factors outlined above. Reference to the work of this group is made in Appendix 1 of the Committee Report *(vide p. 30)*.

Referring to the Committee's final recommendation it would seem highly desirable that these investigations should be continued in conjunction with the 'ITTC 1957 Line' as in the present state of knowledge there would appear to be nothing to be gained in re-opening the skin friction controversy.

REFERENCES

[1] NEWTON R. N.: *Standard Model Technique at Admiralty Experiment Works Haslar*, paper read. Roy. Instn. Nav. Archit. Lond. March, 1960.

[2] SHEPHEARD V. G.: *The Prediction of Ship Performance from Model Tests: The Nature of the Problem.* Symposium on ship trials and service performance analysis. Trans N.E.C. Instn E. Shipb. 76, (1959-60) p. 51.

[3] CONN J. F. C., LACKENBY H., and WALKER W. P.: *B.S.R.A. Resistance Experiments on the Lucy Ashton.* Part II: The ship Model Correlation for the Naked Hull Conditions. Trans. Instn. Nav. Archit. Lond. 95 (1953) p. 350.

[4] CLEMENTS R. E.: *An Analysis of Ship-Model Correlation data Using the 1957 ITTC Line.* Trans. Instn. Nav. Archit. Lond. 101 (1959) p. 373.

[5] NEWTON R. N.: *Resistance: Written Contribution.* Ninth International Towing Tank Conference. Paris, 1960.

Prof. E. V. Telfer.

A NOTE ON THE ITTC STANDARD MODELS

1. The ITTC planning of the standard model tests lends itself to further development. It is evidently not sufficiently appreciated that the Froude is always the *primary* modelling law and that the Reynolds is merely the correcting law. The comparative experiments should therefore have been planned to refer to definite Froude and not to definite Reynolds numbers. Better still they should have been planned to refer to actual half knot intervals for the 400 ft. ship; and to be actually at each half knot, since it is distressing how frequently one finds on expansion that a ship contractual speed has no actual model run for its factual endorsement.

2. If the foregoing is respected there is not the slightest need for any Reynolds number or temperature correction. In fact it is statistically wrong at this stage to make any such correction. What should be done first is to agree on say 10 Froude speeds such as 8, 9 ... 17 knots (or better 20 at half knot intervals). Note the 1 000C_T values for each of these speeds and find their simple arithmetic mean. Call this the set mean. All such means should be plotted to a base of temperature. With a sufficient temperature range covered, a mean line can be passed through the centroid of all the spots. Provided the temperature variation does not exceed $\pm$ 18° F from the 59° F standard (or $\pm$ 10° from the same 15° C standard) the variation can be accepted as linear. Simple regression will give the correct mean slope; and with $R = 10000C_T$ we can thus find $\delta R/\delta T$ = constant.

3. All set means can now be brought to the standard temperature and whatever remaining variation they still possess can be further studied. Plotting to an annual base should reveal whether biological effects are probable. These may easily be thermal drifts; and I am astonished that anti-drift curtains are not insisted on. In any case those who have the curtains should in my opinion carry out tests with and without, to reveal any possible influence of the curtains.

4. The standardised overall mean from the tanks should be plotted to a blockage base of $m = a/A$. Regression analysis will free the data from wall effect, $\delta R/\delta m$ can be obtained and with this each tank's overall mean can be corrected for blockage and whatever difference remains for any tank from the mean of all such corrected means becomes the personal equation or bias of the particular tank.

5. The foregoing analysis is all that is statistically necessary (at the moment) to establish an inter-tank comparison. If it is desired to proceed further, as one should, and derive much more important scientific information from the tests, they may be, used to decide between the Telfer and ITTC formulations. For this purpose the respective relative kinematic viscosity functions require linearisation. For the Telfer the lineariser is $X = 10^2/Re^{1/3}$ whilst for the ITTC it is X_1 where $X_1 = 16/\ (\log Re - 2)^2$. The factor 16 has been chosen to make X_1 unity at $Re = 10^6$ when X is then also unity.

Thus if we take each individual set of tests we can prepare a speed column of 9 to 17 knots at half knot intervals and prepare additional columns of corresponding R, X and X_1. The respective mean values of these quantities are noted. When we have a large number of such sets over a wide range of temperature, we can determine the slope of this mean Froude contour (I prefer to call this a mean isofrud) as follows:

The equation to the mean isofrud is given by,

$$Y = a + bX \quad . \quad . \quad . \quad . \qquad \text{(Telfer)}$$

$$Y = a + cX_1 \quad . \quad . \quad . \quad . \qquad \text{(ITTC)}$$

Since there is no blockage change there is no need to include blockage in the analysis.

By regression analysis the value of b is given by,

$$b = \frac{\varepsilon XY = \varepsilon X\,\varepsilon Y/N}{\varepsilon X^2 - (\varepsilon X)^2 N}$$

and similarly c would be given by

$$c = \frac{\xi X_1 Y = \xi X \xi Y/N}{\xi X_1^2 - (\xi X_1)^2 N}$$

In order to simplify the statistical calculation it is useful to assume that $b = (3 + b_1)$ and $c = (4 + c_1)$. These 3 and 4 values are very nearly the respective two-dimensional extrapolators. The value of each set mean Y should be reduced by 3X and $4X_1$ respectively before evaluating the statistical analysis. When the analysis is completed it can be anticipated that b_1 will have a numerical value of about 0.65 and c_1 a value about 1.4.

6. The significance of these values should now be appreciated. The 0.65 means that the Telfer extrapolator for the standard model is 365, whilst the ITTC extrapolator will be 5.4 × 16 = 86.4 instead of the provisionally agreed value of 75.

The Telfer 365 is physically quite an acceptable value since as a frictional resistance it lies completely below the measured total resistances. It moreover lies sufficiently below since as these standard model tests in Teddington N° 2 tank have the relatively high blockage of 1.24 percent they can be expected to have an average excess specific resistance of at least 0.25 at the low speeds.

On the other hand the anticipated ITTC value of 86.4 is already somewhat *above* the low speed run-in specific resistance and thus will be materially above this same line when blockage excess is duly allowed for. If the standard model has already been tested in Teddington N° 1 or N° 3 tank this point can easily be confirmed.

This application of the ITTC formula structure thus shows two major defects. It produces a mean isofrud slope much greater than the provisional 75 value and when translated into frictional resistance produces values much higher than the total actually measured over a wide speed range. This was also definitely the case with the LUCY ASHTON and possibly is so with all geosim series.

It should thus be clear to the Skin Friction Committee that the ITTC formulation is completely unacceptable as a solution of the ship frictional resistance problem. However plausible it may appear to be in expressing,

$$C_F = f(Re),$$

its differential coefficient

$$\delta C_F/\delta Re = f^1 (Re) = kf (Re),$$

is clearly giving too low a value. *The correct form of function is one which can admit of a slope change proportional not to the frictional resistance ordinate but to materially less than this ordinate.* This mechanism is obvious by automatically supplied by the 1.2. term in the extrapolator formulation.

The second defect of the ITTC formulation is really the same as the first. The value of 75 as a slope factor is too small but had any higher value been proposed in 1957, the resulting frictional resistances being then much higher than the Schoenherr would have caused the immediate rejection of the Skin Friction Committee's proposal. Being certain that the formula would eventually have to be rejected, I insisted on its being recognised as the 1957 *interim* line.

As it is now being used for the calculation of standard model temperature correction it is obvious that it will produce too small a correction. The right value is obtainable by the method of this note. Since the 86.4 factor can be used for temperature correction, it follows that the ITTC correction should be increased by about 15 percent.

7. At the Madrid Conference I recommended (p. 226) also using a roughened version of the standard model. I would now suggest that each tank try out various methods of totally roughening their model. This will first be useful in eliminating viscosity effects from the resistance data and thus enable instrumental and other possible causes of resistance fluctuation to be made more evident. Chiefly, however, I again make the suggestion so that each tank will be encouraged to investigate the potentialities of rough-model testing. I showed in my recent N.E.C. Symposium paper how a suitably roughened model could be used in conjunction with the same model smooth or with a smooth geosim, to determine the smooth extrapolator slope. Actually the method gives a vertically unpositioned curve of model viscous resistance. To position it is necessary to know or to assume the nature of the Reynolds number function on which the viscous resistance depends. For example if the extrapolator function $1/Re^{1/3}$ is accepted it is only necessary to plot the difference between the rough and smooth model total resistance to the $1/Re^{1/3}$ or X base, obtain the correct slope of this line and use this in conjunction with an initial specific resistance value of 1.2 to obtain the total viscous resistance. Alternatively the ITTC function X_I could be used and in this case the total viscous resistance is given by a

straight line drawn parallel to the difference line and through the origin. Whether the difference curve is really linear is the first check on the suitability of the Reynolds number function used. The second control requires the total viscous line so obtained to lie entirely below the original smooth model total resistance. Smooth geosim series testing shows that the ITTC function fails to satisfy this control.

8. The method in its simplest form can be correctly used to produce the temperature or Reynolds number correction for the statistical treatment of the standard model dealt with in section 2 above. Thus, having derived a large number of set means, these can be plotted to a base of set mean Reynolds number. The rough-smooth difference curve can be drawn through the centroid of the set means and should exactly interpolate the data. Similarly the difference curve could be used to calculate the change in total specific resistance at each model speed produced by say ± 10° F change from the standard temperature of 59°F. This change does, of course, depend upon the individual Reynolds number and is not a constant quantity as normally assumed.

REFERENCES

[1] *Temperature Correction in Ship and Model Resistance.* 4e Congrès Int. de la Mer. Ostende 1951, p. 559.

[2] *The Reconciliation of Model Data, Measured Mile Results and Service Performance of Ships.* N.E.C. Symposium 1959/60.

**M. G. Hiranandani; P. K. Kulkarni
and P. R. Goyal.**

EXPERIMENTS WITH NEW TURBULENCE DEVICES

1. The advantages offered by small models for preliminary investigations are often offset by the presence of laminar flow over a large portion of the model, in spite of a trip wire. This is due to the large thickness of laminar boundary layer at the position of trip wire as is evident from col. 4, Table 1; the thickness, at speed equivalent to 10.4 knots, is 2.52 mm for 1/80 model of Mariner Ship. Studs and other devices have also been widely experimented with. A need for a really effective turbulence device with low parasite drag still remains.

2. Dr E.V. Telfer suggested that triangular strips as used by Hama in wind tunnel could be useful as stimulators. Accordingly, the original form and modifications of it were tested. A new form of stimulator consisting of rotating rods was also tested. These are described briefly below:

(*a*) Hama's original proposal consisting of triangular pieces cut from a plastic strip 0.9 mm thick (fig. 1*a*). The accelerated flow through the convergence formed a vortex with vertical axis.

(*b*) The connecting strip, joining the triangles was cut leaving a 2 mm gap. The flow was thus accelerated through the gap to six times the approach velocity Figure 1 *b*.

(*c*) A row of triangles as in (*b*) with another row of small triangles to disperse flow. Figure 1 *c* and Figure 2.

(*d*) Rotating rods.

This device consists of two rods, each 3 mm diameter, coated with 40 mesh coal powder with the help of glue and held 100 mm apart, (fig. 3). The rods are rotated at high speed (2000 to 3000 RPM) by a motor, in inward direction, so that water flowed to the bow of the model with high degree of macro-turbulence. The rods were held 100 to 150 mm ahead of the bow (fig. 4) by a separate fixture so that the drag of the rods did not affect resistance measurement on model.

TABLE 1.

Reynolds numbers at different points on model.

Ship....................	Mariner	Scale........................	1/80
Length Bpp.............	2.012 m	Displacement................	36.2 kg

Vs ship knots	V Model m/sec	Boundary layer thickness at trip wire mm	Local Reynold's number $\frac{Vx}{v}$ $v = 1.009\times10^{-6}$				
			$x = 0.038$ m	0.088 m	0.594 m	0.99 m	1.981 m
			Pt of injection 1	2	3	5	entire model length
2.61	0.15	5.03	0.56×10^4	1.31×10^4	0.88×10^5	1.47×10^5	2.95×10^5
4.0	0.25	3.90	0.94×10^4	2.19×10^4	1.47×10^5	2.45×10^5	4.91×10^5
6.10	0.35	3.28	1.32×10^4	3.05×10^4	2.06×10^5	3.43×10^5	6.87×10^5
10.4	0.6	2.52	2.26×10^4	5.23×10^4	3.53×10^5	5.89×10^5	11.78×10^5

Experiments.

3. The effect of the three turbulence stimulators was seen on 1/80, Mariner model made in wood and painted smooth white. Hypodermic needles were fixed at five positions (fig. 4) for injecting a strong solution of potassium permanganate. All observations about characteristics of flow were visual and therefore could not be extended much beyond 0.5 m/sec model speed due to wave action. The flow conditions in various portions of the model are described in Table 2.

Results

4. The flow conditions are summed up below:

(*a*) With trip wire, the bow portion remains laminar up to 0.45 m/sec and mid-ship portion up to 0.3 m /sec.

(*b*) With single row and two rows of triangles, the bow portion becomes turbulent at 0.25 m/sec. The mid-ship portion, however, becom esturbulent above 0.3 m/sec. only.

(*c*) With rotating rods, the flow over entire model length appears to become turbulent at 0.15 m/sec.

The ineffectiveness of trip wire is already indicated above. Both types of triangular stimulators were very effective in causing transverse mixing in the boundary layer at the bow. The flow in this portion, however, dips so rapidly and follows bottom of the ship that the effect of stimulators is not at all felt at the mid-ship section. In fact this would be true of any turbulence producing device fixed near bow.

This is the reason why the flow is turbulent near the bow with triangles but still remains laminar at the mid-ship section and aft of the model. Another row of triangles at mid-ship section can improve this position.

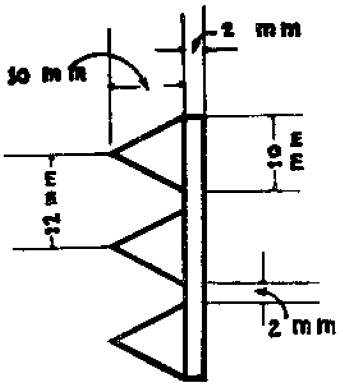
The results obtained with rotating rods were encouraging beyond all expectations. The macro-turbulence was very effective, in dispersing laminar stream lines; if this is interpreted as turbulent flow, then the inception was at as low speed as 0.15 m/sec (Rn(bow) $= 1.3 \times 10^4$; Rn (model) $= 2.94 \times 10^5$) and the effect could be seen over the entire length of the model.

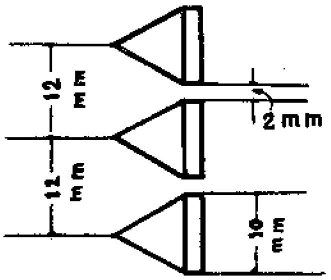
The real test about the effectiveness of any turbulence producing device is in augmentation of resistance due to change from laminar to turbulent flow. Further experiments are in progress in this direction.

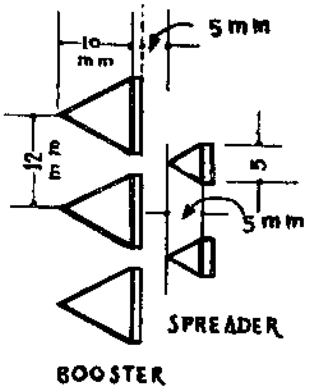
TABLE 2.

Flow characteristics with different turbulence exciters.

EXPT SERIES	TYPE OF STIMULATOR	FLOW CHARACTERISTICS
1	Trip wire 0.55 m diameter	Speeds up to *0.35 m/sec.* Dye formed good stream lines at all injection points. The stream lines from point 4 and 5 were well formed right up to aft. *0.45 m/sec*; stream lines at point 1 and 2 began to diffuse after trip wire.
2	A row of triangles with 2 mm gaps fig. 1 *b*	*0.15 m/sec*; the triangles caused transverse mixing but flow remained laminar, immediately behind and at all sections up to the aft. *0.24 m/sec*; stream line at point 2 began to widen. Stream line at points 4 and 5 remained laminar right up to aft. *0.35 m/sec*; the stream line from point 1 dispersed immediately. The line from point 2 widened slowly and rapidly after trip wire. The stream lines from points 4 and 5 exhibited mixed flow characteristics up to 0.3 m/sec but at 0.35m/sec etc. stream lines dispersed immediately indicating turbulence.
3	Two rows of triangles fig. 1 *c*	Transverse dispersion was better behind the two rows of triangles than in series 2. The behaviour at speeds up to 0.4 m/sec over the entire model was essentially similar to that with single row.
4	(*d*) Rotating rods	*0.15 m/sec*; with rods not rotating, laminar stream lines formed at all points 1 to 5. The rods were then rotated. The stream lines from points 1 to 5 dispersed one after the other, indicating inception of turbulence. When the rotation was stopped, laminar stream lines formed again at all points in the reverse order. In a single run, inception of turbulent and laminar flow was observed three times.


2 mm
10 mm
10 mm
12 mm
2 mm


12 mm
12 mm
2 mm
10 mm


10 mm
5 mm
12 mm
5
5 mm
SPREADER
BOOSTER

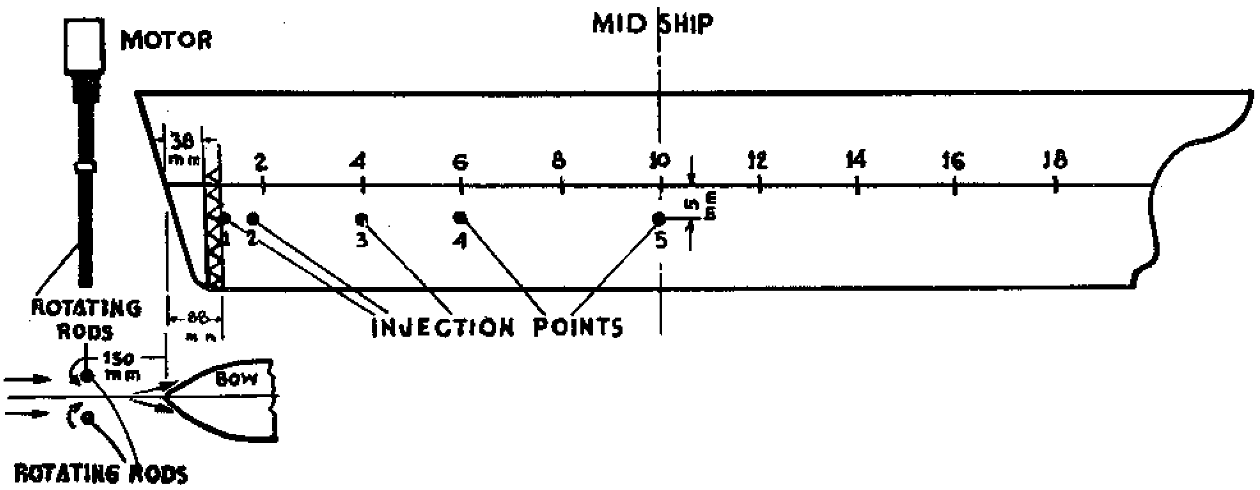

MOTOR
MID SHIP
38 mm
2
4
6
8
10
12
14
16
18
5 mm
1
2
3
4
5
INJECTION POINTS
ROTATING RODS
80 mm
150 mm
BOW
ROTATING RODS

Fig. 1.

Dr. E. Castagneto.

1. *Model-Ship correlation.*

No suggestion has been made by the Committee about the adoption of a standard model-ship correlation allowance ΔC_T to be used in routine works, therefore we are all still kept waiting.

The formal agreement about the use of the ITTC Line 1957 has been limited to scientific works, to be published, but the Superintendents of the Towing-Tanks are gathered up here, at this Conference, first of all, for practical and effective purposes, concerning the uniformity of the experimental technics and the calculation methods, to be used for the everyday's works.

It's true that from a scientific point of view, the present knowledge is not sufficient to choose a correct value of ΔC_T, but the same could have been said of the ITTC Friction-Line, which has been accepted "as an interim solution for practical engineering purposes". Therefore I would rather accept a Committee proposal for the adoption of a unique value ΔC_T to be used with the ITTC Friction-Line as an interim solution for practical engineering purposes.

Since September 1957, the ITTC Line has been used more and more frequently by the Rome Towing-Tank, either for researches planned by the Institute or for experiments on behalf of its users.

Afterwards, the results of a certain number of sea trials have been analyzed and brought to the attention of the Committee. From them, it comes out a medium compensation addendum $\Delta C_T = 0.0001$ for completely welded ships ans $\Delta C_T = 0.0003$ for partially welded ships.

Up to now, the three main Italian Shipyards have adopted the I.T.T.C. Line with the ΔC_T allowance varying between 0.0002 and 0.0004 and an inquiry is going on among all the users of the Rome Towing-Tank for the general adoption of the ITTC Line and a unique allowance ΔC_T for Tank data.

2. *Form effect.*

The Rome Towing-Tank has informed the Committee of the results of tests with two models of submarine and a revolution-body, tested deeply submerged and a surface-ship model.

The data are contained in the Committee Report, Appendix no. 2, in which however the values transcribed as "water plane area" must be read instead as "midship section area". Besides, for a better valuation, it must be added that the C. 881 Model was fitted with the following appendages: rudder and diving rudders forward and aft, sonar, conning tower; the others were naked models.

The tests were carried out with the most possible carefulness.

From our experimental results we can deduct (considering the presence of appendages on the model C. 881), that for the deeply submerged bodies is $C_T \leqq C_F$, that is, with reference to the ITTC Line, the form coefficient $k \leqq 0$.

This would mean that the ITTC Line, in the experimented fields, is higher than that for the flat plate.

For the surface-models, tested at low Froude number presented in the Committee Report, it is always $k \geqq 0$, but the general course of the curves seems to get closer to a law of the kind $C_T = C_F + \Delta C_F$, rather than to the law $C_T = C_F (1 + k)$.

As it is known(*) according to experimental and theoretical researches, for revolution bodies, $k = \sim 0.6 \frac{D}{L}$, which for surface ships could be changed into $k = \frac{\sqrt{Am}}{L}$ (D = diameter, Am = main section's area.) Too different values between ship-models and revolution bodies with the same form coefficients, and between surface models and deeply submerged models require explanation.

However, is the author's opinion that the form coefficient should be obtained with double models tested deeply submerged, rather than with surface models tested at low Froude numbers. This last procedure is based on the hypothesis that, with $V \rightarrow 0$, $R_r \rightarrow 0$, which is doubtlessly evident, and that also $C_r \rightarrow 0$, which is not evident at all, and does not seem it has been proved yet.

On the other side, the procedure of experiments at low Froude numbers is experimentally very hard and uncertain.

(*). E. G. M. PETERSOHN : « *Berücksichtigung der Ablösung bei Widerstandsbestimmungen durch Modellversuche* », Schiffstechnik 1957 — Heft 20.

3. *Measuring Techniques.*

The Rome Tank has purchased a standard model, in laminated fibre-glass (C 950), identical to those furnished to four British Towing-Tanks and kept it experimenting periodically every two weeks starting from January 11th, 1950.

The test procedure and correlating analysis are those shown in the Appendix no. 3 of the Committee Report. The results obtained up to now are shown in the Figures 1 and 2 (*).

A second model, identical as to the shape, but made in wood and painted according to the usual technic followed by the Rome-Tank, has been now completed and will be afterwards periodically experimented together with the plastic model. This will be useful in order to determine the influence of the material and of the painting-procedure. In this connection, it must be pointed out that the plastic model, received by the Rome Tank, does not exactly reproduce the drawing figure no. 1 of the Appendix 3.

Previously a research of the same kind but without the same strictness and completeness had been carried out with a cargo ship-model in painted wood (C 781), during the period May 1956-February 1958.

The main sizes were as follows.

L_{PP}	Length between perpendiculars	m.	5,3500
L_{WL}	Length on water line	m.	5,4900
B_M	Maximum breadth	m.	0,7533
H_M	Draft	m.	0,3075
∇	Displacement in fresh water	T.	0,939476
S	Wetted surface	m^2.	6,1218
C_B	Block coefficient		0,7380

The results obtained are shown in Figures 3, 4 and 5 (*).

It is worth noting that in the above said period the consistency of the results seemed to be unsatisfactory and this was imputed to the bad quality of the painting.

(*) The results are corrected to 59 °F.
Curve (a): day mean value.
(b): day upper and lower limits.
(c): cumulative mean value.

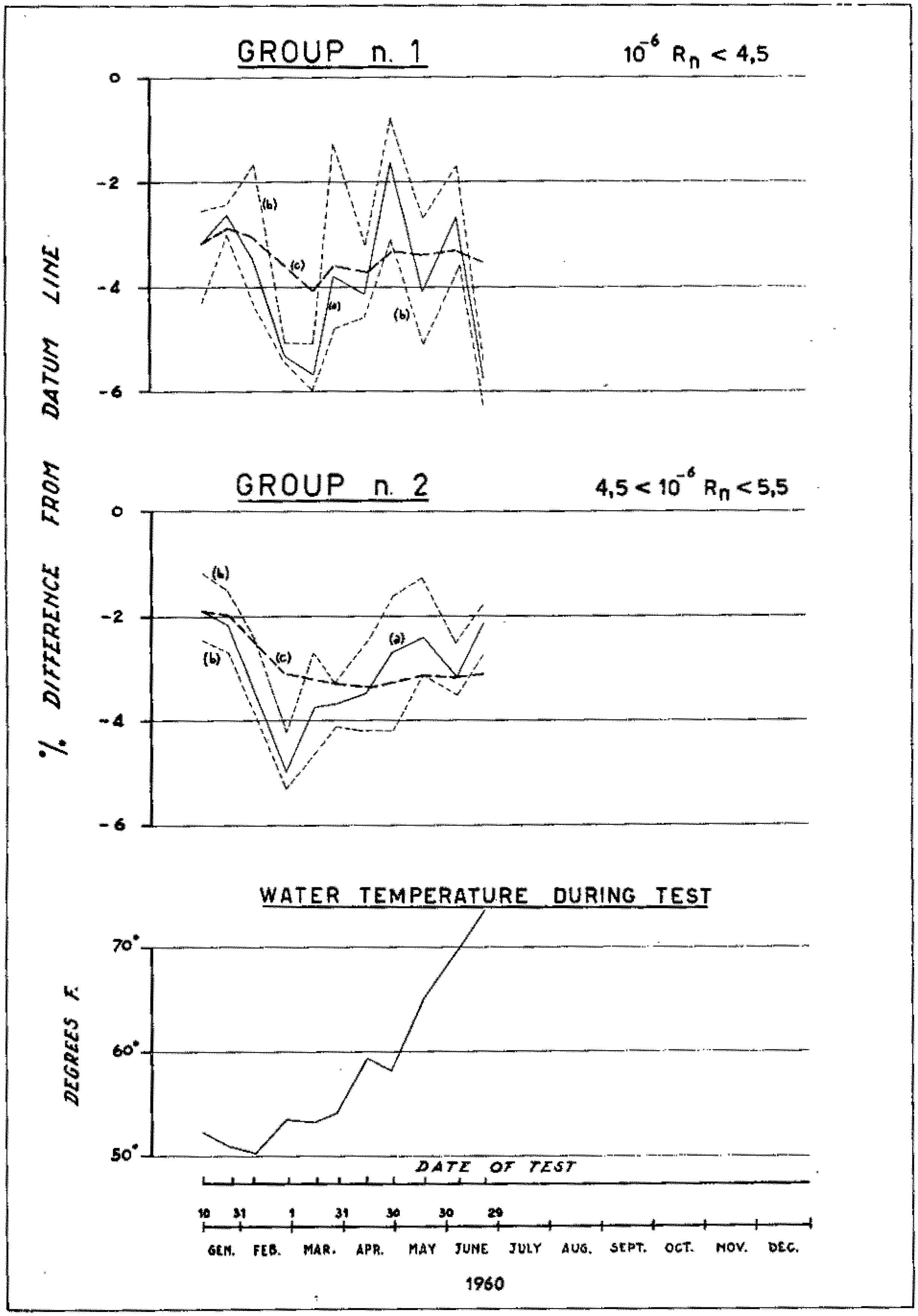


FIG. 1.
Fibreglass standard model C 950.

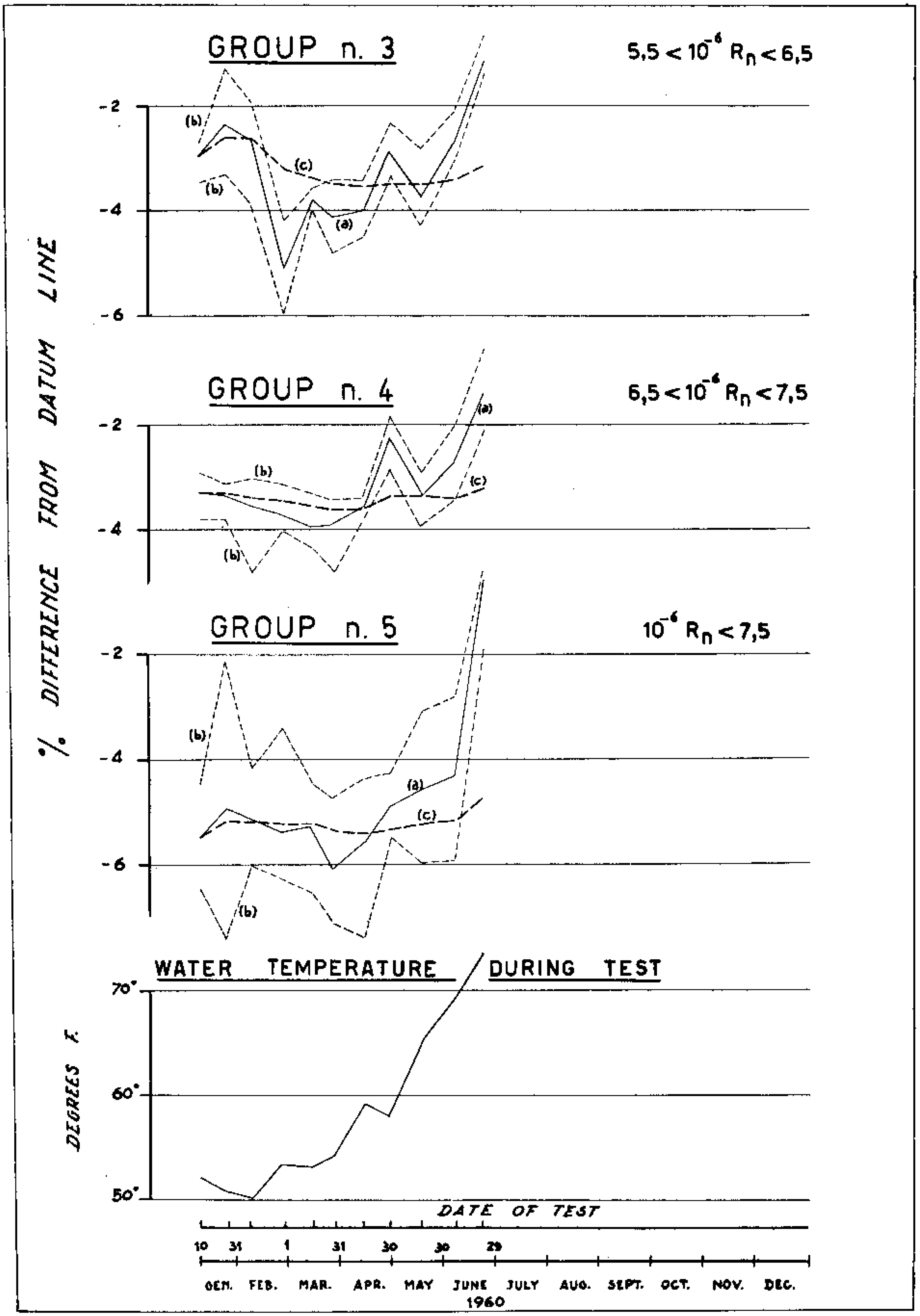


FIG. 2.

Fibreglass standard model C 950.

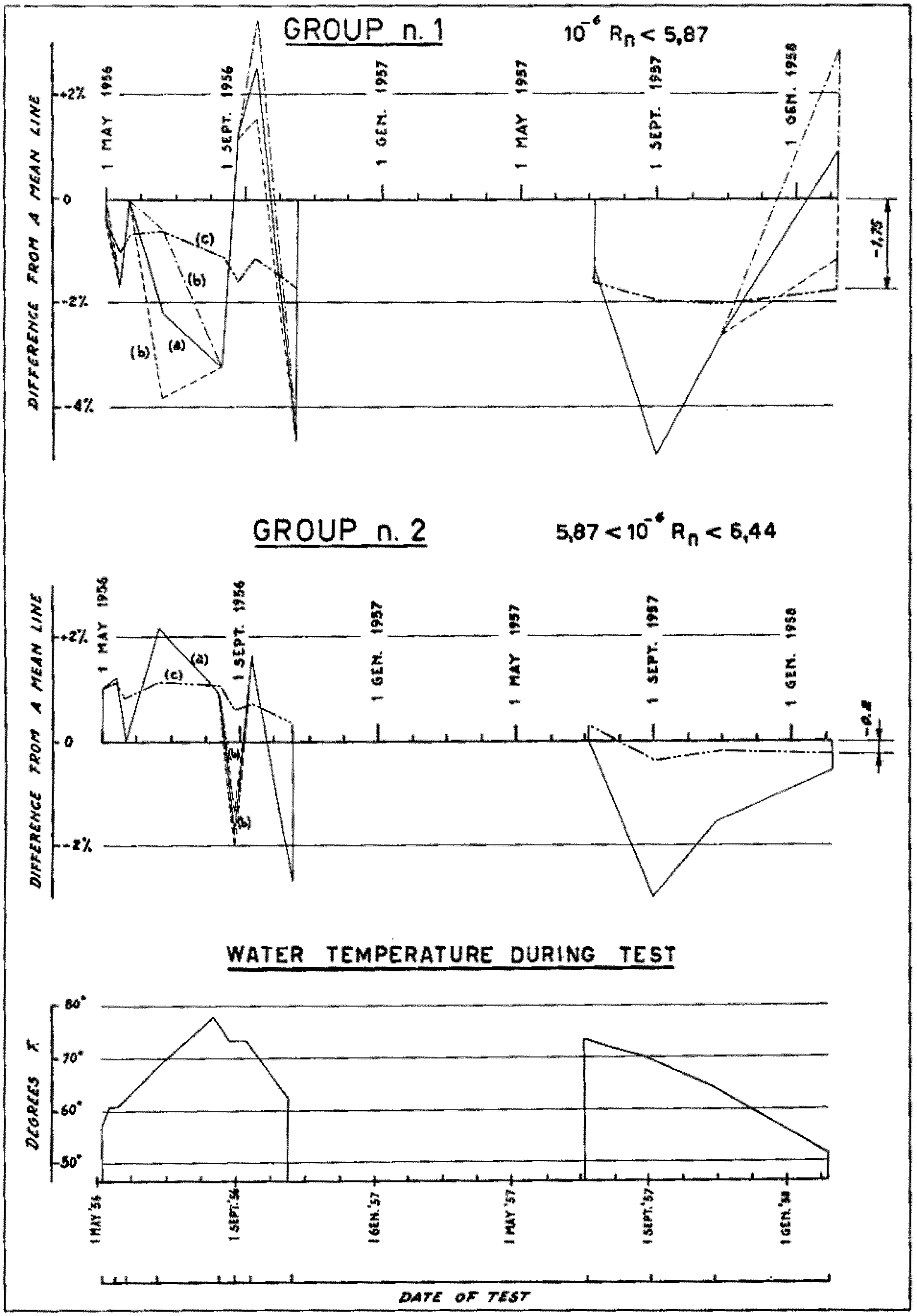


FIG. 3.
Wooden model C 781

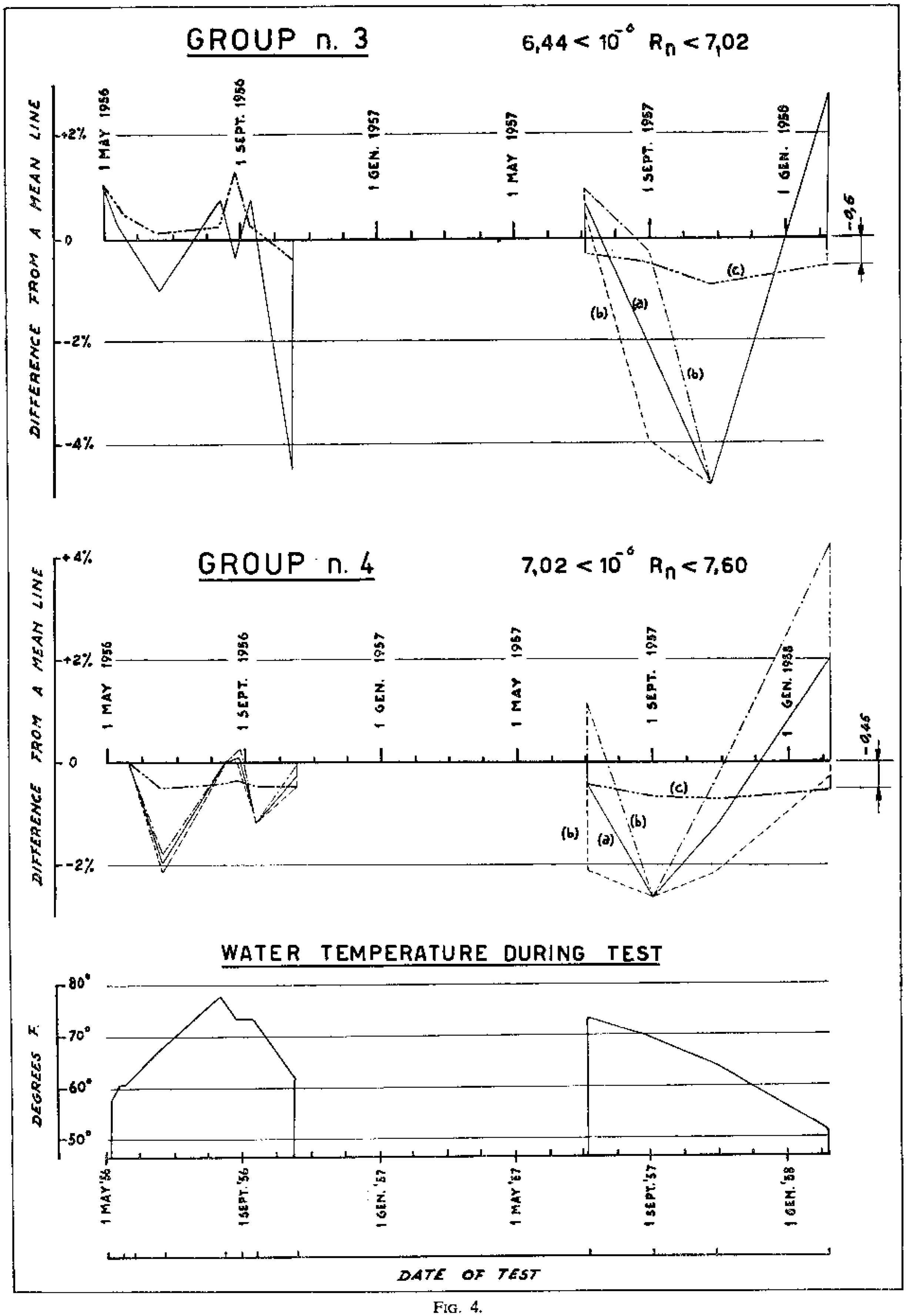


FIG. 4.
Wooden model C 781.

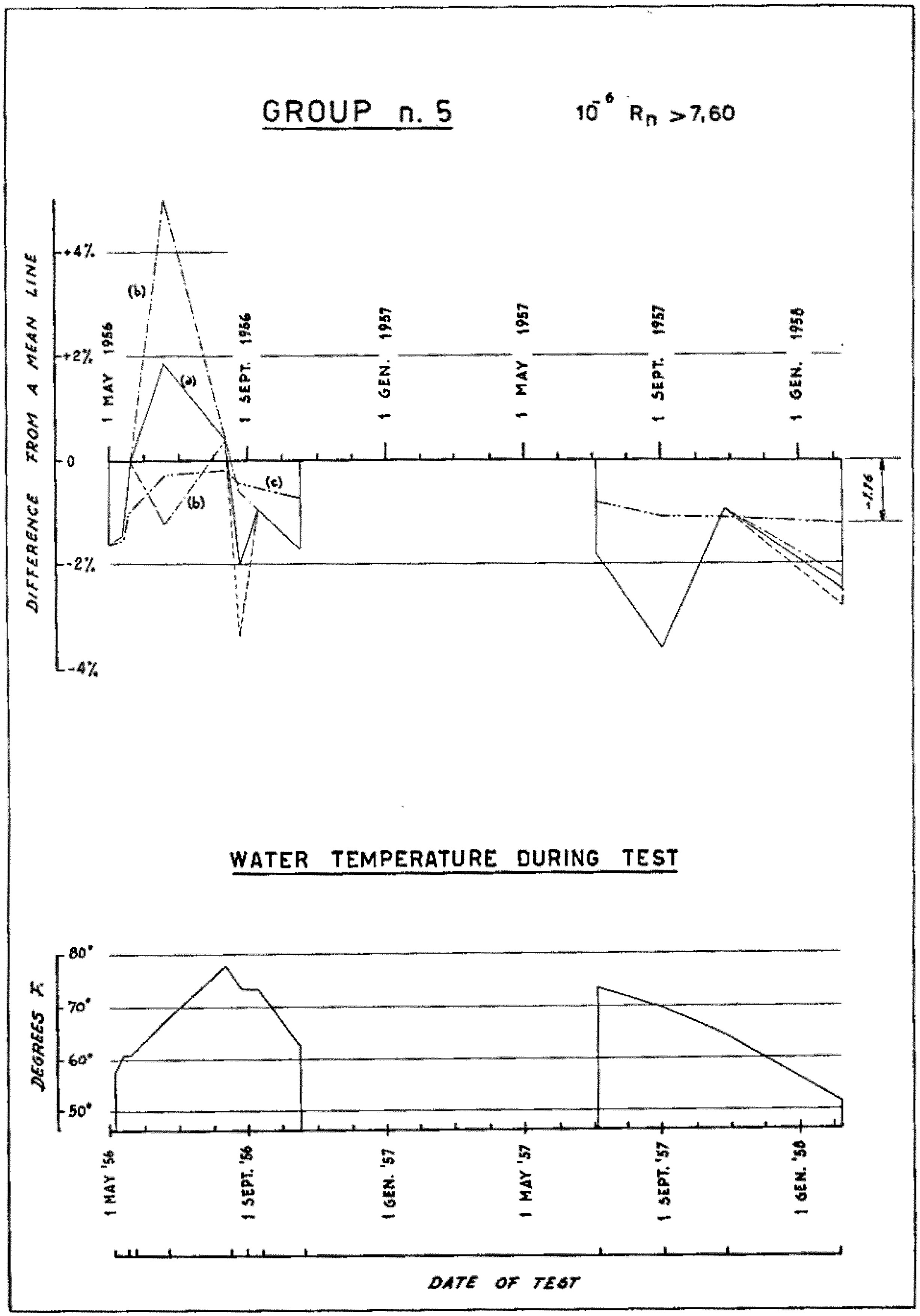


FIG. 5.
Wooden model C 781.

Prof. A. Di Bella.

THE "ITTC" FORMULA ON THE EXPERIMENTS WITH SMALL MODELS OF SHIPS

On the circulating-water-tank of Genoa University, four geosim models have been tested of the well known Taylor design, shown on the page 182 of "The Speed and Power of Ships" edition 1943.

The model scales were 300-150-120-90.

The ship and model dimensions are shown in Table 1.

The experiment results are shown in Table 2.

For the ehp calculation, at first, we have adopted the ITTC formula. But the results of calculations have been inacceptable.

To determine the friction resistance of models, then, we have four wood plates tested, shaped as shown in Table 3. The results of tests are shown in Table 4.

For the friction resistance calculation of ship models it is assumed that, at equal Reynolds number, the friction resistance coefficient of the plate is equal to that of ship model.

For the calculation of ship friction resistance we have adopted the Froude formula.

Table 5 shows the ehp so calculated. We see that, substantially, there is a satisfactory agreement on the results.

We remark that only on the plate no 4 the turbulence has been stimulated. The other plates and the four ship models have been tested without turbulence stimulation.

In the Table 3 the friction resistance coefficients to a base of Reynolds number are reported also: the ITTC line, the Schoenherr line, the Blasius line and the results of the plates tested on the circulating water tank. We observed that for Reynolds number $N_r < 1.600.000$ about it is impossible to adopt a standard formula for the friction resistance calculation; because only for $N_r > 1.600.000$ about the plate tests confirm the ITTC formula. For $N_r = 900.000 \div 1.600.000$ about the Schoenherr formula is confirmed, but for $N_r < 900.000$ about no formula is available.

The small model M_{110} has been tested to aim of study

TABLE 1.
Dimensions of ship and geosim models.

		SHIP	MODELS			
			M_{110}	M_{111}	M_{112}	M_{113}
Scale	λ	1	300	150	120	90
Length waterline	m.	158,801	0,5293	1,0587	1,323	1,764
Breadth	m.	23,165	0,0772	0,1544	0,193	0,257
Draft	m.	7,925	0,0264	0,0527	0,066	0,0879
Displacement	tonn.	15367	$0{,}555.10^{-3}$	$4{,}442.10^{-3}$	$8{,}676.10^{-3}$	$20{,}565.10^{-3}$
Wetted surface	mq.	3959,8	0,0439	0,176	0,275	0,489
Longitudinal coefficient		0,555				

only. We note that the length of Taylor model was 6,302 m. and the length of M_{110} model is 0,5293 m.; therefore the length ratio is 11,9. Consequently we can deduce that for the examined case the effect of scale 11,9 is not remarkable.

It would be interesting to test a Taylor model 10 m. long to proof if the effect of the resulting scale $\frac{10}{0,5293}$ is or not remarkable.

The conclusion is that for small models of ships the procedure of test a plate shaped as shown on Table 3, to determine the friction resistance, is necessary. The turbulence stimulation both in plate or ship model is necessary only on the very small plates.

The ITTC formula for small plates and small models of ship seems not available not even on the circulating water tank.

TABLE 2.

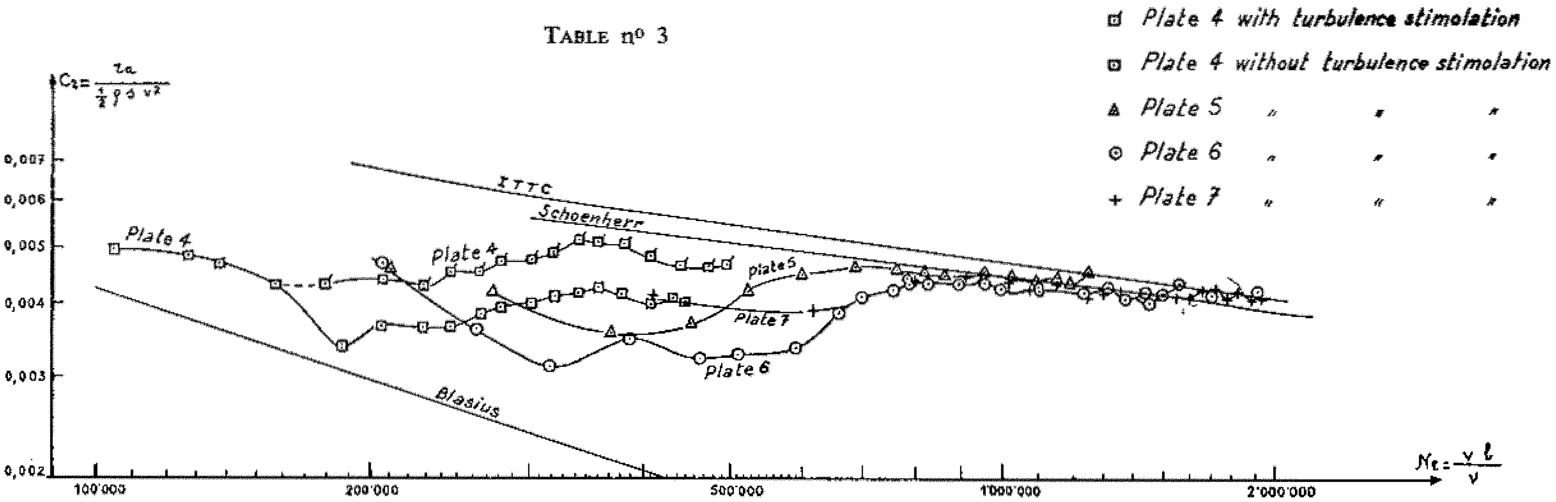
Experiment results of models.

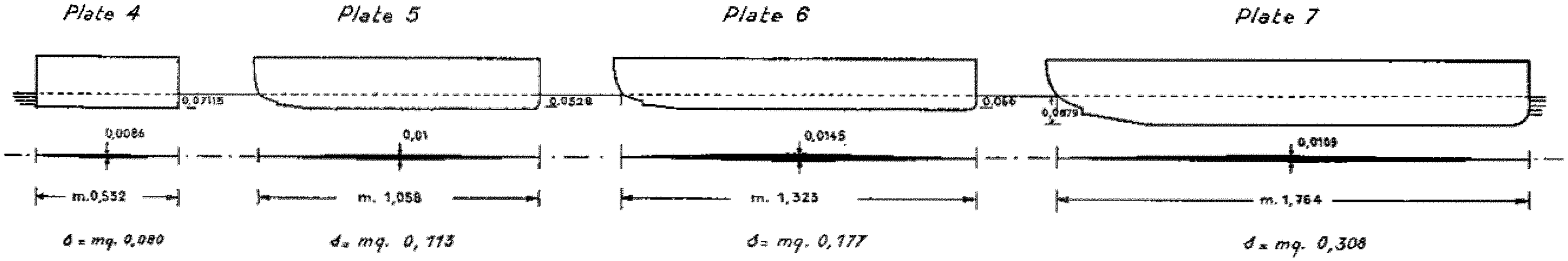
Model M_{110}		Model M_{111}		Model M_{112}				Model M_{113}	
v	r	v	r	v	r	v	r	v	r
0,340	1,43	0,483	10,3	0,483	15,05	0,940	59,75	0,637	51,35
0,375	1,69	0,513	10,7	0,550	20,0	0,987	67,7	0,695	59,4
0,415	1,92	0,513	10,8	0,622	26,4	1,030	75,0	0,788	70,7
0,447	2,25	0,550	12,4	0,695	32,6	1,072	85,9	0,864	85,8
0,483	2,69	0,585	14,8	0,788	41,1	1,100	92,25	0,940	100,5
0,513	3,17	0,585	14,8	0,864	49,0	1,128	96,5	1,009	122,6
0,550	3,70	0,622	17,0	0,940	59,4	1,155	103,6	1,087	139,6
0,585	4,38	0,657	18,8	1,009	71,0	1,167	109,9	1,145	159,0
0,585	4,55	0,657	19,0	1,087	89,5	1,179	112,5	0 657	52.95
0,622	5,00	0,695	21,3	1,087	89,7	0,902	55,1	0,747	65,1
0,622	5,20	0,747	24,0	1,145	100,6	0,882	50,55	0,818	77,0
0.657	5,69	0,747	23,6	1,188	115,0			0,902	92,8
0,657	5,85	0,788	27,2	1,215	121,2			0,676	55,2
0,695	6,70	0,818	29,2	0,513	18,0			0,767	67,0
0,695	6,80	0,818	30,3	0,585	22,83			0,844	81,0
0,747	7,90	0,864	32,9	0,657	29,03			0,957	106,2
0,747	7.90	0,902	37,4	0,747	37,65			0,987	114,2
0,788	9,30	0,902	38,7	0,818	45,3			1,030	126,8
0,788	9,62	0,940	43,0	0,902	56,5			1,099	131,0
0,788	9,60	0,972	47,3	0,972	65,7			1,072	136 9
0,818	11,55	0,972	47,1	1,049	80,08			1,115	148,5
0,818	11,50	1,009	50,8	1,115	93,75			1,167	181,5
0,864	15,60	1,049	53,2	1,167	112,8			1,188	193,3
0,864	15,70	1,049	55,0	0,818	45,7			1,215	200,0
		1,049	52,8	0,844	46,8				
		1,049	50,5	0,882	52,8				
		1,087	62,6	0,530	18,43				
		1,087	62,0	0,719	34,19				
		1,115	67,0	0,805	43,25				
		1,115	66.5	0,922	57,65				
		1,115	65,7	0,844	47,7				
		1,145	79,0	0,957	62,8				
		1,145	77,5						

v = speed $\left(\frac{m}{sec}\right)$

r = model resistance (gr.)

TABLE n° 3





δ = plate surface

TABLE 4.

Experiment results of plates.

PLATE 4				PLATE 5		PLATE 6		PLATE 7	
Without turbulence stimulation		Without turbulence stimulation		Without turbulence stimulation					
v	r	v	r	v	r	v	r	v	r
0,483	3,66	0,622	8,1	0,193	0,94	0,152	0,95	1,125	97
0,193	0,71	0,695	10,0	0,251	1,51	0,234	1,57	1,188	93
0,234	1,064	0,747	10,85	0,340	2,39	0,286	2,58	1,167	87,4
0,251	1,182	0,788	11,6	0,415	3,66	0,375	4,17	1,145	83,3
0,286	1,420	0,657	9,0	0,483	5,55	0,432	5,72	1,115	80,0
0,340	1,62	0,818	12,4	0,55	7,63	0,513	9,67	1,087	74,8
0.375	2,11	0,869	13,9	0,622	10,10	0,603	13,97	1,049	71,3
0,415	2,55	0,902	15,3	0,695	12,35	0,695	18,7	1,009	66,0
0,447	2,97	0,585	6,78	0,788	15,6	0,805	24,6	0,972	60,5
0,483	3,71	0,550	5,77	0,864	18,35	0,193	1,22	0,940	56,7
0,513	4,21	0,513	5,0	0,940	22,10	0,34	3,37	0,902	51,8
0,550	4,93	0,483	4,26	1,009	24,85	0,483	8,13	0,864	47,3
0,585	5,72	0,447	3,66	1,087	22,22	0,564	12,35	0,818	43,5
0,622	6,5	0,415	2,97	1,147	33,25	0,657	16,6	0,788	40,2
0,657	7,44	0,375	2,48	1,099	27,35	0,767	22,31	0,747	36,1
0,695	8,16	0,340	2,03	0,882	19,8	0,864	27,79	0,695	32,21
0,340	1,6	0,585	6,92	0,747	19,15	0,902	30,6	0,657	28,62
0,747	9,22	0,55	6,0			0,55	11,4	0,622	26,2
0,788	10,22	0,415	2,92			0,564	12,21	0,585	23,3
0,818	11,0					0,957	34,1	0,55	20,6
0,818	11,1					1,009	37,6	0,483	15,7
						1,019	40,9	0,375	8,6
						1,100	44,82	0,251	4,0
						1,155	51,0		
						1,215	56,8		
						0,719	19,71		
						0,818	25,4		
						1,072	42,0		
						1,115	46,1		
						1,167	51,0		

v = speed $\left(\frac{\text{m}}{\text{sec}}\right)$

r = plate resistance (gr.)

TABLE 5.

v	e.h.p.				
	M_{110}	M_{111}	M_{112}	M_{113}	TAYLOR
12	—	—	—	1,780	—
14	2,577	2,435	2,564	2,520	2,430
16	3,798	3,565	3,832	3,819	3,700
18	5,500	5,009	5,228	5,370	5,300
20	7,991	7,430	7,578	7,640	7,520
22	11,016	11,180	11,186	12,380	10.730
24	16,130	15,150	15,784	—	15,400
26	23,890	21,980	22,054	—	23,400
28	43,780	—	—	—	41,500

v — Speed (knots)

Dr. M. Kinoshita.

ON ΔC_F ANALYSIS OF SOME SUPERTANKERS RECENTLY BUILT

The members of No. 41 Research Group of the Shipbuilding Research Association of Japan have carried out a series of standardization sea trials on several supertankers newly built during the period from the autumn of 1959 to the spring of 1960, as a part of research programme on "Investigation into Propulsive Performance of Service Condition of Mammoth Tankers", with subsidies provided by the Ministry of Transportation as an aid encouraging test researches.

Table 1 shows the names of the tankers and the shipyards where they were built, and the principal dimensions, the mile courses used and their average depth of water.

In these standardization sea trials, the following items were carried out in addition to the necessary items of measurement conducted at usual standardization sea trials:

(*a*) Measurement of roughness of the underwater surface of the ship's hull.

(*b*) Continuous recording of the magnitude and direction of the tidal current.

(*c*) Continuous recording of the wind direction and the velocity of wind relative to the vessel during her sailing on the trial course.

(*d*) Continuous recording of the ship's relative speed to water in order to determine the necessary minimum distance of an approach run before entering the trial course.

(*e*) Continuous recording by means of the echo sounder of the water depth of the mile course and of its front and rear.

With "S.T. Caltex Plymouth" in particular, the measurement of the thrust applied to the intermediate shaft and the continuous recording of the change in rudder angle during the run on the mile course, were also carried out.

It is not the intention of the present report to describe in detail the methods used in these measurements and the results obtained but, among the results obtained, matters which are considered as being particularly closely related to the problem of ΔC_F are described in the following:

1. As regards structural roughness, the recording was made only for the size of bilge keels, the number of rivet seams of underwater shell plate and the number of raw of rivets of that part, the size, position and number of the zinc plates, and the number, size and position of the shell openings (sea chest, discharge valves, main soil pipes, scupper pipes, etc.) under the load water line. The results obtained are shown in Table 2 in simplified form.

2. As regards the roughness of painted surface of outside bottom plates, it was recorded by the use of the roughness meter of the contact-needle type devised by Osaka University. The analytical results of the data are shown in Figure 1 and Figure 2. These Figures, however, do not include the results of measurement of "S.T. Everest Maru", because these results were considered as lacking in reliability due to insufficient experience.

3. The value of the most representative tidal current on the mile course was obtained from the values of tidal currents continuously recorded at 3 positions suitably arranged along both sides of the mile course and at times also at various depths, and the most typical example of plotting the velocity components parallel to the mile course is shown in Figure 3.

It has been proved that these measured values of tidal currents are helpful in making more precise the correction for tidal current in the standard analysis of trial data.

4. Table 3 shows the ratio to the designed value of torque at maximum continuous output, of the actually measured value of torque due to the so-called sterntube friction obtained by slowly turning the intermediate shaft by means of a turning motor immediately before departing for the sea trial and immediately after returning from it. Despite paragraph (1) in the Note of the Appendix, these actually measured values were not used in the present analysis, but a fixed value of 2 % was adopted.

