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ON THE INFLUENCE OF FORM UPON SKIN FRICTION RESISTANCE

BY

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1. Introduction

In the conventional calculations employed in model experimental work, the total resistance of the model (or ship) is divided into its frictional and residual components. The frictional resistance is assumed to be the same as that of a flat rectangular plate of the same length as the model (or ship) and having an area equal to that of the wetted surface of the model (or ship). The frictional component of the resistance is thus regarded as being independent of form, while the whole of the form effect is included in the residual component, which is assumed to obey FROUDE's law of comparisons. But it has long been evident that the frictional resistance obtained from experiments with plates is not directly applicable to ship-formed bodies; in fact, the form has a considerable influence on the skin friction.

Extensive theoretical and experimental investigations have been carried out in order to evaluate this form effect both qualitatively and quantitatively. The present tests can be regarded as an experimental contribution to the subject.

The experiments can to some extent be considered as forming an extension of the investigations which were carried out some years ago at the Swedish State Shipbuilding Experimental Tank with a view to determining suitable methods of artificially stimulating turbulent flow around model hulls [1].[1]) These tests were made with a series of inter-related, ship-like bodies which had vertical stems and sterns and were symmetrical about midships. The prismatic coefficient, φ, was varied in stages to give $\varphi = 0.80$, 0.70, 0.60 and 0.52.

The effect on the skin friction of these variations in the prismatic coefficient, φ, can be determined from the results of these earlier experiments. This will be further dealt with below.

The chief subject for investigation in the present work has been the effect of the breadth, B, on the skin friction. Two models with prismatic coefficients of 0.80 and 0.60, which had been employed in the previous tests, were adopted as parent forms and the breadth

[1]) Numbers in brackets refer to the list of references on p. 18.

was systematically varied in each case. The variation was carried out in such a way that each model possessed the same block coefficient, prismatic coefficient and principal dimensions, with the exception of the breadth, as the corresponding parent form; the breadth, on the other hand, was decreased to $B/2$ and $B/4$ in each case so that each form tended towards the corresponding plate as the breadth was successively reduced.

For reasons explained in Section 4 below, tests were also carried out with two double models, *i. e.* double in the sense that they were symmetrical about the load waterplane.

The effect of the draught, T, has also been studied by means of tests with one model similar to those mentioned above.

Finally, some more conventional ship models were tested and the results have been compared with some of those published by other experimenters.

Conclusions have only been drawn from the results of these tests to a limited extent. However, to enable the reader to work out the results in different ways and to draw his own conclusions therefrom, the primary test measurements are given in full in Appendix 2.

The investigations described herein were carried out at the Swedish State Shipbuilding Experimental Tank.

2. Symbols and Units

Model Dimensions

L = length on waterline
B = breadth
T = draught
A_m = immersed midship section area
S = wetted surface area
∇ = volumetric displacement
$\frac{1}{2}\alpha_e$ = half angle of entrance on waterline

Ship Dimensions

The same symbols as above, but with the suffix s added, are used for the ship dimensions.

Kinematic and Dynamic Symbols

v = speed in general
R = resistance

ϱ = density of water (102.0 kg sec.^{2}/m^4 for fresh water)

ν = kinematic viscosity of water; see [2][1])

Dimensionless Ratios and Coefficients

$\delta = \frac{\nabla}{L \cdot B \cdot T}$ = block coefficient

$\beta = \frac{A_m}{B \cdot T}$ = midship section coefficient

$\varphi = \frac{\nabla}{A_m \cdot L}$ = prismatic coefficient

$\frac{L}{B}$ = length-breadth ratio

$\frac{B}{T}$ = breadth-draught ratio

$\frac{L}{\nabla^{1/3}}$ = length-displacement ratio

$C = \frac{R}{\varrho/2 \cdot Sv^2}$ = total resistance coefficient

C_f = plate frictional resistance coefficient

$n = \frac{C - C_f}{C_f} \cdot 100\ \%$ = form influence factor

$R_n = \frac{v \cdot L}{\nu}$ = REYNOLDS number

Units and Conversion Factors

Metric units are used throughout.
1 metre = 3.281 feet
1 metric ton = 1000 kg = 0.984 British tons

3. Method of Determining the Influence of Form on Skin Friction

By the form influence factor is meant, in this paper, the percentage difference between the total resistance of the model in the non-wavemaking speed range and that of a smooth plate in turbulent flow at the same REYNOLDS numbers, *i. e.*

$$n = \frac{C - C_f}{C_f} \cdot 100\ \%$$

[1]) For metric units, see also [1] p. 6–7.

The resistance of the plate, C_f, is assumed to correspond to the SCHOENHERR line as expressed by

$$\frac{0.242}{\sqrt{C_f}} = \log\left(C_f \cdot \frac{vL}{\nu}\right)$$

The coefficient of total resistance, C, has been calculated from the results of model tests in the non-wavemaking speed range. Results obtained at very low speeds, where the model is affected by laminar flow in spite of the turbulence stimulator, are of no value in this connection. Fig. 1 illustrates schematically how the results of tests with ship models usually arrange themselves. The turbulent non-wavemaking speed range, within which the form influence can be evaluated, is in most cases relatively short.