5. The tank test for "Everest Maru" and "Attica" was carried out at the Mitsubishi Nagasaki Experimental Tank, the tank test for "Caltex Plymouth", "Kakuho Maru" and "Oriental Giant" at the Towing Tank of T.T.R.I., and the open test of the model propeller for "Caltex Plymouth" at the Mitsubishi Nagasaki Experimental Tank, strictly and in accordance with the respective methods of usage.

TABLE 1.
Principal Particulars and Trial conditions of the Ships tested.

Name of Ship				Everest Maru	Kakuhō Maru	Caltex Plymouth	Attica	Oriental Giant
Owner				Daido Line	Iino Line	Cal. Texas Oil Corp.	Liberian Trans-Atlantic Corp.	Island. Navigation Corp.
Shipyard				Mitsubishi	Iino-Maidsuru	Hitachi-Innoshima	Harima	Saseho
Principal Particulars	Hull		L_{pp}	213.0^m	213.0^m	211.84^m	213.0^m	245.0^m
			$B_{mld.}$	30.5^m	30.5^m	31.70^m	30.5^m	32.9^m
			$D_{mld.}$	15.2^m	15.2^m	15.14^m	15.2^m	18.5^m
		at Desinged Load Draught	d	11.360^m	11.33^m	11.23^m	11.35^m	13.26^m
			C_b	0.800	0.800	0.786	0.800	0.820
			C_p	0.804	0.805	0.791	0.808	0.830
			$C_{\otimes}$	0.995	0.994	0.994	0.990	0.992
			L.C.B	1.73% F	1.65% F	1.37% F	3.86% F	1.54% F
			Gross Ton.	29.216	29.409^t	31.109^t	29.741^t	43.423^t
			Dead Wt.	47.274	47.252^t	46.757^t	47.369^t	71.490^t
			Stem & Stern	Bulbous Bow. Cruiser Stern	Raked Stem Cruiser Stern	Raked Stem Cruiser Stern	Bulbous Bow Cruiser Stern	Bulbous Bow Cruiser Stern
			Rudder	Reaction Rudder	Reaction Type, Stream Lined, Semi-balanced	Stream Lined Balanced Rudder	Stream Lined Balanced Rudder	Stream Lined Balanced Rudder
	Eng.		Type × No.	Turbine × 1	Diesel × 1	Turbine × 1	Turbine × 1	Turbine × 1
			Max. Output	$17.600^{SHP} \times 110^{RPM}$	$16.000^{BHP} \times 119^{RPM}$	$17500^{SHP} \times 105^{RPM}$	$17600^{SHP} \times 105^{RPM}$	$22.000^{SHP} \times 105^{RPM}$
	Propeller		Type	5 Bl. Solid Type	5 Bl. Solid Type	5 Bl. Solid Type	5 Bl. Solid Type	5 Bl. Solid Type
			Dia. × P. Ratio	$6^m600 \times 0.697$	$6^m200 \times 0.716$	$6^m605 \times 0.785$	$6^m604 \times 0.792$	$7^m200 \times 0.722$
			Boss Ratio	0.1818	0.200	0.2173	0.1862	0.1806
			E.A.R.	0.560	0.645	0.555	0.572	0.600
			Bl. Th. Fr.	0.0737	0.0569	0.046	0.0526	0.0583
			Shape of Section	Aeyofoil	Aerofoil	Aerofoil	Aerofoil	Aerofoil
Trial Condition			Date	Oct. 23, 1959	Mar. 3, 1960	Mar. 8, 1960	Jan. 14, 1960	Dec. 8, 1959
			Mile Post used	Miye Mile Post	Araisaki-Nomuro Mile Post	Aoshima-Kominase-Jima Mile Post	Awaji Mile Post	Miye Mile Post
			Weather	Cloudy	Cloudy	Cloudy	Cloudy	Fine
			Sea Condition	Smooth	Rough	Slight	Verry Smooth	Smooth
			Depth of Sea	55 ~ 60 m	90^m	$50 \sim 60^m$	$40 \sim 50^m$	$60 \sim 70^m$
			Temp. of Water	22.4°C	9.5°C	11.7°C	9.5°C	17.8°C
			Spec. Gr. of Water	1.0228	1.0254	1.025	1.025	1.024
	Draught		d_A	11.233^m	11.320^m	11.176^m	11.261^m	13.294^m
			d_M	11.322^m	11.400^m	11.379^m	11.412^m	13.339^m
			d_F	11.410^m	11.320^m	11.240^m	11.372^m	13.192^m
			Trim	0.177^m by Stem	0	0.064^m by Stern	0.111^m by Stern	0.102^m by Stern
			Displacement	60.515^t	60.705^t	61.470^t	60.870^t	90.350^t
			C_b	0.783	0.800	0.787	0.801	0.820
			C_p	0.789	0.805	0.792	0.809	0.830
			$C_{\otimes}$	0.992	0.994	0.994	0.990	0.992
			Imm. of Prop. (I/D)	1.083	0.716	1.051	1.026	1.246
			Date, out of Dock	Oct. 21, 1959	Feb. 29, 1960	Mar. 2, 1960	Dec. 31, 1959	Nov. 26, 1959

TABLE 2.
Structural Roughness on the Hull.

Item \ Name of Ship			Everest Maru	Kakuhō Maru	Caltex Plymouth	Attica
Bilge Keel Length x Depth			54.0^{m} x 430^{mm}	81.0^{m} x 450^{mm}	68.2^{m} x 460^{mm}	69.0^{m} x 460^{mm}
Rivets of Halfboard No. of Rivetted Seam x No. of raw			3 x 2 raws	3 x 3 raws	1 x 2 raws 2 x 3 raws	3 x 2 raws
Zink Plate (Sacrifice anode)	Dimensions		300^{mm} x 150^{mm} x 30^{mm}	300^{mm} x 150^{mm} x 20^{mm}	300^{mm} x 150^{mm} x 30^{mm}	300^{mm} x 150^{mm} x 30^{mm}
	Total	Shell Plate	8	0	0	0
		Stern Frame	20	32	20	47
		Rudder	16	11	18	11
		Total	44	43	38	58
Shell Opening (Total)			13	11	(Incl. Small oxes) 41	32

TABLE 3.
Friction Loss Through Stern tube (in %).

Time \ Name of Ship	Everest Maru	Kakuhō Maru	Attica	Caltex Plymouth	
				by Hitachi-Zōsen Torsion Meter	by Togino's Torsion Meter
Just Before Starting for Trial	4.15	5.79	5.03	5.52	5.74
Soon After Finish of Trial	4.68	5.47	4.78	4.83	4.32

TABLE 4.
Mean value of ΔC_f ($\times 10^3$).

Basic Line \ Name of Ship	Everest Maru	Kakuhō Maru	Caltex Plymouth	Attica	Oriental Giant
I.T.T.C. 1957	−0.235	−0.096	−0.129	−0.243	
Schoenherr		−0.168	−0.211		−0.275
Hughes	K = 0.330 0.057	K = 0.350 0.225	K = 0.330 0.159	K = 0.366 0.092	K = 0.42 0.209

K value was deduced from the results of tank test at low Froude Number.

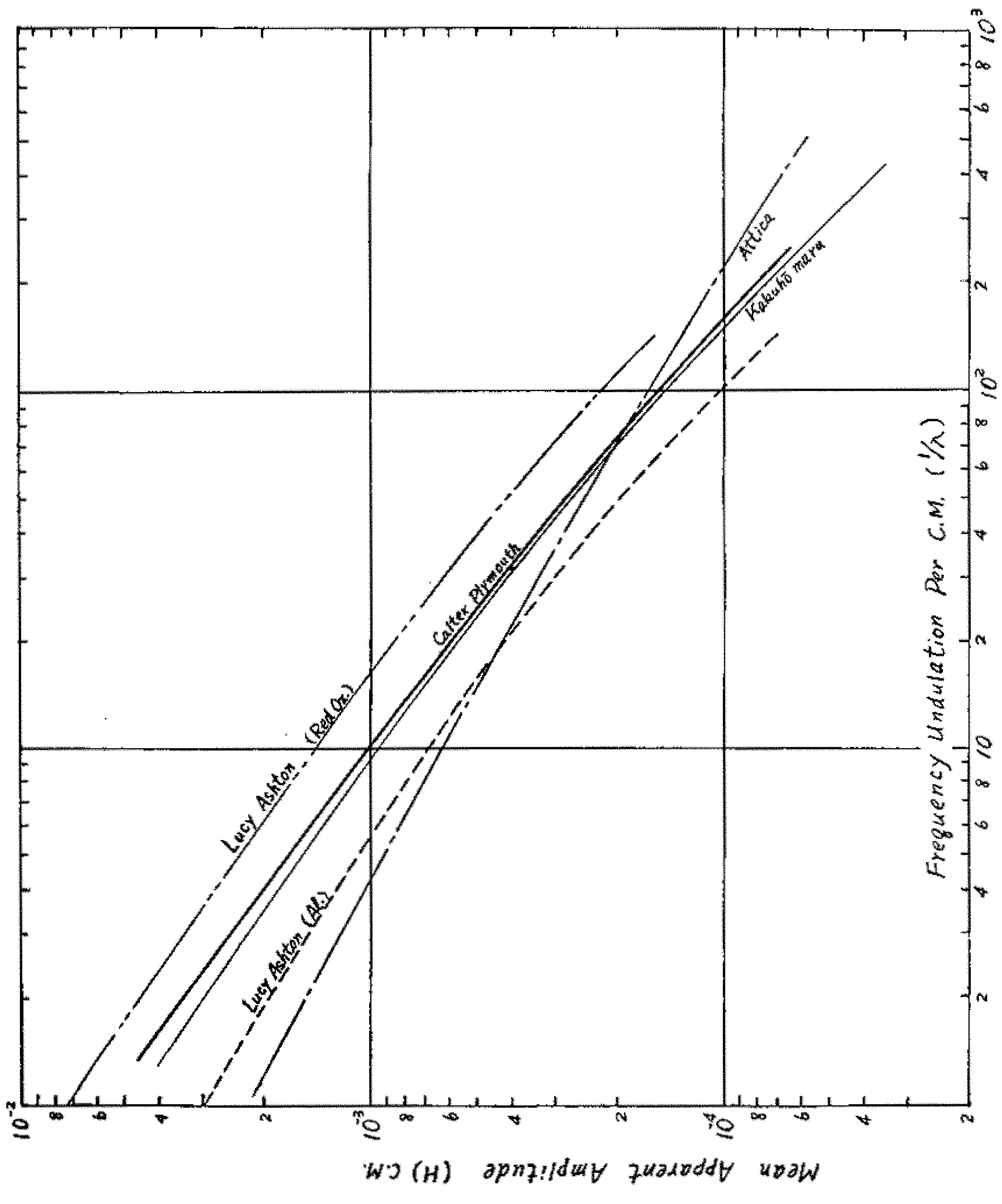

Lucy Ashton (Red Ox.)
Caltex Plymouth
Attica
Kakuhō maru
Lucy Ashton (Al.)
Frequency Undulation Per C.M. ($1/\lambda$)
Mean Apparent Amplitude (H) C.M.
10^{-2}
8
6
4
2
10^{-3}
8
6
4
2
10^{-4}
8
6
4
2
10
2
4
6
8
10^{2}
2
4
6
8
10^{3}

FIG. 1.

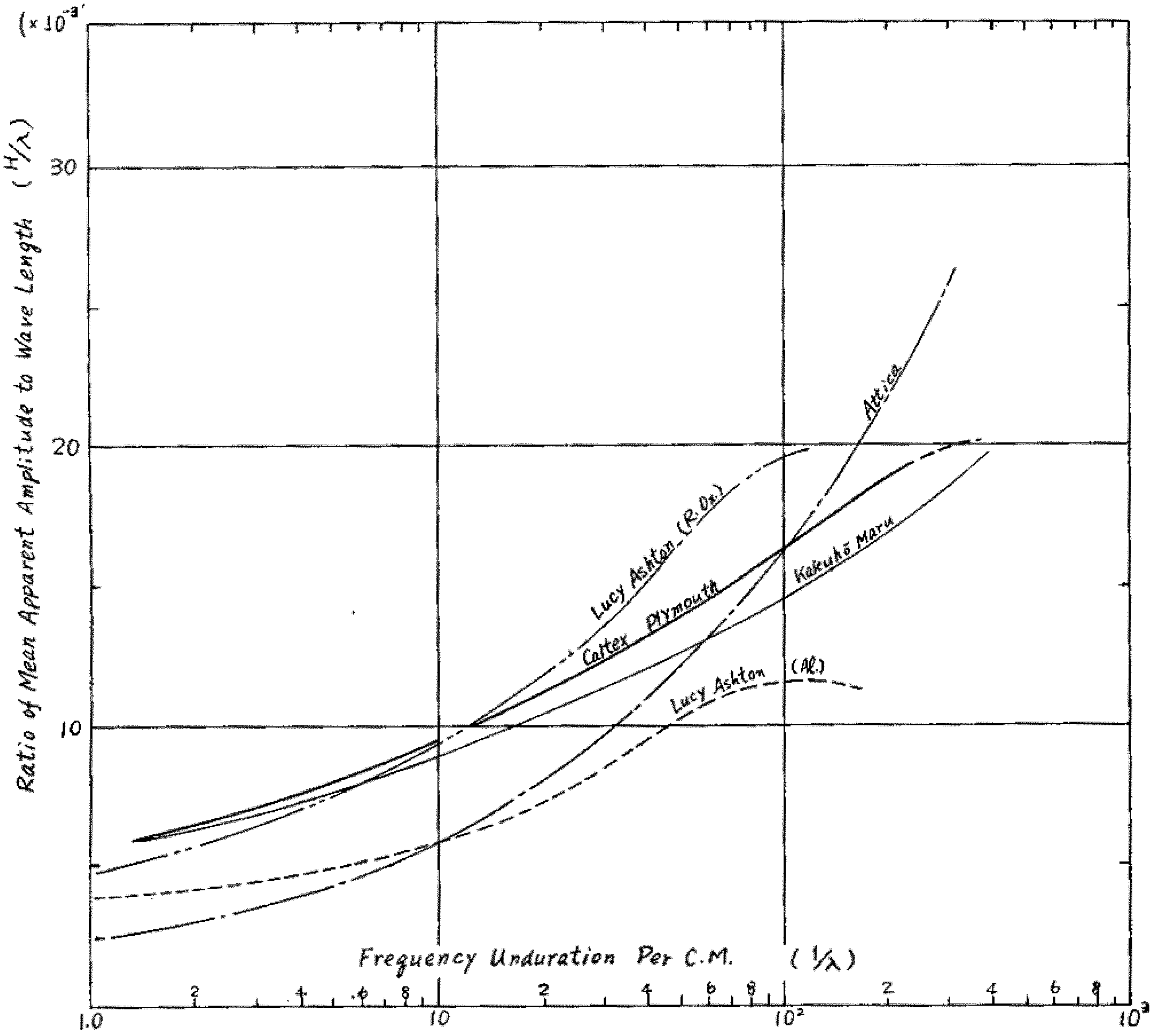

(× 10⁻³)
Ratio of Mean Apparent Amplitude to Wave Length (H/λ)
30
20
10
Frequency Unduration Per C.M. (1/λ)
1.0
2
4
6
8
10
2
4
6
8
10²
2
4
6
8
10³
Attica
Lucy Ashton (R.Ox.)
Caltex Plymouth
Kakuko Maru
Lucy Ashton (Al.)

FIG. 2.

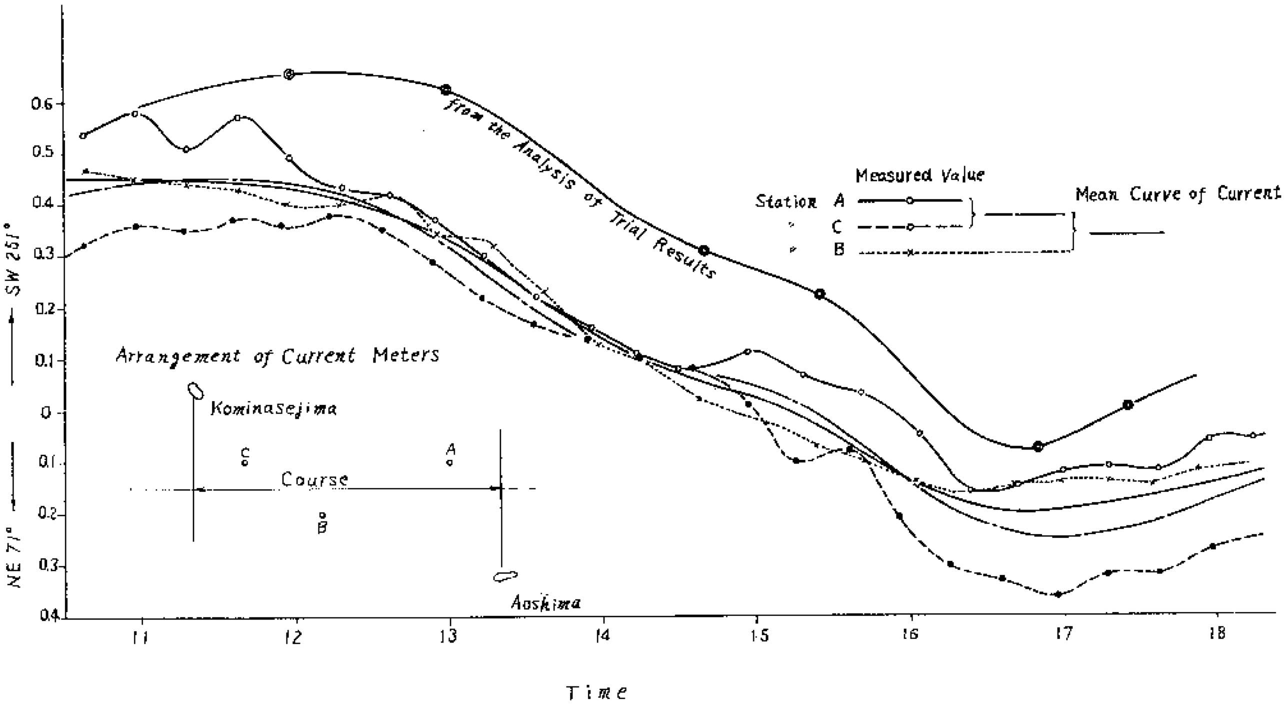


FIG. 3.

Curve of Tidal Current (Parallel Component with Trial Course)
March 8. 1960
off Aoshima-Kominasejima Mile Post

6. The standard method described in the Appendix was, as a rule, adopted for the estimation of ΔC_F from the results of sea trial. However, as stated under Paragraph 4 already, this method was not used for obtaining the value of the friction loss due to stern tube, etc.

Furthermore, as regards propeller characteristics, the open test by the use of the model D = 0,25 m was specially performed for "EVEREST MARU" and " CALTEX PLYMOUTH", despite Paragraph (*c*), and the values thus obtained were used.

7. Figure 4 shows the plotting of the values of ΔC_F thus obtained, and Table 4 shows the consolidation of these values into mean values.

8. Figure 5 shows the scale effect for wake W as consolidated in the form of $1\text{-}w_m/1\text{-}w_s$.

9. It was not possible, unfortunately, to recognize any significant correlation between the structural roughness and surface roughness described under Paragraph 1 and 2, and the ΔC_F shown under Paragraph 7 or the wake described under Paragraph 8, as far as the present experimental data is concerned.

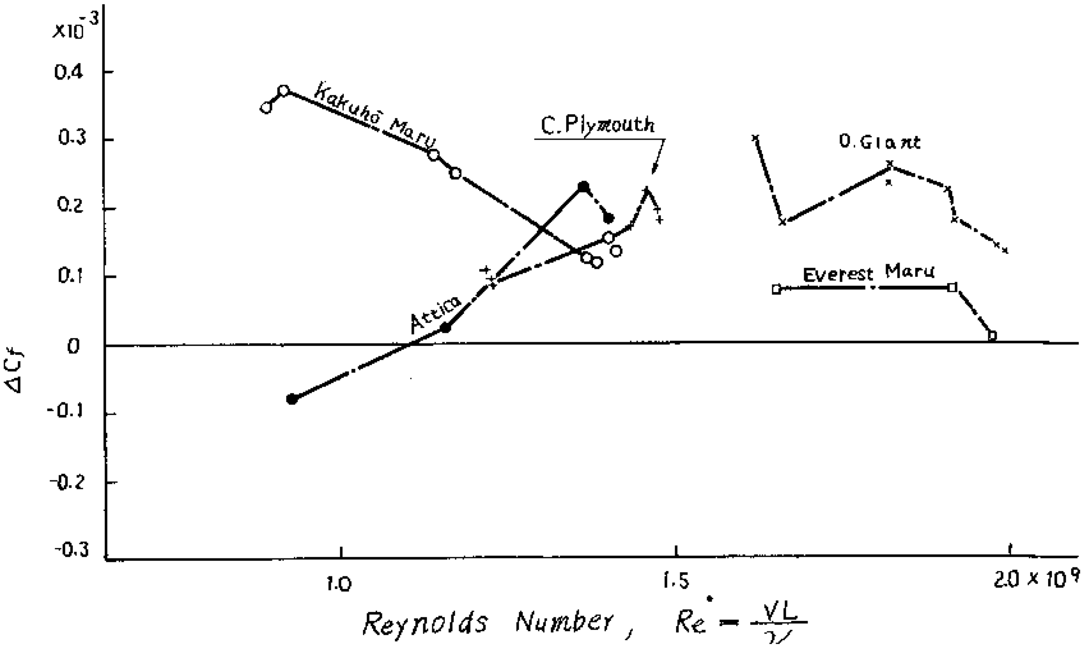


FIG. 4*a*.
ΔC_f Value (Hughes).

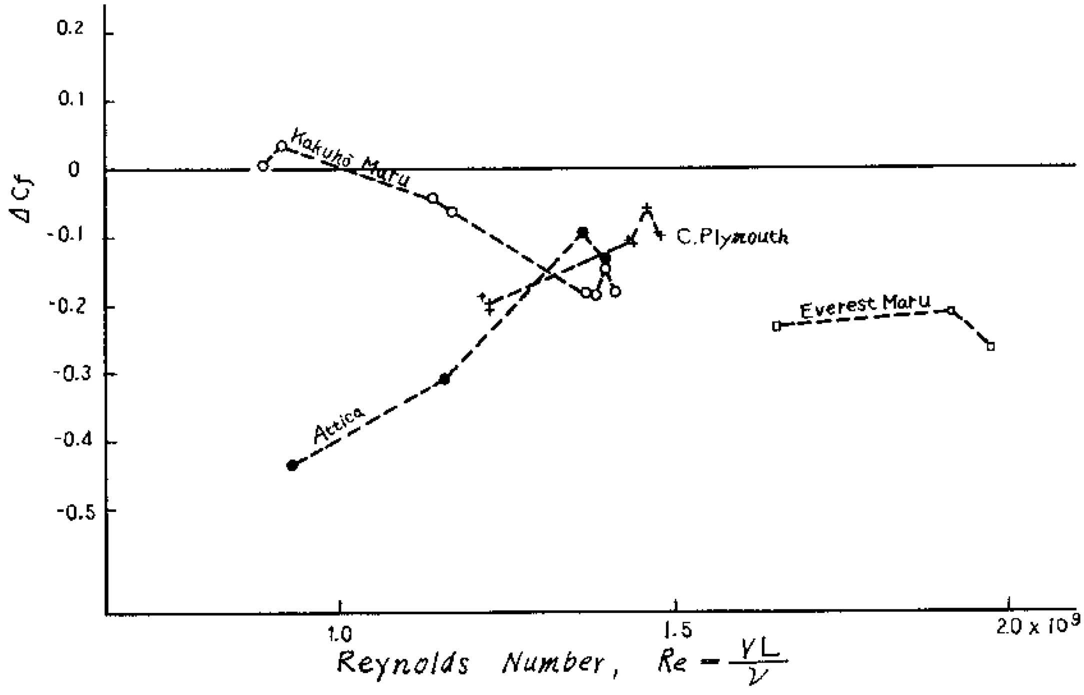


FIG. 4*b*.
ΔC_f Value (I.T.T.C. 1957).

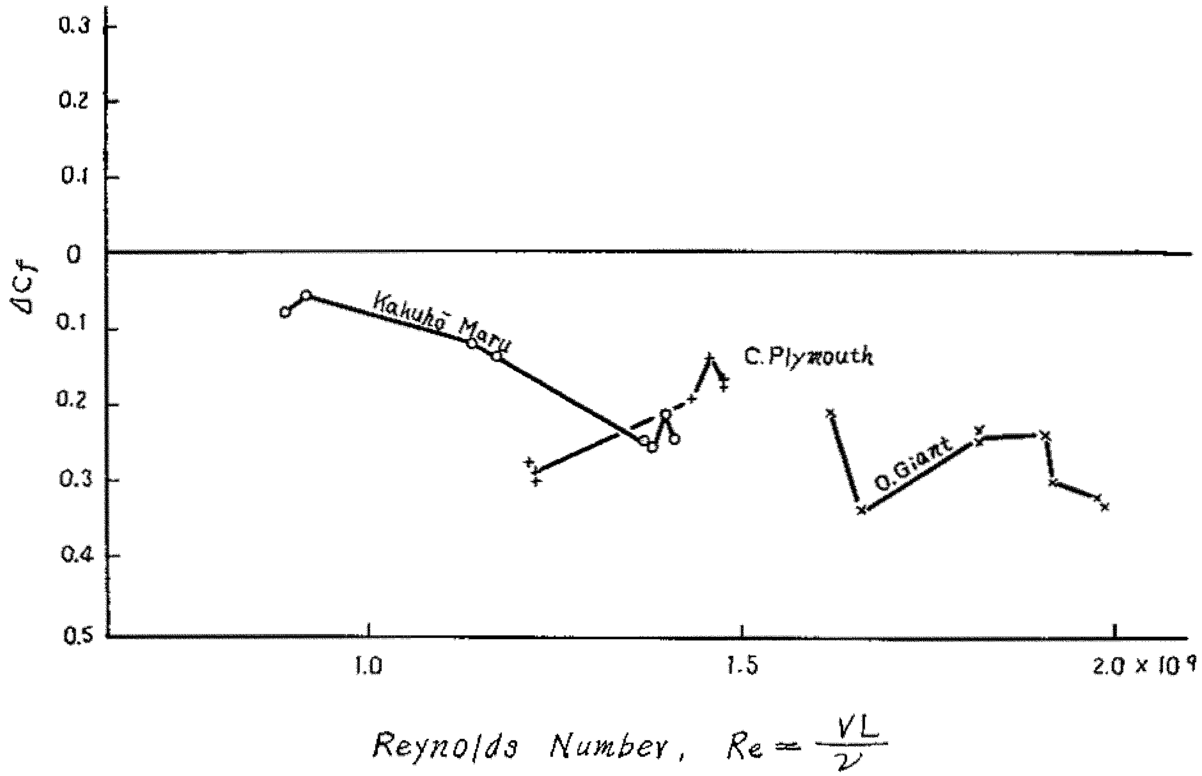


FIG. 4c.
Δ C_f Value (Schoenherr).

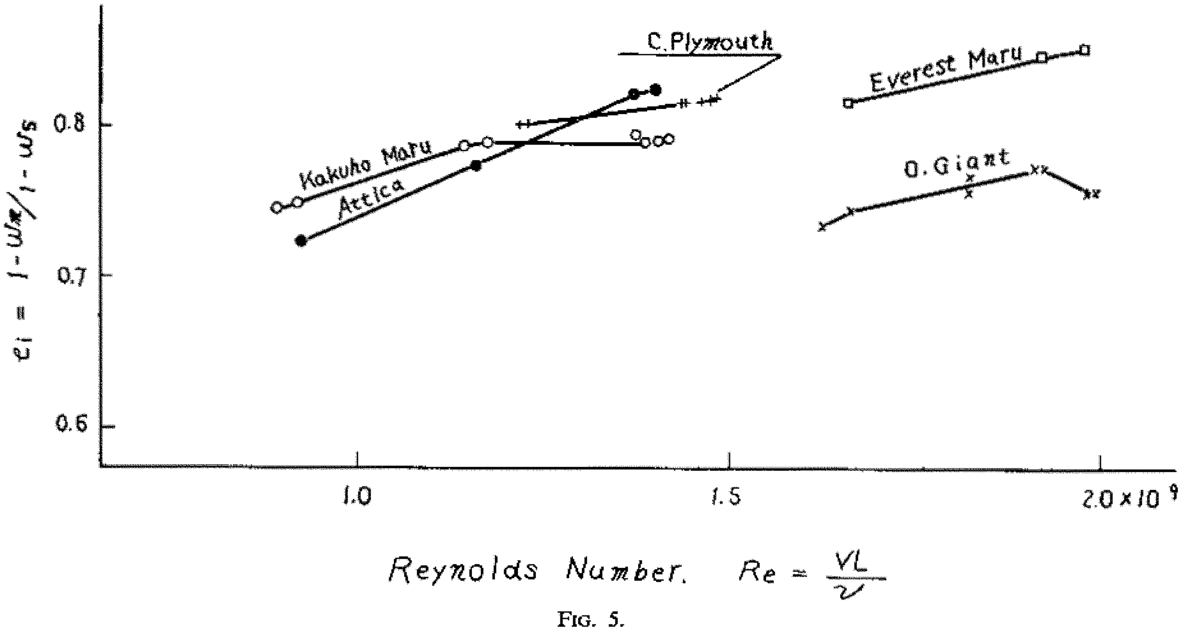


FIG. 5.
Wake fraction.

APPENDIX

NOTE ON STANDARD METHOD OF ESTIMATING ΔC_F FROM THE RESULTS OF SEA TRIAL (I.T.T.C.)

Following corrections shall be made to the values of speed over the ground and the shaft horse-power measured at the time of sea trial.

(1) Losses due to a stern tube etc. The delivered horse-power is obtained from the shaft horse-power as measured by the torsionmeter, by deducting the amount of losses due to the sterntube and the plummer blocks attached abaft.

The frictional torque due to them is assumed to be independent of speed of revolution. For the absolute value of the frictional torque, it is recommended at the fourth meeting of Friction Committee of J.T.T.C. to use since September 1959, the value measured by very slowly turning the shaft of each ship clockwise and anti-clockwise by using a turning motor, if available.

(2) Wind correction. Using the measured values of relative speed and relative direction of the wind during each run over the trial course and values of wind direction effect coefficient surmised from the results of wind tunnel experiments on the similar ships, the wind effect on the delivered horse-power and the speed over the ground can be eliminated.

(3) Tidal current correction. The mean tidal current curve is drawn by plotting the mean values of the current velocity for each to-and-fro sailing, taking the time of trial sailing as the abscissa. The amount of tidal current at each sailing time can be read from this curve, and the true speed of the ship through the water is obtained for each run. Provided that the ship does not sail on the same line, correction shall be made by the parallel shift of the current curve in estimating the tidal current speed.

(4) Corrections concerning the circulating water. These corrections are not required for the installations of the circulating water system adopted in Japan.

Following calculations are further carried out against the above-mentioned standardized values of delivered horse-power and speed of the ship through the water to obtain the values of C_F or ΔC_F.

(*a*) For the thrust deduction and the relative rotative efficiency, the values obtained from model experiment at the corresponding speed are adopted, the thrust identity being employed.

(*b*) Wake is calculated from the analysed results of the sea trial of actual ships.

(*c*) The propeller efficiency estimated from the chart shall be employed. In this case, the chart used (or the Reynolds' numbers employed) should clearly be described.

Note : (1) Corrections shall be made on the effects of difference not only in the developed area ratio and pitch ratio, but also in the thickness ratio and boss ratio.

(2) The values of K_T and K_Q change themselves with respect to the Reynolds' number, but K_Q plotted against K_T is believed to be nearly independent of the Reynolds' number. (Refer to Data Sheet No. 8.)

(*d*) Total resistance coefficient is sought by calculating K_T under the assumption made in the items described above.

(*e*) Any friction line may freely employed in accordance with the custom inherent to each towing tank in Japan. Since 1958, however, it is generally agreed, to try the ITTC 1957 M-S C. line without fail, in addition to those of their own choosing.

(*f*) The wave-making resistance coefficient of actual ships is assumed to be equal to that of the model.

(*g*) In accordance with the method described above C_F or ΔC_F shall be calculated.

Dr. M. Kinoshita.

Standard laminated fibre-glass model.

A standard laminated fibre-glass model was purchased by Mitsubishi Experimental Tank (Nagasaki) from Messrs. Halmatic Ltd. at the end of March this year.

At the beginning of April, the towing tests was started at the Mitsubishi Experimental Tank in accordance with the uniform test conditions adopted by the British Tanks and in June the model was circulated to the T.T.R.I. Tank and Japan Defence Agency Tank.

Above mentioned tests data are reported in Table I — 9 and in Figure 1. In Figure 1, the corrected data of the T.T.R.I. Tank for the difference of blockage between the T.T.R.I. Tank and the Mitsubishi Experimental Tank, are also shown. (The blockage of Mitsubishi Experimental Tank and Japan Defence Agency Tank are practically the same.)

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL 1st TEST

DATE APR. 1. 1960
MODEL № 1430
TANK NAGASAKI (MITSUBISHI)

TEST № TR 1237
$L = 4.8265^{m}$
$S = 4.600^{m^2}$
LARGEST SECTION AREA, $a = 0.204^{m^2}$
$\Delta = 652.9^{kg}$ (F.W.)
TRIM = 0
STIMULATOR = STUDS
SURFACE: NORMAL

TOW-POINT
FROM LWP, LWL
FROM ⊗, 150^{mm} AFT.
WIDTH OF TANK = 12.5^{m}
DEPTH OF WATER = 6.455^{m}
TANK SECTION AREA, $A = 80.7^{m^2}$
$a/A = 0.25\%$

TEMP.
AIR = 18.0°C
WATER SURF. = 14.8°C
" MID.DEPTH = 13.8°C
" BOTTOM = 13.8°C

ρ $[\mathrm{kg\,sec^2/m^4}]$	ν $[\mathrm{m^2/sec}]$
(a) 101.881	1.147×10^{-6}
(b) 101.878	1.141×10^{-6}

(a) FROM SNAME TABLES AT 14.8°C (USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15°C)

RUN No.	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_0 m/s	RESISTANCE R kg	AS MEASURED		CORRECTED TO 15°C	
					R_n $\times 10^{6}$	C_t $\times 10^{-3}$	R_n $\times 10^{6}$	C_t $\times 10^{-3}$
43137	10° 01′	1.895	1.888	4.525	7.975	5.378	8.015	5.376
38	24′	1.663	1.642	2.595	6.999	4.004	7.035	4.001
39	32′	1.423	1.397	1.844	5.988	3.886	6.019	3.884
40	40′	1.182	1.160	1.244	4.974	3.800	5.000	3.798
41	48′	0.947	0.930	0.817	3.985	3.888	4.006	3.884
43142	10° 56′	1.897	1.884	4.447	7.983	5.273	8.024	5.272
43	11° 04′	1.659	1.644	2.605	6.982	4.040	7.018	4.037
44	12′	1.423	1.407	1.876	5.989	3.954	6.020	3.952
45	20′	1.183	1.168	1.262	4.978	3.850	5.004	3.847
46	28′	0.945	0.934	0.824	3.977	3.938	3.998	3.934
43147	11° 36′	1.900	1.888	4.450	7.995	5.261	8.036	5.258
48	44′	1.655	1.646	2.598	6.964	4.049	7.001	4.045
49	52′	1.418	1.407	1.868	5.967	3.964	5.998	3.962
50	13° 20′	1.417	1.414	1.878	5.963	3.992	5.994	3.990
51	28′	1.181	1.175	1.276	4.970	3.904	4.995	3.901
52	36′	0.944	0.933	0.822	3.973	3.937	3.993	3.932
43153	13° 44′	1.892	1.884	4.358	7.962	5.196	8.003	5.193
54	52′	1.657	1.642	2.584	6.973	4.016	7.009	4.013
55	14° 00′	1.421	1.403	1.853	5.980	3.918	6.011	3.915
56	14° 08′	1.183	1.166	1.278	4.978	3.899	5.004	3.896
57	16′	0.948	0.933	0.832	3.990	3.942	4.010	3.937

$R_n = \frac{vL}{\nu}$ in units of 10^{6} $\quad C_t = \frac{R}{\frac{\rho}{2} S v^2}$ in units of 10^{-3}

I.T.T.C. 1957 Ship-model Correlation Line used for Correction to 15°C

Remarks:

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL 2 ND TEST

DATE . APR. 18. 1960
MODEL № 1430
TANK NAGASAKI (MITSUBISHI)

TEST № Tr 1248
$L = 4.8265^{m}$
$S = 4.600^{m^2}$
LARGEST SECTION AREA, $a = 0.204^{m^2}$
$\Delta = 652.9^{kg}$ (F.W)
TRIM = 0
STIMULATOR = STUDS
SURFACE: NORMAL

TOW-POINT
FROM LWP LWL.
FROM ⊠ 150^{mm}A
WIDTH OF TANK $= 12.5^{m}$
DEPTH OF WATER $= 6.68^{m}$
TANK SECTION AREA. $A = 81.8^{m^2}$
$a/A = 0.25\%$
TEMP.
AIR .... = 16·7°C
WATER SURF. = 14·1°C
" MID. DEPTH = 14·1°C
" BOTTOM = 14·1°C

	ρ $[kg\,sec^2/m^4]$	ν $[m^2/sec]$
(a)	101·89	1.169×10^{-6}
(b)	101·878	1.141×10^{-6}

(a) FROM SNAME TABLES AT 14·1°C (USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15°C)

RUN NO.	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_0 m/s	RESISTANCE R kg	AS MEASURED R_n	AS MEASURED C_t	CORRECTED TO 15°C R_n	CORRECTED TO 15°C C_t
43527	13° 30′	1·896	1·889	4·466	$\times 10^6$ 7·829	0·005301	$\times 10^6$ 8·020	0·005290
28	38′	1·663	1·641	2·584	6·867	3986	7·036	3974
29	54′	1·424	1·414	1·867	5·880	3928	6·024	3916
30	14° 02′	1·184	1·173	1·252	4·889	3810	5·009	3799
31	10′	0·944	0·934	0·808	3·898	3869	3·994	3855
43532	14° 18′	1·900	1·887	4·458	$\times 10^6$ 7·845	0·005269	$\times 10^6$ 8·038	0·005259
33	26′	1·657	1·636	2·592	6·841	4028	7·010	4016
34	34′	1·415	1·398	1·839	5·842	3920	5·987	3908
35	42′	1·185	1·172	1·252	4·893	3805	5·013	3794
36	50′	0·949	0·935	0·814	3·918	3857	4·015	3843
43537	14° 58′	1·906	1·891	4·506	$\times 10^6$ 7·870	0·005292	$\times 10^6$ 8·064	0·005282
38	15° 06′	1·654	1·640	2·592	6·830	4043	6·997	4031
39	14′	1·423	1·407	1·843	5·876	3883	6·020	3872
40	22′	1·185	1·175	1·260	4·893	3829	5·013	3818
41	30′	0·949	0·935	0·823	3·918	4267	4·015	3886
43542	15° 38′	1·893	1·883	4·397	$\times 10^6$ 7·816	0·005237	$\times 10^6$ 8·009	0·005225
43	46′	1·650	1·644	2·578	6·813	4040	6·980	4028
44	54′	1·421	1·405	1·856	5·867	3922	6·011	3910
45	16° 02′	1·185	1·172	1·249	4·893	3796	5·013	3784
46	10′	0·945	0·933	0·813	3·902	3897	3·998	3883
47	18′	1·902	1·888	4·465	7·853	5266	8·046	5225

$R_n = \frac{vL}{\nu}$ in units of 10^6 : $C_t = R \Big/ \frac{\rho}{2} S v^2$ in units of 10^{-3}

I.T.T.C. 1957 Ship-model Correlation Line used for Correction to 15°C.

Remarks:

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

3rd TEST

DATE, MAY 27 1960
MODEL № 1430
TANK NAGASAKI (MITSUBISHI)

TEST № TRL 1254
$L = 4.8265^{m}$
$S = 4.600^{m^2}$
LARGEST SECTION AREA, $a = 0.204^{m^2}$
$\Delta = 652.9^{kg}$ (F.W.)
TRIM = 0
STIMULATOR = STUDS
SURFACE:

TOW-POINT
FROM LWP, LWL
FROM ⊠, 150^{mm} AFT.
WIDTH OF TANK = 12.5^{m}
DEPTH OF WATER = 6.481^{m}
TANK SECTION AREA, $A = 81.0^{m^2}$
$a/A = 0.25\%$

TEMP.
AIR = 21.7 °C
WATER SURF. = 17.8 °C
" MID.DEPTH = 14.5 °C
" BOTTOM = 13.9 °C

	ρ $[kg\,sec^2/m^4]$	ν $[m^2/sec]$
(a)	101.828	1.063×10^{-6}
(b)	101.878	1.141×10^{-6}

(a) FROM SNAME TABLES AT 17.8 °C (USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15 °C)

RUN №	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_o m/s	RESISTANCE R kg	AS MEASURED		CORRECTED TO 15 °C	
					R_n	C_t	R_n	C_t
439 76	13° 15'	1.897	1.892	4.540	8.614	5.386	8.024	5.418
78	25'	1.897	1.890	4.480	8.614	5.315	8.024	5.347
80	35'	1.656	1.646	2.573	7.519	4.007	7.005	4.041
82	45'	1.423	1.413	1.834	6.461	3.867	6.019	3.901
84	55'	1.181	1.171	1.242	5.362	3.802	4.996	3.840
86	14 05'	0.949	0.942	0.810	4.309	3.840	4.014	3.877
88	15'	1.899	1.895	4.489	8.622	5.316	8.033	5.347
90	25'	1.659	1.653	2.578	7.533	4.000	7.018	4.034
92	35'	1.419	1.406	1.824	6.443	3.867	6.003	3.901
94	45'	1.184	1.176	1.241	5.376	3.780	5.008	3.817
96	55'	0.944	0.941	0.807	4.286	3.867	3.993	3.904
98	15° 05'	1.898	1.889	4.510	8.618	5.346	8.029	5.378
4000	15'	1.657	1.654	2.594	7.524	4.034	7.009	4.068
2	25'	1.424	1.417	1.859	6.466	3.914	6.024	3.948
4	35'	1.184	1.180	1.249	5.376	3.804	5.008	3.842
6	45'	0.943	0.939	0.810	4.282	3.890	3.989	3.926
8	55'	1.896	1.888	4.509	8.609	5.356	8.020	5.388
10	16° 05'	1.656	1.654	2.572	7.519	4.005	7.005	4.039
12	15'	1.421	1.414	1.852	6.452	3.917	6.011	3.951
14	25'	1.198	1.191	1.282	5.440	3.815	5.068	3.852
16	35'	0.954	0.949	0.835	4.332	3.918	4.036	3.953
18	55'	1.197	1.190	1.276	5.435	3.802	5.063	3.839

$R_n = \frac{vL}{\nu}$ in units of 10^6 $C_t = \frac{R}{\frac{\rho}{2} S v^2}$ in units of 10^{-3}

I.T.T.C. 1957 Ship-model Correlation Line used for Correction to 15 °C

Remarks:

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

1ST TEST

DATE. JUNE 13TH 1960
MODEL No
TANK T.T.R.I No 2

TEST No
$L = 4.8265^{m}$
$S = 4.600\ ^{m^2}$
LARGEST SECTION AREA, $a = 0.204\ ^{m^2}$
$\Delta = 652.9\ ^{kg}$
TRIM LEVEL
STIMULATOR = STUDS
SURFACE;

TOW-POINT
FROM LWP, LWL
FROM ⊗, 150 mm AFT
WIDTH OF TANK = 8·00 m
DEPTH OF WATER = 4·12 m
TANK SECTION AREA, $A = 32.96\ ^{m^2}$
$a/A = 0.62\ \%$

TEMP.
AIR = 21·0°C
WATER SURF. = 16·4°C
" MID DEPTH = 11·3°C
" BOTTOM = 10·6°C

	ρ $[kg\,sec^2/m^4]$	ν $[m^2/sec]$
(a)	101·857	1.1011×10^{-6}
(b)	101·878	1.141×10^{-6}

(a) FROM SNAME TABLES (AT 16·4°C) (USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15°C)

RUN No	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_0 m/s	RESISTANCE R kg	AS MEASURED R_n		CORRECTED TO 15°C R_n	
					R_n	C_t	R_n	C_t
60258/18	13·50	1·893		4·46	8·297	5·314	8·005	5·333
19	14·00	1·664		2·62	7·293	4·039	7·037	4·059
20	·10	1·420		1·89	6·223	4·002	6·005	4·022
21	·20	0·944		0·82	4·137	3·928	3·992	3·952
22	·30	1·185		1·28	5·194	3·892	5·011	3·914
23	14·40	1·894		4·47	8·300	5·320	8·010	5·339
24	·50	1·666		2·64	7·302	4·066	7·045	4·086
25	15·00	1·420		1·89	6·224	4·002	6·005	4·022
26	·10	1·183		1·27	5·186	3·875	5·003	3·897
27	·20	0·945		0·84	4·142	4·016	3·997	4·040
28	15·30	1·894		4·52	8·300	5·380	8·010	5·399
29	·40	1·665		2·66	7·298	4·095	7·040	4·116
30	·50	1·419		1·90	6·220	4·027	6·000	4·048
31	16·00	1·183		1·28	5·186	3·906	5·003	3·928
32	·10	0·945		0·84	4·142	4·016	3·997	4·040
33	16·20	1·896		4·60	8·301	5·462	8·018	5·481
34	·30	1·666		2·68	7·302	4·121	7·045	4·141
35	·40	1·419		1·90	6·220	4·028	6·000	4·049
36	·50	1·181		1·29	5·177	3·948	4·994	3·971
37	17·00	0·943		0·84	4·133	4·032	3·988	4·055

$R_n = \frac{vL}{\nu}$ IN UNITS OF 10^6 $C_t = R / \frac{\rho}{2} S v^2$ IN UNITS OF 10^{-3}

I.T.T.C. 1957 SHIP-MODEL CORRELATION LINE USED FOR CORRECTION TO 15°C

REMARKS;

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

2ND TEST

DATE. JUNE. 14. 1960
MODEL No
TANK T.T.R.I No2

TEST No TRL
$L = 4.8265^{m}$
$S = 4.600^{m^2}$
LARGEST SECTION AREA, $a = 0.204^{m^2}$
$\Delta = 647.9^{kg}$ (F.W.)
TRIM = LEVEL
STIMULATOR = STUDS
SURFACE:

TOW-POINT
FROM LWP, LWL
FROM ⊗, 150mm AFT
WIDTH OF TANK = 8.00 m
DEPTH OF WATER = 4.12 m
TANK SECTION AREA, $A = 32.96^{m^2}$
$a/A = 0.62\%$

TEMP.
AIR = 21.0
WATER SURF. = 16.4°C
" MID.DEPTH = 11.5°C
" BOTTOM = 10.6°C

RUN. No	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_0 m/s	RESISTANCE R kg	AS MEASURED R_n	AS MEASURED C_t	CORRECTED TO 15°C R_n	CORRECTED TO 15°C C_t
602 554	14°.35'	1.895		4.51	8.305	5.362	8.015	5.381
55	45'	1.667		2.65	7.307	4.071	7.050	4.092
56	.55'	1.420		1.89	6.223	4.002	6.007	4.022
57	15°.05'	1.182		1.29	5.180	3.942	4.999	3.964
58	15'	0.944		0.83	4.138	3.976	3.993	4.001
59	15°.25'	1.895		4.52	8.305	5.373	8.015	5.392
60	.35'	1.665		2.64	7.298	4.066	7.041	4.087
61	.45'	1.419		1.88	6.220	3.985	6.002	4.006
62	.55'	1.182		1.27	5.180	3.881	4.999	3.903
63	16°.05'	0.945		0.83	4.142	3.968	3.997	3.991
64	16°.15'	1.897		4.52	8.314	5.362	8.023	5.381
65	.25'	1.665		2.65	7.298	4.081	7.041	4.102
66	.35'	1.419		1.88	6.220	3.985	6.002	4.006
67	.45'	1.181		1.27	5.177	3.887	4.995	3.909
68	.55'	0.946		0.83	4.146	3.960	4.001	3.984
69	17°.05'	1.894		4.49	8.301	5.343	8.010	5.362
70	.15'	1.664		2.65	7.293	4.086	7.037	4.106
71	.25'	1.419		1.88	6.220	3.986	6.002	4.007
72	.35'	1.181		1.29	5.177	3.948	4.995	3.970
73	45'	0.944		0.83	4.138	3.976	3.993	4.001

	ρ $[kg\,sec^2/m^4]$	ν $[m^2/sec]$
(a)	101.857	1.1011×10^{-6}
(b)	101.878	1.141×10^{-6}

(a) FROM SNAME TABLES AT 16.4°C (USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15°C)

$R_n = \frac{vL}{\nu}$ IN UNITS OF 10^6 $C_t = R / \frac{\rho}{2} S v^2$ IN UNITS OF 10^{-3}

I.T.T.C. 1957 SHIP-MODEL CORRELATION LINE USED FOR CORRECTION TO 15°C

REMARKS;

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

1st TEST

DATE. JUNE 18TH 1960
MODEL No
TANK T.T.R.I No 1

TEST No TRL
$L = 4.8265^{m}$
$S = 4.600\ m^2$
LARGEST SECTION AREA, $a = 0.204\ m^2$
$\Delta = 647.9$ kg (F.W.)
TRIM LEVEL
STIMULATOR = STUDS
SURFACE;

TOW-POINT
FROM LWP, LWL
FROM ⊠, 150 mm AFT
WIDTH OF TANK = 10.00 m
DEPTH OF WATER = 5.30 m
TANK SECTION AREA, $A = 53.00\ m^2$
$a/A = 0.38$ %

TEMP.
AIR = 26.0°C
WATER SURF. = 18.5°C
" MID DEPTH = 12.5°C
" BOTTOM = 10.8°C

	ρ $[kg\,sec^2/m^4]$	ν (m^2/sec)
(a)	101.818	1.0443×10^{-6}
(b)	101.878	1.141×10^{-6}

(a) FROM SNAME TABLES (AT 18.5°C) (USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15°C)

RUN. No	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_0 m/s	RESISTANCE R kg	AS MEASURED		CORRECTED TO 15°C	
					R_n	C_t	R_n	C_t
283470	10.50	1.893		4.15	8.750	4.946	8.005	4.994
71	11.00	1.892		4.39	8.745	5.237	8.001	5.286
72	.10	1.667		2.62	7.705	4.026	7.050	4.077
73	.20	1.424		1.85	6.582	3.897	6.022	3.949
74	.30	1.185		1.24	5.477	3.772	5.011	3.827
75	.40	1.182		1.24	5.463	3.790	4.998	3.845
76	.50	0.925		0.78	4.275	3.893	3.912	3.953
77	13.15	0.934		0.84	4.317	4.112	3.950	4.169
78	.25	0.938		0.80	4.336	3.883	3.966	3.942
79	.35	1.882		4.24	8.699	5.112	7.960	5.161
80	.45	1.663		2.57	7.687	3.968	7.033	4.018
81	.55	1.423		1.82	6.577	3.838	6.018	3.890
82	14.05	1.177		1.20	5.440	3.700	4.977	3.755
83	.15	0.956		0.84	4.419	3.752	4.043	3.812
84	.25	0.941		0.80	4.350	3.858	3.980	3.917
85	.35	1.887		4.22	8.721	5.060	7.980	5.108
86	.45	1.665		2.56	7.696	3.943	7.040	3.994
87	.55	1.423		1.82	6.577	3.837	6.018	3.889
88	15.05	1.179		1.22	5.449	3.748	4.986	3.803
89	.15	0.933		0.79	4.312	3.875	3.946	3.933
90	.25	1.886		4.20	8.717	5.042	7.976	5.090
91	.35	1.669		2.59	7.714	3.970	7.058	4.020
92	.45	1.423		1.83	6.577	3.859	6.018	3.911
93	.55	1.183		1.22	5.467	3.724	5.003	3.780
94	16.05	0.943		0.80	4.358	3.842	3.988	3.901

$R_n = \frac{vL}{\nu}$ IN UNITS OF 10^6 $C_t = R / \frac{\rho}{2} S v^2$ IN UNITS OF 10^{-3}

I.T.T.C. 1957 SHIP-MODEL CORRELATION LINE USED FOR CORRECTION TO 15°C

REMARKS;

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

2ND TEST

DATE. JUNE. 20. 1960
MODEL No
TANK T.T.R.I No 1

TEST No TRL
L = 4.8265 m
S = 4.600 m²
LARGEST SECTION AREA, a = 0.204 m²
Δ = 647.9 kg (F.W.)
TRIM = LEVEL.
STIMULATOR = STUDS
SURFACE:

TOW-POINT
FROM LWP, LWL
FROM ⊗, 150 mm AFT
WIDTH OF TANK = 10.0 m
DEPTH OF WATER = 5.3 m
TANK SECTION AREA, A = 53.0 m²
a/A = 0.38 %

TEMP.
AIR = 26.0 °C
WATER SURF. = 19.5 °C
" MID. DEPTH = 11.9 °C
" BOTTOM = 10.7 °C

	ρ [kg sec²/m⁴]	ν [m²/sec]
(a)	101.799	1.019×10^{-6}
(b)	101.878	1.141×10^{-6}

(a) FROM SNAME TABLES AT 19.5 °C (USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15 °C)

RUN. No	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_0 m/s	RESISTANCE R kg	AS MEASURED R_n	AS MEASURED C_t	CORRECTED TO 15 °C R_n	CORRECTED TO 15 °C C_t
283 506	14°00'	1.893		4.31	8.967	5.138	8.005	5.200
7	10'	1.659		2.54	7.860	3.942	7.106	3.998
8	20'	1.427		1.86	6.760	3.902	6.035	3.968
9	30'	1.188		1.23	5.628	3.723	5.025	3.793
10	40'	0.933		0.78	4.420	3.827	3.946	3.902
11	50'	0.942		0.80	4.462	3.851	3.984	3.926
2	15°00'	1.892		4.30	8.962	5.130	8.002	5.192
3	10'	1.653		2.55	7.831	3.987	6.991	4.051
4	20'	1.662		2.57	7.874	3.974	7.029	4.037
5	30'	1.428		1.86	6.765	3.896	6.040	3.962
6	40'	1.419		1.84	6.723	3.902	6.002	3.969
7	50'	1.182		1.24	5.599	3.791	4.998	3.862
8	16.00'	0.952		0.82	4.510	3.864	4.026	3.939
9	10'	1.892		4.43	8.963	5.285	8.002	5.347
21	30'	1.658		2.60	7.855	4.040	7.012	4.104
2	40'	1.665		2.59	7.888	3.991	7.041	4.056
3	50'	1.421		1.85	6.732	3.914	6.010	3.980
4	17°00'	1.177		1.22	5.576	3.762	4.978	3.832
5	10'	0.939		0.79	4.448	3.827	3.971	3.902
6	20'	1.893		4.27	8.967	5.090	8.005	5.152
7	30'	1.650		2.54	7.817	3.984	6.978	4.049
8	40'	1.653		2.54	7.831	3.971	6.991	4.035
30	18°00'	1.424		1.84	6.746	3.875	6.022	3.942
1	10'	1.180		1.22	5.590	3.743	4.991	3.813
2	20'	0.939		0.80	4.448	3.875	3.971	3.950

$R_n = \frac{vL}{\nu}$ IN UNITS OF 10^6 $C_t = R / \frac{\rho}{2} S v^2$ IN UNITS OF 10^{-3}

I.T.T.C. 1957 SHIP-MODEL CORRELATION LINE USED FOR CORRECTION TO 15 °C

REMARKS;

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

1 ST TEST

DATE. JUNE. 24. 1960

MODEL No

TANK MEGURO MODEL BASIN (JAPAN DEFENCE AGENCY)

TEST No TRL

L = 4.8265 m

S = 4.600 m²

LARGEST SECTION AREA, a = 0.204 m²

Δ = 652.9 kg (F.W)

TRIM = 0

STIMULATOR = STUDS

SURFACE;

TOW-POINT

FROM LWP, LWL

FROM ⊗, 150 mm AFT

WIDTH OF TANK = 12.5 m

DEPTH OF WATER = 7.16 m

TANK SECTION AREA, A = 89.50 m²

a/A = 0.228 %

TEMP.

AIR = 23.3

WATER SURF. = 18.45

" MID DEPTH = 12.1

" BOTTOM = 11.5

	ρ [kg sec²/m⁴]	ν [m²/sec]
(a)	101.818	1.0467×10^{-6}
(b)	101.878	1.141×10^{-6}

(a) FROM SNAME TABLES AT 18.45°C (USED FOR "AS MEASURED" CALCULATIONS)

(b) WATER SAMPLE AT TIME OF TEST (AT 15°C)

RUN. No	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_0 m/s	RESISTANCE R kg	AS MEASURED		CORRECTED TO 15°C	
					R_n	C_t	R_n	C_t
71-R6	13°30′	1.892		4.465	8.723	5.326	8.000	5.373
7	42′	1.653		2.518	7.622	3.936	6.990	3.985
8	52′	1.423		1.830	6.561	3.859	6.017	3.910
9	14°02′	1.184		1.248	5.459	3.801	5.006	3.855
10	12′	0.944		0.821	4.353	3.936	3.992	3.994
71-R11	14°27′	1.893		4.502	8.729	5.365	8.005	5.411
12	37′	1.654		2.557	7.627	3.992	6.994	4.042
13	47′	1.419		1.864	6.543	3.952	6.000	4.003
14	57′	1.182		1.254	5.450	3.834	4.998	3.888
15	15°07′	0.944		0.807	4.353	3.869	3.992	3.927
71-R16	15°45′	1.892		4.500	8.723	5.367	8000	5.414
17	16°05′	1.654		2.580	7.626	4.027	6.994	4.077
18	15′	1.420		1.876	6.548	3.974	6.004	4.025
19	25′	1.183		1.260	5.455	3.846	5.002	3.900
20	35′	0.944		0.815	4.353	3.907	3.992	3.965
71-R21	16°48′	1.894		4.490	8.729	5.345	8.009	5.391
22	58′	1.656		2.594	7.636	4.039	7.002	4.090
23	17°08′	1.420		1.865	6.548	3.950	6.004	4.001
24	18′	1.184		1.260	5.459	3.838	5.006	3.892
25	28′	0.946		0.813	4.362	3.879	4.000	3.937

$R_n = \frac{vL}{\nu}$ IN UNITS OF 10^6 $C_t = R / \frac{\rho}{2} S v^2$ IN UNITS OF 10^{-3}

I.T.T.C. 1957 SHIP-MODEL CORRELATION LINE USED FOR CORRECTION TO 15°C

REMARKS;

RESISTANCE TEST OF STANDARD LAMINATED FIBRE-GLASS MODEL

2ND TEST

DATE. JUNE. 27. 1960
MODEL NO
TANK. MEGURO MODEL BASIN. (JAPAN DEFENCE AGENCY)
TEST NO Tr
$L = 4.8265^{m}$
$S = 4.600^{m^2}$
LARGEST SECTION AREA, $a = 0.204^{m^2}$
$\Delta = 652.9^{kg}$ (F.W.)
TRIM = 0
STIMULATOR = STUDS
SURFACE:

TOW-POINT
FROM LWP LWL
FROM ⊠ 150^{mm} AFT

WIDTH OF TANK = 12.5^{m}
DEPTH OF WATER = 7.16^{m}
TANK SECTION AREA. $A = 89.5^{m^2}$
$a/A = 0.228$ %

TEMP.
AIR ………… = 24.3
WATER SURF. = 19.2
" MID. DEPTH = 12.4
" BOTTOM = 11.7

	ρ $[kg\,sec^2/m^4]$	ν $[m^2/sec]$
(a)	101.80	1.027×10^{-6}
(b)	101.878	1.141×10^{-6}

(a) FROM SNAME TABLES AT 19.2°
(USED FOR "AS MEASURED" CALCULATIONS)
(b) WATER SAMPLE AT TIME OF TEST (AT 15°C)

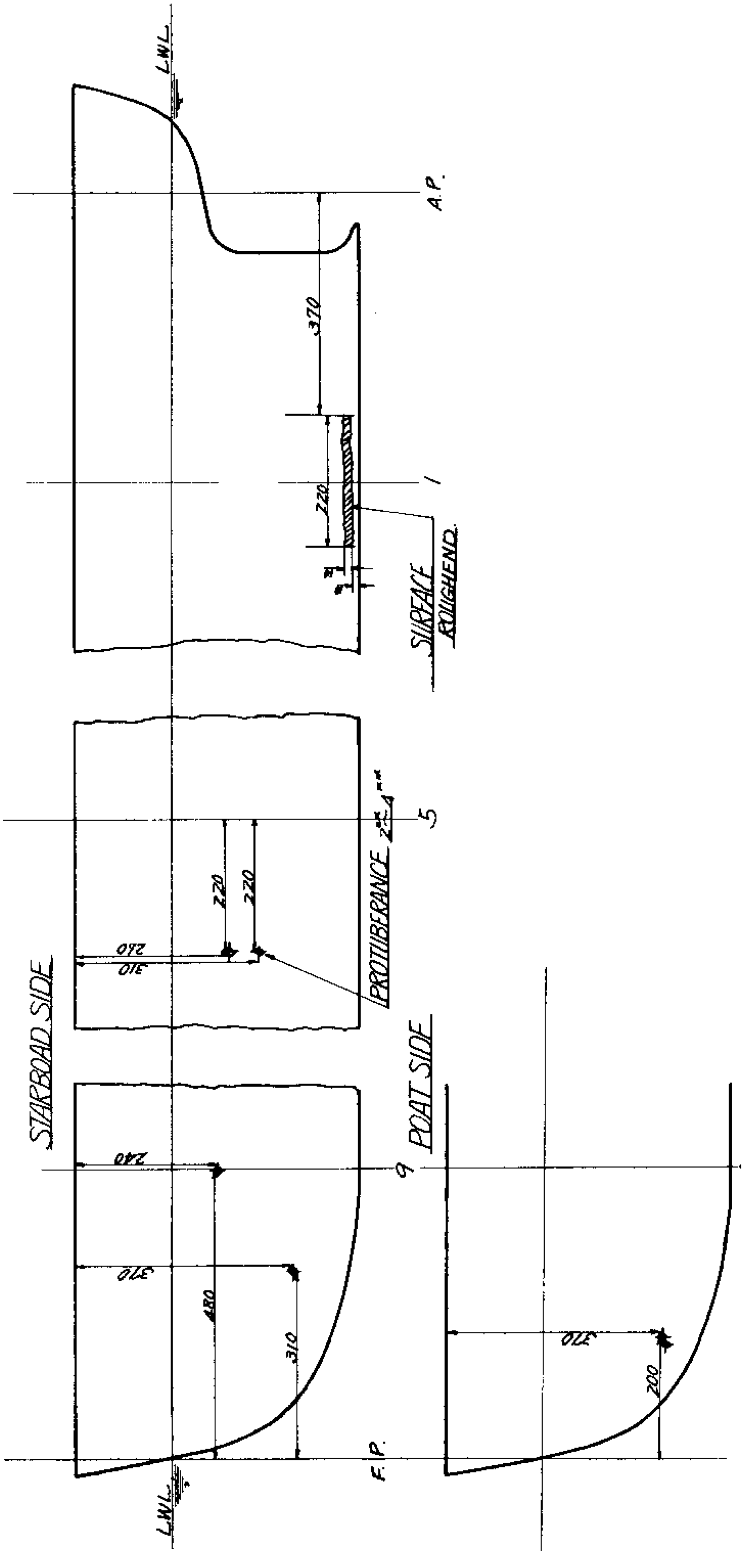
RUN NO.	TIME OF DAY	GROUND SPEED v m/s	SPEED RELATIVE TO WATER v_r m/s	RESISTANCE R kg	AS MEASURED R_n	AS MEASURED C_t	CORRECTED TO 15°C R_n	CORRECTED TO 15°C C_t
71-R52	12°55′	1.895		4.558	8.911	5.421	8.013	5.478
53	13°05′	1.655		2.595	7.783	4.046	6.998	4.107
54	15′	1.421		1.860	6.683	3935	6.009	3.997
55	25′	1.184		1.258	5.568	3.832	5.007	3.898
56	35′	0.944		0.808	4.440	3.874	3.992	3945
71-R57	13°45′	1.894		4.541	8.907	5.406	8009	5.463
58	14°05′	1.655		2.584	7.783	4.029	6.998	4.090
59	15′	1.421		1.876	6.683	3.969	6.009	4.031
60	25′	1.183		1.240	5.563	3.785	5.002	3.851
61	35′	0.944		0.786	4.440	3.768	3.992	3.839
71-R62	14°45	1.890		4.521	8.889	5.406	7.992	5.463
63	55′	1.655		2.566	7.783	4.001	6.998	4.062
64	15°0.5′	1.421		1.857	6.683	3.929	6.009	3.991
65	15′	1.184		1.249	5.568	3.805	5.007	3.871
66	25′	0.946		0.812	4.449	3.874	4.000	3.945
71-R67	15°40′	1.893		4.509	8902	5.374	8.005	5.430
68	51′	1.894		4.526	8.907	5.389	8.009	5.446
69	16°01	1.655		2.580	7.783	4.023	6.998	4.084
70	11′	1.420		1.878	6.678	3.979	6.005	4.041
71	21	1.185		1.254	5.573	3.815	5.011	3.881
72	31	0.945		0.815	4.444	3.898	3.996	3.969
73	46′	0.944		0.800	4.440	3.835	3.992	3.906

$R_n = \frac{vL}{\nu}$ in units of 10^6 : $C_t = R / \frac{\rho}{2} S v^2$ in units of 10^{-3}

I.T.T.C. 1957 Ship-model Correlation Line uses for Correction to 15°C.

Remarks

NOTE OF SURFACE DETERIORATION AT THE 3rd TEST (MITSUBISHI EXP TANK)
(MAY. 27. 1960)



K. Taniguchi.

In Mitsubishi Experimental Tank (Nagasaki), we have been conducting the resistance tests to cover the low speed range ($v\sqrt{gL} \leqq 0.1$) to obtain the form factor K, for these four years.

We use 7 m model as standard size. I report the data of K obtained on these rather large models, in compliance with Dr. Hughes' suggestion, as I think it is valuable to all delegates. Fig. 1 and 2 are typical examples of deducing K and Table 1 are the data of K. Now I can't find the reasonable method of plotting K, I report the K and the relating data only.

Table 1. Data of "K"

MODEL NO.	TYPE OF SHIP	LOAD CONDITION	TRIM (% OF L_{PP})	L_{WL} (m)	L_{WL}/B	B/d	$10^2 \cdot \frac{\nabla_x}{L_{WL}^2}$	$C_{b_{WL}}$	C_m	K
1182	TANKER	FULL LOAD	0	7.147	7.554	2473	0.5277	0.7455	0.9903	0.285
		25,000$^{\#}$ LOAD	0.75 A	7.044	7.445	3.148	0.4242	0.7401	0.9877	0.293
		BALLASTED CONDITION	1.5 A	6.885	7.277	4.638	0.2997	0.7363	0.9820	0.373
		〃 〃	2.5 A	6.933	7.328	〃	0.2935	0.7312	〃	0.362
1194	TANKER	FULL LOAD	0	7.147	7.290	2.594	0.5562	0.7667	0.9880	0.357
		2/3 LOAD	0	6.911	7.049	3.415	0.4579	0.7771	0.9841	0.286
		BALLASTED CONDITION	2 A	6.877	7.015	5.023	0.3078	0.7610	0.9770	0.370
		〃 〃	3 A	6.927	7.066	〃	0.3011	0.7555	〃	0.358
1213	TANKER	FULL LOAD	0	7.135	7.103	2.738	0.5664	0.7823	0.9917	0.330
		〃 〃	1 A	7.168	7.136	〃	0.5585	0.7786	〃	0.328
		2/3 LOAD	0	6.928	6897	3.629	0.4581	0.7909	0.9890	0.300
		BALLASTED CONDITION	1 A	6.866	6.835	5.222	0.3207	0.7814	0.9840	0.328
		〃 〃	2 A	6.891	6.860	〃	0.3172	0.7785	〃	0.366
		〃 〃	3 A	6.982	6.951	〃	0.3050	0.7684	〃	0.391
1231	TANKER	FULL LOAD	0	7.089	7.633	2.651	0.5031	0.7771	0.9899	0.324
		1/2 LOAD	1.17 A	6.853	7.379	4.134	0.3441	0.7747	0.9843	0.305
		1/5 LOAD	2.11 A	6.791	7.313	6.373	0.2220	0.7567	0.9758	0.351
1237	TANKER	FULL LOAD	0	7.120	7.202	2.649	0.5907	0.8113	0.9884	0.457
1240	TANKER	FULL LOAD	0	7.138	7.079	2.789	0.5661	0.7769	0.9911	0.360
		2/3 LOAD	0	6.902	6.845	3.619	0.4650	0.7882	0.9883	0.327
		BALLASTED CONDITION	2 A	6.868	6.811	5.218	0.3200	0.7747	0.9831	0.397
		〃 〃	3 A	6.974	6.916	〃	0.3057	0.7629	〃	0.405
1244	TANKER	FULL LOAD	0	7.124	7.170	2.720	0.5622	0.7864	0.9898	0.306
		1/2 LOAD	1.30 A	6.836	6.880	4.320	0.3874	0.7923	0.9834	0.285
		BALLASTED CONDITION	2.00 A	6.817	6.861	5.195	0.3206	0.7839	0.9805	0.307
		1/5 LOAD	2.08 A	6.789	6.833	6.770	0.2445	0.7728	0.9746	0.281
1245	TANKER	FULL LOAD	0	7.124	7.170	2.720	0.5632	0.7878	0.9898	0.387
		1/2 LOAD	1.30 A	6.861	6.905	4.339	0.3832	0.7928	0.9837	0.319
		BALLASTED CONDITION	2.00 A	6.851	6.895	5.230	0.3159	0.7852	0.9804	0.357
		1/5 LOAD	2.08 A	6.836	6.880	6.823	0.2394	0.7734	0.9744	0.343
1246	TANKER	FULL LOAD	0	7.133	7.457	2.567	0.5374	0.7671	0.9901	0.312
		2/3 LOAD	0	6.896	7.210	3.360	0.4446	0.7766	0.9871	0.288
		BALLASTED CONDITION	2 A	6.862	7.174	4.850	0.3051	0.7615	0.9813	0.320
		〃 〃	3 A	6.951	7.267	〃	0.2935	0.7517	〃	0.356
1247	TANKER	FULL LOAD	0	7.133	7.457	2.567	0.5391	0.7696	0.9901	0.311
		2/3 LOAD	0	6.889	7.202	3.374	0.4460	0.7808	0.9870	0.300
		BALLASTED CONDITION	2 A	6.850	7.162	4.877	0.3067	0.7671	0.9812	0.325
		〃 〃	3 A	6.935	7.250	〃	0.2955	0.7576	〃	0.375
1253	TANKER	FULL LOAD	0	7.145	7.191	2.720	0.5579	0.7850	0.9910	0.387
		〃 〃	1 A	7.164	7.210	〃	0.5537	0.7830	〃	〃
		〃 〃	1 F	7.071	7.117	〃	0.5757	0.7932	〃	0.399
		1/2 LOAD	1.30 A	6.836	6.880	4.331	0.3874	0.7943	0.9857	0.358
		BALLASTED CONDITION	2.00 A	6.817	6.861	5.216	0.3206	0.7871	0.9828	0.373
		1/5 LOAD	2.08 A	6.784	6.828	6.808	0.2450	0.7776	0.9776	0.356
1253-B	TANKER	FULL LOAD	0	7.145	7.191	2.720	0.5527	0.7775	0.9910	0.389
		1/2 LOAD	1.30 A	6.839	6.883	4.274	0.3870	0.7836	0.9859	0.396
		BALLASTED CONDITION	2.00 A	6.818	6.862	5.178	0.3180	0.7753	0.9829	0.401
1258	TANKER	FULL LOAD	0	7.130	7.200	2.670	0.5673	0.7851	0.9898	0.380
		2/3 LOAD	0.74 A	6.987	7.056	3.533	0.4458	0.7842	0.9865	0.325

Table 1. Data of "K" (continued)

MODEL NO.	TYPE OF SHIP	LOAD CONDITION	TRIM [% of L_{PP}]	L_{WL} [m]	L_{WL}/B	B/d	$10^2 \cdot \frac{\nabla_n}{L_{WL}^3}$	C_{bWL}	C_m	K
1258	TANKER	BALLASTED CONDITION	2.00 A	6.857	6.924	5.106	0.3188	0.7805	0.9804	0.340
		1/3 LOAD	1.72 A	6.847	6.914	5.295	0.3079	0.7797	0.9797	0.368
1259	TANKER	FULL LOAD	0	7.125	7.436	2.357	0.5816	0.7580	0.9896	0.312
		20.805^t LOAD	1 A	6.999	7.305	3.061	0.4601	0.7514	0.9864	0.324
		1/2 LOAD	0.98 A	6.809	7.106	4.249	0.3489	0.7487	0.9812	0.293
		BALLASTED CONDITION	2 A	6.815	7.113	4.435	0.3322	0.7452	0.9803	0.270
1261	TANKER	FULL LOAD	0	7.131	7.382	2.543	0.5554	0.7697	0.9900	0.344
		3/5 LOAD	0	6.873	7.115	3.613	0.4256	0.7783	0.9858	0.323
		BALLASTED CONDITION	2.00 A	6.871	7.113	4.864	0.3103	0.7638	0.9808	0.331
		1/5 LOAD	2.60 A	6.858	7.099	6.327	0.2358	0.7520	0.9751	0.411
1262	TANKER	FULL LOAD	0	7.121	7.199	2.634	0.5792	0.7907	0.9884	0.362
		3/5 LOAD	1 A	6.890	6.965	3.731	0.4415	0.7993	0.9836	0.353
		BALLASTED CONDITION	2 A	6.854	6.929	5.069	0.3246	0.7901	0.9777	0.391
		1/5 LOAD	2.90 A	6.844	6.919	6.540	0.2488	0.7791	0.9712	0.368
1263	TANKER	FULL LOAD	0	7.121	7.199	2.634	0.5785	0.7897	0.9884	0.358
		BALLASTED CONDITION	2 A	6.855	6.930	5.048	0.3242	0.7859	0.9778	0.326
1264	TANKER	FULL LOAD	0	7.121	7.199	2.634	0.5789	0.7902	0.9884	0.382
		BALLASTED CONDITION	2 A	6.854	6.929	5.082	0.3245	0.7918	0.9776	0.393
1272	TANKER	FULL LOAD	0	7.116	7.084	2.721	0.5759	0.7865	0.9892	0.359
		3/5 LOAD	1 A	6.910	6.879	3.869	0.4331	0.7928	0.9847	0.334
		BALLASTED CONDITION	2 A	6.868	6.837	5.238	0.3202	0.7840	0.9793	0.402
		1/5 LOAD	2.68 A	6.855	6.824	6.849	0.2423	0.7725	0.9729	0.363
1273	TANKER	FULL LOAD	0	7.121	7.199	2.634	0.5789	0.7902	0.9884	0.379
		BALLASTED CONDITION	2 A	6.854	6.929	5.065	0.3245	0.7891	0.9777	-
1279	TANKER	FULL LOAD	0	7.128	7.194	2.634	0.5677	0.7739	0.9912	0.377
		3/5 LOAD	0	6.853	6.917	3.666	0.4475	0.7848	0.9878	0.359
		BALLASTED CONDITION	2 A	6.821	6.885	5.038	0.3238	0.7733	0.9832	0.380
		1/5 LOAD	2.60 A	6.797	6.860	6.207	0.2622	0.7659	0.9792	0.361
1283	TANKER	FULL LOAD	0	7.143	6.640	2.712	0.6059	0.7243	0.9899	0.376
		2/3 LOAD	0	6.903	6.417	3.542	0.5007	0.7301	0.9868	0.362
		BALLASTED CONDITION	1 A	6.770	6.293	5.132	0.3556	0.7228	0.9808	0.326
		" "	2 A	6.790	6.312	"	0.3525	0.7207	"	0.354
		" "	3 A	6.888	6.403	"	0.3376	0.7103	"	0.382
1179	CARGO SHIP	FULL LOAD (NAKED)	0	7.175	7.335	2.279	0.5831	0.7150	0.9861	0.303
		1/2 LOAD (NAKED)	1 A	6.887	7.041	3.288	0.4348	0.7086	0.9799	-
		FULL LOAD	0	7.175	7.335	2.279	0.5831	0.7150	0.9861	0.249
		3/4 LOAD	0	7.017	7.174	2.680	0.5181	0.7144	0.9836	0.228
		1/2 LOAD	1 A	6.887	7.041	3.288	0.4348	0.7086	0.9799	0.213
		TRIAL CONDITION	2.20 A	6.776	6.927	4.527	0.3176	0.6899	0.9724	0.260
		" "	2.50 A	6.756	6.907	4.775	0.3015	0.6870	0.9709	0.261
1190	CARGO SHIP	FULL LOAD	0	7.198	7.407	2.223	0.5441	0.6636	0.9848	0.293
		3/4 LOAD	0	7.037	7.241	2.624	0.4808	0.6615	0.9822	0.288
		1/2 LOAD	1 A	6.870	7.069	3.197	0.4114	0.6573	0.9785	0.277
		1/6 LOAD	2 A	6.701	6.895	4.645	0.2894	0.6391	0.9679	0.282
		" "	2.5 A	"	"	"	"	"	"	0.309
		" "	3 A	6.706	6.901	"	0.2887	0.6386	"	0.325
1207	CARGO SHIP	FULL LOAD	0	7.205	7.639	2.232	0.4956	0.6453	0.9810	0.248
		3/4 LOAD	0	7.046	7.470	2.597	0.4437	0.6429	0.9780	0.245
		1/2 LOAD	1 A	6.895	7.310	3.127	0.3814	0.6376	0.9737	0.255

Table 1. Data of "K" (continued)

MODEL NO.	TYPE OF SHIP	LOAD CONDITION	TRIM (% of L_{PP})	L_{WL} (m)	L_{WL}/B	B/d	$10^2 \frac{\nabla_n}{L_{WL}^3}$	C_{bWL}	C_m	K
1207	CARGO SHIP	1/6 LOAD	2 A	6.721	7.126	4.384	0.2780	0.6181	0.9623	0.309
		〃	2.5 A	6.726	7.131	〃	0.2774	0.6177	〃	0.328
		〃	3 A	6.743	7.149	〃	0.2753	0.6161	〃	0.294
1208	CARGO SHIP	13,450^t LOAD	0	7.188	7.491	2.181	0.5777	0.7068	0.9878	0.326
		〃 〃	0.64 A	7.204	7.507	〃	0.5737	0.7052	〃	0.300
		12.000^t LOAD	1.09 A	7.149	7.450	2.408	0.5237	0.7002	0.9865	0.268
		9.000^t LOAD	1.95 A	6.955	7.248	3.099	0.4266	0.6945	0.9826	0.319
		6,440^t LOAD	2.70 A	6.640	6.920	4.167	0.3506	0.6997	0.9767	0.278
		6,156^t LOAD	2.12 A	6.642	6.922	4.338	0.3349	0.6959	0.9757	0.280
1209	CARGO SHIP	FULL LOAD	0	7.230	7.054	2.413	0.5108	0.6129	0.9829	0.265
		DESIGNED CONDITION	0	7.044	6.873	2.815	0.4595	0.6109	0.9798	0.288
		1/2 LOAD	1 A	6.938	6.769	3.386	0.3872	0.6007	0.9754	0.293
		1/5 LOAD	2 A	6.873	6.706	4.576	0.2818	0.5784	0.9669	0.368
		〃	2.5 A	6.890	6.723	〃	0.2797	0.5770	〃	0.357
		〃	3 A	6.918	6.750	〃	0.2763	0.5746	〃	0.390
1216	CARGO SHIP	FULL LOAD	0	7.198	7.407	2.223	0.5441	0.6636	0.9848	0.212
		3/4 LOAD	0	7.038	7.242	2.617	0.4806	0.6596	0.9825	0.259
		1/2 LOAD	1 A	6.880	7.080	3.177	0.4097	0.6523	0.9784	0.243
		1/6 LOAD	2 A	6.704	6.899	4.586	0.2890	0.6307	0.9685	0.304
		〃	2.5 A	6.709	6.904	〃	0.2883	0.6302	〃	0.335
		〃	3 A	6.720	6.915	〃	0.2869	0.6292	〃	0.272
1217	CARGO SHIP	FULL LOAD	0	7.180	7.264	2.214	0.6147	0.7179	0.9864	0.317
		3/4 LOAD	0	7.036	7.118	2.614	0.5405	0.7157	0.9840	0.253
		1/2 LOAD	1 A	6.895	6.975	3.211	0.4545	0.7102	0.9803	0.269
		1/6 LOAD	2 A	6.740	6.818	4.715	0.3155	0.6916	0.9711	0.293
		〃	2.5 A	6.742	6.821	〃	0.3153	0.6914	〃	0.310
		〃	3 A	6.752	6.831	〃	0.3189	0.6903	〃	0.319
1238	CARGO SHIP	FULL LOAD (CLOSED SHELTER)	0	7.192	7.240	2.224	0.6270	0.7310	0.9871	0.312
		〃 〃 (OPEN SHELTER)	0	7.098	7.146	2.518	0.5665	0.7282	0.9854	0.304
		1/2 LOAD	1 A	6.881	6.927	3.395	0.4445	0.7241	0.9803	0.289
		FAVOURABLE CONDITION	2 A	6.749	6.794	5.072	0.2997	0.7016	0.9706	0.283
		〃 〃	2.75 A	6.742	6.787	〃	0.3006	0.7023	〃	0.286
		〃 〃	3.5 A	6.739	6.784	〃	0.3010	0.7026	〃	0.324
1260	CARGO SHIP	FULL LOAD	0	7.236	6.857	2.106	0.7242	0.7173	0.9849	0.334
		1/2 LOAD	0	6.837	6.479	3.165	0.5423	0.7203	0.9773	0.280
		TRIAL CONDITION	2.32 A	6.664	6.315	6.035	0.2828	0.6804	0.9568	0.284
		〃 〃	3 A	6.645	6.297	〃	0.2852	0.6824	〃	0.304
		〃 〃	3.5 A	6.627	6.280	〃	0.2876	0.6843	〃	0.314
1281	CARGO SHIP	FULL LOAD	0	7.208	7.377	2.082	0.6435	0.7291	0.9880	0.329
		1/2 LOAD	0	6.813	6.973	3.169	0.4755	0.7328	0.9817	0.312
		1/5 LOAD	1.81 A	6.707	6.864	4.744	0.3177	0.7102	0.9726	0.306
		LIGHT LOAD	2.53 A	6.642	6.798	6.145	0.2446	0.6946	0.9645	0.314
1303	CARGO SHIP	FULL LOAD	0	6.449	6.824	2.213	0.6922	0.7134	0.9850	0.330
		1/2 LOAD	0	6.080	6.434	3.294	0.5265	0.7181	0.9776	0.270
		TRIAL CONDITION	2.5 A	5.941	6.287	6.039	0.2849	0.6802	0.9590	0.287
		〃 〃	3.18 A	5.926	6.271	〃	0.2871	0.6819	〃	0.316
		〃 〃	4.0 A	5.902	6.246	〃	0.2907	0.6848	〃	0.331

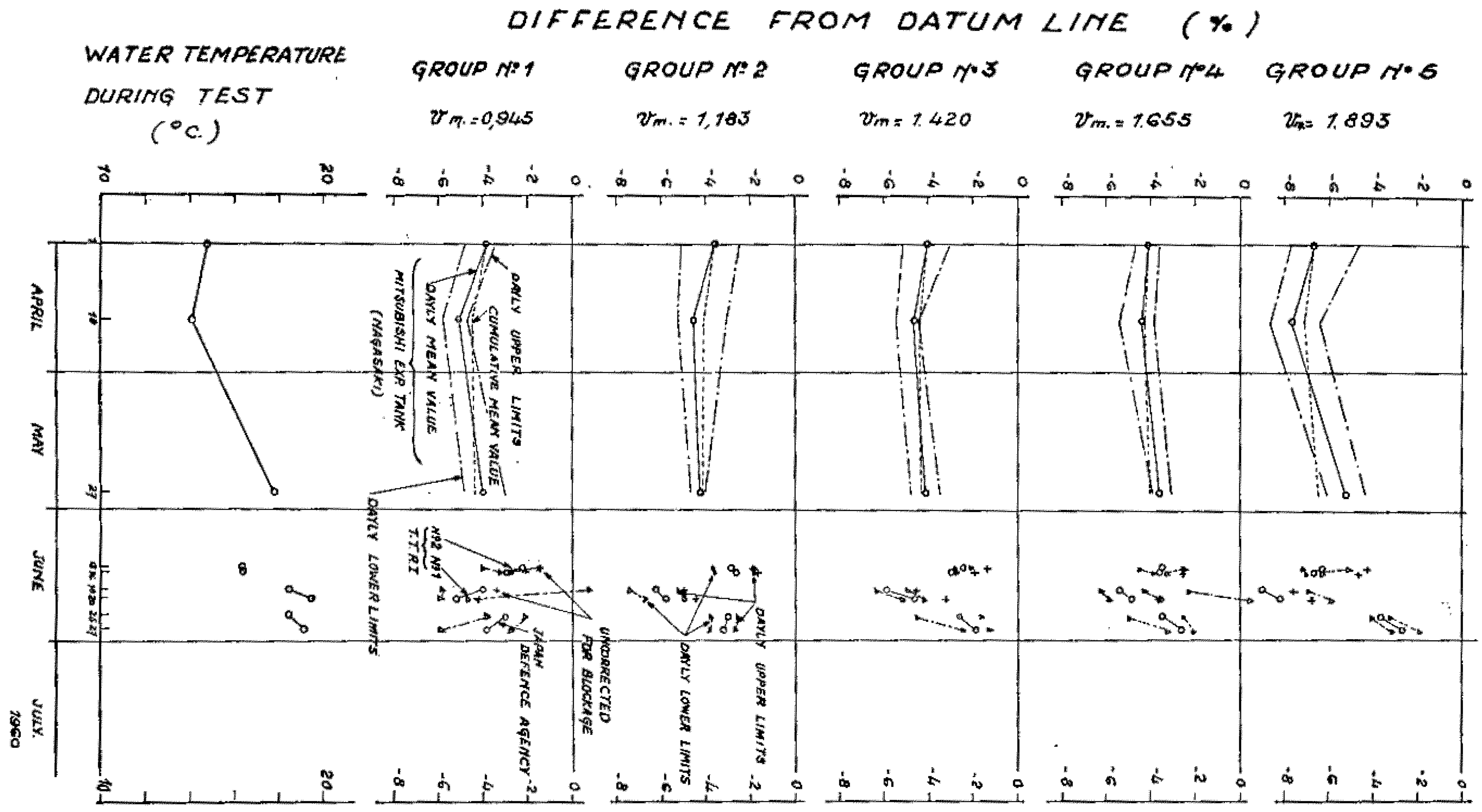
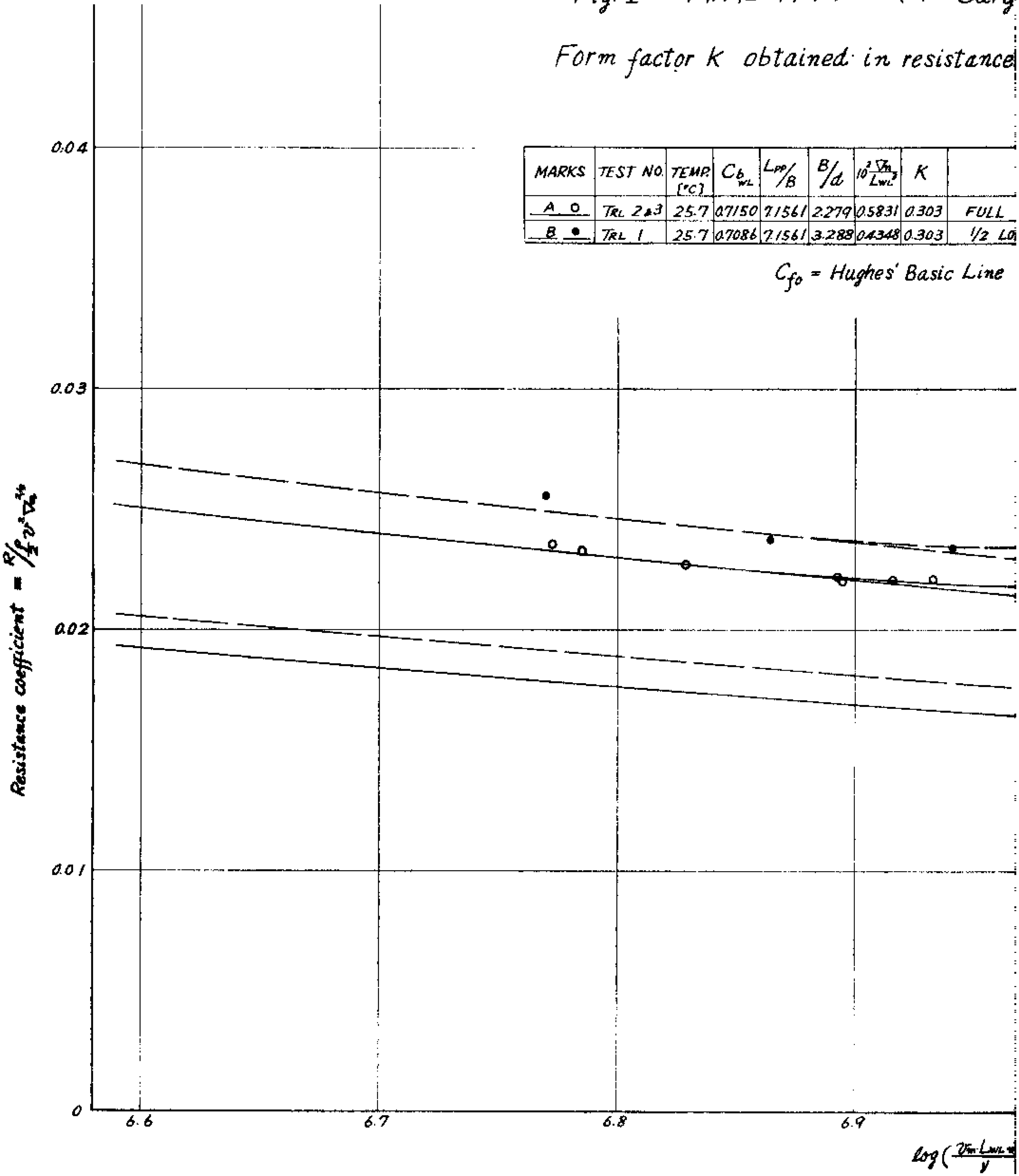

DIFFERENCE FROM DATUM LINE (%)
WATER TEMPERATURE DURING TEST (°C.)
GROUP Nº 1
V_m = 0,945
GROUP Nº 2
V_m = 1,183
GROUP Nº 3
V_m = 1.420
GROUP Nº 4
V_m = 1.655
GROUP Nº 6
V_m = 1.893
10
20
0
-2
-4
-6
-8
DAYLY UPPER LIMITS
CUMULATIVE MEAN VALUE
DAYLY MEAN VALUE
MITSUBISHI EXP. TANK (NAGASAKI)
DAYLY LOWER LIMITS
Nº2 Nº1
T.T.R.I
UNCORRECTED FOR BLOCKAGE
JAPAN DEFENCE AGENCY
DAYLY UPPER LIMITS
DAYLY LOWER LIMITS
1
18
27
APRIL
MAY
JUNE
JULY
1960

Fig. 1 M.No 1179 (7m Carg

Form factor K obtained in resistance



MARKS	TEST NO.	TEMP. [°C]	$C_{b_{WL}}$	L_{PP}/B	B/d	$10^2 \frac{\nabla_m}{L_{WL}^3}$	K	
A ○	TRL 2 & 3	25.7	07150	7.1561	2.279	0.5831	0.303	FULL
B ●	TRL 1	25.7	07086	7.1561	3.288	04348	0.303	1/2 LO

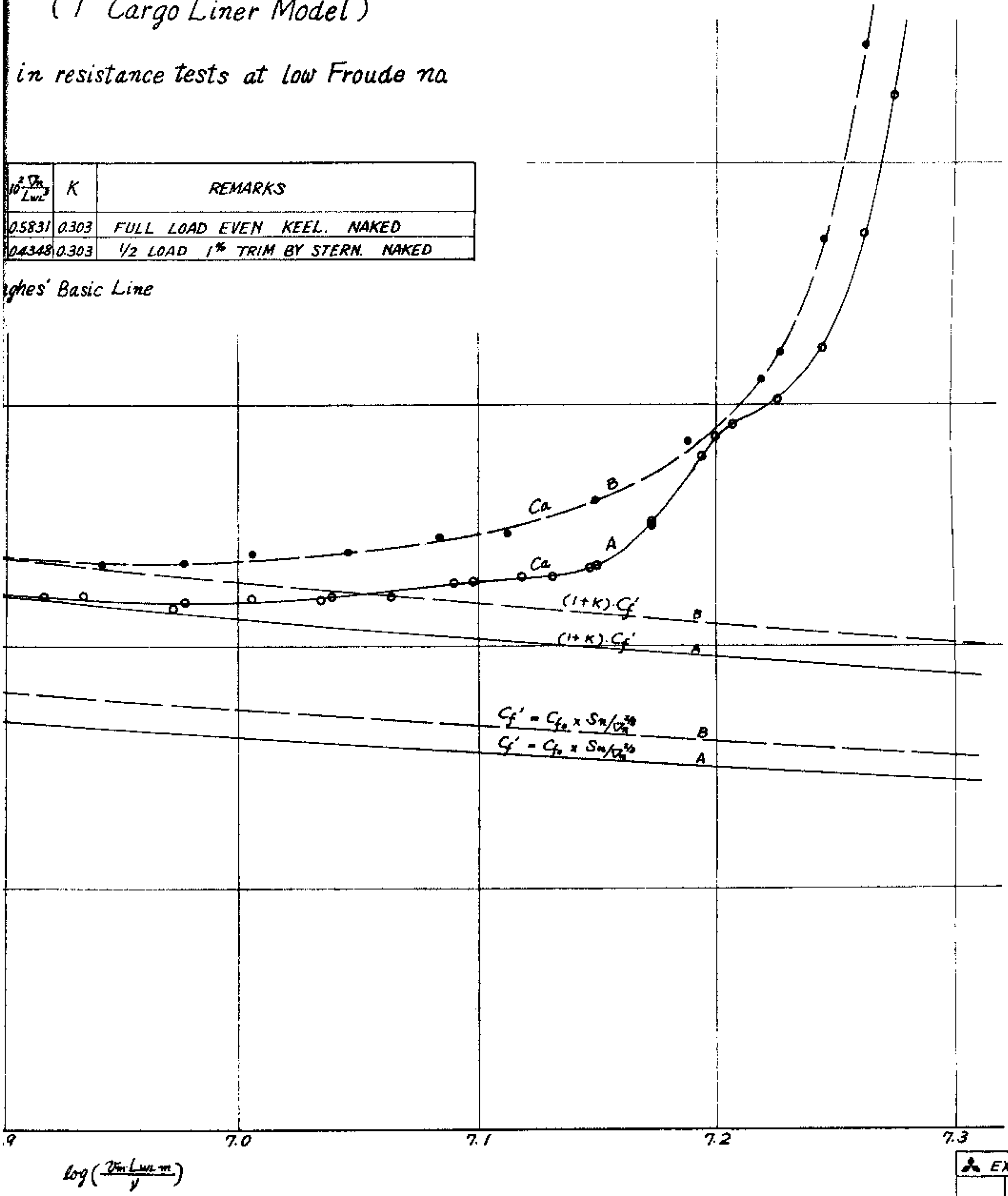
C_{f0} = Hughes' Basic Line

(7m Cargo Liner Model)

in resistance tests at low Froude no.

$10^2 \frac{\nabla_m}{L_{WL}^3}$	K	REMARKS
0.5831	0.303	FULL LOAD EVEN KEEL. NAKED
0.4348	0.303	1/2 LOAD 1% TRIM BY STERN. NAKED

ghes' Basic Line



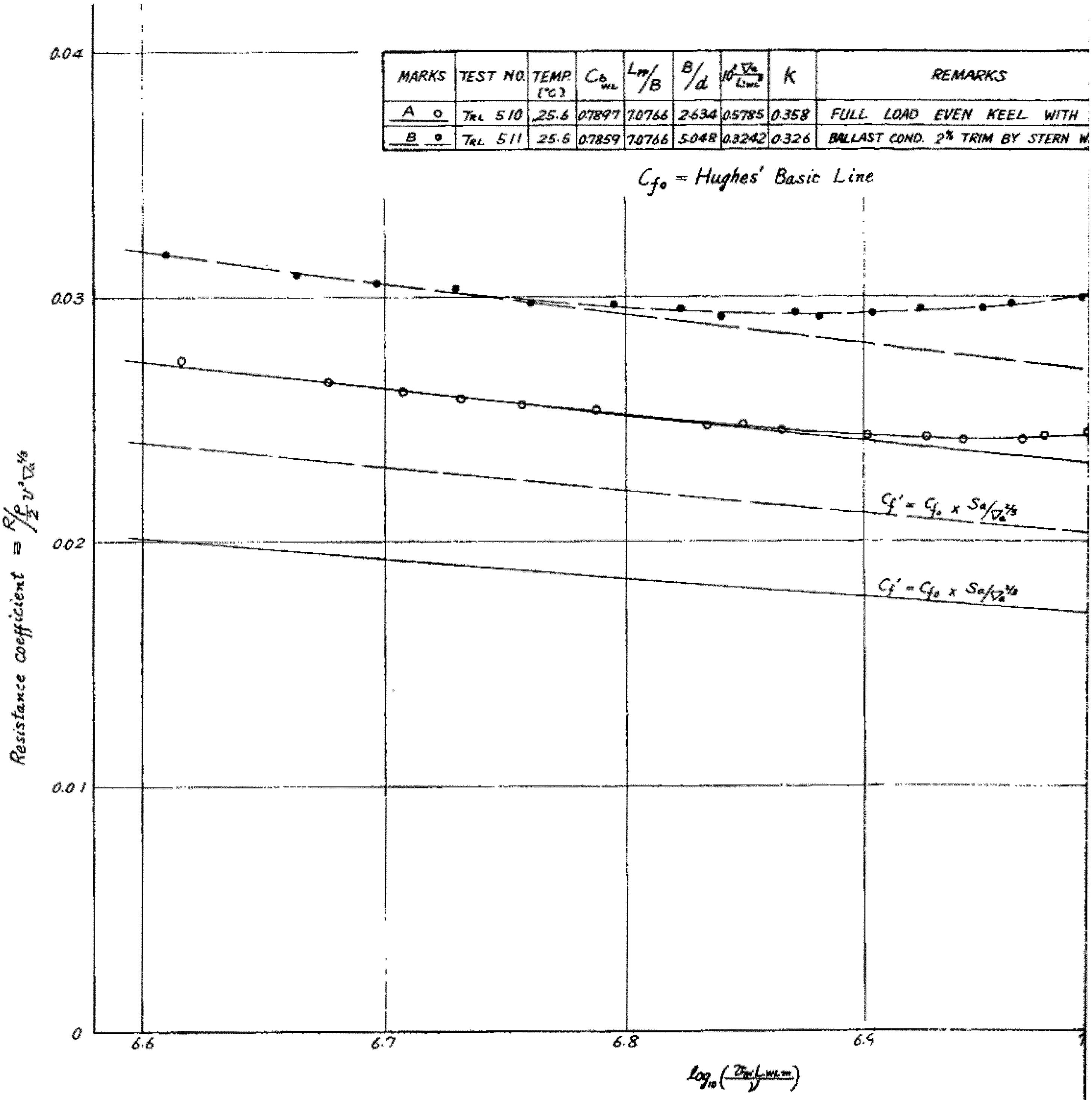
EXPT. TANK
K. Omura
MAY. 14. 1954

Fig. 2   M. No 1263   (7m Tanker Model)

Form factor K obtained in resistance tests at lo

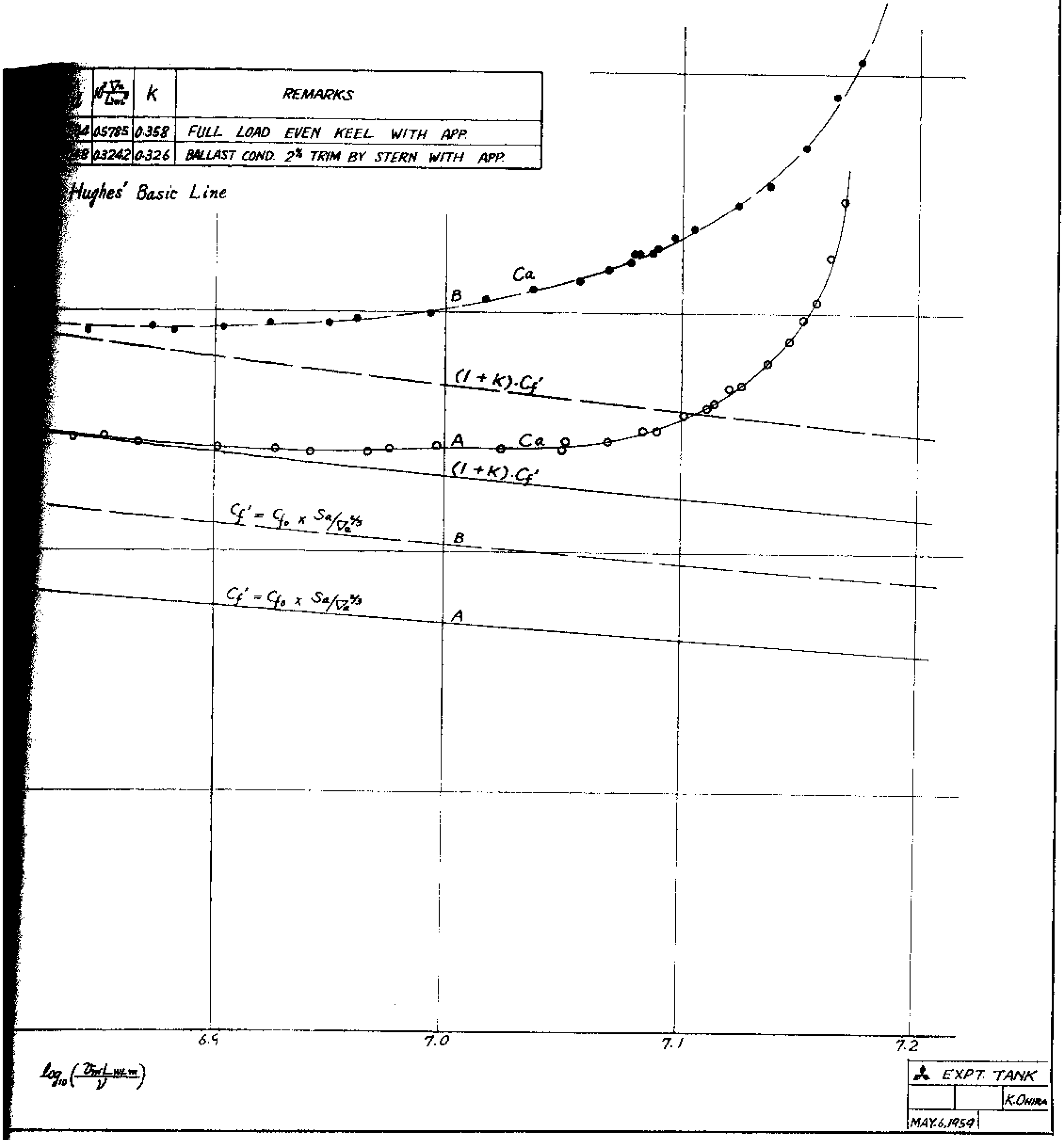
MARKS	TEST NO.	TEMP. (°C)	$C_{b_{WL}}$	L_m/B	B/d	$10^3\frac{\nabla_a}{L_{WL}^3}$	K	REMARKS
A ○	TRL 510	25.6	0.7897	7.0766	2.634	0.5785	0.358	FULL LOAD EVEN KEEL WITH
B ●	TRL 511	25.6	0.7859	7.0766	5.048	0.3242	0.326	BALLAST COND. 2% TRIM BY STERN W

C_{f_0} = Hughes' Basic Line



(7th Tanker Model)

ained in resistance tests at low Froude no.



	$\sqrt[3]{\nabla_m}/L_{wl}$	K	REMARKS
	05785	0.358	FULL LOAD EVEN KEEL WITH APP.
	03242	0.326	BALLAST COND. 2% TRIM BY STERN WITH APP.

Dr L. Landweber.

REANALYSIS OF FLAT-PLATE BOUNDARY-LAYER DATA

Introduction.

The laws of a turbulent boundary layer, especially the shear stress at the wall, have been critically studied in the last few years. Unfortunately, the results of these studies, obtained by different investigators, have not been consistent; nor have the reasons for the rather large discrepancies been discovered.

The contradictory results have stemmed principally from two establishments, the Engineering Laboratory of the University of Cambridge and the Aero Division of the National Physical Laboratory of England. The experiments at Cambridge [1, 2, 3] appear to indicate that the "law of the wall" is the same for steady flow in a pipe and in a boundary layer; those at NPL [4, 5, 6] indicate that this law is quantitatively different for pipe and boundary layer, and the shear stresses at the wall derived from the latter experiments exceed those from the former by about 12 per cent. Since the shear stresses were obtained by indirect means in both laboratories, the publication of a new set of direct measurements of the shear stress on a flat plate by the NACA [7] seemed to have resolved the controversy in favor of NPL, but one cannot help feeling uneasy about these unexplained differences in fundamental sets of experimental data.

It has also become evident, in the last few years, that, in the analysis of velocity-profile data obtained with Pitot tubes in a boundary layer, certain effects which had previously been considered sufficiently small to be neglected, should be taken into account. These include the displacement effect of a Pitot tube and the effects of the turbulence fluctuation on total head readings, the variation of static pressure in the boundary layer, and the momentum equation. Thus it seemed desirable to undertake a review and reanalysis of existing data in order to determine what laws may reasonably be considered to be established.

Determination of Velocity Profiles.

a) Pitot-tube displacement effect. A total head tube, immersed in a shear flow with its center at a distance y from a wall, disturbs the flow pattern and indicates values corresponding to a distance y + ε of its center from the wall. The results of experiments by Macmillan [8] with circular Pitot tubes are summarized in Figure 1. Here D is the external diameter of the Pitot tube, u_τ the shear velocity, $\sqrt{\tau/\rho}$, where τ is the shear stress at the wall and ρ is the density of the fluid, and ν is the kinematic viscosity. It is indicated that the displacement has the constant value of $0.15d$ at distances from the wall exceeding $2d$, but varies considerably at lesser distances.

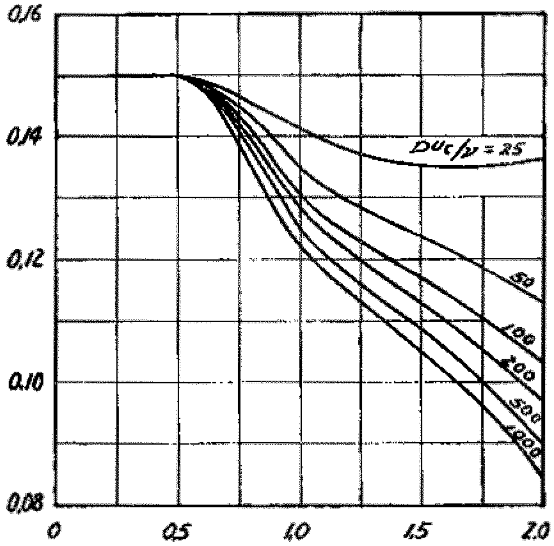


FIG. 1.
Pitot-tube displacement effect.

b) Effect of turbulence fluctuations. In a turbulent stream a total head tube measures

$$p_m = p + \tfrac{1}{2}\rho u^2 + \tfrac{1}{2}\rho\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right) \qquad (1)$$

where p_m is the measured total pressure, p is the mean pressure and u the mean velocity, and u', v', w' are the turbulent velocity fluctuations. The mean pressure is related to the pressure P at the wall (or at the edge of the boundary layer) by the equation

$$p = \mathrm{P} - \rho\overline{v'^2} \qquad (2)$$

so that (1) assumes the form

$$p_m = \mathrm{P} + \tfrac{1}{2}\rho u^2 + \tfrac{1}{2}\rho\left(\overline{u'^2} - \overline{v'^2} + \overline{w'^2}\right) \qquad (3)$$

Put

$$p_m - \mathrm{P} = \tfrac{1}{2}\rho\, u_m^2 \qquad (4)$$

Then the mean velocity may be computed from the relation

$$u = u_m \left[1 + \left(\frac{u_\tau}{u}\right)^2 \frac{\overline{u'^2} - \overline{v'^2} + \overline{w'^2}}{u_\tau^2}\right]^{-\frac{1}{2}} \qquad (5)$$

Here $\frac{u_\tau}{u}$ is obtained either from the inner or the outer law of a boundary layer, depending upon the location of the Pitot tube. For the purpose of applying a small correction to the values of u_m it suffices to use uncorrected versions of the inner and outer laws [8]. If the correction is large it may be necessary to repeat the calculations using the improved values of u/u_τ given by the first approximation.

The ratio $(\overline{u'^2} - \overline{v'^2} + \overline{w'^2})/u_\tau^2$ can be derived from turbulence measurements if it is assumed that these satisfy the similarity relations

$$\frac{\overline{u'^2} - \overline{v'^2} + \overline{w'^2}}{u_\tau^2} = G_1\left(\frac{y u_\tau}{\nu}\right) \quad \text{or } G_2\left(\frac{y}{\delta}\right) \qquad (6)$$

in the ranges of the inner law or outer law respectively. If it is assumed that there is an overlapping range of values of y in which both laws are valid, it is readily shown, by the well-known procedure of deriving the linear logarithmic relation for velocity profiles, that $G^1 = G^2 =$ constant in this range. Examination and analysis of the little available data on the values of the turbulence fluctuations in a boundary layer [10, 11, 12] indicated that the above conclusion is reasonably consistent with the data. Mean curves of G^1 and G^2, shown in Figure 2, were used to correct the measurements.

c) Velocity profile data. The foregoing corrections due to the displacement effect of a Pitot tube and the turbulence fluctuations have been applied to the flat-plate boundary-layer data of references [7] and [13]. Among the numerous papers on flat-plate boundary layers, these were selected because they contained tabulated values of u against y. Tables 1 and 2 show the original and corrected values of u/U and y. The net effect of the corrections when the data are plotted in the form of the inner law is shown in Figure 3.

Determination of Shear Stress.

The shear stress at the wall in a boundary layer has been measured directly, by mean of a dynamometer,

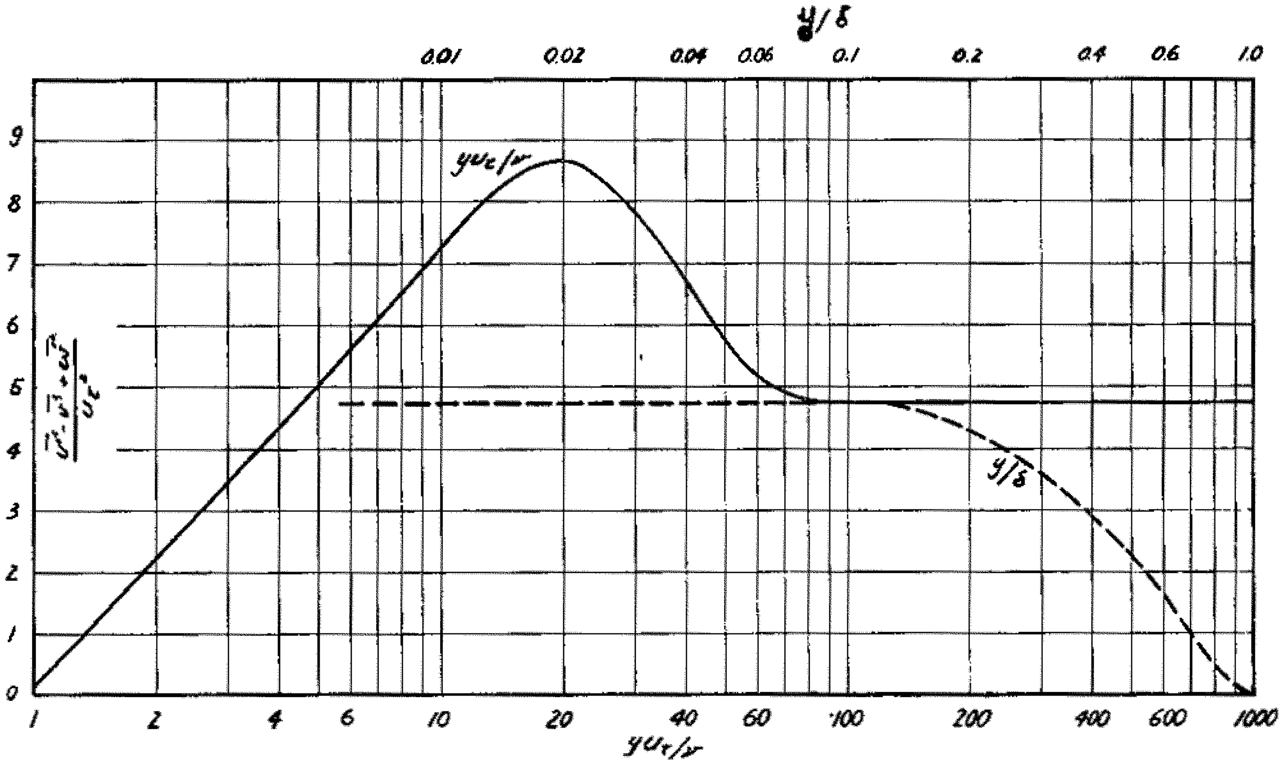


FIG. 2.

Term for velocity-fluctuation correction.

TABLE 1.