It is evident from the above definition that other unconnected influences, *e. g.* that due to any separation of flow, have some bearing on the result. No attempt has been made to assess these different effects. It should, however, be pointed out that in these investigations, the models had relatively sharp after-body waterlines, due to the fact that they had vertical sterns and no propeller apertures. It is therefore hardly likely that separation of flow could occur to any marked extent, in any case not on the finest forms. A special streamline test was carried out in an attempt to determine the flow conditions around the fullest form and this is described in Appendix 1 below.

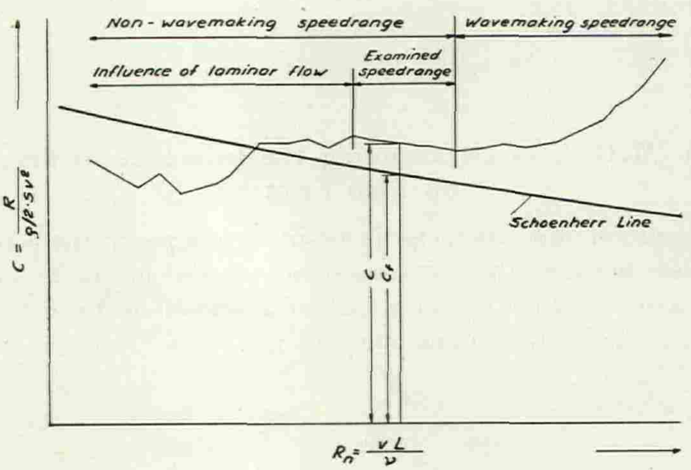


Fig. 1.

The above method of determining the form influence can of course be criticized to some extent.

The method involves the following basic assumtions: —

(1) That the SCHOENHERR line is correct within the examined range of REYNOLDS number.

(2) That the form influence can be expressed as a percentage, independent of REYNOLDS number.

The second assumption is of course very difficult to verify, but, within the range of REYNOLDS number in question in these tests (10^6-10^7), no systematic variation in the percentage is discernible.

4. Models Tested

As mentioned in the introduction, the fundamental investigations were carried out with special models. The parent series, each component model of which was developed from the same basic form, is described in [1]. The models are symmetrical about midships and have vertical stems and sterns in order to eliminate any doubt about their length. The prismatic coefficient, φ, was varied systematically in this series.

The series was extended for the purpose of examining the effect of the breadth on the form influence percentage. The principle of this part of the investigation was that, by means of successive reductions in breadth, the models become more and more like plates (but still retain the prismatic coefficient of the parent form). Model No. 334 ($\varphi = 0.80$) and Model No. 332 ($\varphi = 0.60$) were chosen as the basic forms for this variation. The breadth, B, of each model was altered in two stages, first to $B/2$ and then to $B/4$. In this way, four new models (Nos. 561—564) were developed.

For the purpose of studying the effect of surface disturbance of various kinds and in order to be able to extend, if possible, the non-wavemaking speed range, two double models were constructed. These models (Nos. 586 and 605) are symmetrical about the load waterplane and were designed to be run completely submerged. Model No. 605 was made as a double model of No. 334 ($\varphi = 0.80$, breadth $= B$), while Model No. 586 is a double model of No. 564 ($\varphi = 0.80$, breadth $= B/4$). Particulars of these models, together with those of the parent series (Models Nos. 332—334 and 372) are given in Table I.

Table I

	Unit	Models													
Model No.	—	334	605	563	564	586	333	332	561	562	372	350 (SSPA Standard Model)		
L	m	6.096	Double model[1]) of model No. 334	6.096	6.096	Double model[1]) of model No. 564	6.096	6.096	6.096	6.096	6.096	6.000	6.000	6.000
B	m	0.825		0.413	0.206		0.825	0.825	0.413	0.206	0.825	0.856	0.856	0.856
		B		$B/2$	$B/4$		B	B	$B/2$	$B/4$	B			
T	m	0.344		0.344	0.344		0.344	0.344	0.344	0.344	0.344	0.143	0.214	0.428
∇	m^3	1.349		0.674	0.337		1.180	1.011	0.506	0.253	0.843	0.485	0.744	1.526
S	m^2	7.540		5.696	4.849		6.995	6.450	5.122	4.569	5.970	4.805	5.660	8.228
L/B	—	7.39		14.78	29.56		7.39	7.39	14.78	29.56	7.39	7.01	7.01	7.01
B/T	—	2.40		1.20	0.60		2.40	2.40	1.20	0.60	2.40	6.00	4.00	2.00
δ	—	0.780		0.780	0.780		0.683	0.585	0.585	0.585	0.488	0.661	0.677	0.694
φ	—	0.800		0.800	0.800		0.700	0.600	0.600	0.600	0.520	0.698	0.702	0.707
β	—	0.975		0.975	0.975		0.975	0.975	0.975	0.975	0.938	0.947	0.965	0.982
$\frac{1}{2} \alpha_e$	degrees	32.0		17.4	8.9		23.0	18.0	9.2	4.7	10.5	14.0	14.0	14.0
A_m	m^2	0.277		0.138	0.069		0.277	0.277	0.138	0.069	0.266	0.116	0.177	0.360
$L/\nabla^{1/3}$	—	5.52		6.95	8.76		5.77	6.07	7.65	9.64	6.45	7.64	6.62	5.21
$\nabla^{1/3}/L$	—	0.181		0.144	0.114		0.173	0.165	0.131	0.104	0.155	0.131	0.151	0.192

[1]) Model symmetrical about load waterplane.