Original and Corrected Values of Velocity-Profile Data, Ref. [13].

y		u/U													
		$R_x = 2.2 \times 16^6$		2.7×10^6		3.2×10^6		3.7×10^6		4.2×10^6		4.9×10^6		5.3×10^6	
Orig.	Corr.	Orig.	Corr.	Orig.	Corr.	Orig.	Corr.	Orig.	Corr.	Orig.	Corr.	Orig.	Corr.	Orig.	Corr.
0.0208	0.02517	0.583	0.574	0.572	0.563	0.564	0.555	0.558	0.549	0.550	0.541	0.544	0.535	0.533	0.524
0.03	0.03508	0.604	0.596	0.593	0.585	0.583	0.575	0.575	0.567	0.567	0.559	0.563	0.555	0.554	0.546
0.05	0.05580	0.639	0.632	0.627	0.621	0.617	0.610	0.605	0.599	0.600	0.592	0.596	0.589	0.588	0.582
0.07	0.07615	0.667	0.661	0.652	0.646	0.643	0.637	0.631	0.625	0.624	0.617	0.620	0.614	0.613	0.607
0.10	0.10624	0.698	0.693	0.681	0.676	0.671	0.655	0.660	0.655	0.650	0.644	0.647	0.641		
0.15	0.15624	0.738	0.733	0.721	0.716	0.708	0.703	0.695	0.690	0.688	0.683	0.682	0.677	0.677	0.672
0.20	0.20624	0.772	0.768	0.750	0.746	0.737	0.732	0.722	0.717	0.712	0.707	0.707	0.702	0.702	0.697
0.25	0.25624	0.800	0.796	0.776	0.772	0.761	0.757	0.745	0.741	0.735	0.730	0.729	0.725	0.723	0.719
0.30	0.30624	0.828	0.825	0.800	0.796	0.781	0.777	0.765	0.761	0.752	0.748	0.747	0.743	0.738	0.734
0.35	0.35624	0.853	0.850	0.822	0.819										
0.40	0.40624	0 876	0.873	0.843	0.840	0.820	0.817	0.802	0.799	0.786	0.783	0.778	0.774	0.770	0.766
0.45	0.45624	0.897	0.895		0.879										
0.50	0.50624	0.918	0.917	0.881	0.913	0.856	0.853	0.834	0.831	0.816	0.813				
0.60	0.60624	0.952	0.951	0.915	0.943	0.887	0.885	0.863	0.861	0.843	0.840	0.832	0.829	0.819	0.816
0.70	0.70624	0.978	0.977	0.944	0.968	0.916	0.914	0.889	0.887						
0.80	0.80624	0.994	0.994	0.969	0.984	0.941	0.940	0.916	0.914	0.894	0.892	0.877	0.875	0.863	0.861
0.90	0.90624	0.999	0.999	0.995	0.993	0.963	0.962								
1.00	1.00624	1.000	1.000	0.993	0.997	0.979	0.978	0.956	0.955	0.936	0.935	0.920	0.918	0.902	0.900
1.20	1.20624			0.999	1.000	0.996	0.996	0.983	0.983	0.968	0.967	0.952	0.951	0.934	0.933
1.40	1.40624					1.000	1.000	0.997	0.997	0.991	0.991	0.976	0.975	0.963	0.962
1.60	1.60624							1.000	1.000	0.998	0.998	0.992	0.992	0.982	0.981
1.80	1 80634									1.000	1.000	0.998	0.998	0.996	0.996
2.00	2.00624											1.000	1.000	0.999	0.999
2.20	2.20624													1.000	1.000

TABLE 2.
Original and Corrected Values of Velocity-Profile Data, Ref. [7].

y	u/U $R_x = 2.0 \times 10^6$		y	u/U $R_x = 10.0 \times 10^6$		y	u/U $R_x = 41 \times 10^6$	
	Orig.	Corr.		Orig.	Corr.		Orig.	Corr.
0.0035	0.443	0.429	0.0035	0.482	0.474	0.0035	0.512	0.507
0.0085	0.586	0.577	0.0085	0.591	0.586	0.0085	0.607	0.603
0.0135	0.625	0.619	0.0135	0.636	0.631	0.0135	0.643	0.639
0.0185	0.651	0.645	0.0185	0.659	0.655	0.0185	0.667	0.663
0.0235	0.676	0.670	0.0235	0.678	0.674	0.0235	0.684	0.680
0.0285	0.693	0.687	0.0285	0.695	0.691	0.0285	0.697	0.693
0.0335	0.704	0.698	0.0335	0.708	0.704	0.0335	0.709	0.706
0.0385	0.715	0.710	0.0385	0.719	0.715	0.0385	0.718	0.715
0.0435	0.727	0.722	0.0435	0.729	0.725	0.0435	0.728	0.725
0.0485	0.740	0.735	0.0485	0.737	0.733	0.0485	0.733	0.730
0.0535	0.752	0.747	0.0535	0.747	0.743	0.0535	0.740	0.737
0.0635	0.768	0.763	0.0785	0.780	0.776	0.0635	0.751	0.748
0.0735	0.787	0.783	0.1035	0.809	0.806	0.0735	0.760	0.757
0.0835	0.804	0.800	0.1285	0.834	0.831	0.0835	0.770	0.767
0.0935	0.820	0.816	0.1535	0.859	0 857	0.0935	0.778	0.775
0.1035	0.832	0.828	0.1785	0.880	0.878	0 1035	0.786	0.783
0.1235	0.862	0.859	0.2035	0.901	0.899	0.1285	0.802	0.799
0.1435	0.886	0.884	0.2285	0.921	0.919	0.1535	0.820	0.817
0.1635	0.911	0.909	0.2535	0.939	0.938	0.1785	0.833	0.830
0.1835	0.932	0.930	0.2785	0.955	0.954	0.2035	0.849	0.847
0.2035	0.951	0.950	0.3035	0.969	0.968	0.2535	0.875	0.873
0.2235	0.968	0.967	0.3285	0.980	0.979	0.3035	0.898	0.896
0.2435	0.981	0.980	0.3535	0.988	0.987	0.3535	0.919	0.917
0.2635	0.990	0.990	0.3785	0.993	0.993	0.4035	0.938	0.937
0.2835	0.996	0.996	0.4035	0.996	0.996	0.4535	0.957	0.956
0.3035	0.999	0.999	0.4285	0.998	0.998	0.5035	0.972	0.971
0.3235	1.000	1.000	0.4535	0.998	0.998	0.5535	0.983	0.982
			0.4785	0.998	0.998	0.6035	0.991	0.990
						0.6535	0.996	0.996
						0.7035	0.998	0.998
						0.7535	0.999	0.999
						0.8035	0.999	0.999
						0.8535	0.999	0.999

by Schultz-Grunow [14] and Smith and Walker [7]. An experimentally much simpler, but indirect, technique is that of using a Stanton- or Preston-type total head tube, the readings of which when in contact with the wall indicate the magnitude of the shear stress from a calibration of the tube in a flow of known shear stress. The latter technique is justified by assuming the validity of the inner law, as Granville has clearly shown [15].

Preston calibrated a round Pitot tube with square-cut end in the steady, uniform flow in a pipe where the shear stress is given by the pressure drop. This method of calibration has been criticized since there is conflicting evidence concerning the identity of the inner laws in a pipe flow and in a boundary layer. We will return to this question after the inner law has been discussed.

In principle the shear stress can also be computed from the momentum equation when velocity-profile data at various distances downstream from the leading

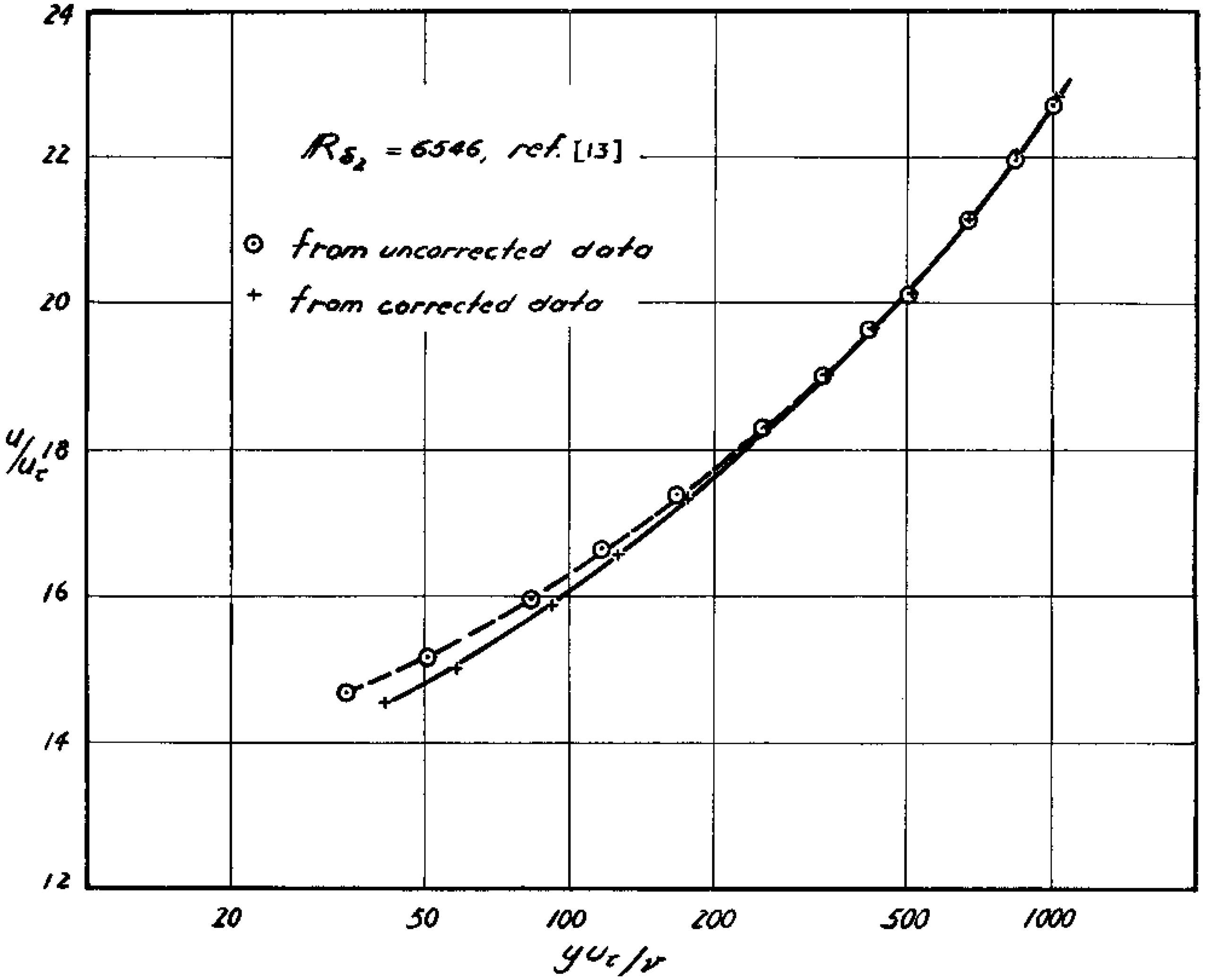


Fig. 3.

Effect of corrections for pitot-tube displacement and turbulence fluctuation.

edge of a plate are at hand [16]. The shear stress is then given by

$$\frac{C_\tau}{2} = \frac{d\delta_2}{dX} + \frac{H+2}{U}\frac{dU}{dx}\delta_2 - \frac{1}{U^2}\int_0^\delta (\overline{u'^2} - \overline{v'^2})\,dy \qquad (7)$$

where

U is the velocity at the edge of the boundary layer

δ is the boundary-layer thickness

$\delta_1 = \int_0^\delta \left(1 - \frac{u}{U}\right) dy$ is the displacement thickness

$\delta_2 = \int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right) dy$ is the momentum thickness

$H = \delta_1/\delta_2$

$C_\tau = \tau/(\frac{1}{2}\rho U^2)$

When the pressure gradient is zero the second term in the right member of (7) vanishes. In experiments, however, a small residual value of $(dU/dx)/U$ is unavoidable. Suppose, for example, that U changes by 0.2 per cent per foot when δ_2 and H have the reasonable values $\delta_2 = 0.01$ feet, $H = 1.5$. Then

$$\frac{H+2}{U}\frac{dU}{dx}\delta_2 = 3{,}5 \times 0.002 \times 0.01 = 0.00007$$

If $C_\tau \approx 0.0035$, neglect of this term in Eq. (7) would introduce an error of four per cent. Thus it is necessary to take extraordinary precautions to ensure that the pressure gradient is extremely small and, in addition, introduce corrections for the residual values of the pressure gradient. Another serious difficulty is that the momentum equation is also sensitive to deviations of the flow from two-dimensionality.

The last term in the momentum equation can be evaluated by writing it in the form

$$\frac{1}{U^2}\frac{d}{dx}\int_0^{\delta}(\overline{u'^2}-\overline{v'^2})\,dy = K\frac{d}{dR_x}\left(\frac{\delta^*}{\sigma}\right) \tag{8}$$

where $K = \int_0^1 \frac{\overline{u'^2}-\overline{v'^2}}{u_\tau^2}\, d\left(\frac{y}{\delta}\right)$ assumed constant

$$R_x = \frac{Ux}{\nu}$$

$$\delta^* = \delta u_\tau/\nu$$

$$\sigma = U/u_\tau$$

Analysis of experimental data indicates a mean value of $K = 1.10$.

For a flat plate in zero pressure gradient the coefficient of shear stress, C_τ should be a unique function of the Reynolds number based on momentum thickness $R_{\delta 2}$. The data of Smith and Walker [7] and Schultz-Grunow [41], based on direct measurements of shear stress, are shown plotted in this manner in Figure 4. Also shown are values computed from the momentum equation from the data of Refs. [3] and [13], and a curve computed from Schoenherr's friction formula [17].,

$$C_\tau = \frac{0{,}311}{ln\,(2\,R_{\delta 2})\,[ln\,(2\,R_{\delta 2}) + 2]} \tag{9}$$

Law of the Wall.

The corrected velocity-profile data, in conjunction with the shear-stress data of Smith and Walker, can now be applied to test the validity of the law of the wall; i.e., of the functional relation

$$\frac{u}{u_\tau} = f\,(y^*)\,,\ y^* = \frac{y u_\tau}{\nu} \tag{10}$$

Data from references [7] and [13] are plotted in this fashion in Figure 5. Laufer's pipe data are also shown for comparison. The dashed line is a mean curve for values of y* from 10 to 100. For larger values of y* the inner law curve appears to depend upon the Reynolds number, Ux/ν, as is indicated by ref. [7], and conditions in the outer part of the shear flow, as is indicated by the difference between the graphs for pipes, channels, boundary layers, and the effects of free stream turbulence. Indeed, Bradshaw and Gre-

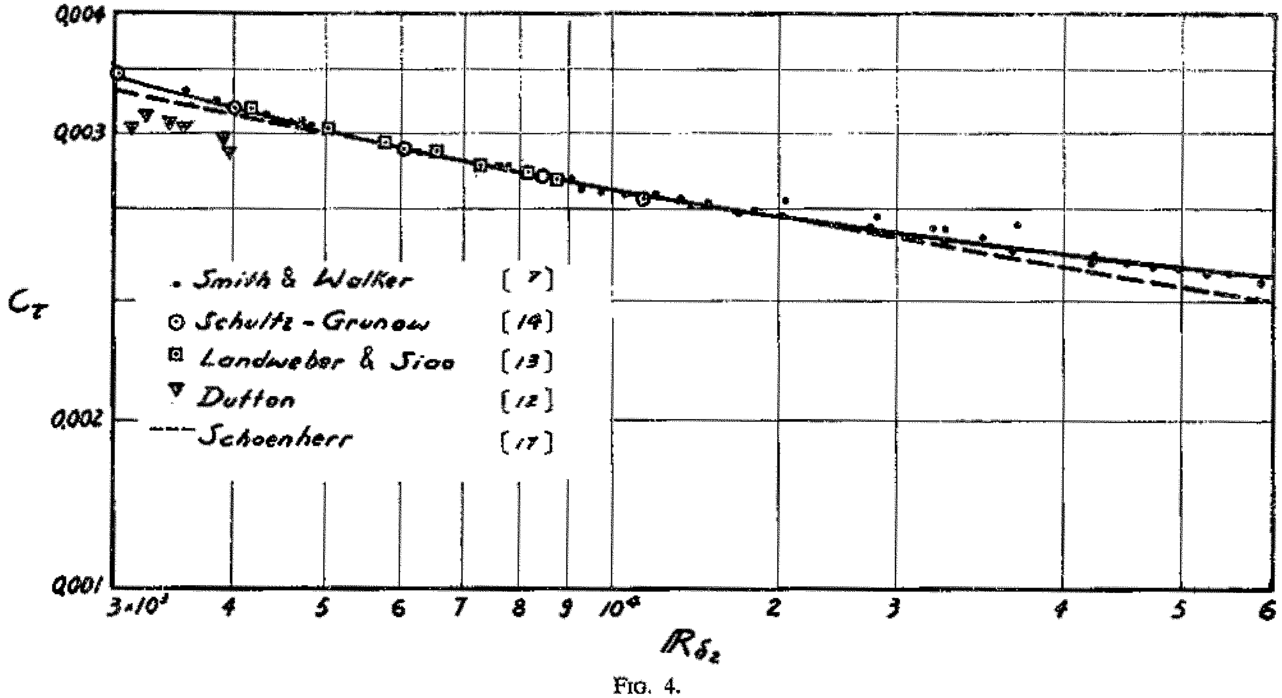


FIG. 4.

Comparison of various determinations of the shear-stress coefficient.

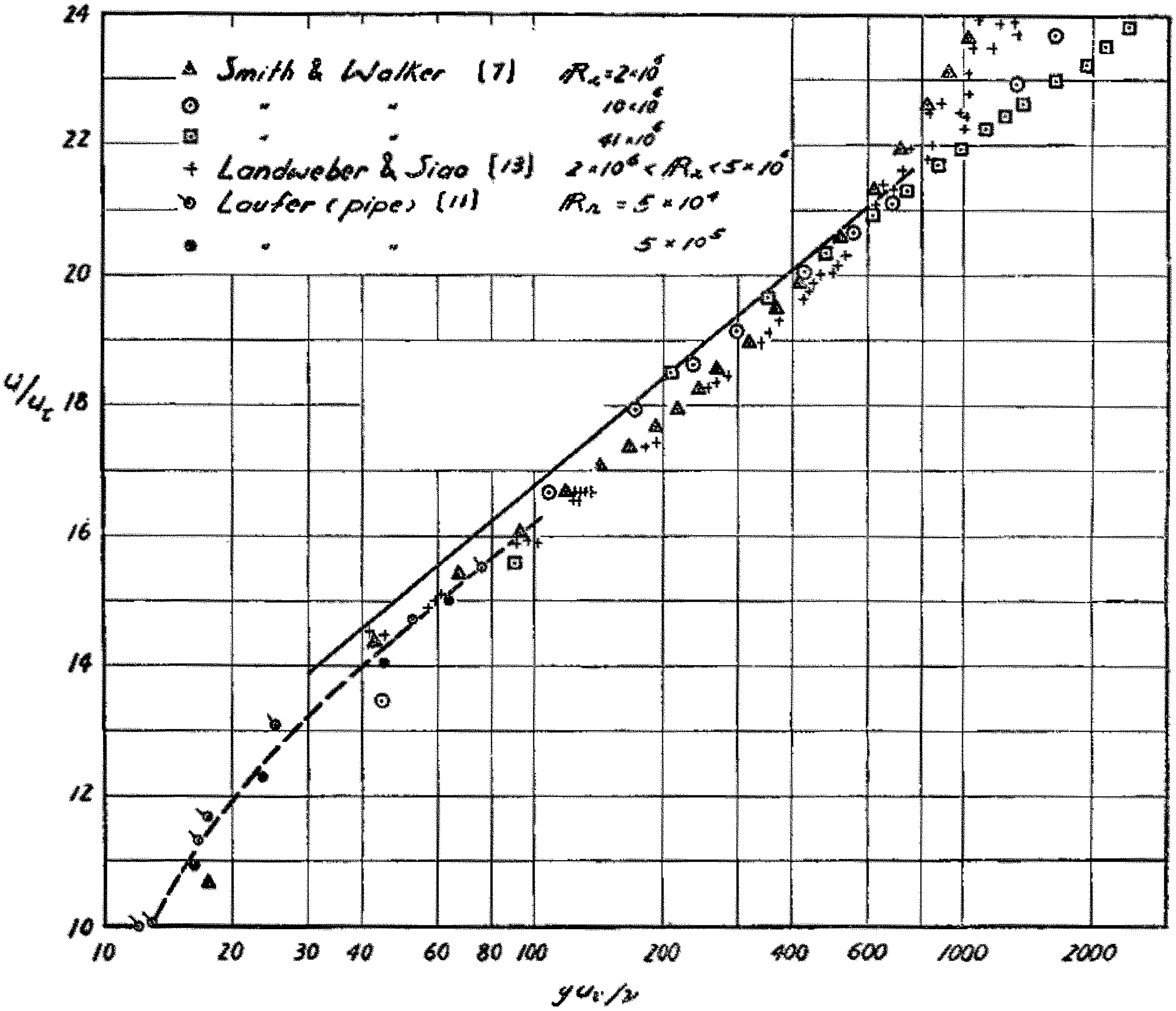


FIG. 5.
Comparison of "corrected" data on basis of inner law.

gory [6] have drawn the even more restrictive conclusion that the inner law is universally valid only for $y^* < 30$.

Calibration of Preston Tubes.

Preston's method of measuring shear stress at a wall is based on the assumption of the functional relation

$$\frac{u_\tau}{u_m} = F\left(\frac{u_m d}{2\nu}\right) \qquad (11)$$

where u_m is the local velocity, computed from the total pressure p_m measured by the Preston tube and the pressure P at the wall from the formula

$$u_m = \sqrt{\frac{2(p_m - P)}{\rho}} \qquad (12)$$

and d is the outer diameter of the tube.

Equation (11) can be derived from (10) by means of the intermediate relations, given by Figure 1 and Eq. (5). Thus we have

$$y = \frac{d}{2} + \varepsilon \qquad (13)$$

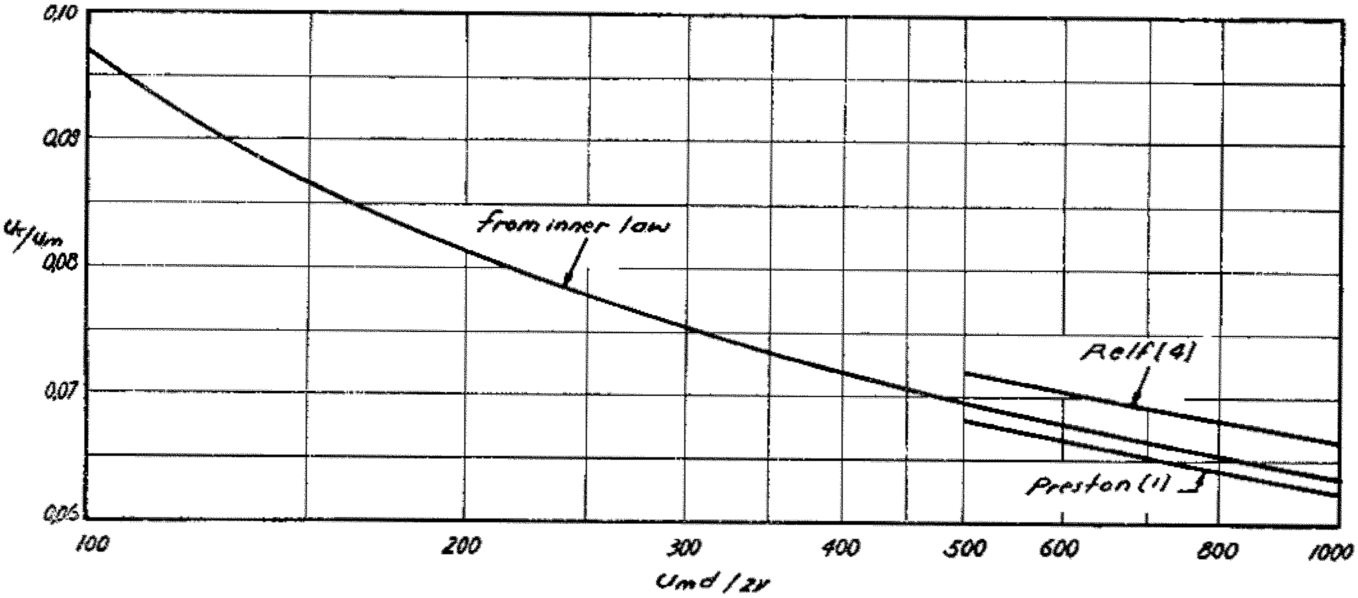


FIG. 6.
Shear-stress calibration for Preston tubes.

$$\frac{u}{u_\tau} = f\left[\frac{\left(\frac{d}{2} + \varepsilon\right) u_\tau}{\nu}\right] \tag{14}$$

$$\frac{2\varepsilon}{d} = g\left(\frac{d\,u_\tau}{2\nu}\right) \tag{15}$$

$$\frac{u}{u_m} = G\left[\frac{\left(\frac{d}{2} + \varepsilon\right) u_\tau}{\nu}\right] \tag{16}$$

From (15) one can obtain $\left(\frac{d}{2} + \varepsilon\right) u_\tau/\nu$ in terms of $du_\tau/(2\nu)$. Secondly, the ratio of (14) and (16) expresses u_τ/u_m in terms of $\left(\frac{d}{2} + \varepsilon\right) u_\tau/\nu$, and hence also of $du_\tau/(2\nu)$. Division of this last quantity by u_τ/u_m gives $u_m d/(2\nu)$, the argument of Eq. (11). By employing this procedure the curve of Figure 6, representing Eq. (11), was obtained from the dashed curve in the inner law plot, Figure 5.

Figure 6 also shows the feet of the calibration curves of Preston and Relf. According to the remarks of the previous section it would not be valid to use such calibration curves beyond the value $u_m d/(2\nu) = 1000$ of Figure 6. The calibration curve derived from the inner law is seen to lie between those of Preston and Relf, and considering the remarks in the Introduction, it is unexpected that it should lie closer to the former than the latter.

This last result led to a re-examination of the apparent agreement of the NPL and NACA data. First it was observed that the NPL plot of the inner law (which is not included in Figure 5 because the data are uncorrected and untabulated) lies considerably below that of NACA, which is, in fact, in better agreement with pipe data. Since the inner law leads to the calibration curve for Preston tubes, the relative positions of the calibration curves are seen to be consistent with the distribution of the data in the inner-law plot. Secondly it was noted in the inner-law plots of ref. [7] that the points corresponding to the smallest value of y in each traverse, when presumably the Pitot tube was in contact with the wall, deviated considerably and unaccountably from the similarity law indicated by the other data. Corrections for Pitot-tube displacement effect and turbulence fluctuations would only serve to increase the discrepancies. Although these traverses were made with flattened Pitot tubes, it appears reasonable to suppose that the NACA velocity data with the round Preston tubes in contact with the wall were also low for the same unknown reason. This would indicate that the NACA calibration of the Preston tubes is questionable, although their other velocity measurements seem to be of high accuracy and consistency.

E. Numata.

CORRELATION BETWEEN RESISTANCES OF LARGE AND SMALL MODELS

Introduction.

Allan B. Murray [1] presented the results of a geosim resistance correlation study at the 1953 meeting of ATTC. Small model test data obtained at the Davidson Laboratory (formerly Experimental Towing Tank) and large model data obtained at the U.S. Experimental Model Basin and the David Taylor Model Basin were compared. The geosim resistance data were in the form of observed coefficients of total model resistance, C_t, at Reynolds numbers, Re, corresponding to the test water temperature, load waterline length and observed model velocities. The following assumptions were made:

1. Tests of the larger model were considered to be fully turbulent even though, in some cases, no turbulence stimulation was used.
2. Residuary resistance coefficients, C_r, were independent of Reynolds number and were equal for both large and small geosims at the same Froude number.

The procedure was to determine a derived coefficient of frictional resistance for a small model as follows:

$$C_t - C_f = C_r$$

where C_f at the large model *Re* was according to the Schoenherr friction formulation adopted by the 1947 meeting of the ATTC,

$$C_r' = C_r$$

where the prime, ′, refers to the small model,

$$C_t' - C_r = C_f'$$

or derived friction coefficient of small model.

A plot of the derived friction coefficieut, C., versus Reynolds number for the smaller model was prepared for each geosim pair with the Schoenherr *Cf* curve being superimposed. A composite plot showing the results for 11 model pairs was also given. A comparison of the general trend of the C_f' points with the Schoenherr friction line showed that the Schoenherr formulation was a satisfactory correlating function for engineering purposes.

In 1954, utilizing essentially the same basic data, Murray [2] prepared a similar analysis to test the friction formulation and form factors proposed by Hughes [3]. It was concluded that as far as the Davidson Laboratory was concerned, it would be better to use the Schoenherr formulation than the Hughes method, although use of the Hughes form factors did tend to collapse the data.

Since 1954 resistance data for six additional pairs of geosim models have been analysed, including five sets of modern super-tanker model results. Both the Schoenherr formulation and the 1957 ITTC correlation line have been used in these analyses. In addition, most of the geosim data presented by Murray [1] have been re-analyzed using the ITTC line.

Results.

Figure 1 presents a composite plot of derived friction coefficients, C_f', versus Reynolds number obtained on the basis of the Schoenherr formulation for 14 pairs of geosim tests. Symbols were chosen so as to differentiate between:

1. the results for the models listed in Table I,
2. the Series 60, 0.60 C_b models,
3. the modern super-tanker models.

It should be noted that no artificial turbulence stimulation was used in any of the tests of the large models listed in Table I. Figure 2 is a similar plot showing the results of analyzing the same data on the basis of the 1957 ITTC line.

Table I lists particulars of the small Davidson Laboratory models and the corresponding large USEMB and DTMB models covered in the paper by Murray [1].

Table II gives the particulars of the more recent pairs of geosim models. Three of the large tanker models were tested at the Netherlands Ship Model Basin and three were tested at DTMB.

Tables III through XVI give the basic model resistance data for all the geosim pairs.

Discussion and conclusions.

Figure 1 shows that the Schoenherr formulation provides a reasonably good overall correlation between small and large geosim resistance test data. With few exceptions, all derived friction coefficients lie within a band covering ± 5.0 percent of the Schoenherr line. The exceptions on the low side represent points obtained at relatively low Froude numbers where the degree of turbulent flow may be in question.

Since the 1957 ITTC line has higher values and a steeper slope than the Schoenherr line at Reynolds numbers below 10^9, the correlation obtained with this line is not as good as with the Schoenherr formulation. Figure 2 shows that the majority of the C_f' points lie below the ITTC line. This means that, in general, if the Davidson Laboratory were to adopt the ITTC line, its ship resistance predictions would tend to be lower than predictions based on tests of 20-foot models at DTMB.

Based on the evidence presented here, it is concluded that continued use of the Schoenherr friction formulation at the Davidson Laboratory will result in ship resistance predictions which will be consistent with results obtained with large models at other basins. It is further concluded that the use of the 1957 ITTC line at the Davidson Laboratory will generally underestimate ship resistance. These conclusions are predicated on the continued use of a long-established test echnique utilizing:

1. varnished wood models about five feet in length with a blockage of less than 0.6 percent tested in
2. the 100-foot basin containing water maintained at a temperature of 70 degrees F with
3. a high level of residual turbulence maintained by starting test runs at two minute intervals and
4. artificially stimulating turbulence through the use of a strut ahead of the model.

References

[1] Murray A. B.: *Frictional Resistance Coefficients at Low Reynolds Numbers Obtained by Comparison of Large and Small Models*, Tenth Meeting of ATTC, 1953.

[2] Murray A. B.: *Correlation of Large and Small Models by the Suggested Hughes Method*, Seventh International Conference on Ship Hydrodynamics, 1954.

[3] Hughes G.: *Friction and Form Resistance in Turbulent Flow*, Trans. INA, 1954.

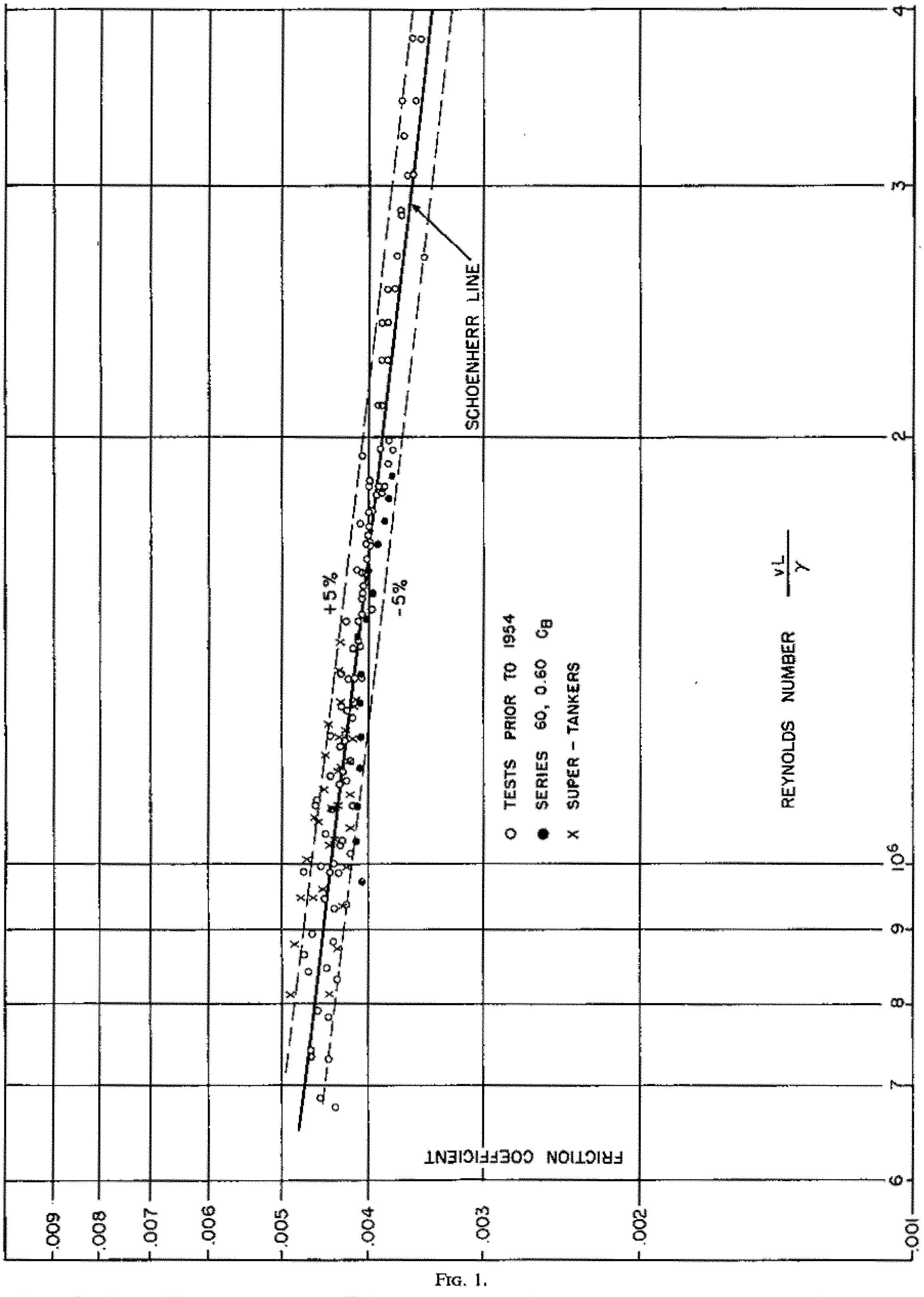


FIG. 1.

Composite chart of frictional resistance coefficients derived by geosim analysis using Schoenherr friction formulation.

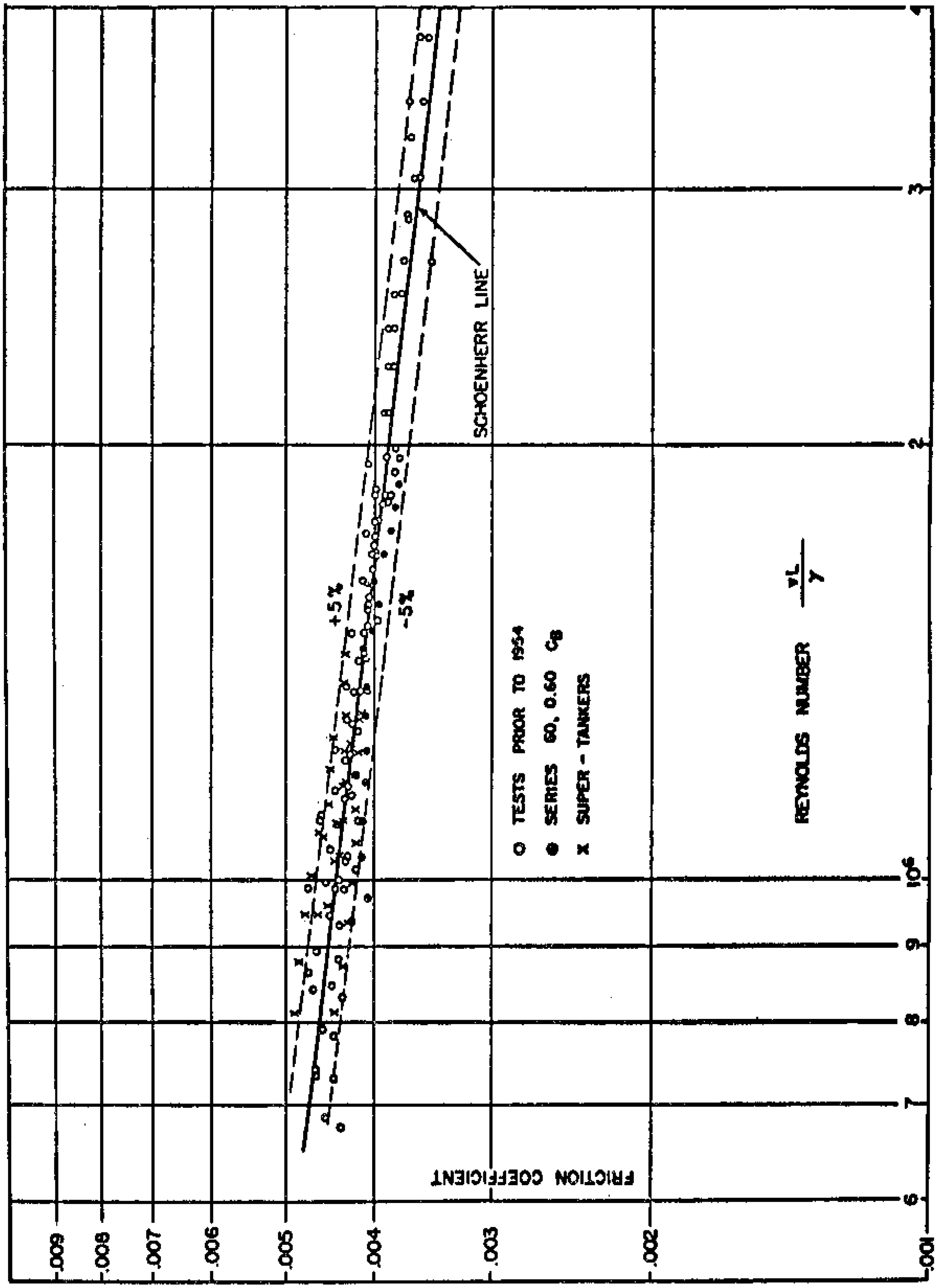


FIG. 2.

Composite chart of frictional resistance coefficients derived by geosim analysis using Schoenherr friction formulation.

TABLE 1

Model Particulars.

TYPE	BASIN	MODEL No.	SCALE Ratio	LWL Ft.	WETTED AREA Sq. Ft.	DISPL. L.b	WATER TEMP. Deg. F	TURBULENCE STIMULATOR	DATE
Hog Island Ship	ETT	102	64	6.19	8.301	93.5	76	1/2" sand strip	1935
	USEMB	3114	19.5	20.32	89.2	3298	65	None	—
C1-B Cargo Ship	ETT	387	96	4.115	2.851	17.28	70	1/8" strut	1941
Light Displacement	USEMB	3593	19.75	20.0	67.35	2038	75	None	—
C1-B Cargo Ship	ETT	387	96	4.115	3.905	31.65	71	1/8" strut	1941
Load Displacement	USEMB	3593	19.75	20.0	92.24	3735	75	None	—
Destroyer	ETT	430	—	5.5	3.57	20.76	71	Strut	1942
Light Displacement	USEMB	3757	—	20.0	47.2	1003	65.5	None	1942
Destroyer	ETT	430	—	5.5	3.67	22.82	71	Strut	1942
Heavy Displacement	USEMB	3757	—	20.0	49.2	1104	65.5	None	1942
Fast Cargo Ship	ETT	1347	105	5.0	4.40	35.06	68.5	Strut	1951
	DTMB	4152	24.175	21.84	82.75	2870	74	None	1951
Fast Cargo Ship	ETT	1348	105	5.48	4.61	36.10	71	Strut	1951
	DTMB	4.342 W	29.32	18.93	59.79	1654	62	None	1950
Passenger Ship	ETT	1448	120	5.183	4.264	32.12	69	Trip Wire	1954
	DTMB	4424	26.06	23.87	90.61	3132	64	None	1952

TABLE 2

Model Particulars.

TYPE	BASIN	MODEL No.	SCALE Ratio	LWL Ft.	WETTED AREA Sq. Ft.	DISPL. Lb.	WATER TEMP. Deg. F.	TURBULENCE STIMULATOR	DATE
Series 60 0.60 C_b	ETT	1445	80	5.084	4.27	33.27	71	Strut	1953
	DTMB	4210 W	20	20.34	68.20	2129	75	Studs	1952
Tanker 0.77 C_b	ETT	1814	120	5.360	5.619	50.20	71	Struts	1956
	DTMB	4635	28	22.90	102.2	3950	69	Studs	1956
Tanker 0.79 C_b	ETT	1928	144	5.006	5.029	42.93	69	Strut	1957
	DTMB	4672	28.14	25.62	130.5	5743	—	Studs	1957
Tanker 0.77 C_b	ETT	1952	144	4.861	4.919	43.65	72	Strut	1957
Load Displacement	NSMB	1609	30	23.33	112.5	4828	58	Trip Wire	1958
Tanker 0.77 C_b	ETT	1952	144	4.861	3.995	26.42	70	Strut	1957
Light Displacement	NSMB	1609	30	23.33	91.28	2922	58	Trip Wire	1958
Tanker 0.82 C_b	ETT	1953—2	170	5.455	6.101	60.88	68.5	Strut	1957
	NSMB	1697 A	40	23.13	109.3	4674	62.4	Trip Wire	1957

Note : All of the above ETT tanker models were tested with rudders, while the large models were tested without rudders.

TABLE 3.

Hog Island ship.

	ETT		USEMB	
Model No	102		3114	
Scale Ratio	64.0		19.5	
LWL, feet	6.19		20.32	
Wetted Area, square feet	8.301		89.2	
Displacement, pounds	93.5		3298	
Temperature, degrees F	76		65	
Turbulence Stimulator	1/2″ sand strip		None	
Blockage, percent	0.99		0.54	
Date	16 July 1935		—	
	SPEED fps	RESISTANCE lb.	SPEED knots	RESISTANCE lb.
	1.336	0.0700	1.582	2.32
	1.470	0.0844	1.813	3.08
	1.601	0.0983	2.034	3.72
	1.733	0.1150	2.194	4.40
	1.866	0.1323	2.304	4.85
	1.977	0.1519	2.445	5.50
	2.129	0.1713	2.553	6.00
	2.261	0.1930	2.675	6.61
	2.394	0.2173	2.75	7.00
	2.526	0.2477	2.93	8.15
	2.658	0.2763	2.867	7.70
	2.792	0.3135	2.923	8.10
	2.924	0.3587	3.01	8.95
	3.056	0.4132	3.05	9.20
	3.188	0.5034	3.153	10.20
			3.17	10.30
			3.20	10.70
			3.263	11.30

Note : 0.040×10^{-3} substracted from Ct_m for sand correction.

TABLE 4.
CI-B Cargo Ship 7.000 Tons.

	ETT		USEMB	
Model No.	387		3593	
Scale Ratio	96		19.75	
LWL, feet	4.115		20	
Wetted Area, square feet	2.851		67.35	
Displacement, pounds	17.28		2038	
Temperature, degrees F	70		75	
Turbulence Stimulator	Strut		None	
Date	15 December 1941		—	
	SPEED fps	RESISTANCE lb	SPEEDS fps	RESISTANCE lb.
	1.601	0.0370	3.800	3.732
	1.733	0.0432	4.180	4.423
	1.866	0.0510	4.560	5.250
	1.997	0.0585	4.940	6.240
	2.129	0.0662	5.320	7.321
	2.261	0.0760	5.700	8.565
	2.394	0.0838	6.080	10.26
	2.526	0.0960	6.460	12.69
	2.658	0.1080		
	2.792	0.1262		
	2.924	0.1435		
	3.056	0.1685		

TABLE 5.
CI-B Cargo Ship 12,825 Tons.

	ETT		USEMB	
Model No	387		3593	
Scale Ratio	96		19.75	
LWL, feet	4.115		20	
Wetted Area, square feet	3.905		92.24	
Displacement, pounds	31.65		3735	
Temperature, degrees F	71		75	
Turbulence Stimulator	Strut		None	
Blockage, percent	0.56		0.36	
Date	15 December 1941		—	
	SPEED fps	RESISTANCE b.	SPEED fps	RESISTANCE lb.
	1.601	0.0498	3.800	4.802
	1.733	0.0588	3.991	5.258
	1.866	0.0695	4.180	5.754
	1.997	0.0798	4.371	6.345
	2.129	0.0938	4.560	6.984
	2.261	0.1067	4.751	7.586
	2.394	0.1185	4.940	8.299
	2.526	0.1362	5.131	9.037
	2.658	0.1545	5.320	9.840
	2.792	0.1860	5.511	10.79
	2.924	0.2135	5.700	11.86
	3.056	0.2672	5.891	12.92
			6.080	14.62
			6.271	16.51
			6.460	19.14

TABLE 6.

Destroyer. Light Displacement.

	TTE		USEMB (*)	
Model No	430-III		3757	
LWL, feet	5.5		20.0	
Wetted Area, square feet	3.57		47.2	
Displacement, pounds	20.76		1003	
Temperature, degrees F.	71		65.5	
Turbulence Stimulator	Struts		None	
Date	20 August 1942		24 June 1942	
	SPEED fps	RESISTANCE lb.	SPEED knots	RESISTANCE lb.
	2.924	0.1472	1.0	0.5
	3.188	0.1756	1.5	1.1
	3.453	0.2067	2.0	1.9
	3.719	0.2403	2.5	3.0
	3.984	0.2877	3.0	4.5
	4.250	0.3298	3.5	6.2
	4.514	0.3793	4.0	8.3
	4.781	0.4298	4.5	11.0
	5.405	0.647	5.0	13.8
	6.481	1.059	5.5	17.7
	7.196	1.281	6.0	24.5
	7.915	1.523	6.5	32.5
	7.915	1.531	7.0	39.9
	8.629	1.712	7.5	46.3
	8.629	1.709	8.0	51.9
	8.988	1.788	8.5	57.0
	9.347	1.854	9.0	61.8
	5.05	0.500	9.1	62.6
	5.761	0.792		
	6.121	0.941		
	6.121	0.946		

(*) From USEMB faired resistance curve.

TABLE 7.
Destroyer. Heavy Displacement.

	ETT		USEMB (1)	
Model No	430-II		3757	
LWL, feet	5.5		20.0	
Wetted Area, square feet	3.67		49.2	
Displacement, pounds	22.82		1104	
Temperature, degrees F.	71		65.5	
Turbulence Stimulator	Struts		None	
Blockage, percent	0.31		0.21	
Date	18 August 1942		24 June 1942	
	SPEED fps	RESISTANCE lb.	SPEED knots	RESISTANCE lb.
	2.924	0.1546	2.0	2.1
	3.188	0.1859	2.5	3.2
	3.453	0.2198	3.0	4.8
	3.719	0.2622	3.5	6.7
	3.984	0.3122	4.0	9.1
	4.250	0.3572	4.5	12.1
	4.514	0.4046	5.0	15.3
	4.781	0.4677	5.5	19.7
	5.050	0.531	6.0	27.5
	5.405	0.705	6.5	36.6
	5.405	0.708	7.0	44.8
	5.761	0.8645	7.5	51.9
	6.481	1.181	8.0	58.1
	7.196	1.413	8.5	63.6
	7.196	1.419	9.0	68.7
	7.915	1.685	9.1	69.7
	7.915	1.691		
	8.629	1.858		
	9.347	2.007		

(1) From USEMB faired resistance curve.

TABLE 8.
Fast cargo vessel.

	ETT		DTMB	
Model No	1347-1H		4152	
Scale ratio	105		24.175	
LWL, feet	5.00		21.841	
Wetted Area, square feet	4.40		82.754	
Displacement, pounds	35.06		2870	
Temperature, degrees F	68.5		74	
Turbulence Stimulator	Strut		None	
Blockage, percent	0.57		0.31	
Date	13 February 1951		17 August 1951	
	SPEED fps	RESISTANCE lb.	SPEED knots	RESISTANCE lb.
	1.601	0.058	2.00	3.45
	1.866	0.080	2.50	5.20
	2.129	0.104	3.005	7.45
	2.261	0.116	3.50	10.60
	2.394	0.129	4.00	14.00
	2.526	0.143	4.50	21.45
	2.658	0.158	5.01	28.60
	2.792	0.175	2.25	4.25
	2.924	0.193	2.775	6.25
	3.056	0.210	3.20	8.50
	3.188	0.228	3.35	9.50
	3.321	0.252	3.65	11.50
	3.453	0.281	3.80	12.40
	3.586	0.321	3.90	13.10
	3.719	0.359	4.05	14.45
	3.850	0.395	4.10	15.20
	3.984	0.425	4.20	16.45
			4.75	25.55
			5.20	31.20
			5.40	35.25
			4.30	17.80

TABLE 9.
Fast cargo vessel.

	ETT		DTMB	
Model No	1348-1H		4342 W	
Scale Ratio	105		29.318	
LWL, feet	5.48		18.929	
Wetted Area, square feet	4.61		59.79	
Displacement, pounds	36.10		1654	
Temperature, degrees F.	71		62	
Turbulence Stimulator	Strut		None	
Blockage, percent	0.57		0.21	
Date	20 February 1951		4 December 1950	
	SPEED fps	RESISTANCE lb.	SPEED knots	RESISTANCE lb.
	3.453	0.2688	1.99	2.45
	1.601	0.0567		
	3.719	0.3539	2.49	3.73
	1.866	0.0754	3.00	5.50
	3.586	0.3070	3.20	6.20
	2.129	0.0970	3.40	7.00
	3.321	0.2348	3.60	7.90
	22.61	0.1085	3.80	9.30
	3.188	0.2154	4.00	11.63
	1.733	0.0657	4.10	12.95
	3.056	0.1973	4.19	14.10
	1.997	0.0854	4.30	15.70
	2.924	0.1803		
	2.394	0.1227		
	3.321	0.2367		
	2.526	0.1357		
	2.658	0.1500		
	2.792	0.1648		

TABLE 10.
Fast cargo vessel.

	ETT	DTMB
Model No.	1448	4424
Scale Ratio	120	26.057
LWL, feet	5.183	23.871
Wetted Area, square feet	4.264	90.61
Displacement, pounds	32.12	31.33
Temperature, degrees F.	69	64
Turbulence Stimulator	Trip Wire	None
Blockage, percent	0.51	0.31
Date	4,5 February 1954	14 February 1952

SPEED fps	RESISTANCE lb.	SPEED knots	RESISTANCE lb.
4.116	0.4176	2.60	5.88
1.336	0.0354	2.80	6.75
3.850	0.3482	3.20	8.82
1.601	0.0516	3.605	11.40
3.586	0.2824	4.005	14.18
1.866	0.0688	4.40	18.20
3.321	0.2245	4.81	25.17
2.129	0.0903	5.02	28.54
3.056	0.1867	3.00	7.76
2.394	0.1142	3.41	10.15
2.792	0.1576	3.80	12.70
2.526	0.1279	4.19	15.52
2.658	0.1439	4.61	21.02
2.924	0.1722	3.50	10.75
		3.72	12.12
		3.90	13.45
		4.10	14.75
		4.30	16.45
		4.50	19.53
		4.70	23.15
		4.905	26.44
		4.21	15.96
		4.30	16.77
		4.40	17.95
		4.60	21.18
		3.105	8.35
		3.31	9.57
		3.86	13.00
		3.95	13.75

TABLE 11.
Series 60, 0.60 C_b.

	ETT		DTMB	
Model No	1445		4210 W	
LWL, feet	5.084		20.34	
Wetted Area, square feet	4.270		68.20	
Displacement, pounds	33.27		2126	
Temperature, degrees F	71		75	
Turbulence Stimulator	Strut		Studs	
Blockage, percent	0.55		0.25	
Date	16 September 1953		22 August 1952	
	SPEED fps	RESISTANCE lb.	SPEED knots	RESISTANCE lb.
	1.997	0.0761	2.00	2.75
	2.129	0.0876	2.20	3.30
	2.261	0.0994	2.395	3.90
	2.394	0.1107	2.60	4.57
	2.526	0.1245	2.80	5.25
	2.658	0.1391	3.00	6.05
	2.792	0.1542	3.20	6.95
	2.924	0.1707	3.40	7.75
	3.056	0.1845	3.595	8.72
	3.188	0.2007	3.70	9.25
	3.321	0.2248	3.795	9.85
	3.453	0.2579	3.90	10.55
	3.586	0.2979	4.00	11.65
	3.719	0.3376	4.10	13.10
	3.850	0.3721	4.18	14.38
			4.30	16.05
			4.40	17.62
			4.50	19.05
			4.60	20.15
			4.70	21.10
			4.80	21.90

TABLE 12.
Super Tanker.

	ETT	DTMB
Model No	1814	4635
Scale Ratio	120	28
LWL, feet	5.360	22.90
Wetted Area, square feet	5.619	102.2
Displacement, pounds	50.20	3950
Temperature, degrees F	71	69
Turbulence Stimulator	Strut	Studs
Blockage, percent	0.62	0.32
Appendages	Rudder	None
Date	17 May 1956	20 November 1956

Speed fps	Resistance lb.	Speed knots	Resistance lb.
1.733	0.0884	1.90	3.95
1.866	0.1007	1.99	4.40
1.997	0.1150	2.085	4.75
2.128	0.1309	2.20	5.35
2.261	0.1484	2.30	5.75
2.394	0.1684	2.40	6.25
2.526	0.1932	2.49	6.75
2.658	0.2228	2.60	7.45
2.791	0.2619	2.70	8.05
		2.80	8.65
		2.90	9.45
		3.00	10.20
		3.05	10.65
		3.10	11.20
		3.15	11.75
		3.20	12.30
		3.25	12.90
		3.30	13.43
		3.35	14.05
		3.40	15.10
		3.50	16.70
		3.55	18.25
		3.59	19.05
		3.65	20.50
		3.70	22.20
		3.75	24.07
		3.80	25.50
		3.85	26.50
		3.895	27.95

TABLE 13.
Super Tanker.

	ETT	DTMB
Model No	1928	46 72
Scale Ratio	144	28.145
LWL, feet	5.006	25.62
Wetted Area, square feet	5.029	130.55
Displacement, pounds	42.93	5743
Temperature, degrees F.	69	—
Turbulence Stimulator	Strut	Studs
Blockage, percent	0.55	0.41
Appendages	Rudder	None
Date	28 May 1957	3 July 1957

SPEED fps	RESISTANCE lb.	$\frac{V}{\sqrt{LWL}}$	RESIDUARY (1) RESISTANCE lb./ton
1.470	0.0566	0.458	0.57
1.601	0.0656	0.493	0.69
1.733	0.0756	0.528	0.85
1.866	0.0872	0.562	1.05
1.997	0.0994	0.597	1.32
2.128	0.1138	0.633	1.68
2.261	0.1297	0.668	2.23
2.394	0.1494	0.703	3.02
2.526	0.1757	0.739	4.22
2.658	0.2048		
2.791	0.2397		

(1) From DTMB faired curve based on Schoenherr friction formulation.

TABLE 14.
Super Tanker. Load displacement.

	ETT		NSMB	
Model No.	1952		1609	
Scale Ratio	144		30	
LWL, feet	4.861		23.33	
Wetted Area, square feet	4.919		112.55	
Displacement, pounds	43.65		4828	
Temperature, degrees F.	72		58	
Turbulence Stimulator	Strut		Trip Wire	
Blockage, percent	0.58		0.69	
Appendages	Rudder		None	
Date	25 October 1957		1958	
	SPEED fps	RESISTANCE lb.	SPEED meters/sec.	RESISTANCE grams
	1.470	0.0560	1.3150	3565
	1.733	0.0772	1.3619	3815
	1.997	0.1038	1.4089	4090
	2.261	0.1338	1.4558	4375
	2.394	0.1507	1.5028	4690
	2.526	0.1742	1.5498	5030
	2.658	0.2022	1.5967	5410
	2.791	0.2344	1.6437	5835
			1.6907	6315
			1.7376	6890
			1.7846	7565

TABLE 15.
Super Tanker. Light displacement.

	ETT		NSMB	
Model No.	1952		1609	
Scale Ratio	144		30	
LWL, feet	4.861		23.33	
Wetted Area, square feet	3.995		91.28	
Displacement, pounds	26.42		2923	
Temperature, degrees F.	70		58	
Turbulence Stimulator	Strut		Trip Wire	
Blockage, percent	0.37		0.44	
Appendages	Rudder		None	
Date	28 October 1957		1958	
	Speed fps	Resistance lb.	Speed meters/sec.	Resistance grams
	1.470	0.0467	1.4089	3545
	1.733	0.0641	1.4558	3820
	1.997	0.0854	1.5028	4110
	2.261	0.1116	1.5498	4420
	2.394	0.1267	1.5967	4740
	2.526	0.1428	1.6437	5095
	2.658	0.1610	1.6907	5465
	2.791	0.1844	1.7376	5875
			1.7846	6330
			1.8316	6845
			1.8786	7480

TABLE 16.
Super Tanker.

	ETT		NSMB	
Model No.	1953-2		1697 A	
Scale Ratio	170		40	
LWL, feet	5.455		23.13	
Wetted Area, square feet	6.101		109.34	
Displacement, pounds	60.88		4674	
Temperature, degrees F.	68.5		62.4	
Turbulence Stimulator	Strut		Trip Wire	
Blockage, percent	0.70		0.65	
Appendages	Rudder		None	
Date	14 October 1957		1957	
	SPEED fps	RESISTANCE lb.	SPEED meters/sec.	RESISTANCE grams
	1.336	0.0625	0.9761	2000
	1.470	0.0744	1.0168	2145
	1.601	0.0878	1.0574	2300
	1.733	0.1019	1.0981	2460
	1.866	0.1160	1.1388	2635
	1.997	0.1322	1.1794	2820
	2.128	0.1500	1.2201	3020
			1.2608	3230
			1.3015	3460
			1.3421	3720
			1.3828	4005
			1.4235	4335
			1.4642	4716

Allan B. Murray.

USE OF SCHOENHERR FRICTION FORMULATION FOR EXPANDING MODEL RESISTANCES TO FULL SIZE

Discussion.

Davidson Laboratory (DL) Note No. 537 (*) compares the resistances of small models tested at DL with the resistances of larger geosims tested at other establishments.

In these comparisons, it has been assumed that no scale effects exist for residual resistance. It has been assumed that fully turbulent conditions exist for the larger geosims. Turbulence was artificially induced in all cases for the small models tested.

The ITTC 1957 line and the Schoenherr line were used for expanding the DL small model results to larger geosims (Fig. 1 and 2). The Schoenherr friction line is more suitable for expanding DL model tests to larger geosims than the ITTC line.

A large part of the ship model test work carried on at DL are preliminary design studies that are followed by large-size self-propelled tests at DTMB. Therefore DL must use a method of expansion that will give a reasonably good prediction of the resistance of the larger model.

At present, DTMB uses the Schoenherr friction formulation in expanding its model results to full size. Therefore, the Schoenherr formulation is used for expanding DL work to full size; were DTMB to use some other formula, DL would probably do a two-step expansion — that is, using the Schoenherr formula up to DTMB size and matching DTMB's method from their size up to ship size.

At present, DL uses various roughness additions to the full size resistance coefficient. Normally the standard is 0.4×10^{-3}. However, the resistance coefficient that is used is determined after discussions with the client.

In view of conditions that now exist, DL will continue to use the Schoenherr friction formulation in making full size resistance predictions from its model tests.

(*). Numata E. : *Correlation between Resistances of Large and Small Models*, Trans. ATTC, September 1959, Davidson Laboratory Note No. 537 (reprinted above as written contribution).