An existing SSPA (SSPA = Statens Skeppsprovningsanstalt = the Swedish State Shipbuilding Experimental Tank) standard model (No. 350) was used for studying the effect of the draught, T, on the form influence factor. This model is made of brass and has vertical ends, vertical sides at the waterline and is symmetrical about midships. Model No. 350 was tested in the non-wavemaking speed range at three different draughts, which corresponded to $B/T = 6.00$, 4.00 and 2.00. Further particulars of this model are given in Table I.

The results of tests with three more normal ship models have also been used for comparison. Models Nos. 582 and 614 are tanker models which are being used for a more extensive investigation being carried out at SSPA, while Model No. 590 is a model of a Victory ship. Particulars of these models are given in Table II.

All the models, with the exception of No. 350 are made of paraffin wax.

Table II

»Normal» Ship Models

	Unit	Models		
Model No.	—	582	590	614
L	m	7.116	5.638	7.117
B	m	0.912	0.788	0.912
T	m	0.365	0.356	0.397
∇	m³	1.895	1.067	1.931
S	m²	9.765	6.420	9.821
L/B	—	7.80	7.16	7.80
B/T	—	2.50	2.21	2.30
δ	—	0.800	0.676	0.750
φ	—	0.806	0.683	0.755
β	—	0.993	0.990	0.993
$\frac{1}{2}\alpha_e$	degrees	27.5	12.0	24.2
A_m	m²	0.330	0.277	0.359
$L/\nabla^{1/3}$	—	5.75	5.52	5.72
$\nabla^{1/3}/L$	—	0.174	0.181	0.175
		Ship Values		
Model Scale	—	1: 28.5	1: 24	1: 22.5
L_s	m	202.8	135.3	160.1
∇_s	m³	43870	14745	22000
S_s	m²	7932	3698	4972

5. Testing Particulars

The tests were carried out in a similar manner to the experiments described in [1]. As before, a special pendulum apparatus was used for measuring the resistance at the lower speeds (resistance values up to about 1 kg). This apparatus and the experimental arrangements are described in the aforementioned publication. The pendulum apparatus measures small resistances with great accuracy and for this reason it is more suitable than the ordinary dynamometer within the non-wavemaking speed range.

Regarding the double models, which were run submerged, it should be mentioned that the narrower one (No. 586) was tested with its centreline plane horizontal. The broad model (No. 605), on the other hand, was run with its centreline plane vertical. In both cases, the highest point of the model was about 0.75 m below the surface.

In most of the experiments, a 1 mm tripwire, stretched around the model at $L/20$ from the F. P., was used as a turbulence stimulator. In one section of the investigations, however, additional tests were carried out both without tripwire and with a 3 mm tripwire.

6. Experimental Results

a. Variation of prismatic coefficient

The results of the experiments with the parent models (those with normal breadth $= B$) are given in [1] but for the sake of completeness, they are shown here in Fig. 2. In these tests, the models were each fitted with a 1 mm tripwire.

It is evident from Fig. 2 that, with the finer models, sufficient turbulence can be assumed to exist only over a small part of the non-wavemaking speed range. The values of the form influence factor obtained from these results are therefore somewhat uncertain. However, some guidance in determining this factor can be obtained by comparing the results with those from the tests with a 3 mm tripwire [1]. As would be expected, with models of the same breadth, the form influence factor shows a tendency to increase with prismatic coefficient.

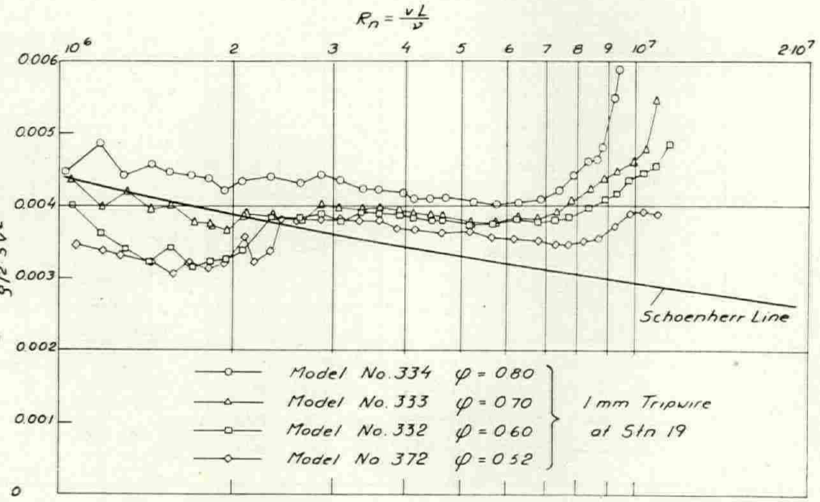


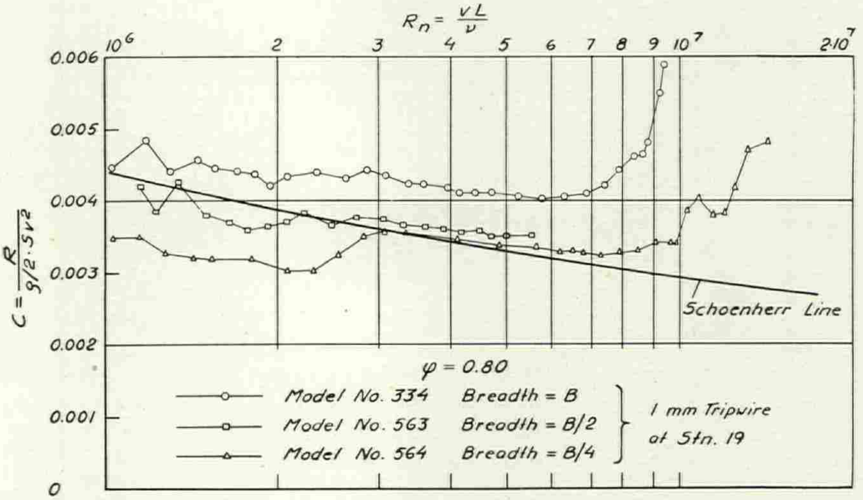
Fig. 2.