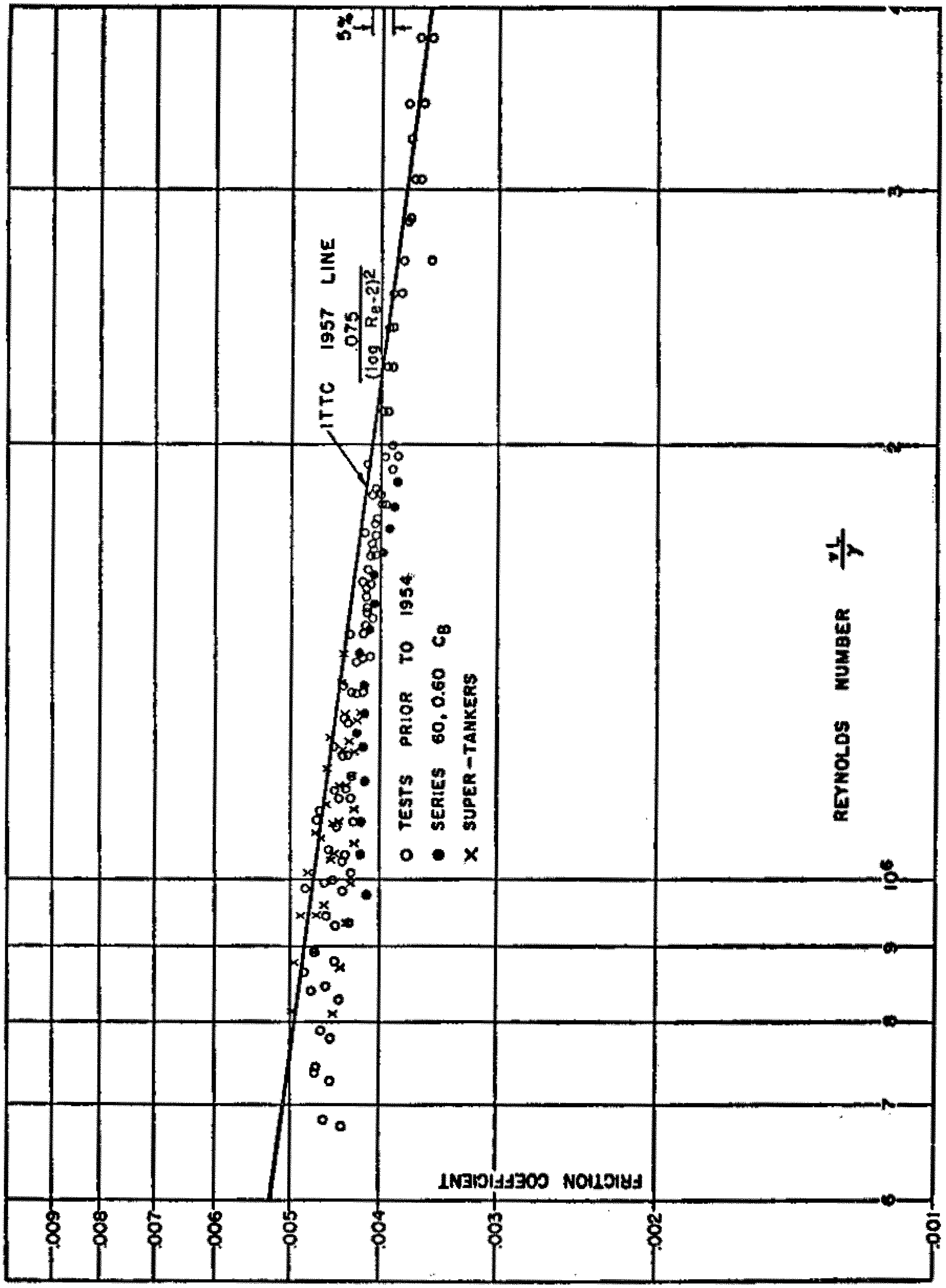


Fig. 1.

Composite chart of frictional resistance coefficients derived by geosim analysis using ITTC 1957 correlation line.

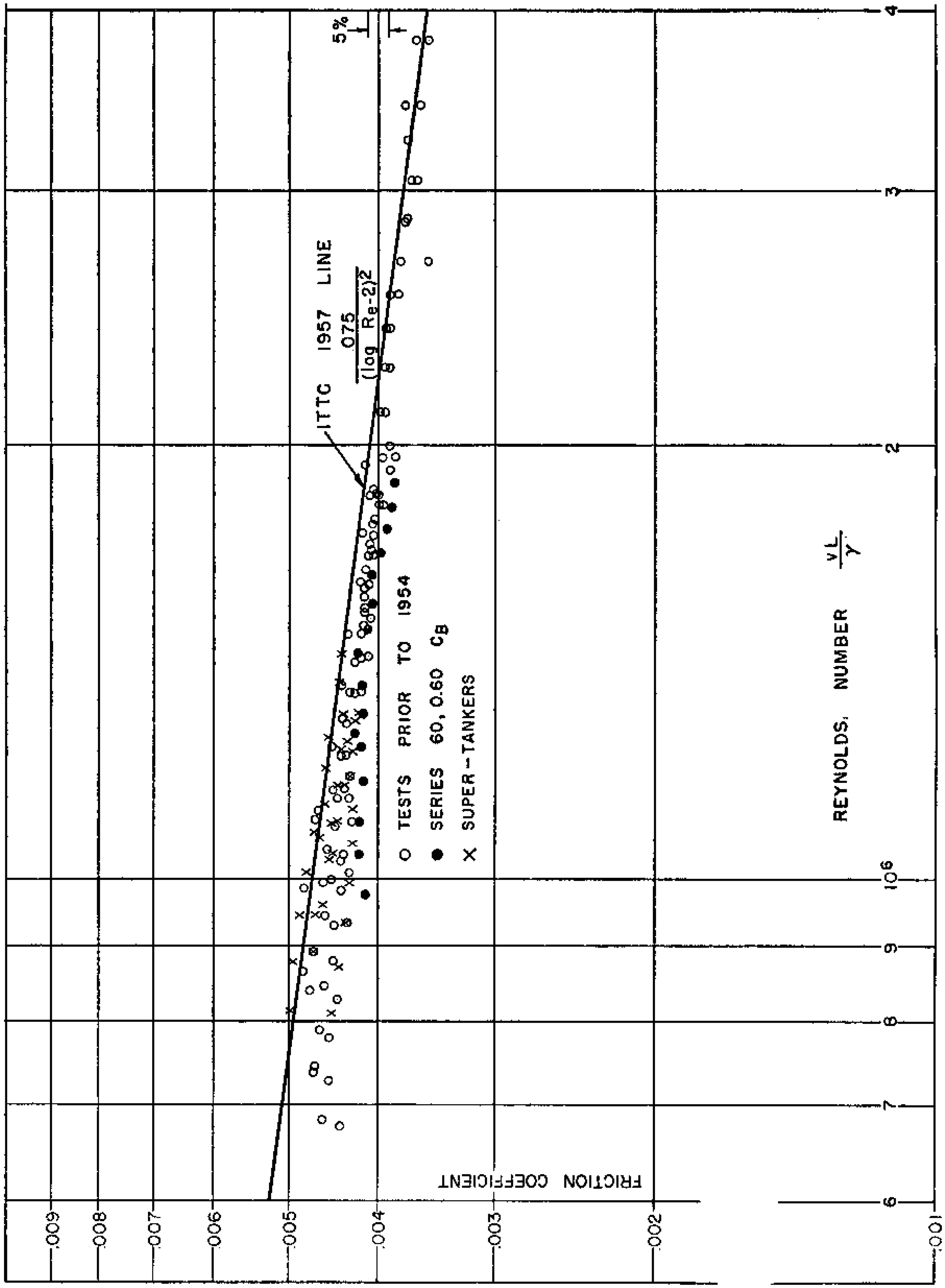


Fig. 2.

Composite chart of frictional resistance coefficients derived by geosim analysis using ITTC 1957 correlation line.

Allan B. Murray.

METHODS OF INDUCING TURBULENCE FOR TESTING SMALL MODELS

Introduction.

The majority of displacement hull testing at the Davidson Laboratory (DL) is carried on in Tank No. 1 It is semi-circular in cross-section and about 100 feet long, 9 feet wide, and 4-½ feet deep. Displacement hull models generally are between 4-½ and 5-½ feet long. The ratio of tank width to model beam is about 13 and the ratio of tank section to maximum model section is above 200. Speeds are from two to five feet per second with Reynolds numbers from 0.9×10^6 to 2.5×10^6. For designed speeds, the Reynolds numbers are about 1.7×10^6.

The greater part of this testing is to predict effective horsepowers for preliminary design purposes. In many cases, a program is undertaken to decrease the hull resistance by testing several variations of the hull lines. Speed in carrying out the work and, to a certain extent, economy are important.

Because relatively small models are used, the control of turbulence is of prime importance. This was recognized in the early stages of DL's development and a great amount of effort was put into research on the subject primarily concerning the problems peculiar to DL. At the same time, methods of obtaining reliable and reproductible measurements of speed and resistance were investigated. This study showed that the testing discipline of the operators was important.

The resistance of five-foot displacement hull models is very small and the high ratio of model inertia to resistance creates a difficult problem of measurement; incomplete turbulence further complicates this measurement problem.

Speed regulation of the carriage, vibration, surface tension, polution of water, and variations in operator mental behavior are as important as properly controlled turbulence.

Test procedures.

After much experimentation, it was decided that the best answer for ship model hulls would be obtained by inducing turbulence with struts (cylindrical rods) mounted on the carriage ahead of the model, and adhering to definite rules of testing. To induce turbulence, two sizes of struts, 1/8-inch and 0.04 inch in diameter, are set with theirlower ends tilted ahead 20° to prevent ventilation, submerged to the draft of the model, and mounted four inches ahead of the stem.

To control reproducibility and help maintain a certain amount of residual turbulence, the water temperature is maintained close to 70°F and the time interval between successive starts is two minutes. At the beginning of the day, several high-speed runs are made before observations are taken. No reading is recorded at any time unless at least three successive runs of two minutes separation have been made. When low-speed data are important, tests are programmed to alternate high and low-speed runs. It is believed that this technique maintains a high and reasonably uniform degreee of residual turbulence in the tank and it does result in good reproducibility of test readings. The use of struts requires no work on the model and therefore saves time in starting the test; furthermore, it is unnecessary to apply a correction as is usually done when sand strips or studs are used.

Before a model is tested, it is carefully washed and soaked in tank water for two or three hours so that the surface is thoroughly wetted. Three series of test runs are then made over the speed range; one without induced turbulence, one with an 1/8-inch diameter strut, and one with 0.04-inch diameter strut. A running plot of resistance coefficient versus speed is kept. At each speed the highest of the three points is considered a statisfactory turbulence value; a faired curve through these values is used for expansion to full scale.

However, the struts create a wake; at low speeds this wake does not affect the results, at higher speeds this wake may give a net resistance value less than that of the test run without induced turbulence. Struts are not considered to be a satisfactory method of inducing turbulence. However the struts and the associated test techniques result in satisfactory accuracy for our applications.

Whenever possible, correlations are made between our test results and those of larger geosims tested at other establishments. By using the Schoenherr friction formulation good correlation with many comparable tests at the David Taylor Model Basin (DTMB) have been obtained. These correlations have been valuable in establishing the adequacy of the small model turbulence inducing methods used at DL.

Reference 1 correlates DL and DTMB results as well as three recent ones with models tested at the

Netherlands Ship Model Basin. These correlations, based on the Schoenherr friction line, indicate a satisfactory level of turbulence. Reference 1 also compares the friction coefficient of DL models with the ITTC 1957 line. This latter comparison indicates a lack of turbulence below Reynolds numbers of 2 × 10^6. This we are not prepared to accept.

ATTC standard model.

A test program to compare resistance tests at DL and at three other American towing tanks was conducted under the jurisdiction of the Model Basin Correlation Subcommittee of the Friction Committee of the American Towing Tank Conference.

The hull form of the ATTC Standard Model is defined by lines given by W.C.S. Wigley for Model No. 755 in his 1927 paper before the Institution of Naval Architects. The form is symmetrical with respect to each of its vertical mid-planes. It is 64 inches long and built of plastic. Since it is a double-ender with relatively fine ends, this model is suitable for a turbulence study and is relatively free of separation difficulties.

This model has removable studs; each establishment tested it both bare and with studs. Four tanks have completed these tests, Hydraulic Laboratory of Newport News Shipbuilding and Dry Dock Company, DTMB, DL, and Webb Institute of Naval Architecture. The published results of the tests of the first three laboratories show good agreement (reference 2).

DL first tested the model by its standard procedure, which includes a bare-hull run and two runs with different size struts. The hull was then tested with studs in accordance with ATTC instructions. (The Appendix shows the tabulated test results.)

Figure 1 is a plot of resistance coefficient versus Reynolds number for the standard DL method using three series of runs — that is, one with a bare hull, one with 0.04 inch strut, and one with 1/8-inch strut. In accordance with the standard practice at DL, the curve is drawn through the uppermost points obtained from any of the three series of runs at each speed. This

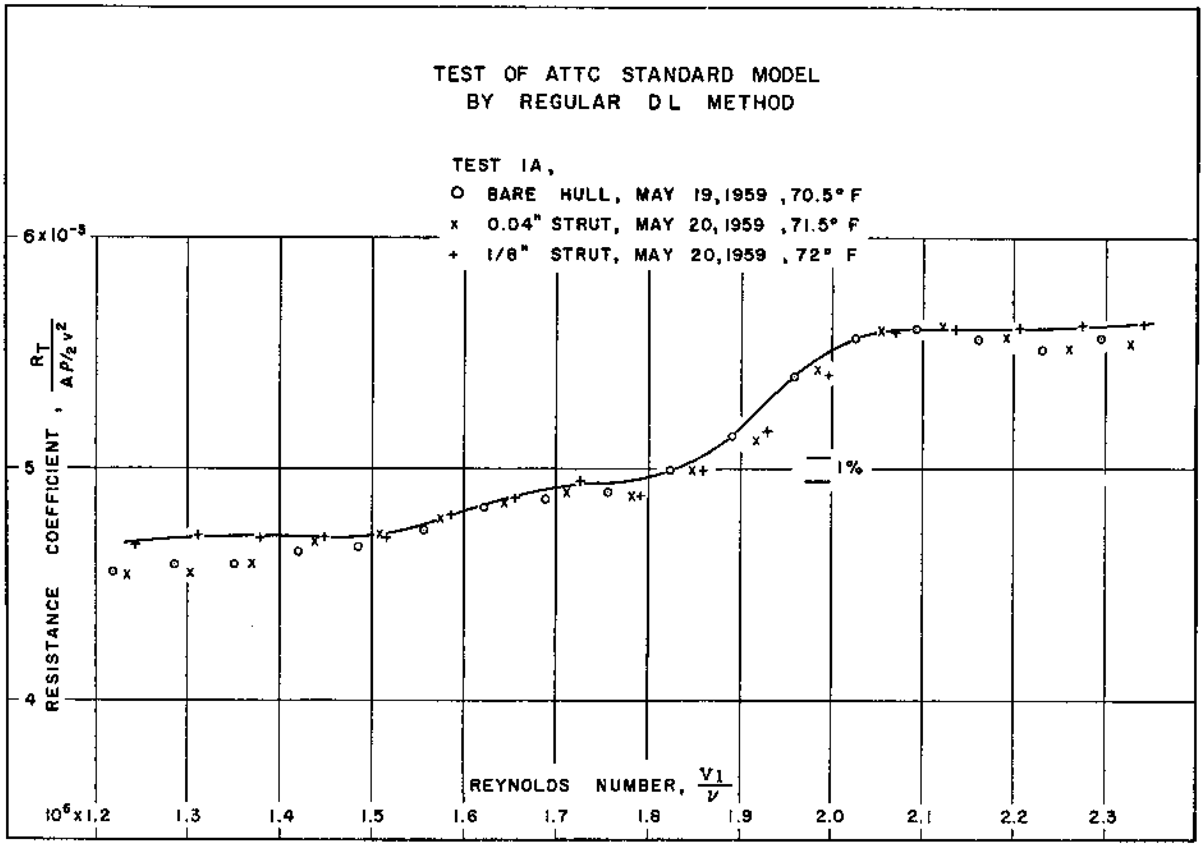


FIG. 1.

curve represents complete turbulence and would be used if the model were used to predict the hull resistance of ship having the hull lines of this model. The variations of resistance coefficients at any given Reynolds number are small but, in general, the 1/8-inch strut is necessary to ensure full turbulence with the standard model.

Subsequent to the above mentioned tests, a series of runs were made of the ATTC model equipped with the specified studs to compare DL test results with results obtained at other testing establishments. Figure 2 shows the results of these tests; the bare-hull test is also included. At the bottom of Figure 2, a solid line is plotted at double vertical scale to show the difference between the stud coefficients and the bare-hull coefficients. In establishing a resistance correction for studs, the differences that exist at the upper range of Reynolds numbers where the curves become roughly parallel are generally used. In this case, there does not appear to be any tendency for the difference to widen at the lower Reynolds numbers. Thus, for a stud resistance correction, an arithmetic average of the differences over the whole range was used — that is, 0.22×10^{-3}. The dotted line on this figure is 0.22×10^{-3} below the stud run and represents the net resistance coefficient of this model. If the stud run were to be considered in complete turbulence, it is reasonable to assume that, since the bare hull coefficient curve is parallel to that of the stud curve, it also is in complete turbulence. The difference, therefore, must be caused by the resistance of the studs.

Figure 3 compares the so-called "accepted" net turbulence lines by the two methods of inducing turbulence. The solid line is the accepted value from the strut series of tests and the circles are the stud test results corrected for stud resistance. While the differences are moderate, the droop of the stud curve at low Reynolds number leads us to suspect that the studs may not be giving full turbulence at the lower speeds.

DL is interested in the stud method of inducing turbulence and will experiment with it. At the present time, however, it will not abandon the strut method

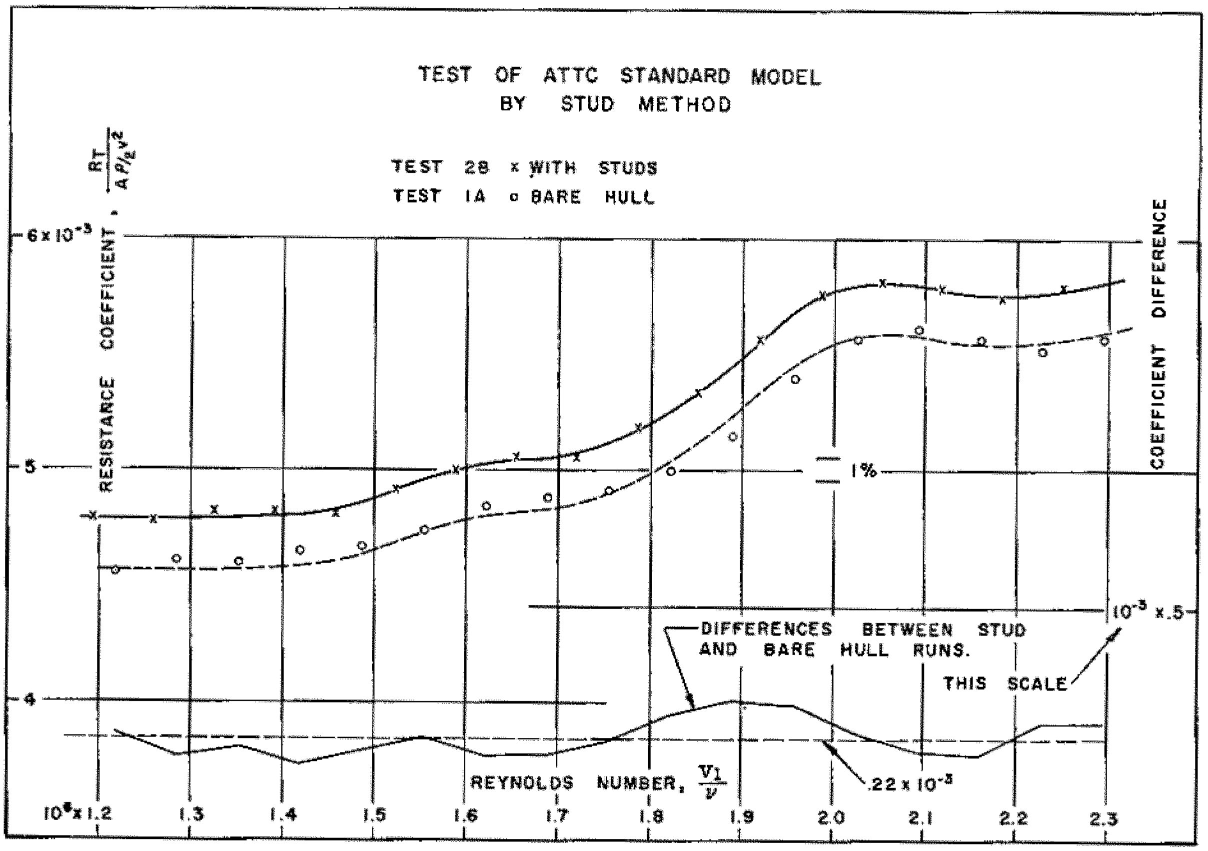


Fig. 2.

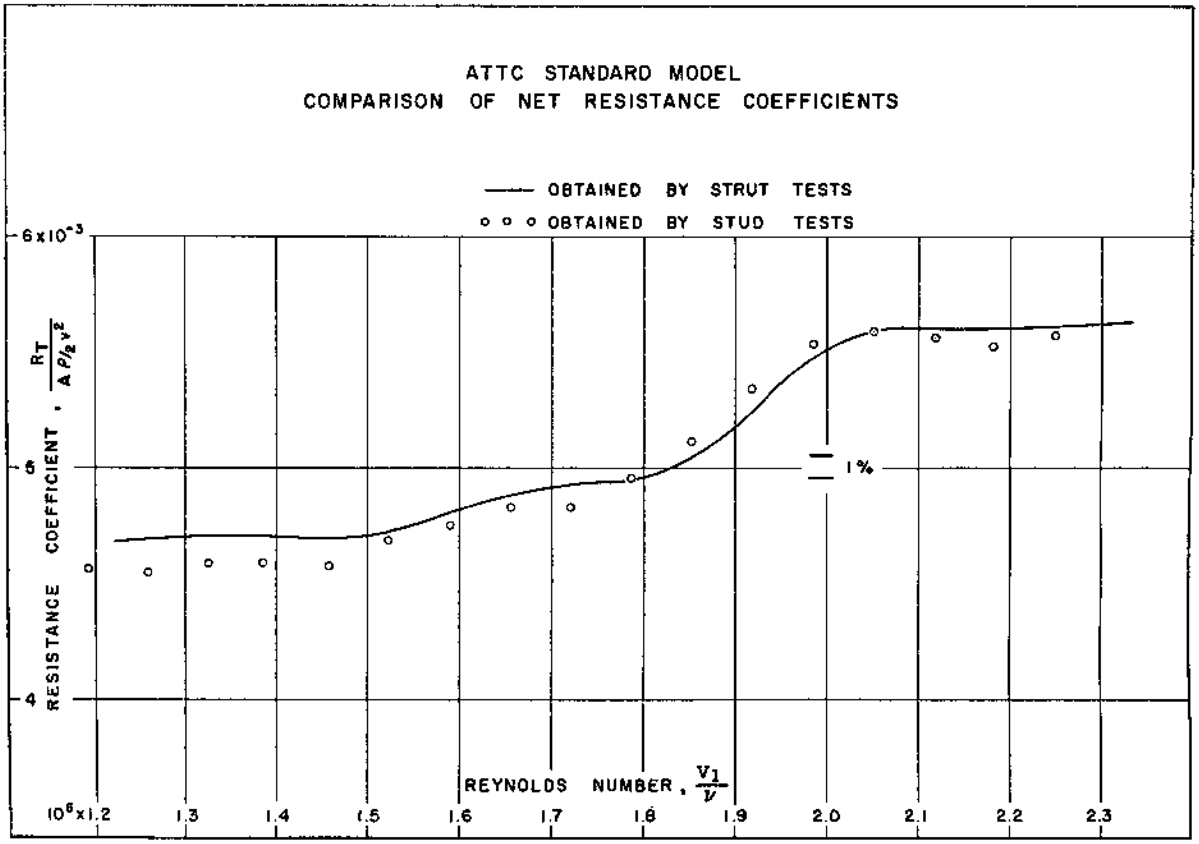


FIG. 3.

for routine testing until the stud method or some other method proves to be more accurate for its purpose and does not require more time.

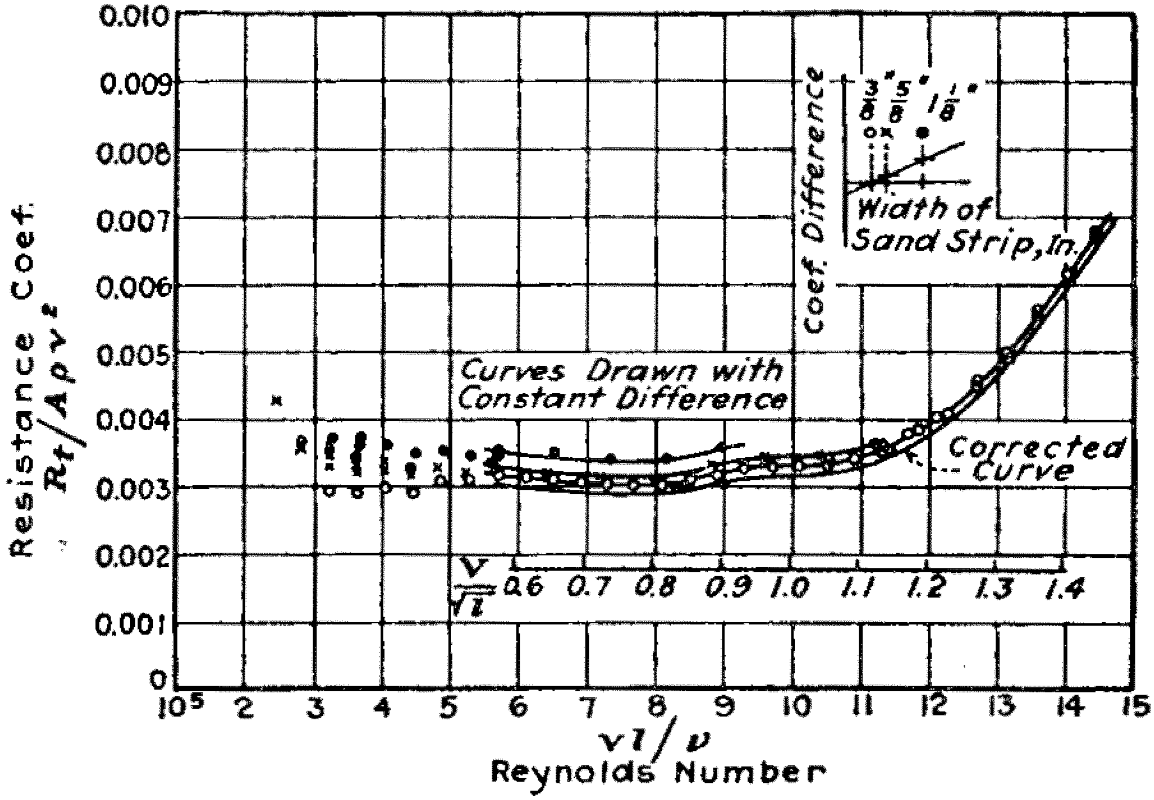
Sailboat models.

The problem of inducing turbulence on sailboat models is a different problem. The load water line (LWL) for such models are between 3.0 and 3.5 feet. As the lengths of the various water lines on such a body gradually decrease toward the bottom of the keel, the LWL is multiplied by 0.7 for calculation of Reynolds numbers. For this type of profile with low Reynolds number, struts have not proven to be sufficiently effective to induce turbulence over the whole bottom.

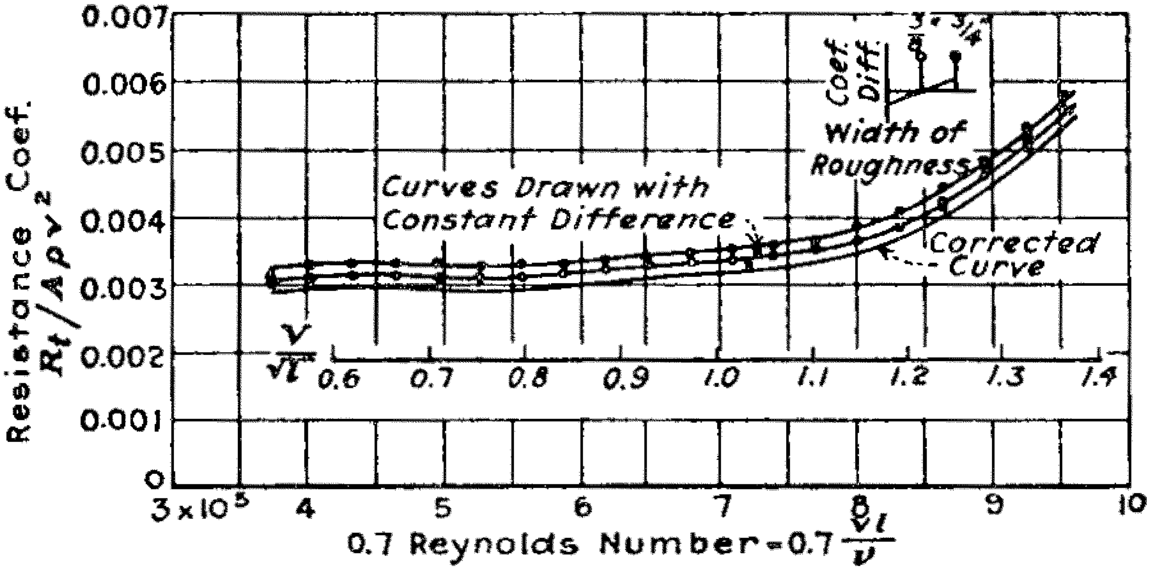
After additional experiments with wire screening, sand strips, bead headed pins, and trip wires, sand strips were finally accepted as the most satisfactory turbulent inducers for this purpose. At present, two separate series of test runs are made; one with a half-inch strip, the second with a one-inch strip. The half-inch sand strip extends from the LWL down each side of the stem to about the bottom of the keel; a length of 20 to 22 inches. With this strip, a full-range resistance-run is made. This is repeated for the one-inch strip. This appears to be rather drastic treatment, but the easy form of a sailboat model requires it. In most cases, there is some drooping of the half-inch sand coefficient line at low Reynolds numbers.

The sand correction is determined by taking twice the average difference between the two sand strip coefficient curves at the highest speed range where the difference is roughly constant. This correction is subtracted from the one-inch sand coefficient line to obtain the accepted net coefficient line. Sand corrections by this method are eight to ten percent of the resistance coefficient values and, admittedly, are high. However, similar boats generally have surprisingly uniform sand corrections. Figure 4 shows the results of early research on sailboat models with sand strips.

DL would, of course, like to find a more satisfactory method of inducing turbulence on sailboat



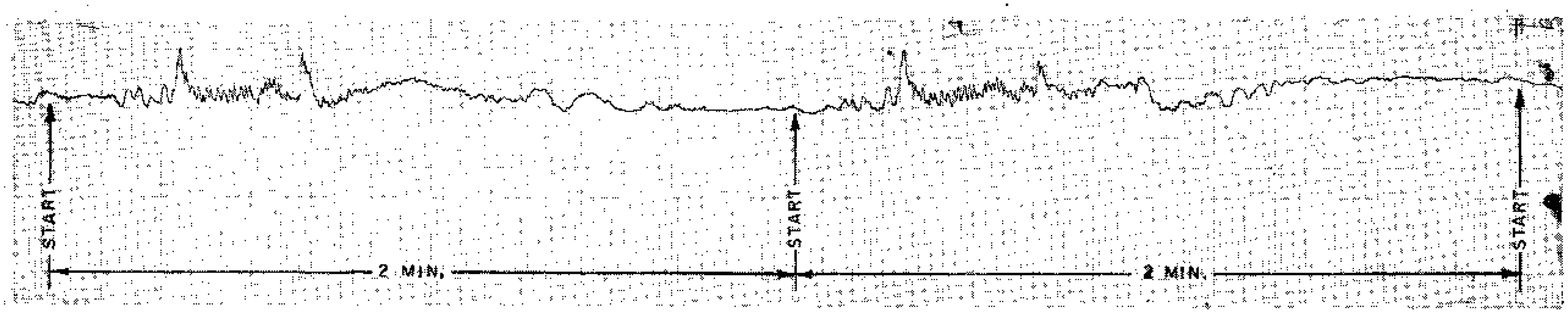
Effect of varying sand width on the resistance coefficients of a 3-foot model.



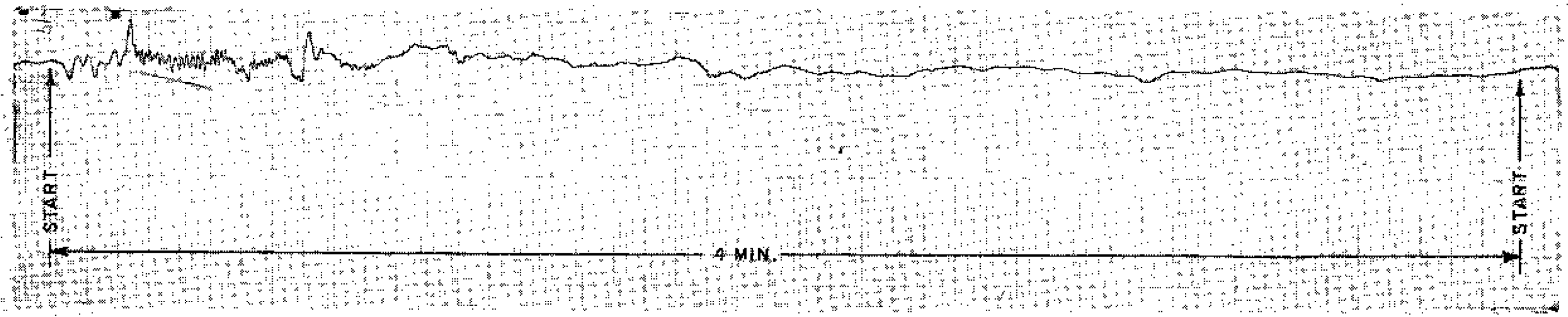
Effect of varying sand width on the resistance coefficients of a 3-foot model of "Gimcrack".

FIG. 4.

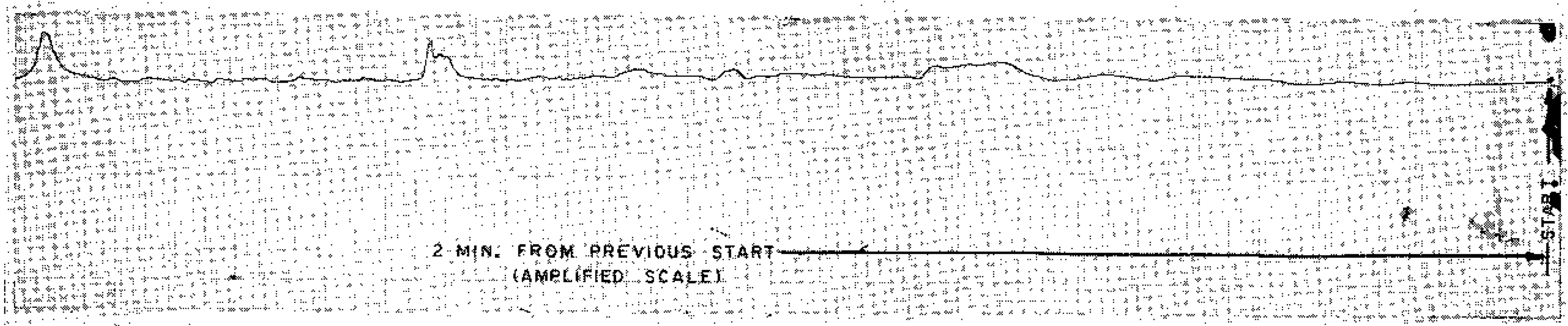
TRACES OBTAINED DURING THERMISTOR-PROBE EXPERIMENT



TWO-MINUTE INTERVAL BETWEEN STARTS



FOUR-MINUTE INTERVAL BETWEEN STARTS



FIRST RUN AFTER OVERNIGHT SHUTDOWN

FIG. 5.

models, both from the standpoint of accuracy and time. However, sailboat prediction have been very successful and there has yet to be a serious reversal of DL's predictions.

Turbulence research.

DL does not consider that any of the present means of inducing turbulence for small models is entirely satisfactory, and would be very interested in any theoretical program aimed at finding out more about the subject and with any experimental program leading to the improvement of testing techniques.

Dr. Karl Larson is now engaged in an experimental study at DL to measure local velocities and local shear stresses with thermistors.

The thermistor is a semiconducting device with a high negative temperature coefficient. Dr. Larsen hopes to determine the degree of turbulence in the boundary layer of models with this device, which also can be used to determine the degree of turbulence in a body of water.

In an attempt to check on the reasonableness of a two minute interval between tests a simple experiment was run with the device. A thermistor probe was placed in the towing tank close to the path of a model to measure the disturbances in the water in the region where readings are taken. This would indicate the persistance of disturbances generated by the model.

Figure 5 is a reproduction of parts of traces taken in this experiment. The top trace shows the results obtained from regular runs with two minute intervals between starts. The first hump indicates the disturbance as the model passes directly opposite the probe. The second major hump is due to the model passing the probe on the return trip. From there on, there is a steady deterioration of the disturbance, though some disturbance still remains at the start of the next run.

The second trace shows the results obtained from a run with four-minute intervals between starts. This indicates the same type of disturbance (as seen in the top trace) up to the end of two minutes, after which there is a steady deterioration of disturbance until the trace indicates very little disturbance.

The third trace with an expanded longitudinal scale represents the first run made after the tank was unused overnight. This trace shows the two humps where the model passed the probe on the test run and on the return run. It also shows the large displacements due to major wave disturbances, but a complete absence of the little wiggles present in the other traces.

When the original test technique was laid out, experiments on time between runs were made on the basis of obtaining reproducible points. The two minute interval was decided on the basis of being the shortest time possible without serious interference from surface waves. If the minute wiggles in the traces shown can be accepted as an indication of residual turbulence in the tank, they may confirm the effects of residual turbulence on the reproducibility of tests points.

A similar experiment was made several years ago by Breslin and Macovsky [3], in which a hot wire anemometer was mounted ahead of a ship model in the David Taylor Model Basin to investigate turbulence stimulation. Part of the experiment investigated the effect of elapsed time between runs on the root-mean-square values of measured turbulence.

Figure 6, reproduced from the reference shows the rapid deterioration of u′ with time.

Dr. Larsen's experiments will be extended to attempt a calibration of the thermistor so that quantitative determination of the intensities of turbulent velocities can be recorded. It is hoped that this will enable more accurate evaluations of the influence of basin turbulence on model resistance.

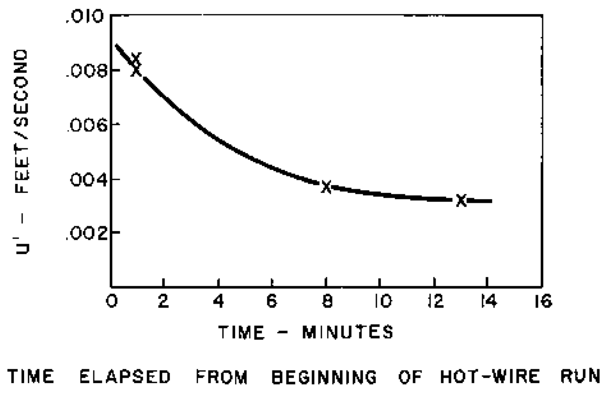


Fig. 6.

Root-mean-square values of turbulence measured at DTMB.

References

[1] Numata E.: *Correlation Between Resistances of Large and Small Models*, Trans. ATTC, September 1959.

[2] Gertler M., and Hancock C. H.: *Comparative Resistance Tests with ATTC Standard Model*, David Taylor Model Basin Report 1357, July 1959.

[3] Macovsky M.S., and Breslin J.P.: *A Study of Rods as Stimulators of Turbulence in Boundary Layers* Trans. ATTC September 1950.

APPENDIX

TABLE 1.

Resistance data for ATTC Standard model (DL No. S-2200).
Test I-A Bare Hull, May 19, 1959. Fresh Water 70.5° F.

SPEED NO.	MODEL SPEED fps	R_T lbs.	$C_T \times 10^3$	$Re \times 10^{-6}$
L-20	3.453	0.2513	4.90	1.756
12	2.394	0.1122	4.55	1.218
21	3.586	0.2756	4.99	1.824
13	2.526	0.1260	4.59	1.285
22	3.719	0.3056	5.14	1.891
14	2.658	0.1394	4.59	1.352
23	3.850	0.3432	5.39	1.958
15	2.792	0.1553	4.64	1.420
24	3.984	0.3791	5.56	2.026
16	2.924	0.1710	4.66	1.487
25	4.116	0.4076	5.60	2.093
17	3.056	0.1897	4.73	1.554
26	4.250	0.4316	5.56	2.161
18	3.188	0.2110	4.83	1.621
27	4.382	0.4544	5.51	2.229
19	3.321	0.2310	4.87	1.689
28	5.514	0.4866	5.56	2.296

TABLE 2.

Resistance data for ATTC Standard model (DL No. S-2200).
Test 1-A With 0.040-inch Strut, May 20, 1959. Fresh Water 71.5° F.

SPEED NO.	MODEL SPEED fps	R_T lbs.	$C_T \times 10^3$	$Re \times 10^{-6}$
L-20	3.453	0.2504	4.88	1.780
12	2.394	0.1119	4.54	1.234
21	3.586	0.2760	4.99	1.848
13	2.526	0.1247	4.55	1.302
22	3.719	0.3038	5.11	1.916
14	2.658	0.1394	4.59	1.370
23	3.850	0.3450	5.42	1.984
15	2.792	0.1566	4.68	1.438
24	3.984	0.3810	5.59	2.053
16	2.924	0.1725	4.71	1.507
25	4.116	0.4082	5.61	2.121
17	3.056	0.1919	4.78	1.575
26	4.250	0.4313	5.56	2.190
18	3.188	0.2119	4.85	1.643
27	4.382	0.4544	5.51	2.258
19	3.321	0.2319	4.89	1.711
28	5.514	0.4844	5.53	2.326

TABLE 3.

Resistance data for ATTC Standard model (DL No. S-2200).
Test I-A With 1/8 - inch Strut, May 20, 1959. Fresh Water 72.0° F.

SPEED No.	MODEL SPEED fps	R_T lbs.	$C_T \times 10^3$	$Re \times 10^{-6}$
L-20	3.453	0.2500	4.88	1.792
12	2.394	0.1150	4.67	1.242
21	3.586	0.2756	4.99	1.860
13	2.526	0.1291	4.71	1.311
22	3.719	0.3064	5.16	1.929
14	2.658	0.1428	4.70	1.379
23	3.850	0.3438	5.40	1.997
15	2.792	0.1575	4.70	1.448
24	3.984	0.3804	5.58	2.067
16	2.924	0.1725	4.70	1.517
25	4.116	0.4073	5.60	2.135
17	3.056	0.1925	4.80	1.585
26	4.250	0.4350	5.60	2.205
18	3.188	0.2125	4.87	1.654
27	4.382	0.4625	5.61	2.273
19	3.321	0.2341	4.94	1.723
28	5.514	0.4925	5.62	2.342

TABLE 4.

Resistance data for ATTC Standard model (DL No. S-2200).
Test 1-8 With Studs, June 17, 1959 Fresh Water 69.0° F.

SPEED No.	MODEL SPEED fps	R_T lbs.	$C_T \times 10^3$	$Re \times 10^{-6}$
L-20	3.453	0.2590	5.05	1.721
12	2.394	0.1779	4.78	1.193
21	3.586	0.2863	5.18	1.787
13	2.526	0.1307	4.77	1.259
22	3.719	0.3166	5.33	1.853
14	2.658	0.1460	4.81	1.325
23	3.850	0.3544	5.56	1.919
15	2.792	0.1610	4.81	1.391
24	3.984	0.3922	5.75	1.985
16	2.924	0.1763	4.80	1.457
25	4.116	0.4232	5.81	2.052
17	3.056	0.1969	4.91	1.523
26	4.250	0.4491	5.78	2.118
18	3.188	0.2176	4.98	1.589
27	4.382	0.4738	5.74	2.184
19	3.321	0.2391	5.05	1.655
28	5.514	0.5069	5.79	2.250

K. Larsen, C. Grosch, and J. Breslin.

MEASUREMENT OF LOCAL HYDRODYNAMIC SHEAR STRESS BY THE USE OF DISK THERMISTORS

Introduction.

This paper discusses the progress that recently has been made at the Davidson Laboratory on the development of a technique to measure indirectly the local hydrodynamic shear stress on a ship model.

The determination of wave-making and form drag of a ship model is based on the assumption that the frictional resistance is equivalent to that of a flat plate having the same wetted area and towed to give the same length Reynolds number as the model. However, the local shear stress varies with pressure gradients, and hence may be expected to be greater than the plate value over the forebody and smaller over the afterbody. To refine model predictions of powering, the frictional resistances of ship forms must be precisely known. If this can be done, then the residuary resistance can be isolated with greater precision.

While researchers such as Liepmann and Dhawan[1], Schultz-Grunow [2], and Kempf [3] have made direct measurements of shear stress by floating-element devices and Smith and Walker [4] have deduced this quantity from Preston tube results, these techniques are difficult to apply to ship models. This is particularly true in testing tanks that are not equipped with man-carrying carriages. In contrast to these, an electrical technique used in this study appears to be quite adaptable. In this experiment, three small disk-type thermistors were flush-mounted in a flat aluminum plate and the shear stress was deduced from the dissipation of heat from the thermistor. Comparison of the results with the Blasius and Prandtl shear stress lines shows promising agreement.

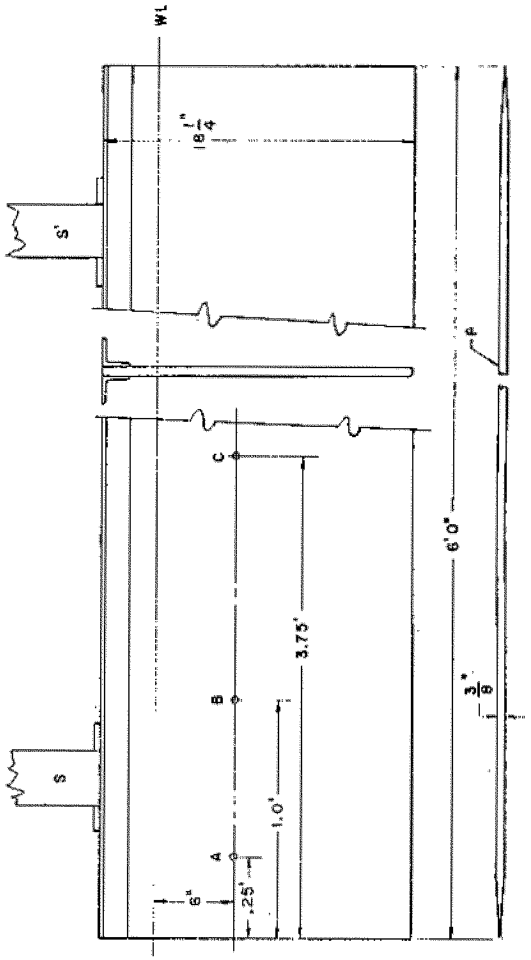


FIG. 1.
Aluminum plate with flush-mounted thermistors.

Description of equipment.

General.

The apparatus is shown in Figure 1. An aluminum plate (P) is suspended vertically from the overhead carriage of the 300-foot tank by two struts (S and S'). The plate is pivoted about the centerline of S and is adjustable to any desired angle of attack, which is indicated on a circular scale attached to S' and centered at S. A, B, and C are Veco 41D1 Thermistors located so that their exposed surfaces are flush with P. These thermistors are circular cylinders 0.1-inch in diameter and 0.095-inch thick. They are mounted in lucite inserts as shown in Figure 2. The plane faces of the thermistors are silver coated. Electrical connection with the exposed face is made to wire A through a thin layer of conducting paint as shown. The strands of lead B are pressed firmly against the bottom surface of the thermistor. The unexposed surface and lead B are electrically insulated from the water to prevent electrolysis. Leads A and B are connected to the observing station through a flexible cable. The carriage speeds are measured directly by timing the passage over a 50 or 100-foot distance laid out on the side of the tank. The speed recorder associated with the tank drive unit detects deviations in speed. To minimize the effects of

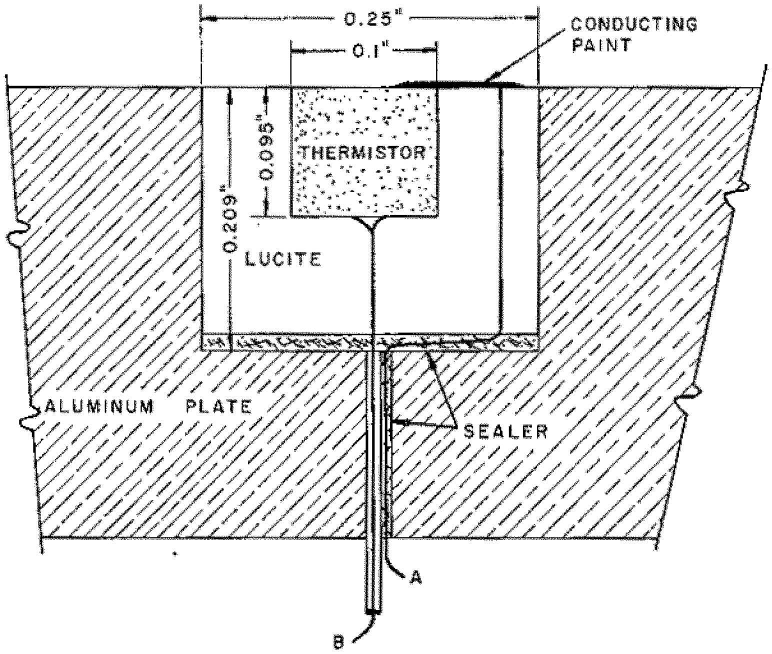


FIG. 2.
Thermistor insert.

vibration and lateral motion of the plate, struts S and S′ are cross-braced to an auxiliary carriage that travels along the edge of the tank.

Thermistors.

Thermistors are semiconducting devices that primarily are made from mixtures of the oxides of manganese nickel, iron, and zinc. These oxides are mixed with an organic binder to the consistency of a paste, formed into the desired shape, heated to drive out the binder, and then sintered at a high temperature. Electrical contact is made by either molding platinum leads into the mixture or by coating the surfaces with a metallic paste that is cured at a suitable temperature. The proportions of the various ingredients are chosen by the desired specific resistance and temperature coefficient of resistance of the finished device.

Functionally, the thermistor is a resistor that can range in value from 50 ohms to a megohm. The most significant property of the thermistor is its high negative temperature coefficient of resistance that can range in value from 3.5 to 4.8 percent per degree centigrade and results in a high sensitivity to changes in the thermal environment.

Thermistors can be made in the form of spherical beads whose diameters are about 0.010 inch. When built into the tip of a probe, this permits localized measurements on a physical scale that is much smaller than is possible with a hot wire.

Because of their small size, the thermal time-constant can be reduced so that rapid fluctuations in velocity can be observed, thereby making it possible to follow actual velocity fluctuations in turbulent flow provided the thermistor is incorporated in a constant-temperature type of bridge circuit.

Circuitry.

The thermistor is incorporated in a self-excited bridge circuit as shown in Figure 3. Resistors R_1 and R_2 are fixed at 1000 ohms each. R_3 is adjusted at 4 000 ohms. G is a Philbrick K2-X DC voltage amplifier whose output is connected to F, which is a Philbrick K2B1 DC follower amplifier. The combination has an open-circuit gain of about 24,000. The excitation voltage of the bridge is obtained by applying the output of the follower amplifier accross terminals *ab*. This excitation voltage is controlled by the magnitude of the error signal appearing across *cd*, which is applied to the input of the K2-X. Because of the high gain of the feed-back loop, the bridge circuit will reach a steady state when the thermistor resistance (R_T) is about 4 000 ohms. With the circuit parameters shown in Figure 3, a steady state occurred when the thermistor resistance dropped to an average value of 3 600 ohms with the plate at rest in water at 70° F.

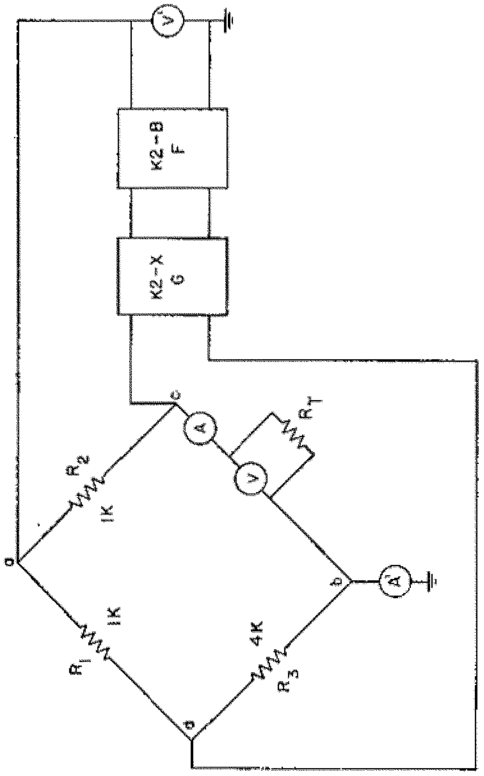


FIG. 3.
Schematic diagram of self-excited bridge.

The power input to the thermistor and the thermistor resistance can be calculated with a milliammeter (A) and a high-impedance voltmeter (V). After calculating the thermistor resistance, its temperature can be read from a graph of resistance versus temperature, as shown in Figure 4. As noted above, with the plate at rest, the bridge circuit will reach a steady state when the thermistor resistance drops to about 3 600 ohms. From Figure 4, it is seen that the thermistor temperature is about 50.2° C. When either the ambient temperature of the water changes or the heat transfer is increased by a flow condition over the thermistor face, the circuit will remain in a steady state only when the power to the thermistor is increased. This is automatically accomplished through the high-gain feed back loop. The increased heat transfer tends to diminish the temperature and increase the resistance of the thermistor. This changes the voltage across *cd*. If this voltage is properly polarized, the input to the bridge and consequently the power to the thermistor is increased. By subtracting the heat transferred by conduction and radiation, the rate at which the heat is transferred to the moving stream can be computed. This information in turn can be related to the local hydrodynamic shear stress.

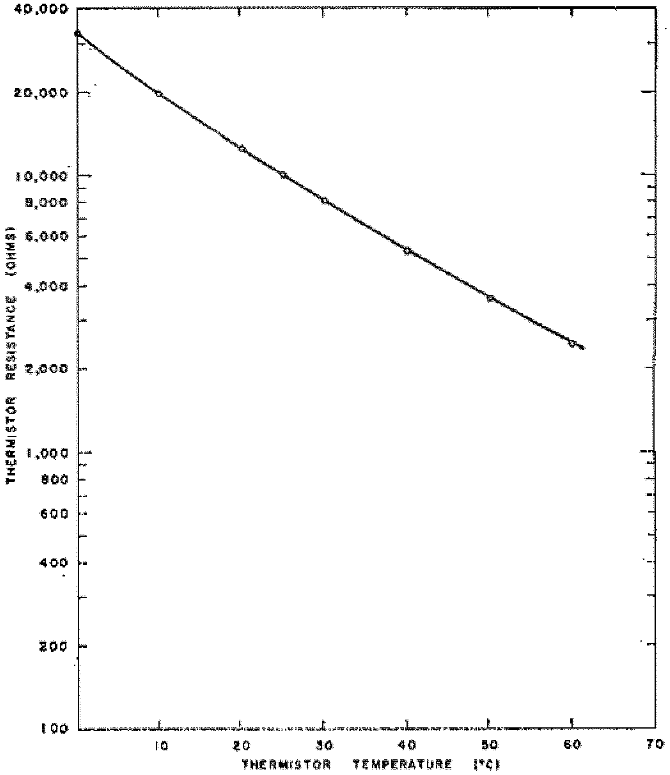


FIG. 4.
4 IDI disk thermistor.
Thermistor resistance vs temperature.

Power losses by conduction, radiation, and convection.

When a disk-type thermistor is flush-mounted in a stationary vertical metal surface as in this experiment, heat generated in the thermistor is transferred to the surrounding area by conduction, radiation, and convection. If the thermistor is mounted on an identical surface that is horizontal and facing downward, the convection will become negligible and the heat loss will be principally due to conduction and radiation. Consequently, the thermistor was removed from the 72 by 18 by 1/4-inch aluminum plate and mounted in a 3-1/4 by 12 by 1/4-inch plate. The power to the thermistor was measured with the exposed face in a vertical position. It was then rotated 90 degrees until the exposed face of the thermistor faced donward. The difference between the power inputs in these two positions is the loss due to convection when the thermistor was in the vertical position. To investigate the effect of plate area, the thermistor was mounted in a third aluminum plate whose dimensions were only 1-1/2 by 4 inches.

In the vertical position, power input to the thermistor in all three plates was 388 milliwatts to within 0.25 percent. In both plates, the power input was 344 milliwatts when in the horizontal position. The convection loss, therefore, was 44 milliwatts and the conduction 344 milliwatts, for a temperature difference of 27.8° C between the thermistor and the ambient water temperature. As the thermistor-temperature changes due to varying heat transfer conditions, the conduction can be corrected through ist direct proportionability to the temperature differential. Therefore, under any conditions, the heat lost to the surrounding area by conduction can be subtracted from the total heat input. No special correction was made for radiation, because it was always less than 6 milliwatts and included in the conduction losses. As the plate moved, the natural convection losses become insignificant.

To reduce the data, the followingprocedure was used. After the plate reached a steady velocity, the current in the thermistor was read from the milliammeter (A) and the potential difference was taken from the voltmeter (V). The total power to the thermistor and its resistance were then calculated from these data. The thermistor temperature could then be determined from Figure 4. From the difference between this and the ambient water temperature, the heat conduction to the plate was computed. This value was subtracted from the total power input and the difference represented the heat transfer due to the behavior of the liquid in the boundary layer. This figure was multiplied by 0.0743 to convert the power loss in milliwatts to calories per second per cm². From Figure 4, the local shear stress was computed in terms of the physical properties of the water and its behavior in the boundary layer.

Relationship between heat transfer and local shear stress.

Hydrodynamic flows are generally considered under three conditions: laminar, turbulent, and transitional flow. In this case, calculations are made for laminar and full-turbulence flows. No study of the transition stage is made in this paper.

It was shown by Blasius [5] that for laminar flow only, the local dimensionless friction coefficient (c_f') is given by:

$$c_f' = \frac{\tau}{\frac{1}{2}\rho U^2} = \frac{0.664}{R_x^{1/2}}, \tag{1}$$

where τ is the local shear stress and R_x is the local Reynolds number. When the local friction coefficient is plotted against the local Reynolds number, the result is the theoretical Blasius line, as plotted in Figure 5. Since the local friction coefficient is a function of the Reynolds number and the dimensionless heat flux (which can be described in terms of the Nusselt number) and is also a function of the Reynolds number, it is possible to establish a relationship between c_f' and q. The local Nusselt number (N_x) is defined as follows:

$$N_x = \frac{x}{k}\frac{q}{\Delta\theta}. \tag{2}$$

where k is the thermal conductivity of water, x is the distance of the local heat source from the leading edge, $\Delta\theta$ is the difference between the temperature of the surface and the ambient water temperature, and q is the heat transfer per unit time and per unit area. It has been shown, however, that the local Nusselt number may be expressed as function of the Prandtl number (P) and the local Reynolds number as follows:

$$N_x = 0.332P^{1/3} R_x^{1/2} \tag{3}$$

The Prandtl number (P) is a dimensionless quantity that introduces the physical properties of the water. It is defined as follows:

$$P = \frac{cu}{K},$$

where c is the specific heat of the water, u is the absolute viscosity of the water, and k is its thermal conductivity.