b. Variation of breadth, $\varphi = 0.80$

The results of the resistance tests with the »family» of models all with $\varphi = 0.80$ are given in Figs. 3—6. Fig. 3 illustrates the influence of the breadth variation in the three surface models and it will be seen that the narrowest model, No. 564, gave results which, within the speed range in question, agree reasonably well with the SCHOENHERR line. The form influence clearly increases with the model breadth.

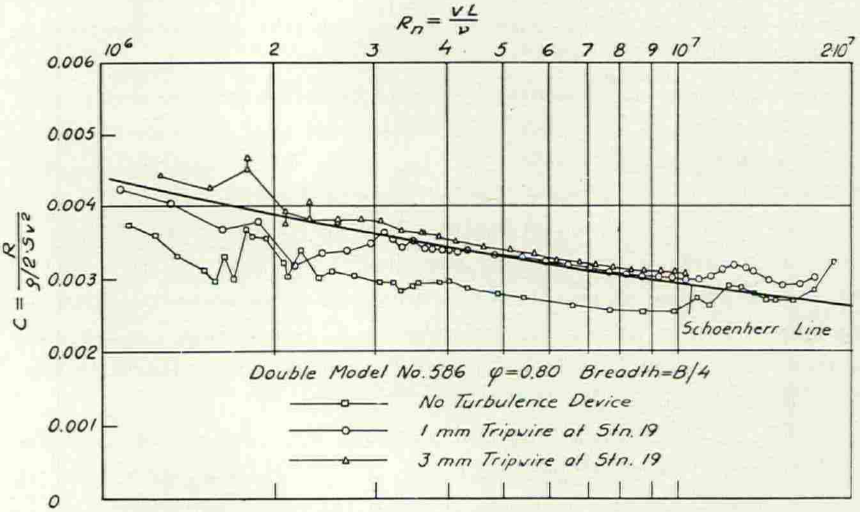
The fact that the narrowest model gave results in close agreement with the SCHOENHERR line was confirmed in tests with the corresponding double model, No. 586. This model enables the non-wavemaking range to be extended to considerably higher values of REYNOLDS number. At a depth below the surface of 0.75 m, no noticeable surface waves were produced until $R_n > 9 \cdot 10^6$. Fig. 4 shows the results of the tests on Model No. 586 without a tripwire and with 1 mm and 3 mm tripwires. A comparison between the narrowest model, No. 564, and the corresponding double model, No. 586, is given in Fig. 5.

In Fig. 6, the results obtained with the broadest model, No. 334, are compared with those from the tests with the corresponding double model No. 605. It will be seen that a considerable part of the resistance curve for the double model follows the SCHOENHERR



$R_n = \frac{vL}{\nu}$
10^6
2
3
4
5
6
7
8
9
10^7
$2 \cdot 10^7$
0.006
0.005
0.004
0.003
0.002
0.001
0
$C = \frac{R}{\rho/2 \cdot S v^2}$
Schoenherr Line
$\varphi = 0.80$
Model No. 334 Breadth = B
Model No. 563 Breadth = B/2
Model No. 564 Breadth = B/4
1 mm Tripwire at Stn. 19

Fig. 3.



$R_n = \frac{vL}{\nu}$
10^6
2
3
4
5
6
7
8
9
10^7
$2 \cdot 10^7$
0.006
0.005
0.004
0.003
0.002
0.001
0
$C = \frac{R}{\rho/2 \cdot S v^2}$
Schoenherr Line
Double Model No. 586 $\varphi = 0.80$ Breadth = B/4
No Turbulence Device
1 mm Tripwire at Stn. 19
3 mm Tripwire at Stn. 19

Fig. 4.

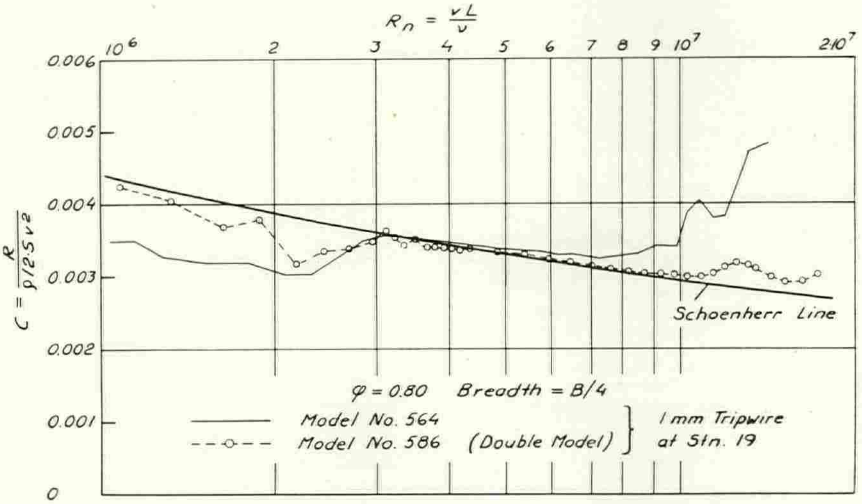

$R_n = \frac{vL}{\nu}$
10^6 2 3 4 5 6 7 8 9 10^7 $2 \cdot 10^7$
0.006
0.005
0.004
0.003
0.002
0.001
0
$C = \frac{R}{\rho/2 \cdot S v^2}$
Schoenherr Line
φ = 0.80 Breadth = B/4
Model No. 564
Model No. 586 (Double Model)
1 mm Tripwire at Stn. 19

Fig. 5.

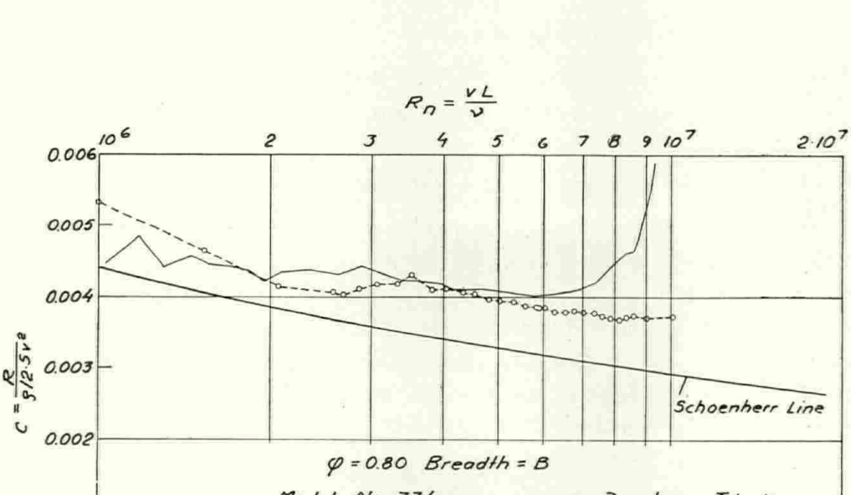

$R_n = \frac{vL}{\nu}$
10^6 2 3 4 5 6 7 8 9 10^7 $2 \cdot 10^7$
0.006
0.005
0.004
0.003
0.002
0.001
0
$C = \frac{R}{\rho/2 \cdot S v^2}$
Schoenherr Line
φ = 0.80 Breadth = B
Model No. 334
Model No. 605 (Double Model)
1 mm Tripwire at Stn. 19

Fig. 6.

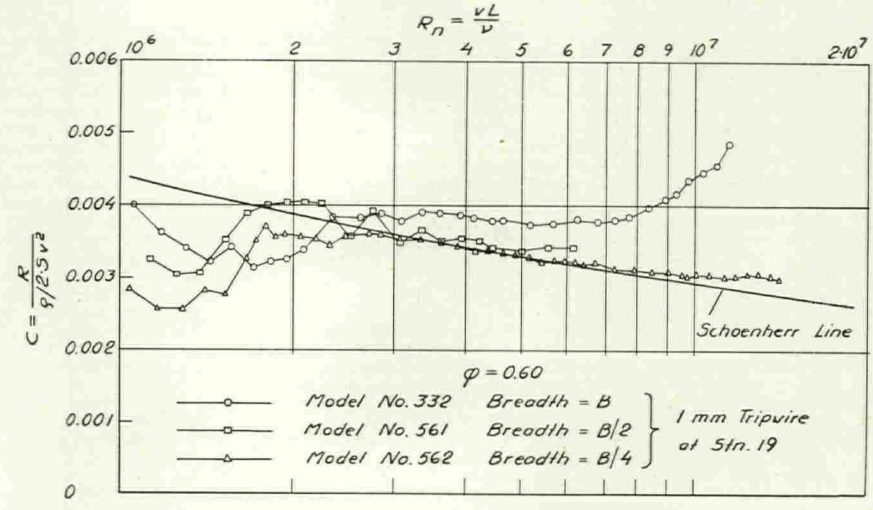


Fig. 7.

line. In the case of the surface model, on the other hand, only a short part of the resistance curve can be regarded as unaffected by both laminar flow and wavemaking resistance.

c. Variation of breadth, $\varphi = 0.60$

Fig. 7, which is similar to Fig. 3, shows the effect of breadth on the form influence factor for $\varphi = 0.60$.

d. Variation of draught (Model No. 350)

As mentioned previously, experiments were carried out with an SSPA standard model, No. 350, with the object of studying the effect of draught on the form influence factor. This model has brass shell plating, so that its surface is different from that of a paraffin wax model. This is possibly the reason for the fact that the 1 mm tripwire was evidently insufficient to promote turbulence in the speed range in question.

Fig. 8 shows the results of the tests with Model No. 350 when fitted with a 3 mm tripwire. The model was run at three different draughts, corresponding to $B/T = 6.00$, 4.00 and 2.00, and the results are surprisingly similar. There is, however, a general tendency for the form influence factor to be lowest at the smallest draught ($B/T = 6.00$).