Solving Eq. 3 for $R_x^{1/2}$ yields

$$R_x^{1/2} = \frac{N_x}{0.332\, p^{1/3}}. \tag{4}$$

Substituting Eq. 4 into Eq. 1 yields:

$$c_f' = \frac{(0.664)\,(0.332)p^{1/3}}{N_x}. \tag{5}$$

The Prandtl number for water is 6.88: therefore, Eq. 5 becomes:

$$c_f' = 0.418\,\frac{1}{N_x}. \tag{6}$$

This may be rewritten as follows:

$$c_f' = 0.418 \frac{k\,\Delta^{\theta}}{xq}. \tag{7}$$

The quantities on the right side of this equation are measurable and, therefore, the shear stress coefficient (c_f') can be determined experimentally. The plotted points on Figure 5 show good agreement with theory. All experimental points have been included. Those with the widest scatter occurred in the early measurements.

When the boundary layer is turbulent the analysis must be modified. If the velocity profile across the boundary layer is assumed to follow the 1/7th power law, it was shown by Prandtl that the local friction coefficient (c_f') is given by the following:

$$c_f' = 0.0256\,(\mathrm{R}_{\theta x})^{-1/4}. \tag{8}$$

where $\mathrm{R}_{\theta x}$ is the local Reynolds number based on a momentum transfer in the boundary layer. The 1/7th power law and the use of Reynolds number based on momentum thickness is valid for moderate Reynolds numbers. The momentum Reynolds number is related to the ordinary Reynolds number as follows:

$$\mathrm{R}_{\theta x} = 0.036\,\mathrm{R}_x^{4/5}\,. \tag{9}$$

Substituting Eq. 9 in Eq.8, the local skin friction coefficient becomes

$$c_f' = 0.0592\,\mathrm{R}_x^{-1/5} \tag{10}$$

The graph representing this equation is the theoretical line at the right of Figure 5.

To develop the friction coefficient in terms of the heat transfer at the thermistor, it is most convenient to use Eq. 8, which expresses the local friction coefficient in terms of the Reynolds number based on the momentum thickness. For turbulent flow the Nusselt number can be expressed in terms of the Prandtl number and the momentum Reynolds number as follows:

$$\mathrm{N}_x = 0.883\,p^{1/3}\,\mathrm{R}_{\theta x} = 0.030\,p^{1/3}\,\mathrm{R}_x^{4/5} \tag{11}$$

Taking the fourth root of both sides yields

$$\mathrm{N}_x^{1/4} = (0.883)^{1/4}\,p^{1/12}\,\mathrm{R}_{\theta x}^{\;1/4}\,. \tag{12}$$

Solving for $\mathrm{R}_{\theta x}^{1/4}$ and substituting in Eq. 8 the local friction coefficient becomes

$$c_f' = 0.0252\,p^{1/12}\,\mathrm{N}_x^{-1/4}\,. \tag{13}$$

The Prandtl number for water is 6.88, therefore, Eq. 13 can be written as

$$c_f' = 0.0296\,\mathrm{N}_x^{-1/4}\,. \tag{14}$$

The Nusselt number, as defined by Eq. 2, can be evaluated for each run in terms of the measured heat transfer at the thermistor and the position of the thermistor on the plate. The values of the local friction coefficient thus obtained are plotted against the local Reynolds number in Figure 5 for comparison with the theoretical Prandtl line.

Criterion for laminar or turbulent flow.

In calculating the experimental local shear stress it is necessary to determine whether the flow is laminar or turbulent, since the relationship between the shear stress and the Nusselt number differs for the two conditions of flow. Equations 3 and 11 show that the relationship between the Nusselt number and Reynolds number is also different for the two types of flow. If the Nusselt number is calculated as a function of the Reynolds number from Eq. 3, the left line on Figure 6 would represent the values of the measured Nusselt number laminar flow conditions. If the Nusselt numbers are calculated as a function of the Reynolds number from Eq. 11, the resulting curve at the right of Figure 6 represents the Nusselt numbers in turbulent flow.

The experimental Nusselt numbers evaluated from heat transfer measurements should fall on one line or the other when plotted against the Reynolds number, and thereby, establish a criterion for the existence of laminar or turbulent flow. The points for the leading thermistor follow the laminar flow line closely. This is to be expected since the flow at that point can be considered as being laminar because of the low local Reynolds number. The remaining points from the other two thermistors do not fall on the turbulent line, but are obviously not on the laminar line. It also appears that many of the points from the other two thermistors approach the turbulent line, especially those from thermistor C. The use of this method as a criterion for the type of flow will require further study. It is interesting to note that the points from all three thermistors labeled with a T lie on or above the turbulent line. These points were obtained by using a 0.040-inch trip wire mounted 1.12 inches from the leading edge. It must be admitted, however, that the spread in the data is sufficiently large that

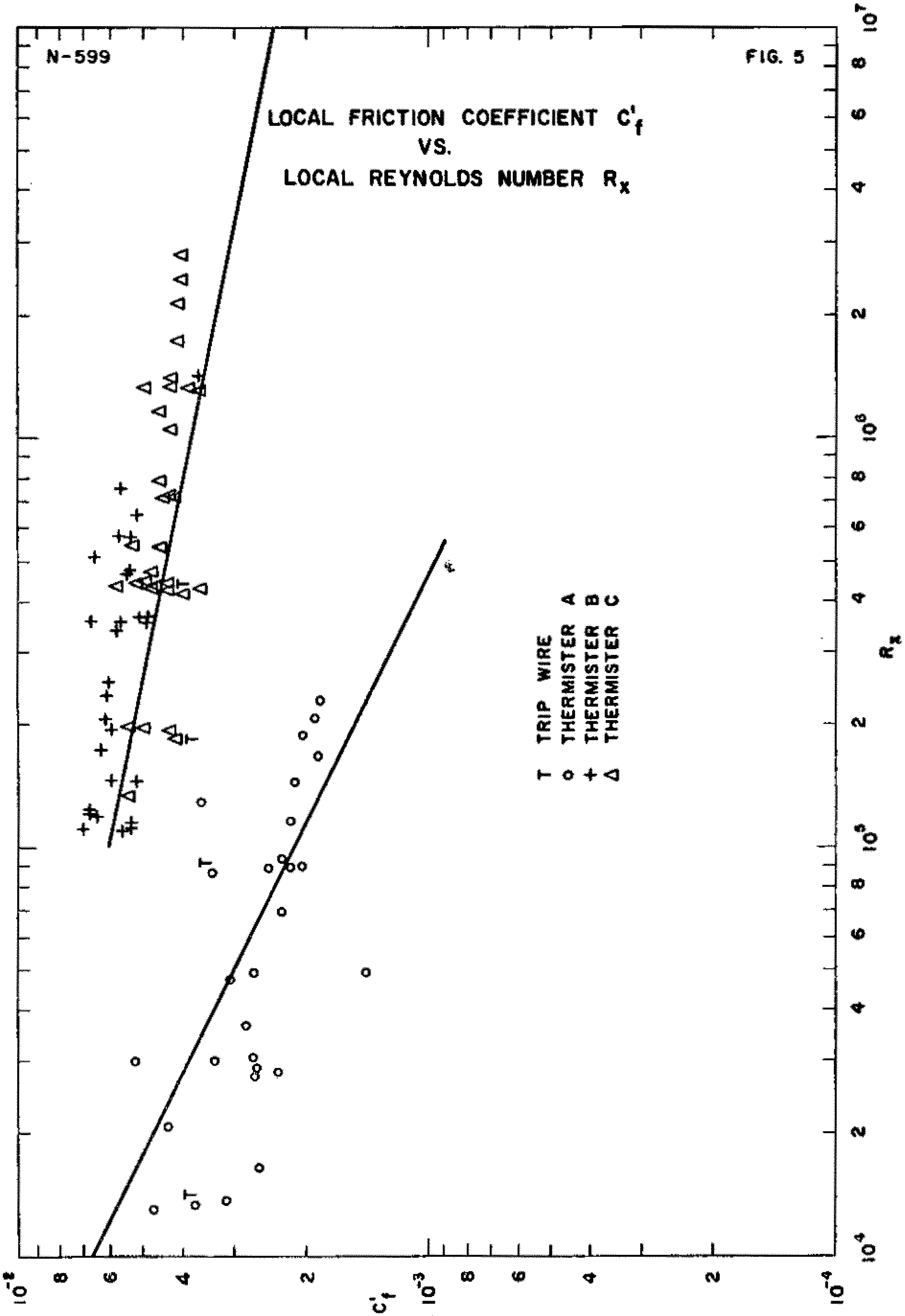

N-599
FIG. 5
LOCAL FRICTION COEFFICIENT C'_f
VS.
LOCAL REYNOLDS NUMBER R_x
T TRIP WIRE
o THERMISTER A
+ THERMISTER B
Δ THERMISTER C
C'_f
10^{-2}
8
6
4
2
10^{-3}
8
6
4
2
10^{-4}
R_x
10^4
2
4
6
8
10^5
2
4
6
8
10^6
2
4
6
8
10^7

Fig. 5.

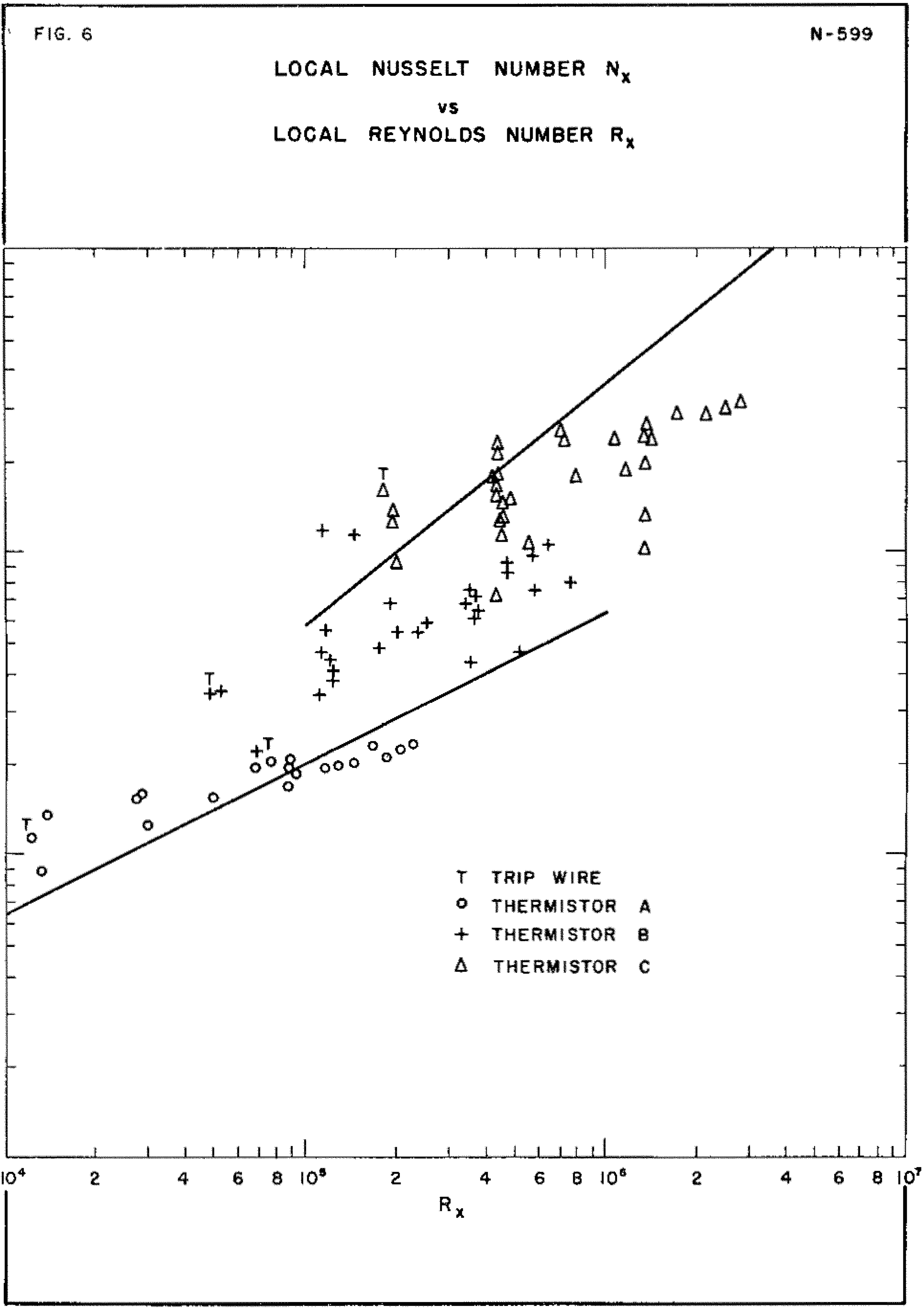


FIG. 6
N-599
LOCAL NUSSELT NUMBER N_x
vs
LOCAL REYNOLDS NUMBER R_x
N_x
10^4
8
6
4
2
10^3
8
6
4
2
10^2
8
6
4
2
10
R_x
10^4
2
4
6
8
10^5
2
4
6
8
10^6
2
4
6
8
10^7
T
T TRIP WIRE
○ THERMISTOR A
+ THERMISTOR B
Δ THERMISTOR C

Fig. 6.

urther experimentation would be required before conclusive evidence could be obtained on the effectiveness of the trip wire.

Sources of error.

The good agreement between the observed shear stress and the predicted theoretical values indicates that local hydrodynamic shear stress could be accurately measured by this method. There are, however, several sources of error that must be carefully examined and corrected if thermistors are to be used as an accurate instrument for measurements of this type.

Ordinary electrical instruments such as milliammeters and voltmeters can introduce errors of calibration as well as reading errors caused by deflections that are less than half scale. These errors can be minimized by the installation of precision multirange instruments operating between two-thirds and full-scale deflection There should be little error in the speed of the carriage The tank speed recorder showed variations of less than one percent during an individual run. The cross-bracing of the struts to the auxiliary camera carriage on the side of the tank reduced the vibration, but could not eliminate all lateral motion of the plate. This can only be further reduced by extensive redesign of the towing system. At the higher velocities where the deviating appeared to be greatest, regardless of the position of the thermistor, there was considerable wavemaking by the plate. Since the thermistors were only six inches below the waterline, these waves may affect their heat transfer characteristics due to additional wave velocity. This will be the subject of further study.

The proximity of the free surface may also cause changes in the local shear stress values through the image effect.

The theoretical relationship between shear stress and heat transfer for a large plate assumes that the angle of attack is zero. The one-half degree angle used throughout this experiment should produce only minor effects upon the flow pattern. This should be investigated by further experiments in which the angle of attack is varied. The angle of attack may introduce cross flow at the surface of the plate. Attempts to investigate this effect by using paint smears showed the relative velocity almost parallel to the longitudinal centerline of the plate. There were slight indications of cross flow, but the magnitude, while uncertain, was small. Both convection and cross-flow effects could be minimized by towing the plate in a nearly horizontal position and installing end plates on the sides.

Two errors may have originated at the thermistors themselves. The heat flow per unit area was calculated on the basis of a large area so that there may be some error due to the finite size of the heat transfer surface. Second, errors may have been introduced by the roughness of the thermistor surface. To establish electrical contact with the grounded lead it was necessary to spread a thin film of conducting paint across the exposed face of the thermistor to the end of the ground lead that protrudes slightly from the lucite. Precautions were taken to make the thermistor surface, and that of the insert, as nearly as possible a continuous part of the plate. However, disturbance of the flow pattern was inevitable because this device was used. A new design for the insert is now under construction and should eliminate any question of disturbance of the flow from this source.

Conclusions.

The use of thermistors to measure local hydrodynamic shear stress appears to be a promising technique, though there are discrepancies between individual points and the theoretical shear stress. Further research in this field should include (1) refinement of the equipment to minimize these sources of error, (2) data obtained simultaneously from a flush-type thermistor mounted near a floating-element shear stress balance, and (3) the installation of thermistor units in a circular pipe, where shear stress measurements can be compared with measured pressure differentials in known lengths of pipe under both laminar and turbulent flow conditions.

Although a large number of commercial thermistors are currently available, there are none available that meet the size and electrical resistance requirements for this application. With the development of smaller disk-thermistors with resistances greater than 10,000 ohms, it should be possible to further localize the shear stress measurements and to follow the fluctuations in thermistor power input with the random changes in the fluid velocities for a turbulent boundary layer. This is presently possible only at very low velocities.

To apply this technique to model tests the thermistor units could be flush-mounted in the model to measure the shear stress at selected points on the model. As a practical procedure the thermistor units should be previously calibrated by locating them near a floating-element shear stress balance operating under controlled-flow conditions. A calibration curve of shear stress versus thermistor power could then be plotted for each thermistor unit. These units could then be installed on the model and the local shear stress at each location read directly from the calibration curve. This procedure would eliminate any questions of the validity of the assumptions that must be made in the development of a calibration made on a theoretical basis.

REFERENCES

[1] LIEPMANN A. W. and DHAWAN S.: *Direct Measurement of Local Skin Friction in Low Speed and High Speed Flow,* Proc. First U.S. Natl. Congr. Appl. Mech. 1951, p. 869.

[2] SCHULTZ-GRUNOW F.: *New Frictional Resistance Law for Smooth Plates,* NACA Tech Memo No. 986, 1941.

[3] KEMPF G.: *Neue Ergebnisse der Widerstandforschung.* Werft Reederei, Hafen 10 234 and 247, 1929.

[4] SMITH O. W., and WALKER J. H.: *Skin Friction Measurements in Incompressible Flow,* NASA Tech Report R-26, 1959.

[5] BLASIUS H.: *Grenzschichten in Flussigkeiten mit Kleiner Reibung* z. Math u Phys 56 1 (1908), Tech Memo No. 1256.

J. N. Prischemihin, A. F. Poostoshny.

INVESTIGATION OF TURBULENCE STIMULATION IN THE BOUNDARY LAYER OF SHIP MODELS TESTED IN TOWING TANKS

INTRODUCTION.

During the last thirty years various methods of artificial turbulence stimulation have been used at the towing tanks. However, because of the absence of suitable means to determine the efficiency of these methods, their choice has been made empirically, and they did not always ensure the required stimulation effect. Scientific approach to studying stimulation problem under tank conditions became possible only due to the application of physical methods of investigations which are widely used in aerodynamics practice. This work carried out at the towing tanks of the Kryloff Institute was intended for studying conditions causing natural transition in the boundary layer of ship models during resistance experiments in a towing tank, investigation of efficiency of various types of turbulence stimulators used in towing tanks; determination of optimum sizes of the most effective type of stimulators and their location on model surface. The investigation of stimulator efficiency has been carried out mainly by means of experimental methods based on the determination of boundary layer flow characteristics of models. Owing to these methods it is possible to determine the edges of laminar and transition regions in the boundary layer of a model, measure mean velocity profiles, estimate the intensity of fluctuations at different points of the boundary layer, and measure local friction forces acting upon a small element of model surface.

1. EXPERIMENTAL METHODS FOR INVESTIGATING BOUNDARY LAYER OF MODELS IN A TOWING TANK.

For investigations carried out at the towing tanks of the Institute the following experimental methods and apparatus were purposely developed and used: hot-wire anemometer technique for determining velocity fluctuations in the boundary layer of models, method of indicating chemical films to determine the extent of laminar area in the boundary layer of models, method of measuring mean velocity profiles in the boundary layer of models using total head tube and special small inertia micromanometers, direct method for measuring tangential forces on a model surface with the use of small-sized high-sensitive dynamometers of electrical type, direct method for measuring stimulator own resistance by means of a special electroinductive type dynamometer, method of estimating small values of the resistance of large ship models.

Hot-wire measuring technique at the towing tanks of the Institute was used to determine the nature of velocity fluctuations and degree of turbulence in the boundary layer of models tested. A thin platinum wire was selected for a transducer, the proper diameter and length of which were determined by experiment provided that they ensured high sensitivity and reliability during the measurements. Platinum wire was mounted on a special removable support which makes it possible to fix it in a required position with regards to streamlines, at a given distance from the model surface. The support was set at different points of the model surface on the foundations primarily mounted flush with model surface. After installation the support by means of a switch arranged on the towing carriage was connected to a measuring bridge which in turn through the amplifier was connected either to a magnetic oscillograph or to a cathode-ray oscilloscope. For recording the magnitude of the effective voltage during the experiment in parallel to a cathode-ray oscilloscope, a valve voltmeter was connected. The relationship between the degree of stream turbulence and the magnitude of the effective voltage at the output of the amplifier was established by calibration. Since the characteristics of calibration curve of transducer $\varepsilon = f(U\nu)$ was linear, it was sufficient to know the magnitude of the effective voltage $U\nu$ for estimation of the turbulence degree in the boundary layer of model. Figure 1 shows a sample of fluctuation records in laminar area (curve I), in transition region (curves II, III) and in fully turbulent region (curve IV) respectively for a model tested in the towing tank.

The most suitable method which would afford the determination of laminar area in the boundary layer of ship models tested in a towing tank to be made is that of an indicating chemical films. As an indicator material at the towing tanks of the Institute acetone solution of hydroquinone diacetyl /$C_{10}H_{10}0_4$/ is applied which is sufficient to check laminar flow in the boundary layer of a model, is harmless for the staff and can be easily manufactured from cheap materials. Com-

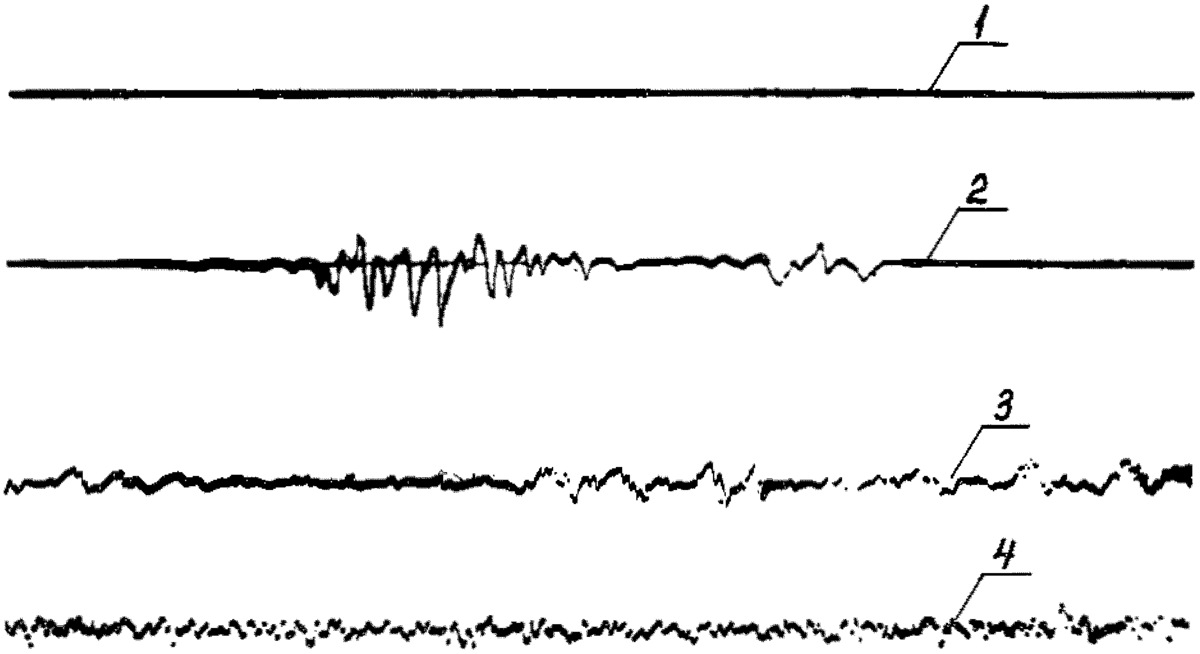


FIG. 1.
Nature of velocity fluctuations in the boundary layer of model.
1 — laminar region; 2 to 3 — transition region; 4 — turbulent region.

parison of the results obtained when carrying out this work using different methods for investigation of the boundary layer on a model, shows that the chemical method which does not require a complicated apparatus and too much labour has proved to be a good one.

Previously, measurements of mean velocity in the boundary layer of models were carried out with the use of total head tubes and water manometers, and this naturally restricted the application of this method. The use in this work of purposely developed small inertia electric micromanometers and a coordinating device for total head tubes was conditioned by the necessity of performing measurements in the laminar boundary layer at the bow of a model where thickness of layer is small enough and pressure ranges lie within 1.0 — 5.0 mm of water. Pressure pick-up of micromanometer which is made in the form of a plastic cylinder is 51 mm diameter and 72 mm long. Installed inside of this cylinder are a diaphragm, to be an elastic measuring element, and an electroinductance transducer which enables the deflection of the diaphragm during the tests to be measured. Since the deformation of the diaphragm was small, it was possible to avoid a large amount of water to be shifted and to ensure small inertia of apparatus in the course of measurements. When testing, the pressure pick-up was placed inboard of the model close to the coordinating device of the total head tube, and by means of rubber pipes was connected to it as well as to the pipe connection of a statical orifice on the model hull. The total head tube through the coordinating device being operated from the towing carriage was projected outside the model, at a given distance normal to its surface. Its traverse was found by means of a special counter within an accuracy of 0.05 mm. The output voltage of the transducer was varied and recorded on a 250 mm wide paper tape of an electronic automatic potentiometer. In order to increase the accuracy of measurements, pressure range which lies between 0 and 200 mm of water was divided into several subranges, one of which permitted measurements to be made within 0 — 10 mm of water. The accuracy of pressure measurements in the upper limit of each subrange was $\pm 2\%$.

The determination of tangential stresses during model testing in a towing tank can be performed either by direct measurement of local friction forces acting upon a small element of model surface, or by measuring hydrodynamic quantities directly associated with skin friction. Direct measurement of friction forces in the towing tanks has been rarely carried out. This is due to difficulties arising from the development of experimental equipment designed for carrying out such experiments. In most cases friction forces are determined by indirect ways, the application of which is based on assumptions not always proved and verified. This latter circumstance was the reason why in carrying out the work under consideration it was decided to develop a small-sized high-sensitive electric dynamometer which could be applied for direct measurement of tangential stresses acting upon a very small element of the surface of a model tested in a towing tank. It consisted of a plastic cylindrical case 45 mm diameter and 80 mm long, inside of which movable parts and elastic elements of the dynamometer were placed as well as an electroinductance transducer. The dynamometer was placed inboard of a model in such a way that one of its bottoms served as if it were a part of the model surface. The bottom had a rectangular cut in its middle, inside of which flush with model surface a working element — mobile quadrate platform having sides 20 mm × 20 mm on the elastic elements was mounted. Travels of the platform proportional to the forces acting upon it were measured by an electric transducer. The gaps between edges of the platform and the cut on its three sides were assumed to be 0.1 mm; the gap between the trailing edge and the cut was assumed to be 0.3 mm. For recording electrical quantities into which the travels of the platform are transformed, use was made of the electronic automatic potentiometer with a paper tape 250 mm wide. This tape width was adequate to record the forces from each of the four subranges into which, as has already been mentioned, the whole range from 0 to 300 mg was divided. The lower subrange varied 0 to 15 mg. So far as the magnitudes of the expected tangential stresses were not covered by the obtained ranges, a second dynamometer was manufactured, which was similar in construction to the previous one, but had a much more rigid elastic system enabling measurements to be made in the range between 0 and 2 gr. On the basis of numerous calibrations made for both instruments, it was possible to determine their error which in relation to the upper limit of each subrange covered was found to be ± 3 %.

Calibration of the dynamometer for tangential stresses was made before each test and no less than once for a seven hour test by using a special device, the dynamometer being immersed in water. After calibration, the dynamometer was mounted on a model and it was subjected to tests, in the course of which measurement and recording of friction forces were taken. The magnitudes of the tangential stresses obtained from direct measurements at two points on the surface of model No. 10 tested in the towing tank of the Institute are given in fig. 13.

With a view to determining the own resistance of a wire stimulator at the Towing Tank a special electroinductance dynamometer has been developed. The principal circuit and the electric transducer of this instrument are similar to those of the dynamometer for measuring tangential stresses. The sizes and configuration of the dynamometer enabled it to be installed at the bow of a model in such a way that a piece of 50 mm long cut out of the trip wire under test was fixed on the mobile platform with 10 mm × 50 mm dimensions. During the resistance tests the forces acting upon the platform and a part of the trip wire fixed on it were measured and recorded on the paper tape of the electronic potentiometer.

The application of modern methods for investigating the boundary layer of models by no means excluded the necessity for measuring their resistances in carrying out comparative resistance tests. In these tests the range of low towing speeds 0.2 — 1.0 m/sec was of particular interest when total resistance even for models 6 or 7 m long did not exceed 6 — 7 kg. With size increase and displacement of models there was a considerable increase of fluctuations in the resistance comparable with the mean value of towing resistance at low speeds of run. For resistance measurements with large models, at low speeds of run, test equipment and apparatus have been developed which ensured effective damping of the resistance fluctuations and small errors involved.

2. INITIAL CONDITIONS FOR TESTS IN A TOWING TANK.

Turbulence stimulation of the boundary layer of models and its experimental investigation depend to a considerable extent on the initial conditions in a tank under which model tests are conducted. These are as follows: degree of initial turbulence in tank water, flow velocities after previous run, model acceleration at the beginning of run, draught of model, roughness of model surface.

Numerous data available show that the extent of the laminar boundary layer and the critical value of the Reynolds number are affected by the changes in the degree of initial turbulence. At the same time, there is no information available at present concerning the amount and the rate of changes in the degree of initial turbulence in towing tanks. When testing in towing tanks initial turbulence is produced by disturbances caused by a moving model. Velocity fluctuations in the vicinity of the turbulence trail extending behind a model can remain for some time after the run is over. The degree of initial turbulence in this case would depend on the intensity of conducting the tests. When increasing the frequency of runs, the degree of initial turbulence should rise. This fact has already been noted, and at several towing tanks attempts have been made to increase the degree of initial turbulence artificially, by reducing time intervals between successive runs with a view to obtaining more consistent results.

As the degree of turbulence in a tank is relatively low, direct measurement of its amount and the rate of changes depending on test conditions present great difficulties. As a result of specially conducted experiments the order of initial turbulence in the towing tanks of the Institute was estimated to be about $\varepsilon \simeq 0.6\,\%$. The investigation of the effect of changes in the degree of initial turbulence on transition was made indirectly, i.e. by measuring the degree of turbulence in the boundary layer of a model towed at a different time interval between runs. A hot-wire anemometer was mounted on a model 6 m long without stimulator, in the fixed position along the model length. As seen from the diagram $Uv = K\varepsilon = f(v)$ given in Figure 2, with reduction of time interval between runs, i.e. with increasing the degree of initial turbulence in a tank water, transition occurs at lower values of the Reynolds number. However, the influence of the degree of initial turbulence in a tank water on natural turbulence of the boundary layer for models 6 m long is small, which is also confirmed by the results of tests conducted with the same aim in view using the method of chemical films. Furthermore, this influence is quite evident mainly at very low towing speeds.

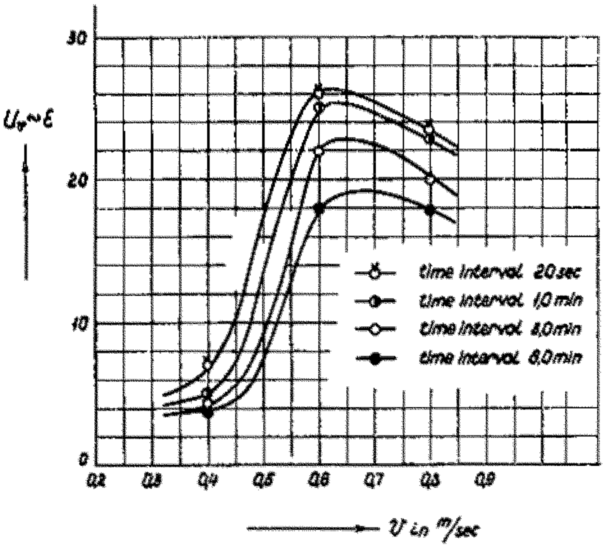


FIG. 2.

Variation in degree of turbulence $\varepsilon \sim Uv$ in the boundary layer of model depending on time interval between runs.

From the experience gained in towing tanks it is known that the flow remaining behind a towed model, since the model returns to its initial position, remains for a long time after the run is over and can affect the magnitude of the model resistance in subsequent runs at low speeds. Since many tests in this work have been carried out at low speeds of run and analysis of the results was often made by comparison of the measured resistance coefficients, it was necessary to estimate the magnitude of the residuary flow velocity in the tank and its dependence on the time interval between successive runs taking into account sizes of model and speeds of return run. Special accurate measurements of the residuary flow velocity (see Fig. 3)

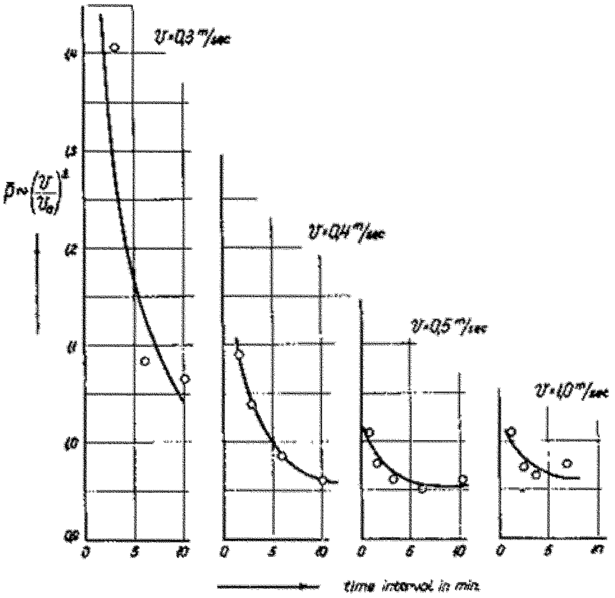


FIG. 3.

Nature of changes in residuary flow depending on time interval between successive runs.

and towing resistance of a model at different time intervals between runs carried out in the towing tank of the Institute have shown that the velocity of the residuary flow may attain 3 - 4 cm/sec and varies depending on time interval between runs and speed of model on its return. Therefore, lest the results of resistance tests be affected by the residuary flow at the towing speeds Vo = 0.3-0.8 m/sec, it was necessary that the interval between runs should not be less than 6 minutes, with speed of model return equal to 1.0 m/sec and that in the range of towing speeds Vo = 0.2 - 0.4 m/sec there should be an additional reduction in speed of return to 0.5 m/sec.

The influence of model acceleration at the beginning of run on the boundary layer stimulation has not been investigated specially, however, all the model tests in the tank were carried out at given values of acceleration equal to 0.03 - 0.65 m/sec^2.

As a result of the experimental investigation dealing with the effect of model draught on stimulation of the boundary layer (see Fig. 4), it was found that with decrease of draught some stimulation effect became evident. This is chiefly due to the influence of wave-making on transition, and it occurs a relatively high values of Froude number when developed wave-making occurs.

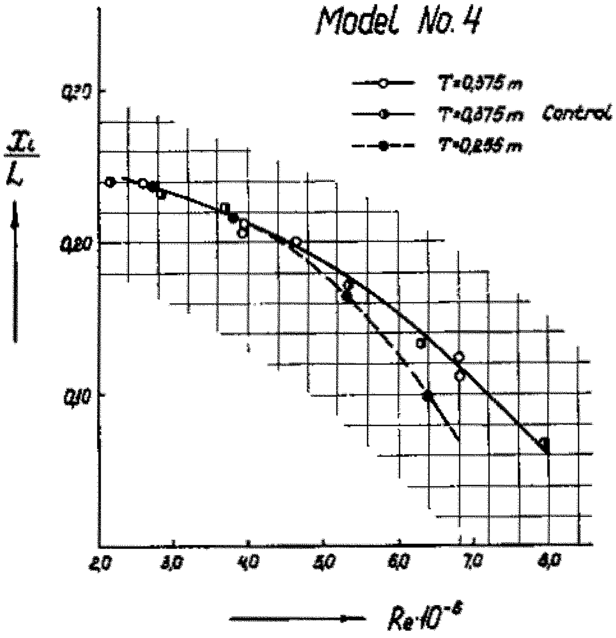


FIG. 4.
Effect of variation in draught on the extent of laminar boundary layer.

The roughness of the surface of tested models manufactured of paraffin-wax in usual way was specially measured on a large number of specimens. On the basis of measurements made it was found that the average degree of surface roughness of the models tested amounted to 3.0 - 5.5 micron. Such a surface may be considered as hydrodynamically smooth in the range of Reynolds numbers $Re = 0.5.10^6 - 1.5.10^7$.

3. *Natural Turbulence of the Boundary Layer on Models Tested in a Towing Tank.*

The questions as to the need for application of stimulating devices and estimation of their efficiency should be decided upon on the basis of investigation of natural turbulence in the boundary layer of models tested in a towing tank.

The principal parameter which determines transition in the boundary layer of a model is the local Reynolds number Re_x. When certain critical values of the local Reynolds number are reached $Re_x = Re_{xc}$ laminar boundary layer becomes unstable and after some transition stage, the flow in the boundary layer becomes turbulent. The value of Reynolds number Re_{xc}, which in conditions of natural turbulence defines the edge of laminar area, is not constant and depends on the nature of pressure distribution along the model surface as well as on the initial conditions of tests (see section 2). Since the pressure distribution along the hull is affected mainly by the shape of ship lines and the ratio of its main dimensions, it is considered that the principal geometrical parameters of hull defining transition in the boundary layer would be the following: fullness of fore-body sections, shape and angle of entrance of waterlines, form of stem, shape of fore-body sections, aspect ratio L/B and ratio T/B.

As long as each class of ships has its more or less definite ratio of geometrical particulars, a small number of shape lines was selected in these investigations with variation only of those hull parameters which most affect the flow condition in the boundary layer of models. As objects for investigations the following models were selected: two series of large models (6 m long) of cargo ships with block coefficient $\delta \cong 0.6$ and $\delta \cong 0.8$, differing in each series in forms of stem and shapes of fore-body sections; three small models (1.5 m long) geometrically similar to the large ones; one small model with block coefficient $\delta \cong 0.7$ and two models with analytical lines. The main particulars and numbers of these models are indicated in Table 1.

TABLE 1.
Main particulars of models.

PRINCIPAL DIMENSIONS AND COEFFICIENTS	SYMBOLS	UNIT	LARGE MODELS			SMALL MODELS					MODELS OF ANALYT. LINES		
			Series $\delta = 0.6$			$\delta = 0.8$		$\delta = 0.6$	$\delta = 0.8$		$\delta = 0.7$		
			MODEL NO.										
			1	2	3	4	5	6	7	8	9	10	11
Displacement	∇	m^3	1.10	1.098	1.10	1.708	1.700	0.0172	0.0270	0.0267	0.0290	0.42	0.82
Length	L	m	6.22	6.22	6.22	6.20	6.20	1.55	1.55	1.55	1.695	5.00	5.00
Breadth	B	m	0.854	0.854	0.854	0.938	0.938	0.214	0.234	0.234	0.236	0.50	1.00
Draught middle	T	m	0.356	0.356	0.356	0.375	0.375	0.089	0.094	0.094	0.108	0.24	0.24
Wetted surface area	S	m^2	6.75	6.68	6.68	8.58	8.56	0.428	0.550	0.560	0.576	3.985	5.37
Block coefficient	δ	—	0.582	0.582	0.582	0.789	0.789	0.582	0.789	0.789	0.687	0.70	0.70
Midship section coefficient	β	—	0.973	0.973	0.973	0.992	0.992	0.973	0.992	0.992	0.988	1.00	1.00
Prismatic coefficient of forebody	φ_B	—	0.627	0.625	0.634	0.907	0.907	0.634	0.907	0.907	0.682	0.70	0.70
Aspect ratio	L/B		7.29	7.29	7.29	6.61	6.61	7.29	6.61	6.61	7.18	10.0	5.00
Angle of entrance of waterlines	$\alpha/2$	degree	4.0	10.0	4.0	42.0	55.0	4.0	42.0	55.0	12.0	8.5	14.0
Shape of forebody sections			U	V	*b*	U	V	*b*	U	V			

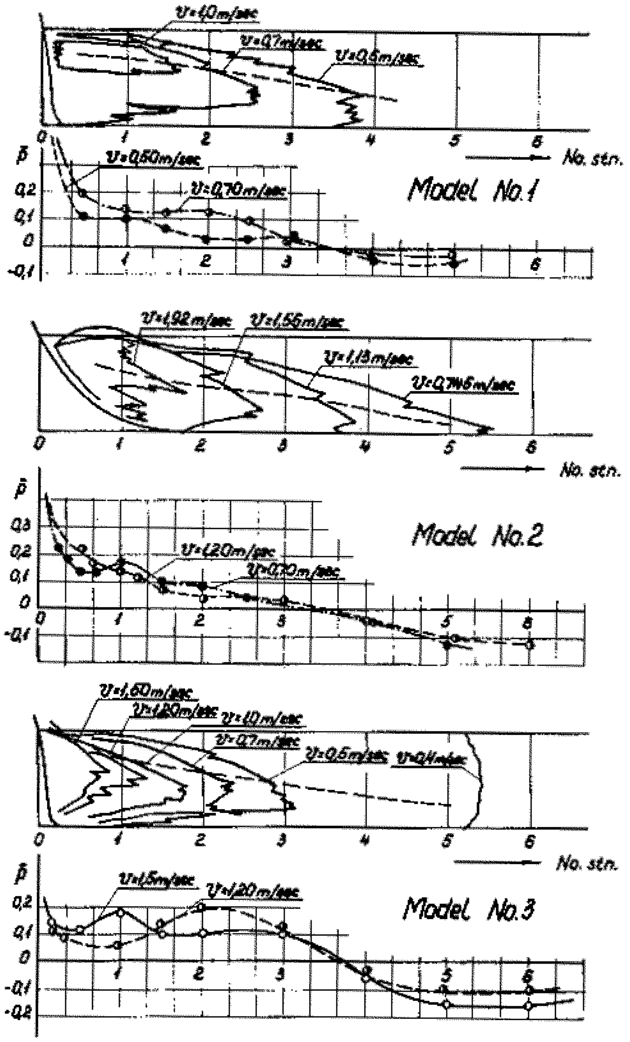


FIG. 5.

Edges of laminar area in the boundary layer of models.

The shape of stem for models with $\delta \simeq 0.6$ is indicated in Figure 5. Models with $\delta \simeq 0.8$ have the shape of stem similar to that of model No. 1. The shape of fore-body sections; U-shaped, V-shaped and with bulbous bow (*b*) is indicated in Table. Models with analytical lines have vertical stem, rectangular sections and parabolic waterlines.

The tests were carried out under given and controlled initial conditions in the tank (see section 2), the influence of which was allowed for both in conducting experiments and in the treatment of their results.

It is quite natural that when testing the mentioned models not all of the experimental methods considered in section I were used, and only in the most interesting cases several methods under similar conditions were applied. As a rule, during the test the edge of the laminar area was determined first by using chemical indicator technique and the most typical streamline was defined with the use of paint. Then the degree of turbulence along this streamline was measured using hotwire anemometers with a view to determining the extent of transition region and for checking the results obtained by the chemical method. While testing, pressure distribution along the selected typical streamline of many models was determined as well.

Figure 5 shows the results of tests with series of models having block coefficient $\delta \simeq 0.6$. On the section along the centre line the edges of laminar boundary layer region are drawn for 3 to 6 speeds of run, and typical streamlines are indicated along which the measurement of pressure distribution was made and boundary layer velocity fluctuations were determined. The results of pressure measurements are given as diagrams $\bar{p} = f(x)$. The results obtained seem to indicate the existence of the developed laminar areas in the boundary layer of models under conditions of natural turbulence, even at Reynolds numbers up to $Re = 1.1.10^7$. The form of edges of laminar areas is determined to a great extent by stimulation effect of free stream surface. Dependence of the extent of laminar area on the nature of pressure changes along the model surface is clearly illustrated, for example, by model No. 3.

The results of the above tests and similar experiments with the other models indicated in Table I are plotted in Figure 6 as the ratio between the greatest extent of laminar boundary layer and the length of corresponding model on the base of Reynolds number. It is evident from the above data that the curves $\frac{x1}{L} = f(\mathrm{Re})$ change to a regular way reflecting the features of the main geometrical paramceters of models tested. With large models having angle of entrance of waterline $\alpha/2 = 4^\circ$ to 15° (models Nos. 1, 2, 3, 10, 11) dependence $x1/L$ on Re has the same character differing from that for models with angle of entrance of waterline $\alpha/2 = 40^\circ$-55°. However, with small models the angle of entrance of waterline does not influence the shape of curves $x1/L$. It is supposed that the alteration in the shape of curves $x1/L$ and their mutual intersection are due to wavemaking produced by models. In the range of Reynolds number $\mathrm{Re} = (1.0\text{-}2.5) \,.\, 10^6$

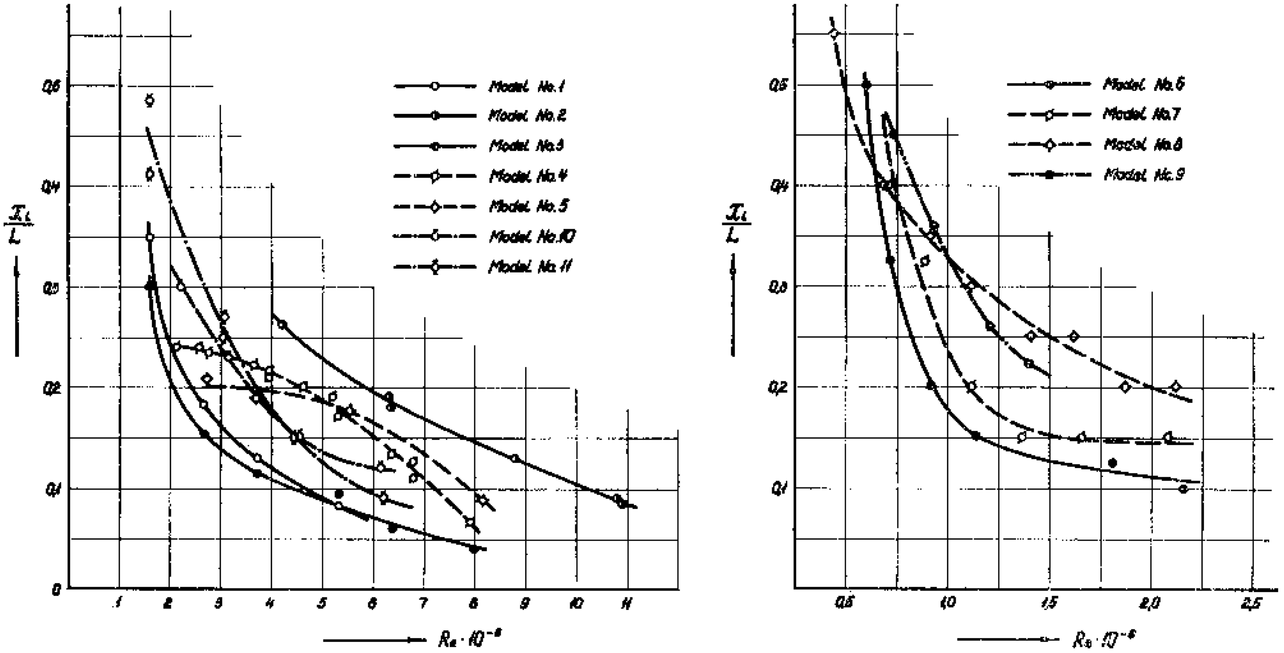


FIG. 6.
Extent of laminar areas in the boundary layer of models.

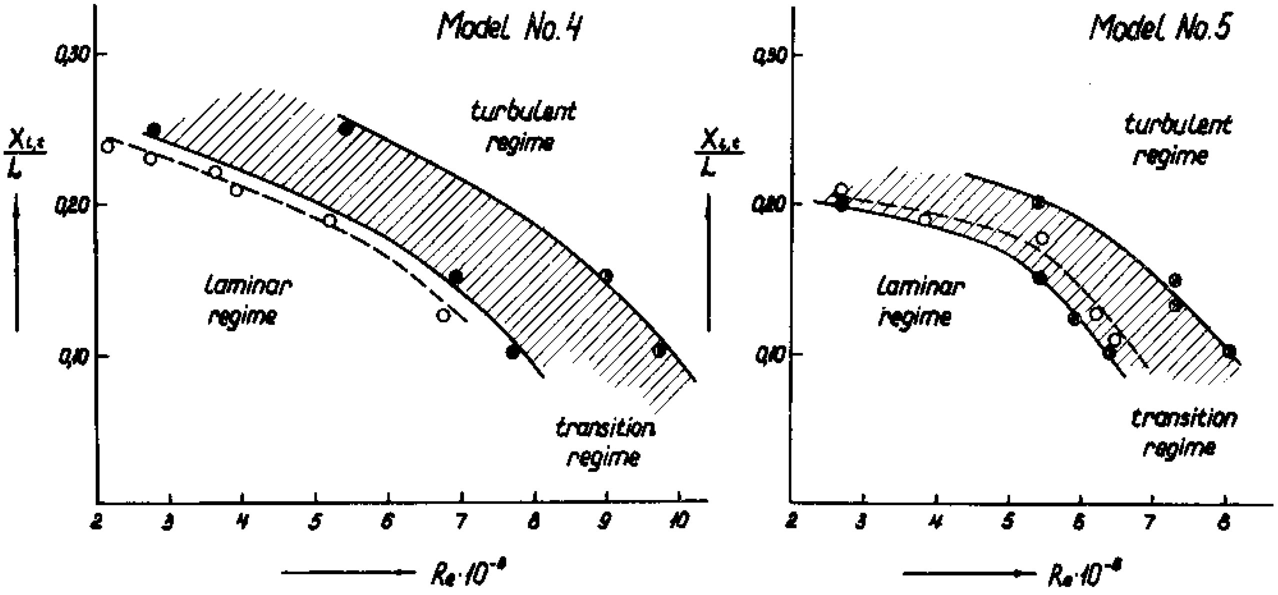


FIG. 7.
Extent of transition region in the boundary layer of model.
○○○ — edge of laminar region according to chemical method.
●●● — edge of laminar region according to hot-wire method.
◐◐◐ — edge of transition region according to hot-wire method.

and Re = (3.5 - 7.0) . 10^6 for models with small raked stem and rounding at a given Re with increasing block coefficient the extent of laminar area increases. Tests with model No. 2 confirm considerable influence of stem shape. Increase of stem rake and radius of rounding is accompanied by a considerable extension of laminar areas. There is appreciable influence of shape of fore-body sections: U-shaped sections favour the earlier boundary layer transition. A bulbous bow (models Nos. 3.6) is the most favourable from the stimulation point of view. Aspect ratio of a model does not influence markedly the transition under conditions of natural turbulence.

Table 2 contains the critical values of local Reynolds numbers as calculated from the results of above tests. During the tests with models Nos. 1, 4 and 5 the extent of laminar area along the selected streamline on a model hull was determined not only by using the chemical method, but also when using hot-wire technique. The agreement between results obtained by two quite distinctive experimental methods, as seen from Figure 7, may be considered as good.

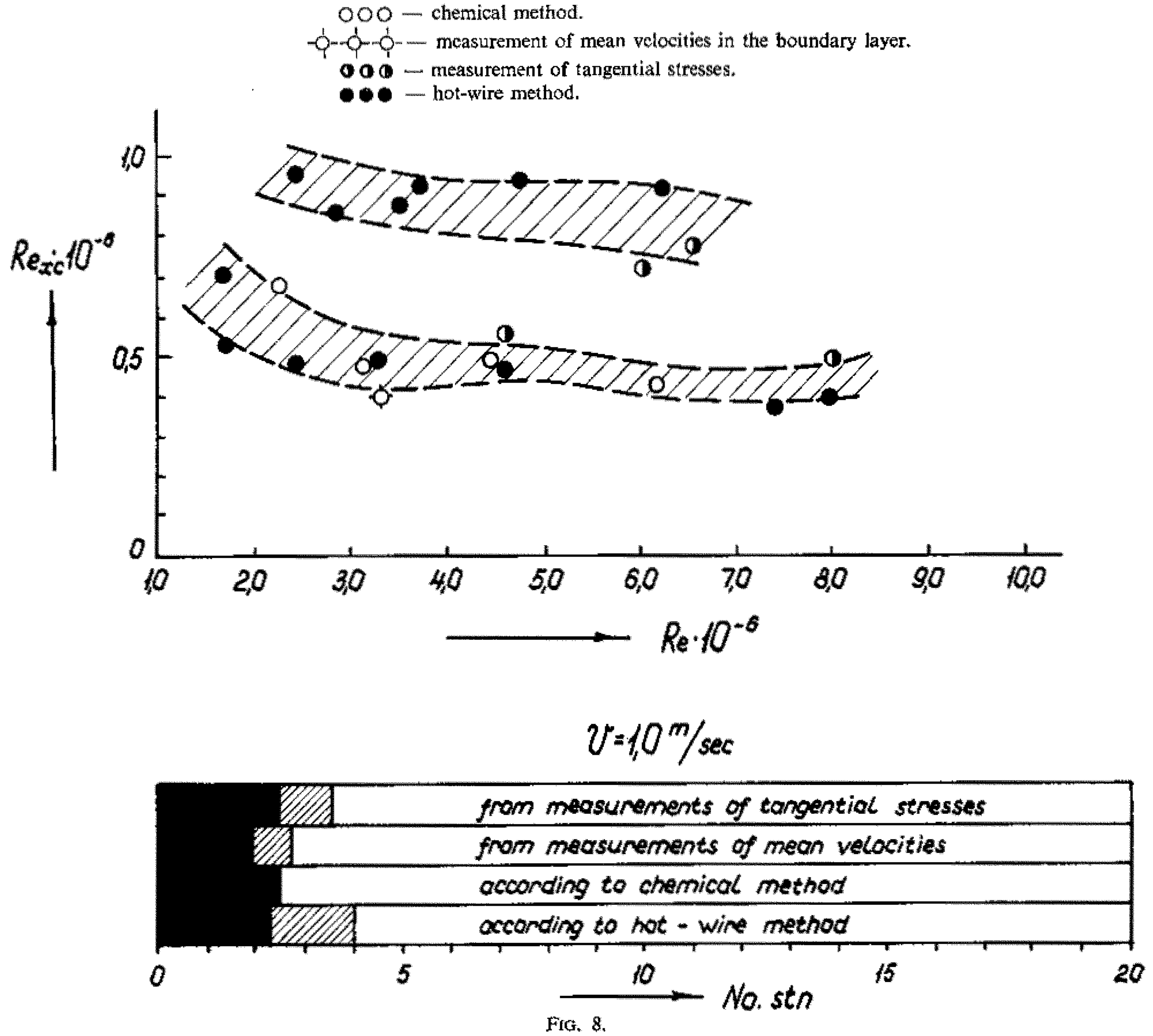


FIG. 8.

Critical values of local Reynolds number and extent of laminar, transition and turbulent boundary layer region, from the results of tests with model No. 10 in the tank.

TABLE 2.
Values of the critical Reynolds number $Re_{xc} \cdot 10^{-5}$ obtained from the test results by chemical method.

Model No. Re	1	2	3	4	5	10	11	Model No. Re	6	7	8	9
2.10^6	4.8	—	4.1	4.8	—	6.4	7.7	$0.6.10^6$	3.0	—	2.6	—
3.10^6	4.8	—	4.2	7.0	6.0	7.1	7.8	$0.8.10^6$	2.1	2.8	3.0	3.4
4.10^6	4.8	10.9	4.4	8.6	7.8	7.0	7.1	$1.0.10^6$	1.8	2.3	3.3	3.3
5.10^6	4.5	11.4	4.4	9.4	9.3	6.8	6.2	$1.2.10^6$	1.7	2.2	3.5	3.2
6.10^6	4.0	11.7	4.3	9.1	9.9	7.2	5.6	$1.4.10^6$	1.8	2.2	3.7	3.1
7.10^6	—	11.8	3.8	7.6	9.4	—	—	$1.6.10^6$	2.0	2.4	3.8	—
8.10^6	—	11.7	3.4	4.9	7.5	—	—	$1.8.10^6$	2.1	2.6	3.9	—
9.10^6	—	11.2	—	—	—	—	—	$2.0.10^6$	2.2	2.9	4.0	—
1.10^7	—	10.4	—	—	—	—	—	$2.2.10^6$	2.4	3.2	4.1	—

By means of hot-wire technique the extent of transition region (see Fig. 7) on the models in question was investigated. The extent of transition region in per cent to model length when Reynolds number is varied $Re = (2\text{-}8).10^6$ amounted to 7 % for model No. 1, 6 % to 8 % for model No. 4 and to 5 % to 7 % for model No. 5. Thus, despite the difference in geometrical particulars of models, the extent of transition region in the boundary layer changes but little and averages to 4 % - 8 % of model length.

The determination of the edges of laminar and transition regions in the boundary layer of model No. 10 having analytical lines was made by all methods available for boundary layer investigation. These included the method of chemical indicator films, hot-wire method, method of measuring mean velocities and direct method of measuring friction stresses. The results of the experiments as the relation $Re_{xc} = f(Re)$ are plotted in Figure 8, where the regions of the critical values of local Reynolds numbers covered by all methods are indicated (shaded). Shown in the same figure is a diagram dealing with the extent of laminar and transition regions in the boundary layer of model No. 10, along the waterline situated at ½ draught of model, at the speed of run 1.0 m/sec. As seen, better agreement in the results concerning the extent of laminar and transition regions was obtained when measuring tangential stresses and fluctuations in the boundary layer, i.e., the magnitudes which to a great extent present physical processes occurring in the boundary layer of models. Consistency in the results of experiment conducted using the chemical method with the above results should also be noted.

The investigations carried out in this work have shown that when testing under conditions of natural turbulence the extents of laminar areas in the boundary layer of models amount to a considerable magnitude (up to 5 % of model length) at Reynolds numbers to $Re = (7\text{-}9).10^6$, and in some cases to $Re = (12\text{-}13).10^6$. In this connection there is evidence for application of the efficient turbulence-producing devices.