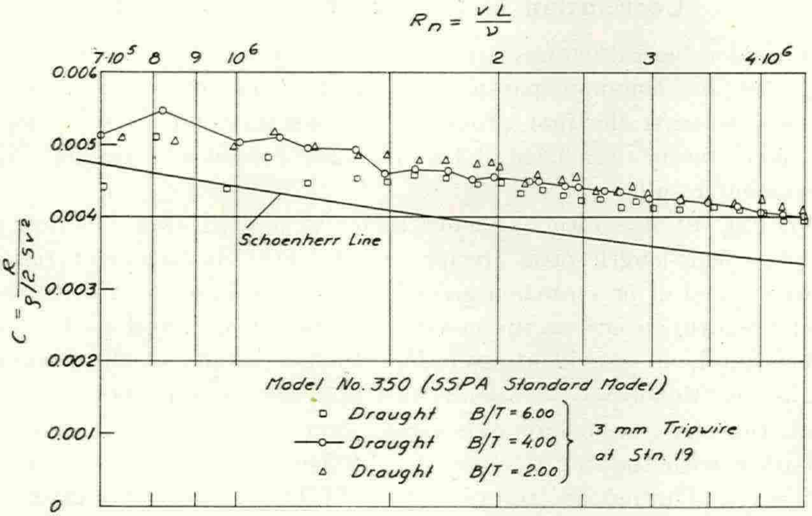


Fig. 8.

e. Tests with »normal» ship models

In order to be able to compare the above results with those obtained with more normal ship models, some additional tests were carried out with three existing SSPA models over the non-wave-making speed range. The results of these tests are shown in Fig. 9.

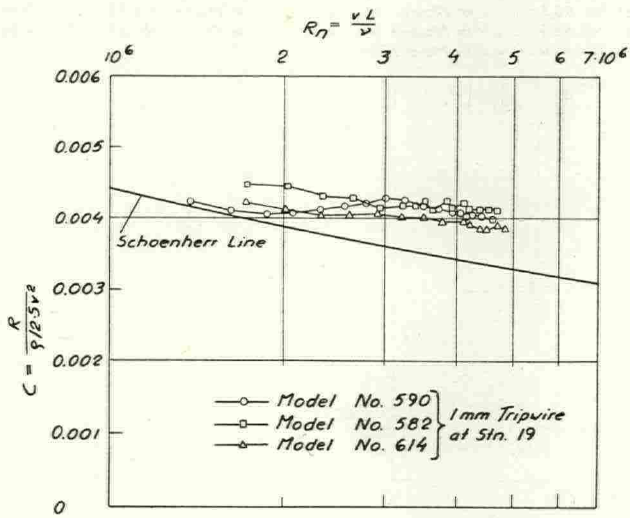


Fig. 9.

7. Correlation of the Experimental Results

Considerable difficulties are involved in presenting all the results together on common parameters. The choice of suitable parameters presents the first problem. For instance, plotting the form influence factor on a base of the prismatic coefficient does not give consistent results.

In Fig. 10, the form influence factor is plotted as a function of displacement-length ratio (reciprocal of length-displacement ratio). This method of presentation gives the best correlation of the fullness and breadth variations discussed in Section 6 *a*, *b* and *c*. On the other hand, as is evident from Fig. 10, the results of the draught variation (Model No. 350) dealt with in Section 6 *d*, do not conform with the other results on this basis. Some improvement might be obtained with the introduction of a further parameter such as B/T.

The form influence factors plotted in Fig. 10 are also given in Table III, together with the appropriate parameters. Also included in the table are the mean Reynolds numbers, corresponding to the speed ranges over which the form influence factors were determined. The frictional coefficients, C_f (Schoenherr), and the corresponding estimated total resistance coefficients, C, are also given in Table III.

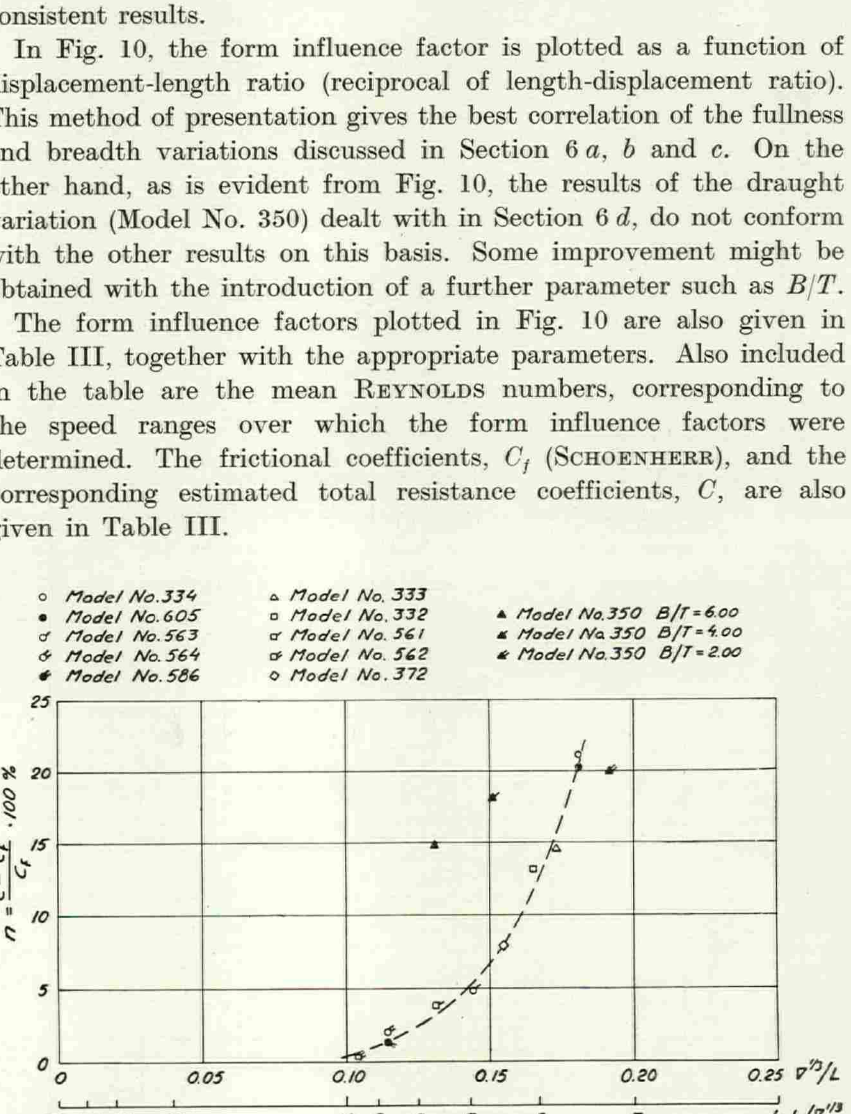


Fig. 10.

Table III

Model	φ	$V^{1/3}/L$	B/T	Figures from which n is obtained	R_n	$C \cdot 10^4$ Approximate value	$C_f \cdot 10^4$ According to SCHOENHERR	$n = \frac{C-C_f}{C_f} \cdot 100$
No.	—	—	—	Nos	—	—	—	%
334	0.800	0.181	2.40	2, 3, 6	$4 \cdot 10^6$	41.45	34.23	21.1
605	0.800	0.181	2.40	6	$4 \cdot 10^6$	41.14	34.23	20.2
563	0.800	0.144	1.20	3	$4 \cdot 10^6$	35.87	34.23	4.8
564	0.800	0.114	0.60	3, 5	$4 \cdot 10^6$	34.91	34.23	2.0
586	0.800	0.114	0.60	4, 5	$6 \cdot 10^6$	32.35	31.93	1.3
333	0.700	0.173	2.40	2	$4 \cdot 10^6$	39.20	34.23	14.5
332	0.600	0.165	2.40	2, 7	$4 \cdot 10^6$	38.70	34.23	13.1
561	0.600	0.131	1.20	7	$4 \cdot 10^6$	35.53	34.23	3.8
562	0.600	0.104	0.60	7	$4 \cdot 10^6$	34.33	34.23	0.3
372	0.520	0.155	2.40	2	$4 \cdot 10^6$	36.93	34.23	7.9
350	0.698	0.131	6.00	8	$2.5 \cdot 10^6$	42.70	37.19	14.8
350	0.702	0.151	4.00	8	$2.5 \cdot 10^6$	43.92	37.19	18.1
350	0.707	0.192	2.00	8	$2.5 \cdot 10^6$	44.63	37.19	20.0

Some of the difficulty of correlating such results is due to the degree of uncertainty involved in the method of determining the form influence factor. The low resistance values obtained in the non-wavemaking speed range contain relatively large measurement errors. At SSPA, however, these errors have been limited to some extent by using a special dynamometer (pendulum apparatus), as mentioned in Section 5, for measuring the resistance at low speeds. Also, as is apparent from the diagrams, the turbulent non-wavemaking speed range is in some cases difficult to define.

8. Comparison with »Normal» Ship Models

In Fig. 11, the mean curve taken from Fig. 10 is compared with values calculated from the test results of »normal» ship models of various types. Three of the latter models (Nos. 582, 590 and 614) were tested at SSPA, but other results were obtained from well-known publications (see list of references below).

Within the range $L/V^{1/3} = 5 - 6.5$, the mean curve agrees well with the marked spots (corresponding to »normal» ship models). On

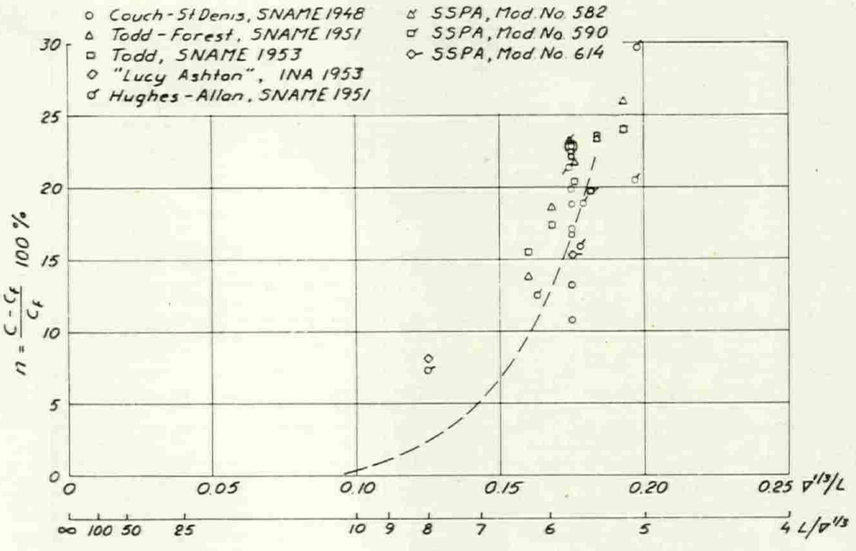


Fig. 11.

the other hand, at higher values of $L/\nabla^{1/3}$ the curve has a tendency to depart from the spots (*e. g.* that referring to the »Lucy Ashton»). In the latter range, however, the models on which the curve is based differ more radically from the »normal» ship models.