4. *Effectiveness of Turbulence-Producing Devices used at Towing Tanks.*

Stimulators which are applied in resistance tests at towing tanks are to ensure that transition in the boundary layer occurs at lower values of local Reynolds number compared with natural transition; in this case the edge of laminar area should be defined at a given position along the model length.

The main types of stimulators used at the towing tanks at present are the following: trip wire, studs and sand strips. These are placed at the bow of models and produce disturbances immediately in the boundary layer. Up to recently, at a number of towing tanks stimulators in the form of badly shaped bodies (rods, grids, rough profiles) placed in front of a model were used intended for increasing the degree of initial turbulence of tank water.

Investigation of the efficiency of the above stimulators in this work has been performed by means of the experimental methods considered in section I when testing with the models as those used for investigation of natural boundary layer turbulence, the main particulars of which are given in Table I.

Trip wires were 1.0 mm, 1.5 mm and 2.0 mm diameter respectively. The studs used were of two types: conical studs 3.0 mm diameter, 2,5 mm projection, those of 1.0 mm diameter, 0.9 mm projection and studs with semicircular heads 2.5 mm diameter, 2.0 mm projection. Sand strips were 10 mm wide and 25 mm respectively with grain size 0.6 mm.

Trip wires and sand strips were arranged on the models in accordance with the practice adopted in most towing tanks, i.e. at a distance equal to 0.05 of model length from the forward perpendicular; the influence of alteration in location of stimulator along the model was also estimated. When arranged in one row studs were fitted at a distance of 25 mm from the stem spacing 25 mm and 12 mm respectively; when arranged in two rows, the first row was fitted at the same distance as before, but the second row moved vertically at half the interval was 50 mm distant from the first, the spacing in this case being 25 mm.

The models with stimulators of the above types and sizes fitted in turn were run at several towing speeds using the chemical method.

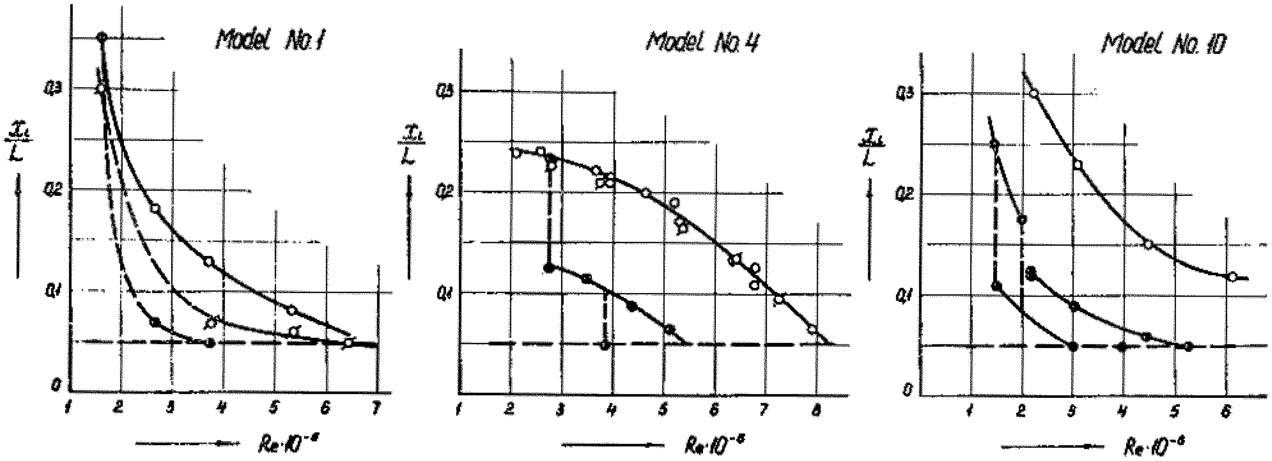


FIG. 9.

Results of investigation of stimulator's efficiency obtained by chemical method.

○○○ — no turbulence device.

◐◐◐ — trip wire of 1.0 mm diameter.

●●● — trip wire of 2.0 mm diameter.

○○○ — one row of studs.

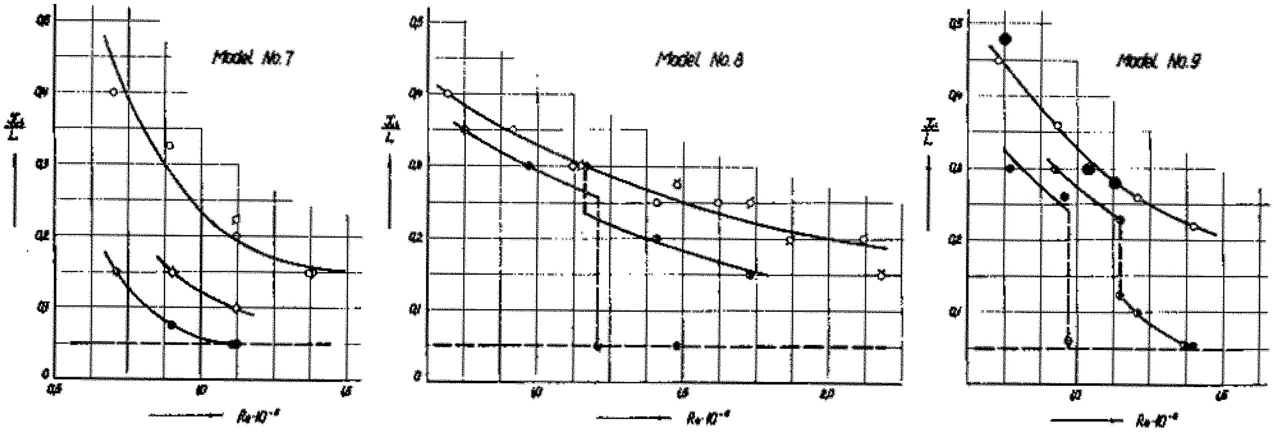


FIG. 10.

Results of investigation of stimulor's efficiency obtained by chemical method.

○○○ — no turbulence device.

◐◐◐ — trip wire of 1.0 mm diameter.

●●● — trip wire of 2.0 mm diameter.

ŏŏŏ — one row of studs.

ø ø ø

-ϕ-ϕ-ϕ- — two rows of studs.

◉◉◉ — sand trip.

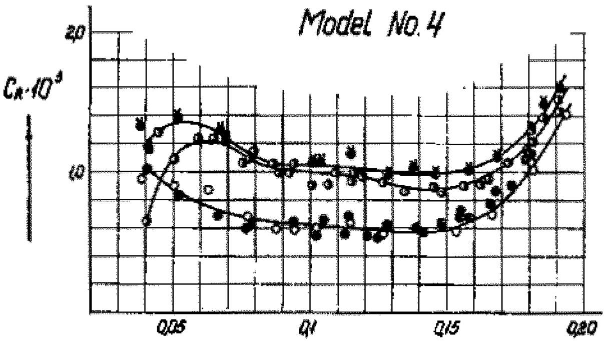


FIG. 11.

Results of comparative resistance tests of model.

○○○ — no turbulence device. ●̌●̌●̌ — 2.0 mm trip wire.
◐◐◐ — 1.0 mm trip wire. ●●● — studs.

During the intervals between tests measurement of model resistance by means of purposely developed resistance dynamometer (see section I) was made. Sometimes tests were repeated and use was made of hot-wire anemometers which were placed along the typical streamlines on the model hull. Investigation of the efficiency of wire stimulators was also performed by using the method of mean velocity measurement and tangential stresses in the boundary layer of models.

The limited scope of this report makes it possible to discuss only a few of the most typical results of the experimental investigations made with regards to efficiency of stimulating devices.

Figures 9 and 10 show the results of investigating the efficiency of various stimulating devices when testing with three large models (Nos.1. 4 and 10) and with three small models (Nos. 7, 8 and 9) using the chemical method. The diagrams show the experimental values of the largest relative extent of laminar area in the boundary layer of models with fitted stimulators such as: trip wire, studs and sand strips, and models without any stimulators. Full lines correspond to the nature of variation in the extent of laminar area depending on Reynolds number under conditions of natural turbulence, for a selected type of stimulator. "Jumping" reduction of laminar area during transition, as well as the curves $x1/L = f(\mathrm{Re})$, when the number of intermediate points is not sufficient, are shown by a dotted line. The edge of laminar area fixed at the place of wire when arranged at a distance of 0.05 L from the forward perpendicular is also defined by a dotted line drawn parallel to axis of abscissae.

It appears from the results just discussed as well as from those of similar investigations with other models that the nature of changes of curve $\frac{x_L}{L} = f(\mathrm{R}e)$ for model with fitted stimulator remains exactly the same as that for natural turbulence. Only in separate cases there is a sudden reduction in the extent of laminar area followed by the gradual change or fixing of the latter at the stimulator itself.

When under conditions of natural turbulence there occur large and stable laminar areas in the boundary layer of certain models, laminar regime maintains its stability even if stimulators are used. Thus, in

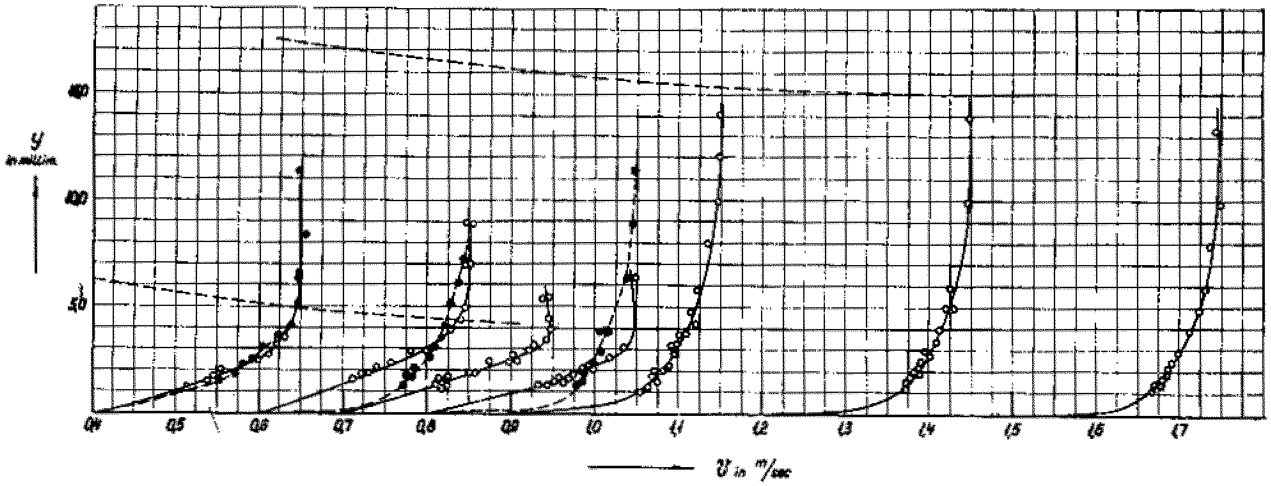


FIG. 12.

Effect of trip wire on the change of velocity profile in the boundary layer of model No. 10.

○○○ — no turbulence device. ●●● — 1.0 mm trip wire.

testing model No. 1 trip wire of 1.0 mm diameter proves to be effective at the Reynolds number Re = $3.7.10^6$(Fr = 0.09), whereas studs reduce the extent of laminar region by 50 %; at the same time, trip wire of the same diameter placed on models Nos. 4 and 10 steadily fixes the edge of laminar region at the place of stimulator only at the Reynolds number Re = $5.4.10^6$ (Fr = 0.13) and Re = $5.3.10^6$(Fr = 0.17) accordingly. Studs (when spaced 25 mm and 12 mm respectively) prove to be quite ineffective. In tests with small models 1.0 mm trip wire appears to be an insufficiently effective stimulator over the whole range of Reynolds numbers Re = $(0.5\text{-}1.5).10^6$ (Fr = 0.08 - 0.29) and one row of studs is not able to cause appreciable stimulation effect. Only use of a 2.0 mm wire enables in this case to stimulate sufficiently the boundary layer at Reynolds numbers Re = $(1.0 - 1.2).10^6$.

By arranging the studs in two rows their effectiveness is markedly increased (see Fig. 9, model No. 7). Studs with semi-circular heads are more effective compared with those having conical heads. However, in all models tested trip wire proved to be the most effective stimulator.

The investigation of efficiency of sand strips 25 mm wide and with grain size 0.6 mm that has been carried out on several models (see, for example, model No. 9 in Fig. 9) made it possible to ascertain that this type of stimulator was less efficient compared with trip wire and studs. It should be noted, however, that the effectiveness of sand strips can change markedly depending on the size of grains, width and position of strips in relation to a model hull. The question as to the most suitable location of sand strips and the choice of grain sizes was not investigated in this work, since as compared with other stimulators sand strips are more complicated for producing and installing on a model, and they do not ensure the required stimulation effect.

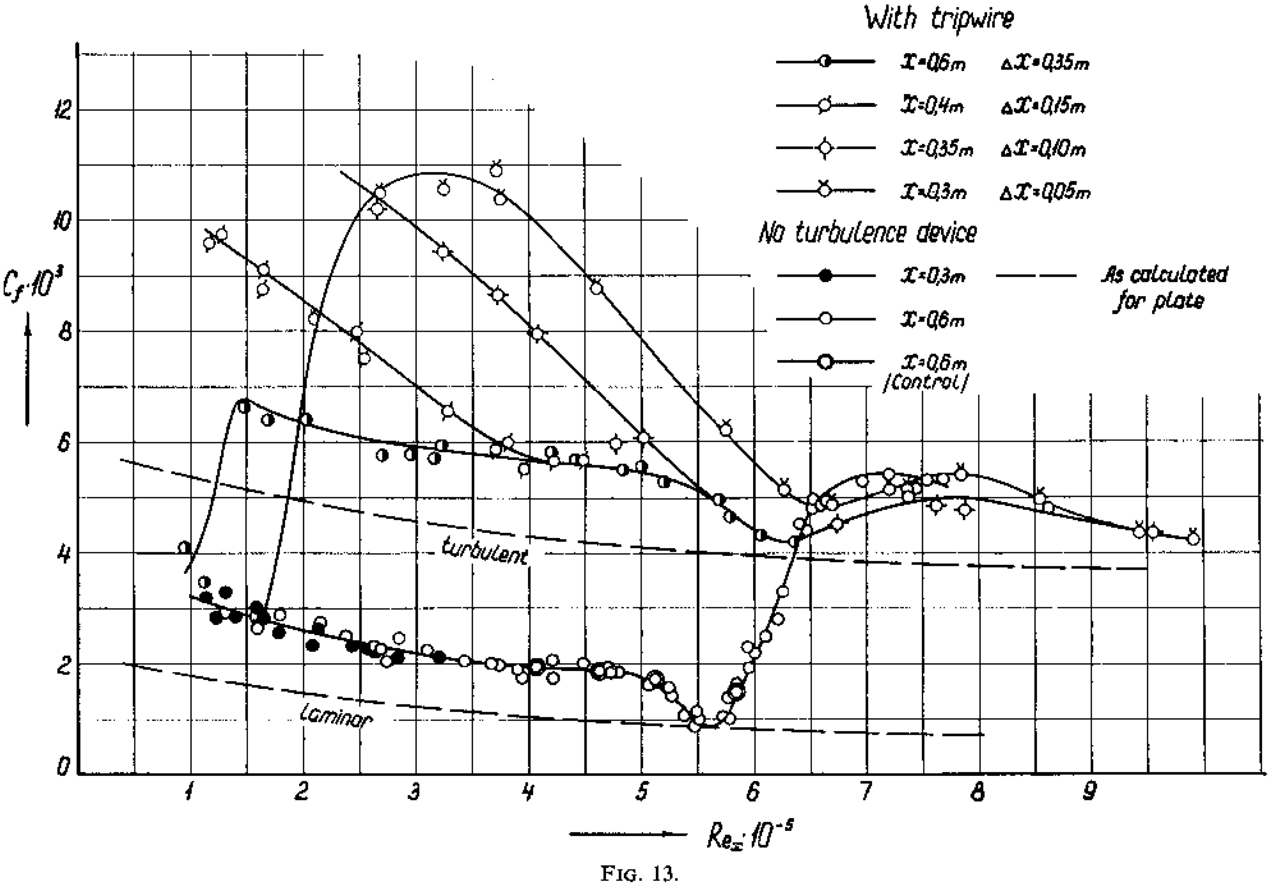


FIG. 13.

Dependence of the coefficient of tangential stresses on Reynolds number from measurement of local friction forces on the model surface.

As has been stated, effectiveness of stimulators was investigated also by measuring the resistance of each model with fitted various stimulators in succession. As an example, Figure 2 gives the results of resistance measurement for model No. 5 obtained by means of a purposely developed strain-gauge dynamometer. When testing, the following stimulators were placed on the model in succession: trip wire of 2.0 mm diameter and 1.0 mm respectively with conical heads, arranged in one row, spacing 12 mm and studs. Studs proved to be ineffective over the whole range of Froude numbers covered including service speeds.

In testing model No. 10 when using the total head tube and electrical small inertia manometer (see section I), measurement of mean velocity profiles was made at section of boundary layer, at a distance of 0.6 m from the stem and at the depth of 0.12 m from water surface. The results of measurements as curves $\frac{U}{U\delta} = f(y, v)$ are given in Figure 12. Laminar velocity profile at the section under consideration in conditions of natural turbulence persists up to the speed of run $V = 0.8$ m/sec. When trip wire of 1.0 mm diameter is placed at station I ($x = 0.25$), at the speed of run $V = 0.4$ m/sec, there is a slight change in velocity distribution; however, just as the speed increases, already at $V = 0.6$ m/sec, velocity profile approaches to turbulent. Comparison of the experimental results with theoretical relations for the plates (see, for example, the curves showing the calculated boundary layer thickness in laminar and turbulent regimes defined by dotted lines, Fig. 12), as well as consistency in the results obtained in checking tests made it possible to ascertain that the results obtained were reliable.

Investigation of the wire efficiency was also made in the course of testing with several models using hot-wire technique. While testing with model No. 10 under conditions of natural turbulence and with a 1.0 mm wire fitted, measurement was made of tangential stresses on the model surface (see section 5 and Fig. 13).

Specially conducted experiment affirmed the validity of the recommended by most towing tanks location of a wire on models of large sizes, at a distance equal to 0.05L from the forward perpendicular.

The main reason for the restricted application of rods, grids and rough profiles arranged in front of the towed model is a wake appearing behind a stimulator and resulting in decrease of speed of water surrounding the model. Due to the change in the wake intensity with distance away from the stimulator, it is practically impossible to apply sufficiently accurate corrections allowing for resistance to be affected by wake. However, as the data available are not adequate to assess the magnitude of wake and effectiveness of turbulence-producing devices dealt with, it was decided to investigate the flow behind certain types of these devices. A rod of 10 mm diameter, three rods of the same diameter spaced 100 mm apart, six rods of 3 mm diameter, spaced 50 mm, a grid with 20 mm × 20 mm dimensions and 1.0 mm diameter of wire, a rough profile were selected for the tests.

During the tests the magnitude of a wake behind the stimulator was measured and rough estimation of the turbulence degree in a wake was made. Experiments have shown that the magnitude of wake behind the stimulator at a distance of 1.0 m varies from 6.0 % to 28 % (depending on the configuration of stimulator used) and decreases appreciably, down to 4.0 % - 13% at a distance equal to 4 m. The assessment of the degree of initial stream turbulence during the experiments was made behind a rod stimulator from the resistance of sphere, the diameter of rod being 10 mm. The resistance of sphere in water was measured by a specially developed strain-gauge dynamometer. While treating the results, correction was introduced to allow for the influence of wake. The magnitudes of the degree of initial turbulence are given in Table 3.

In spite of the possibility of producing the high degree of initial turbulence, the stimulators just discussed when testing in a towing tank cannot be used, due to the existence of a wake varying in direction regarding the motion of model and having great magnitude.

TABLE 3.

Variation in degree of stream turbulence behind a rod stimulator.

Distance from stimulator in m	1.0	2.5	3.88
Degree of turbulence in per cent	2.87	2.10	1.56

As a result of numerous model tests carried out in the Towing Tank with the use of different and mutually checked experimental methods, it was found that when resistance tests were carried out in a tank of Froude type with models 5-6 m long having main particulars similar to those indicated in Table I, the most effective

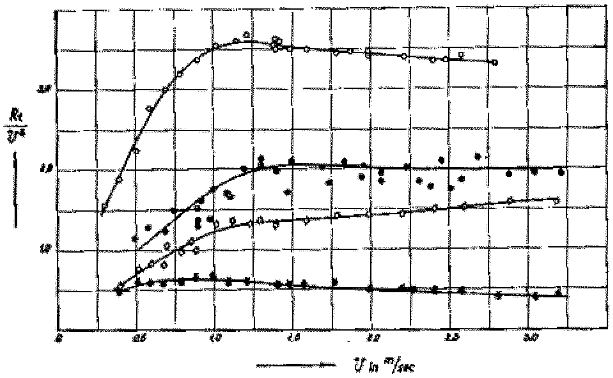


FIG. 14.

Results of measurement of trip wire resistance.

○○○ — 2.0 mm diameter wire.

●●● — 1.5 mm diameter wire.

⌀⌀⌀ — 1.0 mm diameter wire.

●●● — resistance of dynamometer platform.

stimulator was a 1.0 to 1.5 mm diameter trip wire located at 0.05L from the forward perpendicular. In this case, the edge of laminar area was fixed at the place of trip wire, at Reynolds numbers $R = 3 - 4.10^6$. In testing with models 1.5 to 2.0 m long having similar lines and main particulars as mentioned above, trip wire appeared to be also the most effective stimulator, but with 2.0 mm wire. Here the laminar edge was established at the place of wire, at Reynolds numbers $Re \geqslant 1.10^6$.

5. *Investigation of the Trip Wire Resistance.*

Resistance of a stimulator placed on the surface of a model tested, though not relatively great, however introduces some element of uncertainty in the results of resistance tests with large models, and when determining the resistance of small models this can give rise to appreciable errors. However, it was impossible to exclude this resistance due to the inaccuracy of the only practical way for determining the resistance of model with stimulator and that without it, at the towing speeds, at which there are no appreciable laminar areas in the boundary layer of model.

With a view to obtaining the more accurate data about the resistance of wire stimulators and also to be able to make assessment of the effect of variation in wire diameter on its own resistance in carrying out this work, special resistance tests with models were run in the towing tank when using the electroinductive dynamometer developed for this purpose (see section I). During these tests resistance measurements were made on the portion of a wire 50 mm long cut out of the wire stimulator, at the usual location, i.e. at a distance of 0.05L from the forward perpendicular. Resistance of the dynamometer platform on which a cut part of the wire under test was fixed, was excluded from the results, after particular measurement of this resistance was made, when the stimulator was not connected with the small platform but was located at a distance of 0.05-0.10 mm from it. The results of measurements for wires 1.0 mm, 1.5 mm and 2.0 mm respectively are given in Figure 14. In the same figure the resistance of the platform is also indicated. As seen in the diagram, the character of changes in resistance depending on the speed of run is essentially the same for all the three of stimulator's sizes and starting from the speed of 1.2 m/sec it can be assumed to be proportional to the square of model speed.

For the models tested in carrying out this work, the calculation of wire's resistance allowance made in accordance with the test results showed that at the relatively high speeds of run this allowance is only a part of the total increase in residuary resistance coefficient of model when the stimulator is fitted compared with that without stimulator. Indeed, in the case of model No. 10, at Froude number $Fr = 0.2$ the allowance for the resistance of a 1.0 mm wire is equal to $\Delta C_t' = 0.044.\ 10^{-3}$, while the allowance for the resistance of the same wire which is found to be the difference of resistance for the above model with fitted stimulator and that whithout it is equal to $\Delta\ C_t = 0.08\ .\ 10^{-3}$. The noted differencies in the allowances for resistance of stimulator there were observed in towing tanks and formerly in rough estimation of the wire resistance. The cited data obtained by direct measurements of the resistance, combined with the results of boundary layer investigations, seemed to indicate the existence of some unknown additional reasons causing the increase of the resistance of models when stimulators are fitted.

With a view to investigating the hydrodynamical aspects of the effects of wire stimulators, tests with model No. 10 having parabolic lines were carried out. In carrying out these tests tangential stresses on the model surface were measured under conditions of natural turbulence and with a 1.0 mm wire stimulator fitted at a distance of 0.05L from the stem. While testing, the dynamometer for tangential stresses (see section I) was arranged on the waterline of model, at a distance of 0.12 m from the water surface spacing $x = 0.3$ m and $x = 0.6$ m from the stem with no stimulator fitted and spacing $\Delta x = 0.35$ m; $\Delta x = 0.10$ m; $\Delta x = 0.05$ m from the stimulator. As a result of the experiment performed on the base of the measured tangential stresses the relation $C_f = f(\text{Re})$ shown in Figure 13 was obtained. In the same figure values of skin friction coefficient for the plate in laminar and turbulent flows as calculated according to formulae: $C_f = \frac{0.664}{\sqrt{\text{Re}_x}}$ and $C_f = \frac{0.370}{\text{Lg Re}_x^{2584}}$ respectively are plotted.

It is evident from the diagram (Fig. 13) when testing under conditions of natural turbulence the coefficient of tangential stresses C_f at sections $x = 0.3$ and $x = 0.6$ with increasing the Reynolds number in the range of $\text{Re}_x = (1\text{-}5) \cdot 10^5$ varies equidistantly to laminar friction of the plate exceeding the values of this curve by the amount equal to $\sim 1.0 . 10^{-3}$. When a stimulator is fitted on a model at the section $x = 0.6$ m, i.e. at a distance of $\Delta x = 0.35$ m from the stimulator, skin friction coefficient varies equidistantly exceeding the values of this curve by a definite amount equal to $\sim 1.3 . 10^{-3}$. The estimation made to determine the local friction forces for model No. 10 when using pressure distribution obtained from the experiment did not permit to explain the said systematic increase in friction coefficient compared with that of the plate due to the curvature influence. The additional resistance of the working element of the dynamometer due to the flow passing in the gaps between the small platform and the model hull evidently accounts for this discrepancy. The mentioned resistance should vary in proportion to the square of speed. In the case under consideration this takes place when the difference in the measured local friction coefficient of the plate is practically independent of the model speed and only in the turbulent regime it is slightly greater.

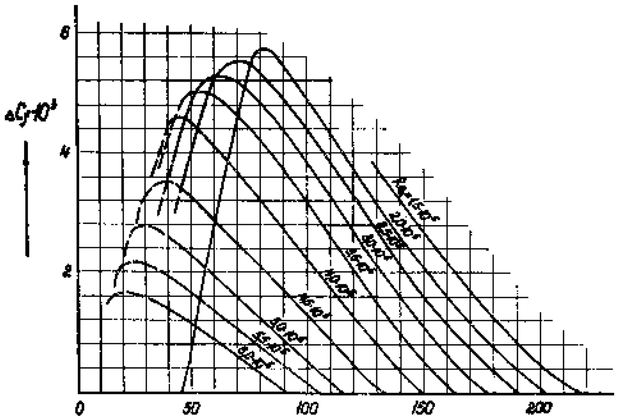


FIG. 15.

Curves of changes in tangential stresses due to trip wire.

Variation in the measured values of skin friction coefficient with and without stimulator that takes place at the Reynolds numbers corresponding to Froude numbers $\text{Fr} = 0.2\text{-}0.22$ for model No. 10 is due to the change in water speed surrounding the hull at the place of dynamometer due to wavemaking.

At Reynolds number $\text{Re}_x = 5.0 . 10^5$, under conditions of natural turbulence there is a sudden increase in the measured friction coefficient corresponding to the transition region in the boundary layer of the model. Friction stresses in this case somewhat exceed those for the turbulent region, at section $\Delta x = 0.35$ m. With subsequent increase of Reynolds number, friction stresses decrease again varying approximately equidistantly to turbulent friction line of plate.

The validity of the results obtained is confirmed by a number of data. The value of the critical Reynolds number $\text{Re}_c = 5.6 . 10^5$, at which a change of local friction coefficient typical for transition takes place, approaches values of the critical Reynolds numbers obtained under conditions of natural turbulence in testing model No. 10 when using the chemical method ($\text{Re}_{xc} = 5.0 . 10^5$) and hot-wire technique ($\text{Re}_{xc} = 4.8 . 10^5$). The values of skin friction coefficient for the model in question not fitted with stimulator which were found by measurement at sections $x = 0.3$ and $x = 0.6$, practically coincided, which is to be expected for the model with fine lines. Measurements made at different times with a view to checking the results in these tests showed that this coincidence is quite satisfactory.

The results of measurements of tangential stresses made on the surface of model No. 10, at different distances from the stimulator are given in the same figure. The rate of changes in skin friction coefficient then will be quite different from that at a great distance away from the stimulator. With Reynolds number increasing tangential stresses on the model surface immediately behind a stimulator show a sharp increase attaining a maximum value, which (at $\Delta x = 50$ mm) is 5.5. times as large as compared to that for laminar regime and approximately twice for turbulent regime.

As Re_x increases, tangential stresses decrease to values, corresponding to the measured stresses on the surface of model, at a distance great enough behind the stimulator. Then in the range of the stated Froude numbers the effect of free surface is evident (see curves C_f at $\Delta x = 0.05$ m and $\Delta x = 0.10$ m). When using the test results with model No. 10 and extrapolation diagram for tangential stresses behind a stimulator, along the waterline, was drawn and shown in Figure 15. The region of the increased tangential stresses behind the wire stimulator, at the Reynolds number $Re_x = (1.5\text{-}4.0) \,.\, 10^5$ extends for the distance of 200 - 150 mm behind it. With Reynolds number increasing this region is reduced. Fourfold increase of Re_x decreases the extent of raised tangential stresses twofold.

Taking into account the above results of tangential stresses measured exactly behind the wire, the fact may be considered as established that, apart from the general stimulation effect exerted in the boundary layer of towed model, the stimulator is responsible for the local hydrodynamical influence on the fairing of model resulting in increase of tangential stresses on the model surface in the limited region behind the stimulator. Additional resistance of the model due to this influence must be regarded as component of the total resistance of stimulator. Therefore, the resistance of the stimulator should be considered to consist of own resistance and resistance due to its local effect.

The magnitude of the additional resistance coefficient of model as influenced by the local effect of stimulator $\Delta C_t'' = 0.043.10^{-3}$ has been determined by integration of the measured tangential stresses, at Froude number $Fr = 0.2$. Thus, the resistance coefficient of a 1.0 mm wire for model No. 10, at Froude number $Fr = 0.2$ equal to the sum of the stimulator's own resistance and the resistance owing to its local effect, amounts to $0.087 \,.\, 10^{-3}$, which almost coincides with the value of correction for stimulator's resistance $\Delta C_t = 0.08 \,.\, 10^{-3}$ determined from the measurement of the model resistance with stimulator and without it.

The decrease of the resistance coefficient for the model referred to, due to the effect of fixed laminar area, as shown by the test results, at Froude number $Fr = 0.2$, with 1.0 mm wire found by calculation is $0.096 \,.\, 10^{-3}$. Thus, the resistance augmentation for the model in question due to the resistance of stimulator itself, in this case is fully compensated by decrease the resistance coefficient due to the persistence of the laminar area ahead of the stimulator. The above results of the experiments and calculations can be applied for estimating the trip wire resistance when used in resistance tests in towing tanks.

Conclusions.

1. Resistance tests with models in towing tanks of Froude type, at Reynolds numbers smaller than $1.5.10^7$, should be carried out with the use of turbulence-producing devices.
2. The most effective of the stimulators used in towing tanks at present is a trip wire.
3. When testing in tanks with models 5-7 m long a trip wire of 1.0-1.5 mm diameter is recommended. With large raked stem, as well as with large angles of entrance of waterlines the diameter of trip wire should be 2.0 mm.
4. The usual practice in towing tanks of placing a trip wire at 0.05L from the forward perpendicular may be considered as justified.
5. The use of the recommended sizes of trip wire in testing with models 5 to 7 m long enables to obtain reliable results of resistance tests at Reynolds numbers varying from $(3.0 - 4.0) \,.\, 10^6$ to $1.5 \,.\, 10^7$.
6. When carrying out resistance tests with model lengths smaller than 5 m in towing tanks of Froude type, diameter of trip wire should be chosen 1.5 to 2.0 mm. A correction for the wire own resistance should be introduced in the results of tests, to be determined from the results given in this work.
7. Trip wire resistance should be considered to consist of the stimulator own resistance and that due to its local effect on the tangential stresses in the restricted region behind the stimulator.
8. While testing in a tank it is necessary to take account of the residuary flow after previous runs maintaining definite time intervals between successive runs.
9. Should doubt arise as to reliability of the results of resistance tests, it is recommended to check the flow in the boundary layer of the model tested by means of the chemical method showing the required accuracy.
10. In view of complexity and variety of phenomena occurring in the boundary layer of models tested in towing tanks, further study of these phenomena based on the investigations of boundary layer of models is necessary.

LIST OF SYMBOLS

L	model length on waterline.
B	breadth of model.
T	draught of model.
∇	displacement.
S	wetted surface of model.
δ	block coefficient.
φ	prismatic coefficient.
φ_β	prismatic coefficient of fore-body.
β	midship section coefficient.
$\frac{L}{B}$	aspect ratio of model.
α	angle of entrance of waterline
x	distance from the forward perpendicular to a given point of model surface.
y	distance in normal from the model surface to a given point.
z	distance of a given point of surface from reference plane.
X_L, X_t	coordinates of the edge for laminar and turbulent regions in the boundary layer.
δ	thickness of boundary layer.
v	model speed.
U	mean flow velocity in the boundary layer.
U_δ	flow velocity at the edge of boundary layer.
U'	fluctuation velocity component in the boundary layer.
$\sqrt{\overline{U'^2}}$	mean square value of fluctuation velocity component in the boundary layer.
ρ	fluid density.
ν	kinematic coefficient.
g	acceleration due to gravity.

$Fr = \frac{v}{\sqrt{gL}}$	Froude number.
$Re = \frac{vL}{\nu}$	Reynolds number.
$Re_x = \frac{ux}{\nu}$	local Reynolds number
$Re_{xc} = \frac{vx_t}{\nu}$	critical Reynolds number.
$\epsilon = \frac{\sqrt{\overline{u'^2}}}{v}$	degree of turbulence.
R	towing resistance of model.
R_t	resistance of stimulator.
τ	tangential stresses on the model surface.
P	normal pressure.
C_T	total resistance coefficient of model.
C_R	residuary resistance coefficient.
$C_f = \frac{\tau}{\frac{\rho v^2}{2}}$	coefficient of tangential stresses.
ΔC_t	allowance for the resistance of stimulator to resistance coefficient of model.
$\Delta C_t'$	allowance for the stimulator own resistance to resistance coefficient of model.
$\Delta C_t''$	allowance for resistance owing to local effect of stimulator to resistance coefficient of model.
ΔC_f	variation in coefficient of tangential stresses on the model surface due to stimulator.
$\bar{p} = \frac{p}{\frac{\rho v^2}{2}}$	pressure coefficient.

INFORMAL DISCUSSION

MORNING SESSION

The Chairman, Prof. van Lammeren.

Prof. van Lammeren opens the Session.

Prof. Prohaska.

Prof. Prohaska reads the Committee Report.

Prof. G. Kempf.

Proposal for measuring technique with full models (5,6).

My proposal of testing the resistance of models of full form with a block coefficient greater than 0,8 not only on a fixed straight course but similar to the ship on a sinusoidal yawing course of about ± 1° deviation to get more steady measurements has been followed by the Hamburg Tank for a normal model of 6 m length and a block coefficient of 0,8.

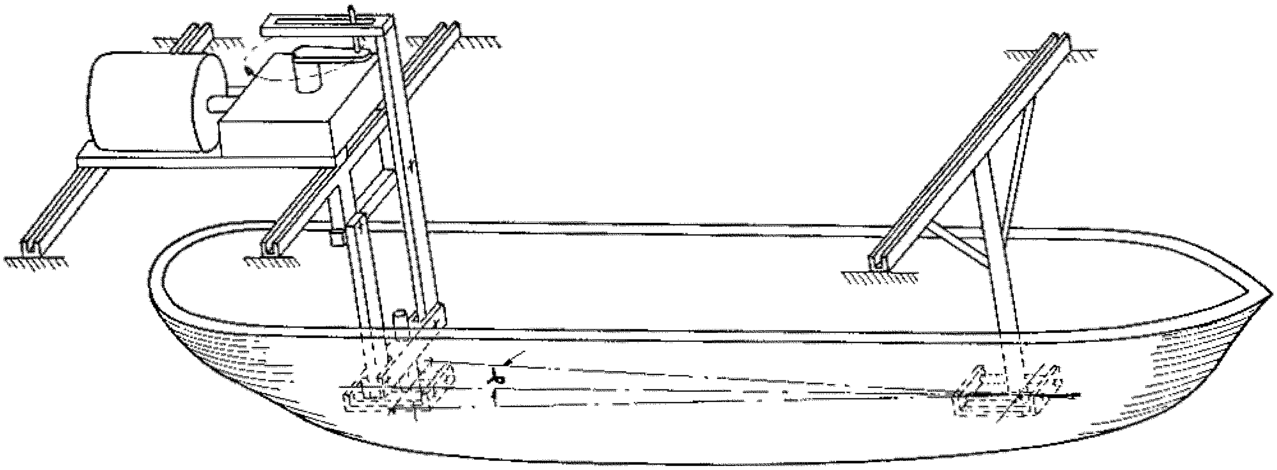
I am very grateful to Prof. Lerbs and Dr. Grim for having executed these experiments with several angles and periods of yawing at service speed.

The result was the following:

The resistance of the yawing model with a course angle of ± 0,8° alternating in a period similar to that of the ship was 2 % greater than the average resistance of the model on a fixed straight course. For full models the difference of resistance measurements from their average will be mostly no less than ±2 %. The resistance of the yawing model lies at the upper limit of the resistance-taper of the straight running model.

Therefore the upper limit of the resistance taper instead of its average seems to be more realistic for model-ships correlation of full forms.

For self propelled full models the yawing method will give more realistic results for the model-ship correlation.



γ = yawing amplitude.

FIG. 1.

Yaw-making device.

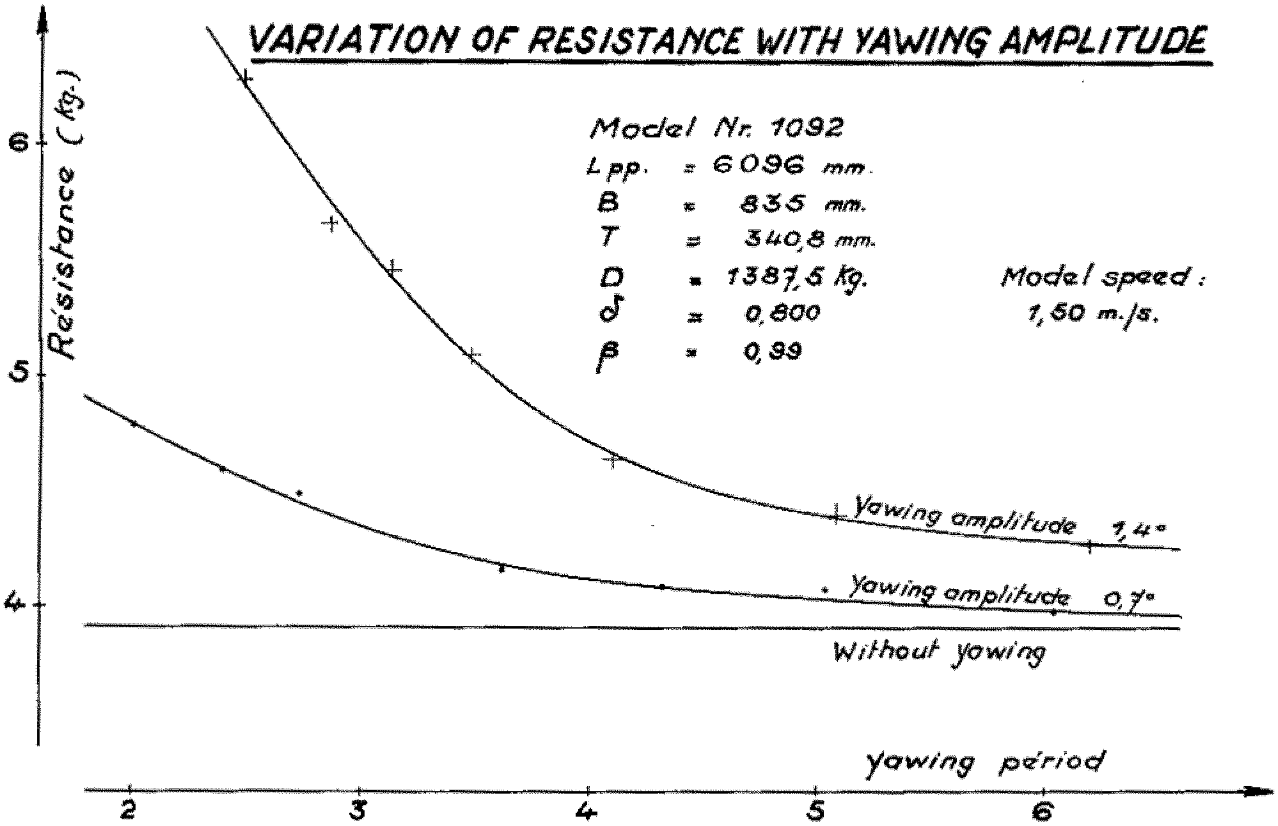


FIG. 2.
Variation of resistance with yawing amplitude.

R. Adm. Brard (translated from French).

1. The Committee Report points out that during the last three years Towing Tanks and Hydrodynamic Laboratories have done a great amount of work on the problems connected with Resistance.

However, on the most essential point for practical purposes, i.e allowances which are to be brought to the friction line chosen as a reference, no rule can at the present time be recommanded by the Committee.

This conclusion, although rightful in the whole, may be, owing to its negative character a subject of concern for the customers of Towing Tanks to a greater extent than it would be well-founded. I think it would be perhaps possible to improve it by investigating separately each parts of the general problem.

2. I think that some of these problems are related to the model, others to the ship and others to ship-model correlation, i.e scale effect.

In the first group we find those that Mr. R.N. Newton listed under the heads *a*) blockage effect and, *b*) unexplained changes in the properties of the tank water. I should like to add a′) relative to form effect and b′) relative to change in the state of the model surface.

3. As regards item *a*), the Committee points out that various procedures are available for calculating blockage effect, at least for rather low values of Froude number. As for me, I should wish an endeavour to be done in order to define accurately what the blockage effect actually is, and how it is brought about (is it due, as suggested by M. Wigley at the 8th ITTC to the energy transmitted to the water by the model itself and to the resulting oscillations of water).

I should like also that a formula would be given for calculating blockage effect, which at least gives the main part and leaves only a random residue.

As regards point *a*′) namely form effect, various opinions have been expressed; it has been said that it is independent of the scale and also that it decreases when the size of model increases. On this point also, I believe that it would be necessary to bring precisions, or at least that recommendations be formulated on the procedure to be adopted in order to advance the question.

As regards point *b*) my opinion is that the use of standard models will result in some progress, but I do not believe that point *b'* (i.e. change in the state of the model surface) might be disregarded. The effect of this state must not to be neglected as mentionned by Dr. Castagneto, when painted wood models are used, but it is also present for wax models. Therefore, in all towing tanks special care is taken for the models to be correctly wetted when running a test. It would be interesting to make sure by means, for instance, of measurement in the boundary layer, that no change has been brought in the flow around the models by changes in the state of the surface from one day to the other.

In his paper Prof. E. V. Telfer indicates that a statistic of standard model test results is able to give evaluations both of blockage effect and of yearly variations of resistance. If this is also the opinion of this Conference, the towing tanks using standard models must be invited to transmit their results to the Committee and this latter invited to perform such a statistical analysis in a form similar or identical to the forms suggested by Prof. Telfer.

4. Problems relative to full-scale ship have been listed by Mr. Newton under heads *d* to *j*.

I think that trial results, as reported by M. Clements, show superabundantly, the advantage of welding. On the other hand, conclusions are by far less clear regarding state of the surface. Doubt comes, as it seems, from the fact that this state is not known in many cases (26 out of 47 for "A" class). Then it would be of interest that the Conference recommends a procedure convenient for determining this state of surface with sufficient accuracy to provide usefulness and in a time sufficiently short for shipowners and shipbuilders to agree willingly to its application.

5. Problems relative to model-ship correlation are in most cases common problem for both Resistance and Propulsion Committee. This is the reason why, speaking as Chairman of the Standing Committee, I asked in October 1959 to both Committee to collect together some of their results. So I will have to mention those problems again when speaking of propulsion. One of them, however, seems to me to be essentially the concern of Resistance Committee, I mean the scale effect on following wave. I think that many tanks have already observed that there are some risks of scatter in the results of resistance measurements in areas where there is high interaction between the forward and the after system of waves. Some tanks (Haslar for instance) seem to bring an allowance for this scale effect. Could the Conference indicate which procedure is recommended?

6. I think that the Conference could usefully express an opinion on Prof. Kemp's suggestion concerning yawing models.

7. Finally, rather divergent views, at least apparently have been expressed on the ITTC-57 line; some delegates feel that the slope is too steep and the values of C_F for lower Reynolds number too high.

In order to avoid some errors of interpretation by the Towing Tank customers, it would be useful that the Conference would remind for what specific purpose this line has been imagined.

Dr. K. E. Schoenherr.

Remarks on Friction Formulation.

Since the last Conference at Madrid the Taylor Model Basin has studied the friction formulation proposed at that Conference as an interim solution, pending final clarification of the problems, but has felt it unwise to adopt this formulation immediately unless all members of the American Towing Tank Conference should agree to use it. Obviously, regional agreement must precede international agreement.

At the 1959 Conference of A.T.T.C. the question of changing to the new formulation was discussed but it was agreed to take no action on it.

In the experience of the Taylor Model Basin, the A.T.T.C. 1947 formulation plus a correlation allowance derived from full scale tests has served its purpose very well, so that there is no compelling reason for dropping it post haste. On the other hand, there are good reasons for going slow on making a change. To name a few: Taylor's Standard Series, which is generally used as a measure of comparison of the resistance of new designs was recomputed to the A.T.T.C. formula, in 1947, and Series 60, now widely used by merchant ship designers for estimating purposes, is also based on this formula. To recompute these series and the large amount of other data on which naval designers rely to a new formulation is a major job and naturally one hesitates to undertake it when basically nothing is to be gained by it. Another reason for going slow is the fact that the Davidson Laboratory has found that the I.T.T.C. formulation does not give uniformly improved correlation of small and large model tests as it was claimed to give when the new formulation was proposed.

In view of this, the Taylor Model Basin will use the I.T.T.C. 1957 formula for scientific work of international scope but will continue to use the A.T.T.C. formula for its every day work, at least until the next meeting of the American Towing Tank Conference in 1962, at which the question of making a change will be rediscussed. In the meantime, the work of deriving correlation factors from full scale tests, such as those presented by Mr. Hadler, will be continued.

Mr. R. N. Newton.

I will try to keep my remarks as general as possible and refer to the three items which are dealt with in the Committee Report.

Model-Ship Correlation Allowance ΔC_T :

It might be argued that because, at the present time, it is not possible to decide upon values for $\Delta\ C_T$, the interim 1957 I.T.T.C. line can serve little purpose. Actually this is not so; the I.T.T.C. line is useful for international interchange of information if the participants state what ΔC_T they use in the analysis so that a broad comparison of results, at least, is provided.

Viewed in retrospect, if an *interim* model-ship correlation line had not been arrived at, we would still be arguing about it, indeed we still are apparently, and giving no real attention to the much more important task of trying to arrive at reliable allowances, i.e. the task of reducing the scatter and magnitude of these allowances as determined by present methods of analysis.

This should be made the primary objective of the Committee in the next three years, or longer if necessary. The difficulty is to decide upon a method of tackling the problem. Several methods have been suggested in the present report, in some formal contributions, and in other publications. Most of these fail to reduce either the magnitude or the scatter, leaving the owner or user in considerable doubt as to the validity of the prediction.

Much time could be spent in debate on possible methods of approach but whether this would provide any real guidance to the Committee is doubtful and there is no time to waste on futile argument. Having said this I venture to suggest that linear regression, statistics, or similar mathematical device is no substitute for application of empirical data and logical reliable analysis in the search for consistent and reliable allowances.

Some idea of what can be done to break down ΔC_T into components and reduce the magnitude and scatter is indicated in the A.E.W. formal contribution and it is suggested this, or similar approach, should be adopted.

I would go further and make two other suggestions, irrespective of what method of approach is adopted:

(*a*) It is highly important that attention be directed to the probability that different correlation allowances may be necessary for different types of ship.

(*b*) It is also important to decide upon standard conditions of experiments and trials with which to associate the finally derived correlation allowances.

Standard Models.

In continuance of the discussion on the paper presented at the R.I.N.A. in April, the following comments bear serious consideration:

(i) It took R. E. Froude several years of investigation to arrive at a method of correcting for random variation in resistance. The method he developed is still in use at A.E.W. and very effective. As such it is worth trying.

(ii) It has yet to be established whether a form as full as the one presently being used by several ship tanks will serve the purpose as well as the fine, double ended, IRIS form.
Dr. Kempf's formal contribution and his remarks this morning are very significant in this connection.

(iii) A mean curve through the resistance variations of a standard model, measured at frequent intervals over a space of years is as liable to exhibit a level characteristic as it is to rise or fall, gradually or suddenly.

Form Effect.

If the curves given in Appendix 2 are supposed to demonstrate so-called "form effect" then it is not surprising that the Committee "has not felt itself able to undertake any detailed analysis" for they indicate no consistent trend.

Dr. Masao Kinoshita.

On ΔC_F analysis of some supertankers recently built, my opinion concerning the model-ship correlation allowances for use with the I.T.T.C. 1957 line, was fully summarized in the Committee Report. That was we are not yet in a position to make any recommandations of specific values of the correlation allowances for prediction work.

And now, in spite of a few but carefully obtained data presented in my own contribution "On ΔC_F analysis of some supertankers recently built", which has been compiled after that Committee Report, I do not think it necessary to amend my opinion.

The Towing Tank Committee of Japan has a plan to continue a joint programme of organized research in finding out the proper values of ΔC_F for use with the I.T.T.C. line, which can be use in common to high speed vessels and mammoth tankers.

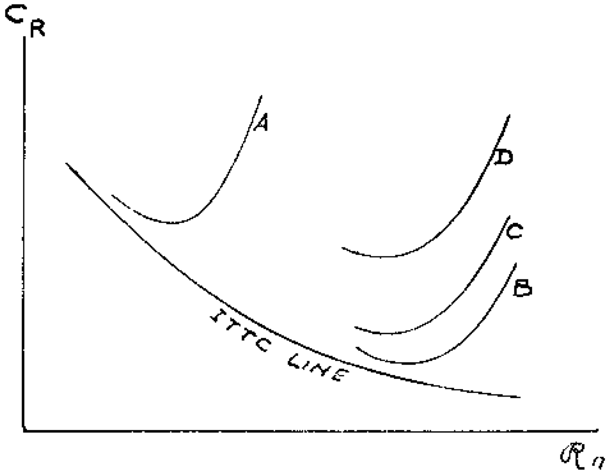
The I.T.T.C. line implies a form factor in it as a mean value, for instance $K \sim 0.12\text{-}0.13$ or $\Delta \log A \sim 0.28$.

I am of the opinion that the first thing we should do in the coming three years is to make an effort to introduce an adequate system of form factors into the 1957 I.T.T.C. formulation, by which the existing large scatter of the ΔC_F values, just looking like the Milky Way in the sky, may be made narrower, and by which the existing discrimination between the ΔC_F values of high speed cargo vessels and oil tankers due to the difference in their shape just looking like separate constellations in the Milky Way may disappear.

Prof. C. Prohaska.

In the figure below curve "A" represents the specific resistance of the model from which "B" the specific net-resistance of the ship is deduced. Adding ΔC_T, one obtains curve "C" and dividing by the propulsive efficiency, curve "D", a non-dimensional power coefficient, is obtained.

Where — and only where — this curve corresponds with the data obtained from the trials, the ΔC_T has been correctly assessed. It is therefore obvious that ΔC_T is dependent on the efficiency coefficient used. The usual procedures for ship predictions is to apply the efficiencies derived from the model test. Whether or not it is desirable to change this procedure will be under discussion next week; but I would like to take this opportunity to draw your attention to two contributions under the heading of Propulsion; namely, that of Mr. Lindgren and Mr. Johnson, and that from HyA Denmark.



Next, referring to Dr. Schoenherr's remarks on the respective merits of the A.T.T.C. and I.T.T.C. lines and to the written contribution from the Davidson Laboratory regarding comparative tests between large and small models, I have some doubts regarding the conclusions drawn from this comparison. Since the small models were tested with a strut as a stimulator, the wake of the strut might have influenced the resistance of the models. At HyA we have made repeated tests with one standard model (fitted with studs) and got very consistent results at all Reynolds' numbers. We also tested it with a strut in front of the model. The dimensions of the strut were scaled up from the E.T.T. strut and so was its distance from the stern of the model. The experiments indicate a *reduction* of resistance of about 4 per cent, corresponding roughly to 10 per cent of the strut resistance. If a similar correction were applied to the E.T.T models, they probably would fit the I.T.T.C. line better than the A.T.T.C. line.

Dr. F. Castagneto.

In my written contribution I pointed out the need of an agreement on a standard overloading ΔC_F to be used in all routine work with the I.T.T.C. skin friction line. The same proposal I have already supported at the last Conference in Madrid; therefore I was rather disappointed finding no recommandations on this matter in the Committee Report.

It is true that from a scientific point of view, our present knowledge is not sufficient to choose a correct value of ΔC_T, but the same could have been said of the I.T.T.C. line itself, which has been accepted "as an interim solution for pratical engineering purposes".

The necessity of discontinuing use of Froude coefficients was very felt in Italy, and the I.T.T.C. line was accepted with favour by naval architects, shipbuilders and owners. Consequently the new correlation method was used more and more frequently, and since last July it has become the official correlation method to be used by the Rome Tank in all routine works for customers.

Lacking international decisions, a standard overloading $\Delta C_F = .0002$ was agreed for tank experiments, and this value has been considered by italian shipbuilders, the most suitable for all news ships.

To facilitate comparison with models previously tested, customers will be supplied for a certain period of time (two of three years) with both I.T.T.C. and Froude results.

Besides, the official towing test reports will quote in a footnote the amount in effective horsepowers, of a ΔC_T unity (0.0001) wich is of the simple form $\Delta P_E = k. V^a$.

Values for different overloadings may in this way easily be deduced by customers themselves. No extra allowance is added, for the present, by our ship model bassin, to tank data, and ship estimates are left to the shipbuilders experience and responsibility, but almost all sea trials results are collected for future analysis.

Mr. A. J. W. Lap.

I should like to make a few remarks about different subjects that are dealt with by the Resistance Committee.

In the first place, with regard to ΔC_T values, the results of an analysis of numerous trial trips conducted by the N.S.M.B. are given in the Committee Report and I have little to add to the remarks made in our contribution to this report. The scatter of the results is very great as seems to be usual with ΔC_T values.

However, the scatter of the ΔC_T allowances on base of the I.T.T.C.1957 line is not greater than that on base of the Froude skin friction coefficients, so that, in principle, the scatter as such cannot be a reason for not trying to establish certain average ΔC_T values on base of the I.T.T.C. 1957 line. The difficulty is, however, that due to differences in measuring and analysing techniques the average ΔC_T values have a tendency to vary from tank to tank.

I should also like to make some remarks concerning the subject of turbulence stimulation. Three most interesting contributions on this subject have been submitted for discussion.

I do not want to discuss the merits of the various stimulators dealt with in these papers, but I should like to discuss the general importance of stimulation with regard to the extrapolation problem. Also, I should like to compare some of the conclusions mentioned in these papers with our experiences at the N.S.M.B. We have some 20 or 25 years of experience with the application of 1 mm tripwires for all our commercial test work as well as for our models used for research. And although I must confess that there are exceptions, and I shall return to these later on, I can say that for most normal cases the generation of turbulent flow and the maintenance of this flow along the whole ship model seems to be not too great a problem, provided:

a) the size of the models is sufficiently large.

b) the speeds of the models are not exceptionnally low.

For the N.S.M.B. using models of 6-7 meters in length and corresponding minimum speeds of the order of 1 meter per second, the problem of stimulation is therefore not a really pressing problem.

As I said there were exceptions and one of them occurs when we are testing models of the earlier mentionned size in our shallow water laboratory. During these tests the minimum speeds are usually much lower, also because we have to use a form factor extrapolation method for this work. For single models we use therefore in this case a normal tripwire at 5 per cent of the length aft of the fore perpendicular, but, in addition, we apply a second tripwire of the same diameter at 10 per cent of the length behind the fore perpendicular. In this way we have found our test results to be pretty consistent.

In our shallow water laboratory we are testing, however, very frequently very large formations of barges, usually varying from 12 to 32 in number, each barge having a length of 4-5 meters and the whole formation having a length of from 20 to 35 meters. For these tests we have adopted the standard procedure of applying the earlier-mentioned twin arrangement of tripwires to every second barge in length. That means that, if we have a fleet of 32 barges in a formation of 8 in length and 4 in width, we apply the twin tripwires to 4 groups of 4 barge models as well as to the towboat model that is pushing the whole formation. We have the experience that this arrangement of tripwires is absolutely necessary if consistent results are to be obtained in the relatively low speed regions concerned.

All this is in agreement with the conclusions of the contribution by Prischemihin and Poostoshny, who recommend a tripwire to be used for models of the size we use them. Instead of the greater tripwire diameter, which they recommend for difficult cases, we use the twin tripwire arrangement.

So when summarizing I can say that in our opinion for the big models there is not such a great problem with regard to the choice of the type of stimulator. Most of the current types, such as tripwires, sand strips, studs a.o. have a sufficient performance, although one is sometimes slightly better than the other.

Now trying to circumscribe the importance of stimulation with regard to the smaller models, I think the problem is the following.

Generally speaking, the tank using big models are of the opinion that a somewhat steeper correlation than the Shoenherr line is necessary. This opinion is based on the comparison of, on the one hand, results obtained with medium size and big models and, on the other hand, on the necessity of having at the ship end positive correlation factors ΔC_T.

Contrary to this, and this becomes completely clear from the contributions by Murray, Numata, and Henschke, and also from other earlier publications, the users of small and very small models seem to be in favour of an extrapolator which is in any way not steeper than the Schoenherr line, because with a steeper line the correlation between their results and those obtained with big models seems to become worse instead of better.

So here we are divided into two groups, each having more or less opposite views with regard to the steepness of extrapolation in the model range that is needed and the arguments of both groups are based on very practical requirements. I am therefore of the opinion that in trying to come to an uniform extrapolation procedure further investigations into the field of turbulence stimulation and also turbulence detection are of the utmost importance, since the results of such investigations might show us, how far the model size may be reduced without penalty and which stimulators have to be used and possibly standardized in order to find an extrapolation procedure that will satisfy both the users of big and small, but not too small, models.

The present state is, in my opinion, that in the small model range the slope of the extrapolator that is found to be necessary for a good correlation with big model results is too much dependent on the techniques and stimulation methods used. We have therefore to standardize these techniques and stimulation methods before an agreement between both viewpoints can expected to be obtained. I have no doubt that an important part of the activities of the new Resistance Committee will have to go into this direction.

I should also like to say a few words about the question of the form factors and some experiences we have had with them so far at the N.S.M.B. Several data on form effects have been brougth to our knowledge, especially by our Japanese friends.

I think that we can agreee that the form effect, with which I mean the difference in specific frictional resistance between a ship form and the corresponding flat plate, is mainly due to the difference in velocity distribution in the potential flow outside the boundary layer along the model and the plate, on the one hand, and on the direct effect of the curvature of the ship forms on the boundary layer, on the other hand.

The first mentioned factor is rather strongly affected by the blockage. For a high value of the blockage factor and therefore especially at shallow and restricted waters, very high form factors are therefore found if the total specific resistance is plotted in the usual way on a Reynolds number base.

In the case of big fleets of large models, pushed by a towboat and tested at shallow water, the form factors become therefore so great that neglecting them leads to trial and service predictions which in our opinion are so ridiculously high, that no shipowner would ever believe them.

In our shallow water tank, which has now been in operation for two years, we have therefore applied the Δ log A form factor method right from the beginning. But since we are of the opinion that the number of form factor extrapolation methods can be reduced by giving them a common base in the I.T.T.C. 1957 line, we have decided to use our method on base of the I.T.T.C. 1957 line in order not to complicate things.

In this way we have found our predictions to be in reasonable agreement with the actual service performances of the towboat concerned.

Possibly it is interesting to mention some more of our experiences in the application of form factors for routine work in this field, because exactly here all phenomena and therefore all difficulties are so very pronounced. The form factors are very great and, due to the relatively low model speeds at which they have to be determined, the difficulties in determining them exactly are also relatively great. Accordingly, we have found that in comparative tests with models of slightly different forms, the comparison of such models may be seriously affected by an erroneous determination of the form factors at the very low speeds.

In those cases we use therefore the same form factor for all the variations in form of the model or model fleet. In this way we are neglecting a usually small error in the actual form factor but on the other hand we have the advantage of avoiding a much greater possible experimental error in the determination of the form factor. So, when working in this way, we prevent the drawing of wrong conclusions from our predictions at the higher speeds, where the experimental accuracy suffers much less from insufficient turbulence stimulation and other difficulties.

I wanted to mention these experiences, which we have in a rather specialised field of our work, because they are so very pronounced. In principle the same things will occur, however, altough to a much smaller degree, when form factor methods will be applied to single models in deep water.

We, at the N.S.M.B. are therefore inclined to think that the application of form factors for this deep water work cannot be recommended unless these form factors can really be standardized so that the effect of errors in their experimental determination is excluded. And even then we think that a number of difficulties will be met with in routine work.

Mr. A. V. Sentic.

I wish to make a brief comment in connection with Mr. Newton's written contribution. Mr. Newton enumerated the components of the correlation allowance. I fully agree with all of them, but I believe that one or, may be, more components are still missing in Mr. Newton's list. I would call these missing components, inaccuracy of the ship full form and peculiarities of the quality of the sea water. I shall try to explain it.

Within last two years our Institute executed measured mile trials on twelve sister cargo ships of 10.000 tdw. All those ships were built by the same shipyard, according to the same lines plan, and mostly fitted with the same propellers. But in spite of that, at trials they gave different results. There were differences of about 23 % in power between the best and the worst ship. We have analysed this case and we were not able to find any intelligent explanation for such a phenomena.

The trials of both ships, I mean the best and the worst one, were carried out under ideal weather conditions, the difference in their displacement was merely 3 %, they had practically equal propellers, they were both newly painted just out of dock, the measurements were done by the same people and with the same instrumentation.

The only possible explanation is that in reality these ships had not equal hull form, though they are supposed to have it. Until now we don't know at all what is the accuracy of a ship hull form compared to her lines plan. On the other hand maybe there are some unexplained changes in the quality of the sea water as there are in the quality of the tank water.

Therefore I would suggest to make a thorough investigation of the trial trip records of sister ships in order to find out why equal ships on trials don't give equal results. Furthermore we should try to find out if the quality of the sea water is liable to such peculiarities as were observed in the quality of the tank water. This would be another component of the correlation factor to be added to Mr. Newton's list.

Mr. H. B Lindgren.

My first point is similar to the point a moment ago mentioned by Prof. Prohaska. It seems to me as if an allowance of the type ΔC_T can cause a great deal of confusion. Our experience from the analysis of model and ship test results is that in the region of Reynolds number $\approx 10^9$, ΔC_T should be about .0002 — .0003. On the other hand, in case the influence of scale effects on the propulsive factors are regarded (primarily wake scale effects) the figure lowers to zero or .0001. This is, however, necessary in case the prediction of ship trial results should be correct not only with regard to power but also with regard to the number of revolutions.

The correlation between resistance of large and small models has been treated by Numata and Henschke among others. They both conclude that the ITTC line is too steep. At SSPA we have reanalysed 10 series of geosim tests with different type of ship models. The residuary resistance coefficients obtained have been plotted on base of blockage assuming that the frictional resistance coefficients follow the ITTC 1957 formula. Higher residuary resistance for the larger models indicates that the friction line is too steep. Other possible explanations are that wall effect has influenced the resistance of the larger models or that laminar flow has affected the smaller models. Only for three of the series, this situation occurred and a normal correction for blockage effects was enough to change the trend. For seven series the case was the opposite, i.e. the residuary resistance coefficients were lower for the larger models. This indicates that the ITTC line *ought to be slightly steeper*. All the results correspond to $R_N > \cdot 10^6$, whereas most of the Numata and Henschke investigations were carried out in a slightly lower region ($5.10^5 - 4 . 10^6$).

Prof. A. Di Bella

Prof. Di Bella reads his formal contribution.

Mr. S. T. Mathews.

I should like to say a few words regarding the data supplied by the National Research Council on form effect and shown in the Committee Report. Those data were supplied in the form of experimental spots which are plotted in the figure and joined by straight lines. Normally at National Research Council we plot resistance experiment results in lbs on a base of model speed in ft/sec. and in the Committee Report I have seen for the first time the information supplied by National Research Council plotted as resistance coefficients on a Reynolds number base. The information given was taken from our files of routine tests which we carried out some years ago and it covering a wide range of forms. In the past we did not usually test models to such low Froude numbers and the data given were all we had in this low range. It suffers a great deal in accuracy due to the scarcity of experimental spots and the low values of resistance for which our present dynamometer is not suitable. In our future routine work we are gathering more low speed data and a more suitable dynamometer is being provided. The existing data, as been stated by the Committee, does show the importance of form effect.

Regarding the standard model, the procedure used for carrying out tests in the British Tanks appears to be excellent. However, the method of comparing results would seem to assume that a given Froude number can be very accurately pre-set when carrying out experiments. Since this is not possible at National Research Council and may also not be in other tanks, I would like to ask if the Committee will take the resulting variations in Froude number from the nominal values in tests into consideration for the analysis of future data supplied.

Regarding the logarithmic method of presentation of propulsion data referred to by Pr. Prohaska, we have used similar methods now for some years at National Research Council for both resistance and propulsion data and it has the merit that all the compatible information about coefficients in use can be considered either on one propulsion diagram or one resistance diagram.

Dr. G Hughes.

I should just like to say a few words about Mr. Lap's remarks concerning the large "form factors" he has found necessary to use to give good model-ship correlation for the long barge trains he has tested in shallow water. He himself indicated that this is really a shallow water or blockage effect; I think therefore he should not confuse this effect wih "form" effect, which is, by definition, an effect of the "form" compared with a flat plate and strictly should be considered with reference to infinitely wide and deep water and has nothing to do with restricted water.

With regard to form and boundary interference effects generally it is questionable whether this Committee can, working as a Committee, determine the dependence of these factors on the hull and tank parameters. It seems to me that this dependence can be determined only by individual effort, and that the Committee's proper function is to consider any such individual proposals and to see if agreement can be reached by the Conference to favour the adoption of any single proposal or to accept a compromise solution if differences exist between individual proposals.

Prof. E. V. Telfer.

Dr. Hughes has already given an excellent defence of the criticism I am about to make. Each Committee has certain terms of reference and all these terms of reference suggest that the Committee should answer certain questions quite definitely and specifically. The Committee's work consists of the work of its members, and I do feel that we should accept a Committee policy that involves the Committee working from a productive standpoint rather than merely taking note of the work of others and confessing they are quite unable to make anything of it! This is a type of criticism that applies to the work of all Committees, and I think it should be noted above all by the Standing Committee.

I wish to introduce the Poona work on turbulence and emphasize the possible advantage of open throat over closed throat triangular trips. This was made evident by flume tests. More work on throat width should be explored. Both variations of the Hama trip are clearly high velocity, high vorticity devices. All other usual devices as trip wires and studs are low-velocity high vorticity devices and then produce a wake. This is particularly the case with rods ahead of a model; and our suggestion of rotating rods appears to get round this difficulty although much more calibration is obviously required.

I would add one word reinforcing Prof. Prohaska's criticism of Dr. Breslin's remarks. I feel our american friends are deceiving themselves in assuming that the 5 ft model, even by stirring up the water, is getting complete turbulence. I think Stevens should try to make the resistance of their models at the low speeds much more turbulent than at the present moment. The need for such work is clearly emphasized by Prof. Di Bella's remarks, which show the complete hopelessness of small models if you do not try to get artificial turbulence induction. I would stress the fact that the American small model in prefering A.T.T.C. line to I.T.T.C. line are ignoring the fact that the latter is chiefly based on the high model and hence more reliable experiences. The small model school should accept the I.T.T.C. line and endeavour to improve their turbulence induction methods.

Prof. G. Weinblum.

In the last years Prof. Schlichting and his school have closely investigated experimentally the effectiveness of trip wires in an unbounded liquid and they have recently proposed a criterion given by the formula $\frac{vd}{\nu} > 700$ or 1.000, say.

A paper by Kraemer will shortly be published in the journal "Zeitschrift für Flugwissenschaften" The formula has the well known shape of the universally accepted smoothness criterion $\frac{vK}{\nu} < 100$.

It is suggested that the validity of the formula should be carefully checked first for wholly submerged bodies; the conclusions may be unfavourable for small models.

Dr. F. H. Todd.

I would like to recommend to the Resistance Committee that it pay special attention to the analysis of $\Delta\ C_T$ into its separate components and give guidance to the towing tanks on how to determine these factors in the light of our present knowledge.

Mr. Newton has mentioned a number of these components, but one is of special interest to those of us engaged in merchant ship design—the measurement of appendage resistance and its extrapolation to the ship. This is particularly important in attempting to decide between the adoption of full bossings or A brackets and open shafts. The latter arrangement may be expected to give rise to less vibration, but the effect on resistance is not known properly. Some tanks assume the specific resistance of both A brackets and bossings as measured on the model to apply directly to the ship, whereas others halve the resistance for A brackets but leave that for full bossings unaltered. Since the appendage resistance in such cases may amount to 12 or 14 per cent of the total in fine, high speed ships, the relative merits of the two arrangements depend very greatly on a solution of this scaling problem.

Another matter to which the Resistance Committee should address itself is that of developing a standard method of making blockage corrections. The present series of standard models, all the same size but run in different sized tanks, should give valuable data on this point. It has been suggested this morning that the present standard model is too full for the purpose, but there has been no evidence of this in the tests carried out at N.P.L., which have given very consistent results. In any case, such a model is typical of much of our work and indeed is finer than the greater number of our models.

Mr. Sentic's contribution on full scale trial differences is in line with British experience, and points to the need for further work on the effects of structural and paint roughnesses.

Reference is made in the Committee Report to the standard model testing now being undertaken by four of the British tanks engaged in commercial testing (John Brown's, Denny's, Vickers' and N.P.L.), and the fact that similar work is also being taken up by numerous other tanks throughout the world using standard fibre-glass models made from the same mould. In Britain this work is coordinated by the British Towing Tank Panel, whose membership consists of the Superintendents of the Admiralty Experiment Works, Haslar, Saunders-Roe tank, and the four above-mentioned tanks, together with Mr. Lackenby, the Naval Architect of the British Shipbuilding Research Association. The British tanks had hoped to present to this Conference a joint statement of the results they had obtained up to this time, but this has not been possible, and the tank Superintendents concerned have asked me, as Chairman of the above Panel, to make on their behalf the following general statement on the position of this work.

The four standard models now being used by the British tanks were first tested in No 2 tank at N.P.L. in order to provide a basis of comparison of the results. When these results, corrected to 59°F by the I.T.T.C. line, were plotted, there were distinguishable differences between one model and another, but a mean line was drawn through all the results which took in most of them within a scatter band of ± 1%. This mean resistance curve is defined in tabular form in the Committee's Report.

The individual models were then sent to the various tanks and testing at approximately two-weekly intervals commenced in May, 1958, in each of the four establishments. The test results are sent to N.P.L. from time to time where they are correlated and presented in the standard form shown in Figure 4 of the Report. After the first 18 months a preliminary assessment of the results was made, as a consequence of which it was agreed to adopt a more tightly-controlled programme of testing. The complete list of testing conditions then adopted by the British tanks is given in the Report. It is considered that the period of testing since adopting this procedure is too short for firm conclusions to be drawn, and the British tanks prefer a longer period before publishing the results of their work.

Mr. D. I. Moor.

As stated in the Committee Report, the British Towing Tank Panel some time ago set up a small committee to study the available data with a view to recommending numerical values for the various factors used in estimating ship measured mile trial performance from model results by the B.T.T.P. 1959 standard procedure. In common with the proposals of the I.T.T.C. Propulsion Committee, the British procedure assumes for the time being values of unity for the scale effect factors on appendage resistance and quasi-propulsive coefficient, so that the whole difference in power between the model and the ship is accounted for by the overload fraction x, where $(1 + x)$ is equal to the Resistance Committee's factor z.

Unfortunately, we have not yet been able to make any definite proposals for numerical values, but the Conference may be interested in the principles on which we are working.

We first agreed that it is essential to define the conditions of ship and environment assumed to apply. We considered it insufficient to use such definitions as "a clean newly painted ship" since, even within such definitions, there could be variations in conditions which might have a significant effect on performance. The conditions which influence the performance of a given ship form include primarily:

Ship:

Length, Breadth, Draught, Fullness.
Shell Construction and Condition.
Type, Construction and Condition of Appendages.
Type, Size and Disposition of Freeboard and Superstructure.
Number of Propellers, Immersion of Propellers.
Type, Construction and Condition of Propellers.
Speed.

Motions:

Rolling, Pitching, Yawing, Heaving, Swaying, Surging.
Rudder Action.

Environment:

Place.
Depth of Water.
Wind Force and Direction.
Sea Length, Height and Direction.
Swell Length, Height and Direction.
Salinity and Temperature of Water.

We decided to lay down a set of basic trial conditions and to consider deviations from these within sensible limits, including a specific set of average trial conditions. These conditions are applicable to any size or type of ship, but the correlation factors for one type of ship are not necessarily applicable to another type, and we have therefore decided to consider separetely:

Single screw tankers.
Single screw cargo vessels.
Twin screw cargo vessels.
Twin screw passenger liners.
Single screw trawlers.

Within each group, both load and ballast conditions, and the effect of length and speed will be considered.

We consider that it is essential to analyse trial and model data for a large number of ships with the greatest possible range of size in each group. All the data of the B.S.R.A. - N.P.L. ship-model correlation programme have been made available and have been augmented by the results of a large number of other ships outside the range covered by that programme, obtained direct from the builders. Only trials up to the standard of the B.S.R.A. Trials Code have been accepted, and all model results were obtained in No. 1 Tank at the National Physical Laboratory, in order to avoid any inter-tank differences.

In order to evaluate the effect of each of the deviations in conditions from the basis, the overload factors $(1 + x)$ or z are being examined by standard statistical processes. $(1 + x)$ is assumed to be composed of a number of independent components, dx, each dependent on one of the separate disturbing influences already mentioned. A generalised relation between increase in resistance and each disturbing influence is assumed on similar lines to those described by Mr. Newton in his written contribution, and it is then assumed that the partial increase in resistance for a ship is proportional to that estimated from the generalised relation. The proportioning factor for a particular sample of ships is evaluated by regression analysis, which also tests the validity of the assumptions made, taking into account the possible influence of errors in measurements on model and ship. It is intended to obtain by this process values of dx for the whole range of condition of ship and environment mentioned earlier, together with the appropriate confidence limits.

I would like now make three more personal remarks:

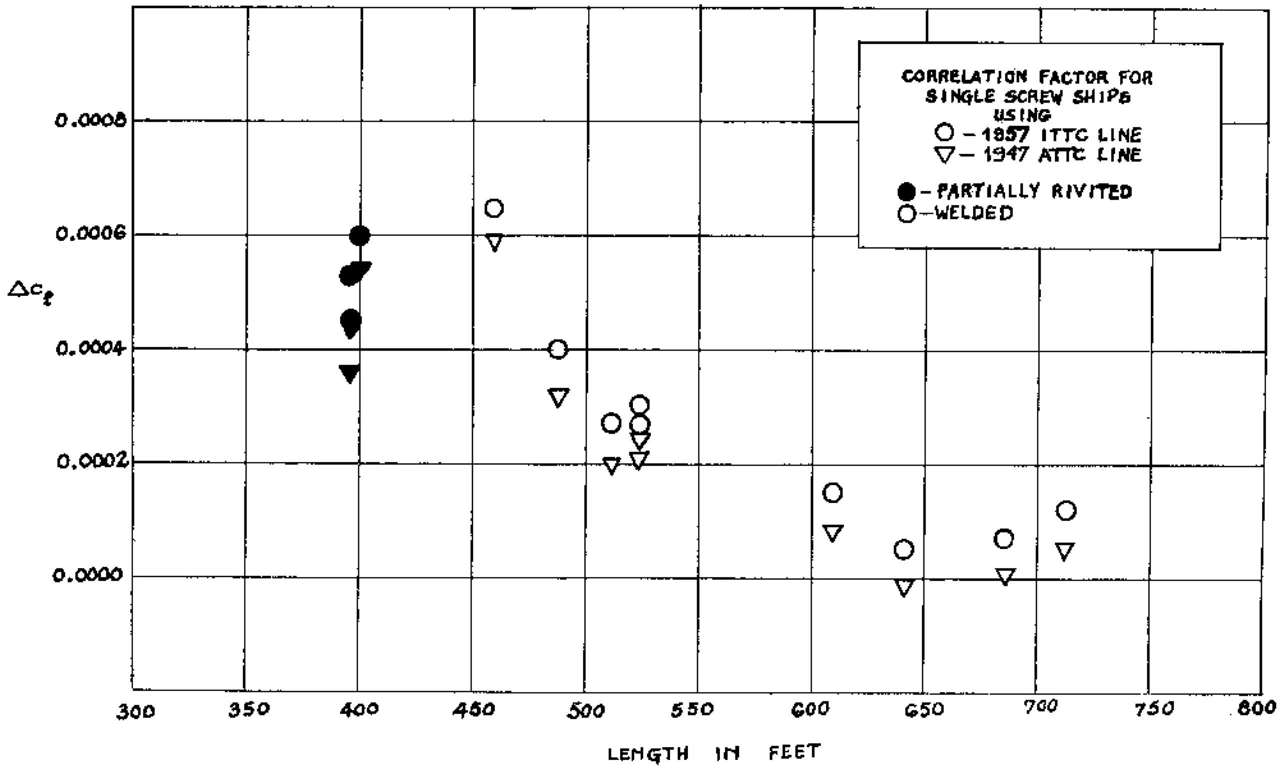
(1) It has been suggested that the derivation and analysis of empirical ship-model correlation factors (ΔC_T) is the wrong approach and that the effort would be better spent on fundamental research into flow and scale-effect problems. While agreeing that full understanding of the latter is the ultimate goal towards which we must continue to strive, I feel that it is likely to be a very long time before we attain it, whereas great progress has in fact already been made towards the selection of satisfactory empirical factors. We must all predict the performance of ship *now*, and I therefore consider that every effort should be made to obtain a satisfactory, temporary, empirical solution while we seek the more precise, long term, rational solution. In either case we ought to be prepared to accept that there must be quite wide tolerances on our predictions of ship performance, owing to the innumerable variations in conditions and tolerances on measurements on both the model and the ship.

(2) It has been suggested that each tank will require its own set of ΔC_T values. This should not be so if we considered the prediction from model to ship in three stages—from actual model to standard model conditions, from standard model to standard ship conditions, and from standard ship to actual ship conditions. To achieve the first we must agree on satisfactory blockage and perhaps "Iris" corrections. The Committee state in their report that there is sufficient data available to make blockage corrections, and I think they should be urged to recommend a standard method of doing so. The fibreglass model experiments now being carried out in many tanks should assist in assessing the "Iris" problem. Once the results for standard model conditions have been obtained, there should be no need for different correction factors in different tanks for the remaining two stages, providing the method adopted is universally correct.

(3) We have again heard today, from Mr. Sentic, of large differences between the results of sister ships. It is by now so obvious that most of such differences are due to different shell conditions, that we in Britain now regard surface roughness measurements as absolutely essential for any ship trial intended for ship-model correlation. We have already obtained quite good correlation between ship results and measurements made by the simple BSRA method, and I would urge that such measurements should in future always be made.

Mr. J. B. Hadler.

At the David Taylor Model Basin self-propulsion tests are carried out for progressive speeds at the self-propulsion point of the ship. This point is



determined on the basis of the 1947 ATTC line plus a ship correlation allowance, ΔC_f, which is usually 0.004 for commercial ships.

The results of model predictions are compared with carefully conducted standardization trials. Only those trials which were conducted in deep water with favorable weather conditions, clean ship bottom with fresh commercial paint and tested over a progressive speed range are considered. The effects of wind resistance are corrected to zero relative wind. The model tests which are conducted for purposes of correlation are performed in the usual manner. The test results were analyzed using both the 1947 ATTC line and the 1957 ITTC correlation line for the determination of the frictional components of resistance.

The results of 10 single-screw merchant ships ranging in length from 400 to 700 feet have been analyzed. Seven of these ships were of welded hull construction and only 3 were primarily of riveted construction. The results of these trial correlations, ΔC_f, have been plotted against ship length, (Figure 1.) These results show a difference between the two correlation lines ranging from 0.00006 to 0.00008 for model sizes varying from 20 to 26 feet. From these results it would appear that the following value of ΔC_f for welded single-screw ships would be applicable where 20-foot models are used for prediction:

Length	1947 ATTC ΔC_f	1957 ITTC ΔC_f
400	0.00050	0.00055
600	0.00015	0.00020
800	0.00005	0.00010

It may be noted that the results for the 1957 ITTC correlation line are similar to those recommended by SSPA, Gothenburg.

It is not possible from the results of these 10 trials and those of numerous military ships tested by DTMB to offer any correlation factors for the prediction of RPM. Scale effects seem to be quite important to the accuracy of RPM prediction. Since we still have much to learn about viscous flow around ship hulls and propellers, it does not appear possible at this time to relate RPM predictions with full-scale results by the means of any simple geometric parameter.

I would like now to make a comment on Mr. Sentic's remarks. We conducted a series of trials on four U.S. Navy destroyers. They were six or seven years old at the time of these tests. We sandblasted the hulls and removed all the paint. The trial results for the ships built in different yards agreed within a small percentage. We also found on another Navy ship that when we cleaned the hull and painted it with a standard navy paint we increased the shaft horsepower by 23 %.

I am also going to take the liberty of answering Prof. Telfer's remark. We have on our staff at the present time in a consultant capacity Dr. Hama. I have given the paper to which Prof. Telfer refers, to Dr. Hama for his remarks. He suggests on the rotating stimulators that the flow measurements should be made behind the rotating rods to ensure that there is no change in the oncoming flow field to the ship model. He also comments on the use of the triangular stimulators. He does not consider that it is good practice to separate the triangles. Their greatest effectiveness occurs when they are close together. If you wish to increase the transverse dispersion of turbulence it is best to place the stimulators on two staggered rows.

Dr. Graff.

Being concerned with a particular field of tests, I should like to draw your attention on the special problems of the resistance of a ship in shallow water. I think they will be of interest for you because on one hand, they can be of primary importance in this specific field and on the other hand their solution can be a great help for the work of all tanks.

These special problems are :

1° Changes in the wave-making resistance due to non-uniform flow. We have investigated this problem by means of both theoretical calculations and experiments. In calculating wave-making resistance we have found a solution involving in its core a mean flow velocity. This value is not the mean volumetric value. Hence the wave-making resistance values, as compared with the still water tests move towards greater speeds when running upstream and towards lower when downstream.

These results can also be expressed under the form :

When running upstream wave-making resistance values are lower and when running downstream greater than in still water. In every cases experiment results have shown a very good concordance with theoretical calculations.

2° Skin friction effect in shallow water.

In shallow water skin friction effect increases considerably when the depth of water decreases. We have investigated this effect by resistance measurements at small Froude numbers for several depths of water. As you know, these experiments are difficult due to the lack of accuracy of measurements and the incertitude relating to turbulence stimulation. Further it would be determined what part of the measured viscous resistance is due to skin friction and what part to separation. Relating to this last point we came to the conclusion that isolated test series cannot be sufficiently probative and that it is necessary to determine mean values from a number of test series. Now, I should like to draw the Delegates' attention on the procedure proposed, a long time ago, by Prof. Horn, in which the skin friction effect is calculated from the sinkage of the model. I must confess I am unable to support this procedure by an irrefutable theoretical demonstration, nevertheless whenever an experimental verification was possible, a good agreement between calculation and test results was found. As far as I am concerned I feel from the shallow water measurement that this procedure deserves a greater consideration. Since, practically, during model tests, the sinkage of the model is always measured, many data are available in all towing tanks. It would be perhaps interesting that the Resistance Committee collect these data and analyse them by statistical methods. We are also endeavouring to clarify these problems by developing new test procedures. I would quote, as an example, the investigations on the effect of local roughness and the determination of pressure distribution generated on the bottom of the tank by a ship which is, to some extent a reflected image of the pressure distribution on the ship itself and in certain cases, has provided interesting informations.

3° Variations in the channel section.

Ship-model correlation is by nature more difficult in shallow water than in deep water. Practically model tests and trials can never be carried out in the same conditions due to the fact that the depth and the width of a channel are continuously varying and that only mean values can be obtained from trials. Since these variable conditions cannot be reproduced in towing tanks, unless very complicated facilities be available, it is necessary to try to provide mean conditions for carrying out the test, specially mean depth. We are yet today uncertain whether we actually take into account all factors or whether there is certain other factors which normally cancel each other but in some particular cases can cause erroneous predictions. In order to deal with these problems more accurately we are building a ship-model fitted with such an apparatus that accurate and complete measures be possible as well as the analysis of every factors which can affect the resistance values. I hope to be able to present a contribution on the subject at the next Conference.

Dr. L. Landweber.

As a member of the Resistance Committee I feel it necessary to observe that all of the previous contributions on this subject have been of a practical nature. This indicates that very few of the member laboratories of this Conference are pursuing the sort of fundamental investigations on which a rational solution of the viscous drag of a ship may be based. This is very unfortunate since the practical studies, on which tremendous efforts have been spent, have resulted in discouragingly slow progress. Since the aerodynamic laboratories, which have contributed greatly to our knowledge of incompressible, viscous flow, are turning more and more to problems of supersonic flow and space projects, it becomes even more important that the ship-research laboratories undertake such basic studies.

At the University of Iowa research in viscous drag has continued in two directions. The boundary-layer investigations on a flat plate and the exterior of a circular cylinder with axis parallel to the stream have been extended to the case of an ellipsoid of three unequal axes. The purpose of these experiments is to attempt to discover the laws of three dimensional boundary-layer which could then be applied to develop procedures for computing the viscous drag of ships. At the present time, there appears to be as much controversy about these laws as there is about ship-model correlation lines. This is discussed in my formal contribution to this Conference.

The second investigation at the University of Iowa is concerned with the development of the method of separating viscous from wave drag by mean of a wake survey, suggested by Tulin. If this method proves to be practically feasible, it would eliminate at once the need for concern about turbulence stimulation, provided the flow outside the boundary layer of the model does not differ severely from that of the ship due to the occurrence of severe laminar separation about the model. The member laboratories are urged to consider undertaking the investigation and development of this promising technique in their own tanks.

Mr. H. Lackenby.

I was very interested in the remarks of Mr. Sentič on his experience with the scatter of ship-model correlation factors for sister ships. As Dr. Todd has already mentioned, in joint work on this subject carried out by N.P.L. and B.S.R.A. we have had almost identical experience. I am referring here to trials on a group of 18,000 ton d. w. tankers, all of them sister ships, in which the scatter of the measured power at a given speed amounted to about 20 %. These trials were all carried out in reasonably good weather.

As already mentioned by Mr. Moor considerable importance at B.S.R.A. to hull surface roughness and comprehensive roughness surveys are made for every ship in our trials programme. In the light of present knowledge in the analysis of hull roughness and its effects we think that only about half of the overall scatter referred to above can be accounted for by variations in surface roughness. There is no doubt, however, that this effect is very important and, as mentioned in Sir Victor Shepheard's formal contribution, B.S.R.A. is putting in hand fundamental work to throw more light on the physical nature of hull roughness. In this connection it is proposed to use, if practicable, the surface pitot tube developed by Prof. Preston. This will involve systematic laboratory work using roughened pipes with a view to throwing more light on the significant roughness parameters as far as resistance is concerned. We then hope to use the Preston tube on ships to measure directly the resistance due to actual hull roughness. It may well be that when more appropriate roughness parameters have been developed more of the scatter in ship-model correlation factors might be explained in terms of hull roughness.

In regard to Mr. Newton's contribution I would agree with his policy of making as many direct corrections as one can in the ligth of existing knowledge and it is interesting to see the success he has had for the class of ship with which he is concerned, namely warships.

Mr. Newton mentions that in the case of the fuller merchant ships there may be more variation in the ship-model correlation factors due to greater propulsion scale effect and this might well be so. I think it is also to be pointed out here that hull surface condition might be a contributory factor in this. Doubtless naval vessels receive more maintenance than the average merchant ship and there is consequently likely to be more variation in hull surface roughness in merchant ships. Again, in merchant ships the skin friction resistance accounts for a greater percentage of the total resistance which will accentuate this effect.

I should also like to comment on the suggestion made in Professor Kempf's contribution that for full forms above 0.75 block coefficient the model should be made to yaw in the same manner as the ship at sea in order to ensure similarity. This is a very interesting suggestion, but, I think, one has to bear in mind that the shedding of eddies and separation in the afterbody is a viscous effect controlled by Reynolds number and it may well be that the model behaviour cannot be reproduced on the full scale. This, nevertheless, underlines the importance of carrying out work on flow separation in full forms and finding out how this behaviour varies with change in scale. Experience may show however, that the proposal made by Prof. Kempf for model tests on full forms would give a reasonable approximation to the flow behaviour which actually takes place on the full scale ship.

The main point made in Mr. Numata's paper is that in correlating tests on small models at the Davidson Laboratory with those on larger models at T.M.B., the Shoenherr line gives a better correlation than the I.T.T.C. 1957 line. I think one has to be careful in drawing a general conclusion from this, however, as it may well be that the difference between these large and small models may be explained by more than extrapolator slope alone. Bearing in mind the results given in Mr. Hiranandani's paper one wonders whether some of the difference might be explained by differing extents of laminar flow on the large and small models. This does not alter the fact however that, from the practical point of view of correlating model results between the tanks concerned, the slope of the A.T.T.C. 1947 line is more appropriate than the somewhat steeper I.T.T.C. 1957 line.

Dr. F. Gutsche (translated from German).

I would like to direct your attention on a physical fact, which in addition to the many other influences on the total resistance eventually may be a source of variable influence on the friction resistance and therefore has to be regarded in analysing the results of trial trip. It is well known that the vortices behind the roughness elevations on the shell of the ship generate small air bubbles in the boundary layer of the ship. The result of this air emanation is seen at the ship sides and behind the ship in the foamy inner region of the boundary layer. Up to the date it is not clear what influence is set up by this emanation. It may be assumed, that the effect of this formation of small air bubbles may lead to a diminution of the sheer stress in the inner boundary layer and furthermore may cause a diminution of friction resistance with increasing length of the ship.

If the above hypothetically assumed effect should be real physical fact and its influence on frictional resistance would have been observed by special tests, then we had a new component of influence which had to been regarded in analyzing trial results and possibly may help us to clear up the great differences in effective horse powers existing even for sister ships.

The influence itself is known for partly cavitating hydrofoils when the drag lift ratio is diminished in the stage of beginning cavitation. Tube experiments with roughened inner surface like Nikuradse's tubes using water with variable air content may be apt to enlighten this problem.

The Chairman.

We will adjourn now, but before doing so, I would like you to give a vote of thanks to the reporter and all those who have contributed to the discussion.

AFTERNOON SESSION

Dr. Landweber.

The present contribution is concerned with the basic laws for the shear stress along a boundary, and certain questions concerning the validity of the inner laws, about which I made some brief remarks this morning. The period between this Conference and the previous one is notable in that two aerodynamic laboratories each produced three papers in which, apparently, there was a difference of about

12 to 14 % in the shear stress at a wall. This is rather discouraging, since both groups seem to have worked very carefully.

In view of this controversy it appeared desirable to review the Iowa work on boundary layers, which had been presented at the previous meeting, and in the course of this, to add certain corrections which subsequent work appeared to indicate were appreciable. These corrections refer to more refined consideration of the effect of the displacement of a pitot tube when put into a shear flow. The pitot tube appears to measure the total head not at its immediate location, but at a somewhat greater distance from the wall. Also the turbulence fluctuations, which affect both the determination of the velocity at a point, and the local pressure, were taken into account.

All I can attempt to do here is to summarize this work, the report on which, unfortunately, although it was intended to be available to the Delegates, has not yet arrived from the United States. Consequently I will content myself with showing, first of all, the net result of applying the corrections that I just mentioned (*).

To sum up, what has been accomplished in this contribution is an indication of the importance of applying these corrections in analysing boundary-layer data. Secondly, it was found that the law of the wall appears to be valid only for values of the parameter up to about 100. Thirdly, it was shown that there is a procedure which enables one to obtain a calibration of the Preston tube on the basis of the law of the wall.

Dr. Breslin.

In the discussion this morning, Prof. Telfer, Mr. Lackenby and perhaps one or two gentlemen have taken the Davidson Laboratory to task in regard to our stand on the 1957 ITTC line. I would like to leave the detailed rebuttal to my colleague Mr. Murray, who can give you several good reasons why we have adopted the stand we have, as an interim solution; but I do rise to the bait that the Davidson Laboratory is rather backward in its scientific attitude toward these problems; that we are not doing anything forward looking. In that regard, I would like to call to the attention of those Delegates who perhaps have not had the opportunity to look at some of the contributions, the fact that a good portion of the internally sponsored research at the Davidson Laboratory in the last year has gone into improving our techniques, improving our knowledge of what is taking place in the boundary layer of ship models.

Now, we have admittedly just started on this, and as in all internally sponsored research it is supported with a modest sum of money. We are nevertheless very definitely interested in pursuing on a persistent basis an approach which will lead to a more rational procedure than is, perhaps, being used now. In any event, whether the procedure turns out to be different than the one we are using or not, we will have more reason for the steps we shall take.

In particular, I would like to call your attention to the discussion of M. Murray entitled "Methods of Inducing Turbulence for Testing Small Models" in which stimulating devices are looked at on the basis of the total measured resistance. On the other hand, I was interested in starting a programm which is aimed at looking at things in detail, because I do not think that one can answer the question of turbulence stimulation and its effects on the frictional resistance of a ship model by working only with the total measured result. So from that point of view, we have attempted to develop a device which, ultimately, would give us the local shear stress at several or possibly many points along the length of a model.

We have given a description of the preliminary work in this development in a written discussion entitled "Measurement of Local Hydrodynamic Shear Stress by the Use of Disk Thermistors" by Larsen, Grosch and myself. I would like to read the introduction in order to give you some idea of the spirit in which this work was initiated — if you will permit me, just to read the first page; it should not take more than a minute. — (Reads introduction on contribution by Larsen, Grosch and Breslin).

I shall not take up more of your time with the details of this. The thermistor is a heat-sensitive device, for those of you who are not familiar with it, the idea itself, is not new, there has been similar work in Germany some time ago, of which Prof. Wieghart has just reminded me. In any event, the application of these techniques should give us a new tool to look in detail at what is happening to the shear stress along the length of a ship model.

Mr. A. B. Murray.

It may be supposed from Dr. Hughes comments that obtaining a new friction line flatter for the small

---

(*) See Figure 3 of the formal contribution.

model range and steeper for the ship size would be difficult. It is probably true. If this would be an attempt to obtain a new flat plate line I would say no, do nothing about it; but if we call it a correlation line, I think we should do anything that will improve the correlation job.

I could suggest a line that would probably result in a very complex mathematical formula but it might accomplish what we are after. Being near the end of the session we can perhaps afford to be a bit humorous.

Let some of the theoretical boys see what can be done about a formula for such a suggested line.

On another subject, I find it a little difficult to sit back and admit—or have the Conference admit—that all models under 15 feet are useless. We at the Davidson Laboratory do not feel that the small model will do everything that has to be done for the shipbuilder. There are certainly limitations. We know that the small models as used by us, Newport News, Webb Institute and others, have a definitely useful purpose. The Davidson Laboratory has had to the present something like 2.300 projects involving about 1.800 models and we get more each years. Thus I think we do a useful job.

This is a little off the subject, Mr. Chairman, but might be a useful comment. The United States find it difficult to excel in Rome at the Olympic Games. However, the United States won the 5 ½ meter competition with a boat that Davidson Laboratory helped to develop with a model three foot on the water line, and we have had something to do with several other vessels that have excelled.

Mr. F. S. Burt.

In the expectation that some of you may be inspired by Dr. Landweber's remarks this morning to attempt to measure skin friction by wake traverses, I would like to add a few clarifying remarks to my rather brief written contribution.

These remarks were based on analysis of some 35 pitot-static wake traverses on a series of models in 3 different tunnels, one water and two air, both under conditions of low tunnel interference in a 13 feet by 9 feet wind tunnel and with high blockage ratios in slotted wall working sections.

The drag coefficients were evaluated from these readings by the formula of B.M. Jones:

$$C_D = \frac{8}{2} \int C'_D \, r dr \quad \text{where } C'_D = 2\sqrt{g-p}\,(1-\sqrt{g})$$

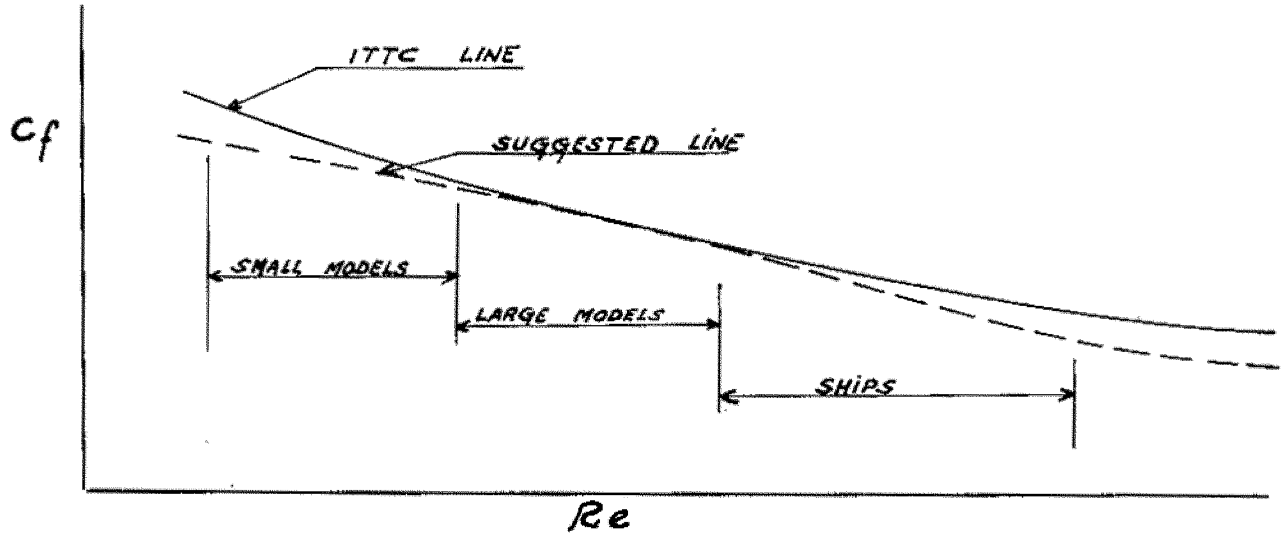
$$g = \frac{H - P_o}{H_o - P_o} \qquad p = \frac{P - P_o}{H - H_o}$$

H = Total head. P = Static pressure. d = model diameter. r = radius from axis

and the suffix $_o$ denotes conditions in the free stream.

The limits of the wake are defined by $g = 1, \therefore C'_D = 0$. The traverses were made at a distance of approximatively ½ model diameter behind the tail.

The assumption made in deriving this formula is that the flow in any stream tube of the wake can be considered to remain at a constant total head between the measuring station and a position far enough down stream to give free stream static pressure. It does not seem essential to the argument that the later posi-



tion should actually exist in the flow to be considered and hence it follows that the drag coefficients evaluated will give close approximation to the free stream drag provided the tunnel interference does not appreciably effect the development of the boundary layer on the body.

The point of my written remarks was that although the models and their position in the tunnels was axisymmetric we could not automatically assume in all cases that the drag coefficient computed from point of starboard traverses gives close agreement. This is largely due to the fact that small variations in the total head near the edge of the wake as they are multiplied by a large value of r in the integral can materially effect the computed drag coefficient.

Nevertheless even in the few cases where marked assymmetry occurred including the one extreme case quoted of a 1.5 variation in drag coefficient computed by port and starboard traverses a mean value always gave overall agreement within $\pm$ 4 %.

Assuming the arguments given in Tulin's 1951 D.T.M.B. paper are now verified experimentally then it would appear that wake traverses behind towed ship models should give a good evaluation of skin friction drag even if used under conditions of high blockage if the whole area of the wake is covered and perfect symmetry not automatically relied on.

Capt. H. E. Saunders.

I regret that the presentation of information concerning the performance of small models during resistance tests has left the impression that the Davidson Laboratory at Stevens and the David Taylor Model Basin have serious difference of opinion about them.

Small models, at first less than 1 meter in length, have been tested at Washington since the 1920's; Dr. Schoenherr and Dr. Landweber have taken an active part in this work. There is a small basin at the David Taylor Model Basin, and we believe that small models, as well as large models up to 10 meters in length are all found useful in predicting the resistance of ships.

Prof. E. V. Telfer.

I want to present a small note on the ITTC standard model approach which I did not intend to give unless the subject had been previously discussed. The subject was discussed, and I merely wish to present it for the sake of the record. All I am doing in this note is to give a different approach from that recommended by the Skin Friction Committee itself, but I think the approach is a simpler one, and will enable this much overworked Committee to do productive work much more easily and much more quickly.

As a reply to Capt. Saunders I would refer him to my 1927 INA paper in which I drew very largely on data of 2 ½ ft to 40 ft geosims placed at my disposal by his predecessor Capt. Mc Entee. These showed the then uselessness of small model tests. Despite this I made a plea for small models and the late Ken Davidson followed up this plea some years later. Small models offer too much scope for inaccuracy and their turbulence technique should be improved.

The Chairman.

Now we will have the reading of the Secretary's summing up of the contributions of this morning. This summary will be the basis for recommendations and conclusions to be made up by the Committee on Resistance, so if you have to offer any criticism, please do it now. That will facilitate the work of the Committee considerably, so the conclusions and recommendations can be presented next week in the final session, without much discussion. Otherwise we will have to start all over again.

Mr. H. Volpich.

We have heard this morning quite a lot about ship model correlation and the disconcerting discrepancy between predictions and trials as pointed out by Messrs. Sentic and Lackenby. I fully associate myself with Mr. Moor in his suggestion that accurate roughness measurements on the ship's hull and propeller are absolutely essential and I go now a step further to suggest to the Committee that they should recommend a standard procedure of taking roughness measurements and of the analysis of such measurements. I think our procedure as recommended by the B.S.R.A. and adopted by all the British Towing Tanks and shipyards using the B.S.R.A. standard gauge is pretty reliable. If there is any better method, as there may be, let's have it, but by all means let us have it internationally standardised to arrive at figures which can be compared between one and the other country.

Dr. G. Hughes (The Secretary.)

Before making this summary, I would like to stress one or two points. First of all, the number of individual topics covered in this session is so large that I feel any attempt to make a summary in such a short time must leave that summary probably completely inadequate.

I would also like to say that it is my duty as your Secretary of this session merely to state what I think are the main things that have been said; to be completely impartial in my presentation; to draw attention to all points of view, whether they are minority points of view or not; and I hope that I will draw attention to the main points particularly but to some of the minor points as well. But if any delegate feels that I do omit something that should be included, I hope he will realise that it is rather a difficult position.

I will give the summary under headings of subjects, and I hope I will not need to refer to any delegate by name.

I have divided the subjects as follows:

(*a*) Ship-model correlation.

This is sub-divided into three parts:

(i) Small to large model correlation.
(ii) Larger model geosims.
(iii) Extrapolation to the ship.

(*b*) Form effects.

(*c*) Blockage effects.

(*d*) Turbulence stimulation.

(*e*) Measuring techniques and conditions of model tests.

(*f*) Fundamental considerations.

(*g*) Criticism of the Committee's work, including functions of the Committee.

I will now deal briefly with these subjects in turn.

(a) Ship-model correlation.

(i) *Small-large model correlation.* The general view of the small model user is that a line not so steep as the 1957 I.T.T.C. line is required to correlate small with large model results. This is a statement of fact concerning the actual model results and is independent of the reasons for this requirement. Views have been expressed, such as under-stimulation, the wake effect of struts, etc., as reasons for this requirement, but the practical view of the small model user is that, as things are, a line of less slope is a necessity.

(ii) *Larger model geosims.* These require for good correlation within their range a line steeper than the 1957 I.T.T.C. line. This view is supported by much other work in addition to that referred to at this meeting.

Therefore there is an anomaly here between small and large models which is difficult to resolve, and it would appear to be impossible to resolve this unless means can be found to increase the resistance of small models or to depress that of large models.

(iii) *Extrapolation to the ship.* This might be called the ΔC_T or allowance problem. One tank has started the full implementation of the use of the I.T.T.C. line and has urged that this course should be adopted generally. There is reluctance of other tanks to do so yet and further investigation was urged, such as of

(1) better analysis of trial results, especially in the details of the components which make up the correlation,
(2) the effect of surface roughness, especially at the ship end. The view was expressed that half the scatter would be eliminated if we could properly take account of this effect,
(3) effects at the model end, such as due to form and blockage.

It was urged that one of the primary objectives of the Resistance Committee should be to determine the appropriate ΔC_T values.

(b) Form effects.

There is an increasing awareness of the need to consider the effect of form. The collection of the necessary data and its analysis presents a considerable problem. These questions may be asked:

(i) Can the Committee do this analysis, or.
(ii) Is this a matter for the individual, the Committee acting as co-ordinator for results already analysed. A large amount of data now exists and more is being produced.

(c) Blockage effects.

Similarly with this subject a fair amount of data exist and more will be available soon. The Committee has been urged to make specific recommendations. Should this be done or should individual tanks make their own corrections in the light of the available data?

(d) Turbulence stimulation.

On this subject also the necessity for continued investigation has been urged. New methods of stimulation have been suggested, such as the use of Δ-shaped stimulators and rotating rods. Attention has also been drawn to the possibility of under-stimulation in small model tests, and to the wake effect of struts placed ahead of the model. Fundamental flow studies have also been urged, including the measurement of the local shear stress.

(e) Measuring techniques and conditions of model tests.

Under this heading may be mentioned the references made especially to the effects of very full models and the increase of resistance due to yaw. Methods of testing to find the latter effect were proposed.

The value of the standard model work to give information on the experimental variation from day to day was noted. Their usefulness to provide data on blockage effects was also stressed.

(f) Fundamental considerations.

A strong plea was made for more time to be devoted to the more fundamental studies, and a prediction was made that many of the correlation problems will not be solved unless we examine the fundamentals more closely.

(g) Criticism of the Committee's work, including functions of the Committee.

Some light-hearted remarks with however more serious implications raised questions concerning this Committee (and appropriate perhaps to all of the Committees) which may be summarised as:

(i) How much detailed work can be done by the Committee?

(ii) How much rather depends on the work of the individual who gets his own data and is in the best position to analyse it and also has the time to do it?

(iii) Does this not also apply to co-ordinating work? Is not the individual best able to do this also?

(iv) Is this Committee (and perhaps others) too large for effective co-ordinating work?

This, gentlemen, concludes my summary. I realise that it is probably much too brief, but time is short, and probably I have not touched on possibly quite important topics. If I have not, or not referred adequately to some of those I have referred to, I hope you will excuse me, and may be you can rectify that now.

Prof. C. W. Prohaska.

The Committee appreciates very much, that the summary given by the Secretary was agreed upon. It will facilitate the work of preparing the conclusions and recommendations to be discussed next week. But there might be among you somebody who had ideas that would be useful for us in preparing the recommendations for the future work of the Committee. Specific ideas, which have perhaps not been clearly brought forward in the summary. If anybody could help us in this respect now, it would be very useful and it will shorten the discussions next week.

Mr. A. Emerson.

Attention is drawn to the need for more information about the additional resistance due to the turbulence stimulator.

For the large models the resistance calculated by the approximate method given by Allan and Hughes is probably sufficiently accurate. As a use of middle size models about 2.5 m long, I am conscious that the possible error in the calculated stimulator drag may be 2 % and for the smaller models there is no experimental basis and there may be quite large errors.

It is suggested that any new turbulence stimulator results are of little use unless they are accompanied by observations on the boundary layer conditions (an ink stream is hardly sufficient), and by data to estimate the added resistance.

Prof. G Weinblum (translated from German).

I am under the impression that one rather interesting but perhaps old-fashioned problem is the problem of wave resistance, and in my opinion the great pioneers, Reech in France and William Froude, designed their tanks primarily to evaluate this wave resistance. Now in the last 60 years a not yet adequate but promising hydrodynamic theory has been developed on this subject. It is the present speaker's opinion that to deal properly with this basic problem of ship research this high Assembly should give more weight to problems of the hydrodynamic theory of wave resistance and its correlation with experiments. I had suggested earlier—I was supported very strongly by Prof. Barrillon—that the Resistance Committee should devote itself to the study of this problem and especially see what kind of results are available, and how they can be used for our practical work.

Mr. D. I. Moor.

It is sometimes obvious that even the largest establishments have comparatively few ship trial data available. For instance Mr. Hadler has described the results of only 11 trials with 9 ships and we in Britain have had great difficulty in obtaining the much larger number of results required for a large statistical investigation. It is not sufficient to collect together the *results* of published analyses of numerous small samples by different individuals, since it is unlikely that all the details required for further examination will be available in each set. I would therefore like to suggest that this Conference set up some machinery for pooling full basic ship trial data, in some way similar to the well known SNAME data sheets for models. It is particularly desirable that results for ships over 750' long which are still comparatively rare, should be made available.

Prof. E. V. Telfer.

It is important before admitting large differences between sister ship performances to compare the respective generalized power diagrams deduce therefrom the with and against weather speed and power curves; and only then compare the vessels' with weather performances. Any difference then remaining should arise from the hull surface condition and should also be detectable by a transverse shift of the power diagrams.

Prof. R. Couch.

The number of problems listed by the Committee in this field is rather large. I suggest that the Committee try to establish a priority of importance of the problems and concentrate on them.

Mr. A. B. Murray.

Dr. Prohaska has mentioned the important wake effect of struts when used for turbulence stimulation. The Davidson Laboratory recognizes this fact and makes it standard practice to make resistance tests bare hull as well as two sizes of struts 0.04 inches and 0.125 inches. In general the values used at the design speed are usually those from the bare hull tests or from the tests with the small strut. Davidson Laboratory depends primarily for turbulence on a standard tank temperature of 70° F and a large amount of residual turbulence by making successive test runs at intervals of two minutes. Its use of struts is primarily to ensure the bare hull test without struts is in a reasonably turbulent condition.

It may well be that this method produce wakes and currents that result in a net resistance that is too low. However, from repeated test, we find on excellent reproducibility of the results which is very important. If it were possible to devise a practical method that would ensure one hundred percent turbulent flow on our small models of five foot length we might find that the I.T.T.C. correlation line would give a better correlation with larger models. However, until this ideal is reached we feel it is desirable that we continue to work with the 1947 ATTC (or Schoenherr) line.

Tests with the single ATTC standard 64 inch plastic model indicate very close agreement with the D.T.M.B. and the Newport News tanks thus we are not too concerned about our testing techniques.

We can well recognize large struts such as used by Dr. Prohaska could cause considerable wake effect. D.T.M.B., some years ago, experimented with quite large struts with unsuccessful results.

As a change of subject the Davidson Laboratory feels that the matter of flat plate resistance should be put on the shelf for the present and devote increased effort to the matter of three dimensional friction resistance and to form factors. Work such as that of Granville and that carried on by N.P.L. and others be encouraged. We agree with Mr. Moor that the final roughness addition may have await the solution of propeller and propulsion scale effects.

We appreciate the criticisms of Dr. Telfer and we are well aware of our limitations. We agree with the strong need for the scientific approach to the matter of turbulence for small models. We should emphasize however, that the I.T.T.C. should not neglect the practical aspects of model testing because we must continue to live.

Stevens is working on the matter of turbulence. It is studying the use of studs such as those being used by Prof. Nevitt at Webb Institute. As Dr. Breslin mentioned, we are also experimenting with the use of electronic methods of measuring turbulence both on the surface of models and in the body of water itself. This technique is described in some detail in the paper mentioned by Dr. Breslin.

Such research takes time and ordinary everyday chores must be carried on with the tools at hand with which we are familiar. Stevens does not feel that it is misleading its clients, if it were so we would not continue to exert. It is, however, attempting to improve its methods at all times.

Prof. Schuster.

I would like to make some recommendations concerning the analysis of the dispersion of the measured values. Differences in the performance of sisterships can be caused by the mentioned differences of surface roughness, the different trial conditions, vibrations and probably by the comparatively wide tolerance of the used measuring methods. The electrical torque measurement contains generally deviations up to 1 %. The conversion again brings a deviation of 1-2% due to the differences of the Joule's Models of the shaft material. The r.p.m. measured as a mean value over a longer period, say one minute may also differ with 1% from the momentary value corresponding to the torque readings. Thus the total error of 3% or more in the calculation of the performance has to be taken into consideration. In addition sisterships constructed by different shipyards or even on different shipways vary in their performance due to the different vibrations and friction conditions in the stern gear. Thus more than half of the 10 % dispersion here, could be explained by these reasons.

In model tests the tolerance is held very small by calibration, but the influences of the restricted water and of the several means for turbulence stimulation can be considerable. The Committee should not only be informed whether the blockage effect was taken into consideration or not and if e.g. trip wires were used, but also which method of calculating the blockage effect was used and how thick tripwires were. According to the experience made by the Berlin Towing Tank trip wires with diameters less than 0.6 mm are of no use. The diameter required has to be at least 0.8 or 1 mm independent of the size of the model. In former conference and lately in the Zagreb Symposium I have repeatedly recommended a method, originating from Kreitner, for the calculation of the blockage effect. Some tanks seem to use it, others have developed other methods. It would be very interesting to know how the different methods of calculation give different results concerning the performance.

At last I would like to remind that the differences in the model test results of several towing tanks are only to be found in the tank values. For the prognosis each tank adds its own percentage of allowance for trial conditions. Although the influences of gear friction, resistance of the bilge keel, of waves and wind should be the same, the allowances very often are different. An analysis of these prognosis allowances which give more or less the same result everywhere therefore could give already some means of judging the different test conditions in the different tanks.

Mr. L. Mazarredo.

We have begun at El Pardo a Programme on form effect.

Different models of coaster ships, with the same size wetted surface and so on, but different forms, will be tested to ascertain form factors eliminating other influences.

This is a part of the whole work which will also include a tank ship and a twin-screw passenger ship geosims in order to get form factors of three very different typical ships, which might be useful in this matter of model correlation.

I want to add that the standard fibre glass model has been already tested at El Pardo, but since very few results are as yet available they have not been reported.

Prof. C. W. Prohaska.

I have a few words to add to what was said when we called for advice as regards recommendations. Mr. Moor suggested that there should be found means of pooling information such as that given by Mr. Hadler. Those means have been in existence for three years, but the previous Friction Committee never received any replies of that kind although it called for them. It did not even receive any from Mr. Moor although the British tanks have put very valuable material at his disposal. We certainly hope we receive more data during the next three years, and not at the very latest date.

I would like to add a more serious remark to Mr. Murray. I am very sorry that I was one of those, who, as he said, criticized the use of small models. It was not my intention to criticize the use of small models as such. I only said that the reason for the ATTC being better than the ITTC line might be found in the use of a strut as stimulator. Personally I very much admire the work done in many tanks, and specially at the Davidson Laboratory, on small models, and although we at HyA use standard 6-8 m models and have worked with models of almost 11 m in length, we are now starting work also on 5 foot models.

I agree with Prof. Telfer that some sort of power diagram should be used in the analysis of trial ships, but our Committee feels that this will be a matter for the Propulsion Committee to consider.

To Prof. Schuster I would like to say that the question of blockage of course is a very important one. We hope that the standard model testing can give us some idea as to the blockage effect, at least for that particular form, and we hope we will receive from as many tanks as possible any data they have which will help us to try to recommend something for the next Conference. I agree with the views the Secretary expressed here: it is not really our job as a committee to do the research work. Research work should be done by the individual delegates of the Conference. In conclusion I would like to thank all those who have tried to help us to make future work easier, and also in preparing the conclusions and recommendations for next week. May I be permitted also here to thank all my colleagues of the Resistance Committee for their excellent co-operation during the past three years.

The Chairman.

This ends my duty but before closing this session I would like to ask to give a hearty vote of thanks to our Secretary who has done such excellent work. I thank you all for your assistance and for your co-operation.