9. Acknowledgement

Thanks are due to Mr. Dacre Fraser-Smith, B. Sc., who translated the paper from the Swedish.

10. List of References

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[6] CONN, J. F. C., LACKENBY, H. and WALKER, W. P.: »B. S. R. A. Resistance Experiments on the Lucy Ashton, Part II», *Trans. I. N. A.* 1953, p. 350.

[7] HUGHES, G. and ALLAN, J. F.: »Turbulence Stimulation on Ship Models», *Trans. S. N. A. M. E.* 1951, p. 281.

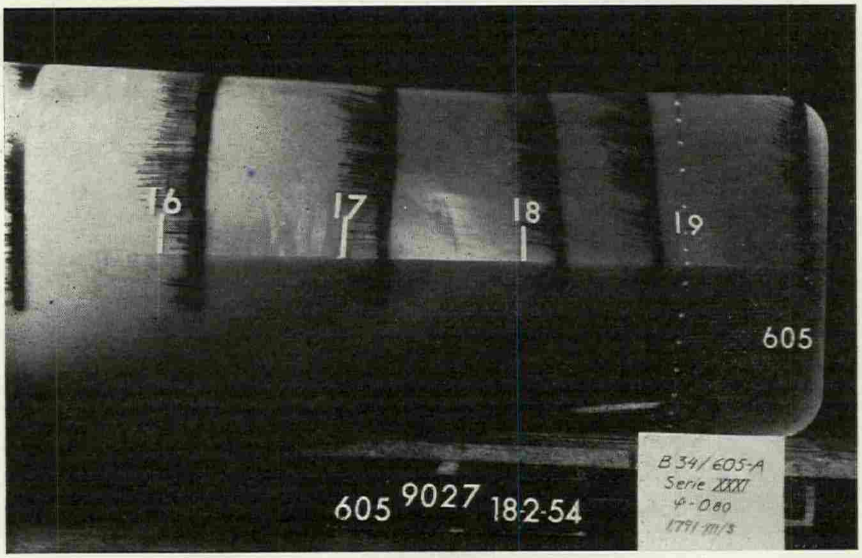
Appendix 1

As mentioned in Section 3 above, a special streamline test was carried out with Model No. 605 (double model, $\varphi = 0.80$, breadth $= B$) in order to investigate the extent to which flow separation occurred on the after-bodies of the fullest models. The flow pattern in the neighbourhood of the plane of symmetry of the double model was studied at the same time, in order to determine whether any unsymmetrical cross-flow (across the plane of symmetry) took place on this model.

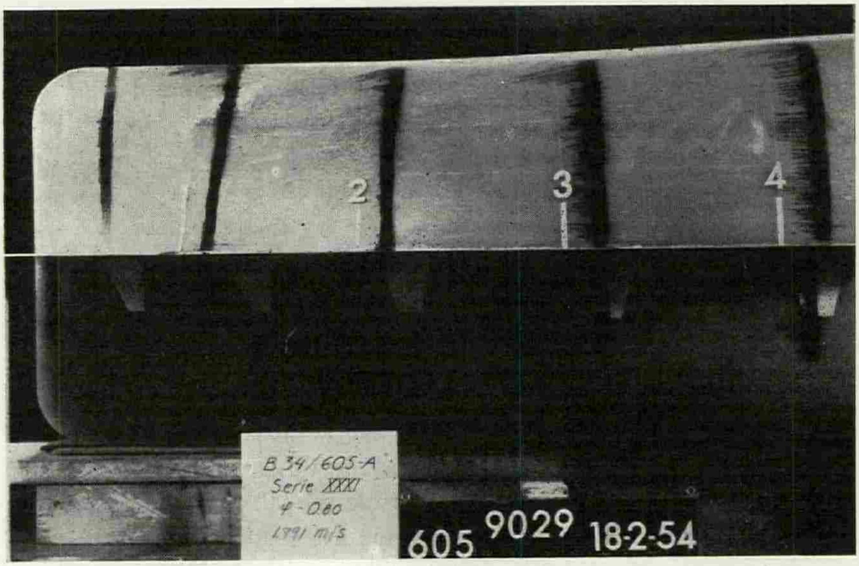
The method adopted for this test was that normally used at the Tank. A black paint composed of lampblack and linseed oil was applied to the model in equidistant transverse strips. Before the paint had had time to dry, the model was launched and a run was made. To facilitate particular study of the flow around the after-body, a plate was fixed on the side of the after-body in the plane of the waterline (the plane of symmetry of the double model). This plate was also painted in the manner described above.

The streamline test was carried out at a speed, v, of 1.8 m/sec., corresponding to a REYNOLDS number, R_n, of $9.1 \cdot 10^6$. The results of the test are evident in Figs. 12—14, which are photographs of the model after removal from the tank at the end of a run. The wet paint has been forced out in lines by the flow during the run and the direction of the flow along the surface of the model can thus be seen.

The lines are clearly discernible in the upper picture in Fig. 12, which shows the fore-body of the double model. The horizontal line along the model at mid-depth is the intersection of the plane of symmetry with the model surface. The position of the tripwire at Station No. 19 ($L/20$ from F. P.) can also be seen in this picture.



Fore-Body



After-Body

Fig. 12. Model No. 605. Streamlines at $v = 1.8$ m/sec.

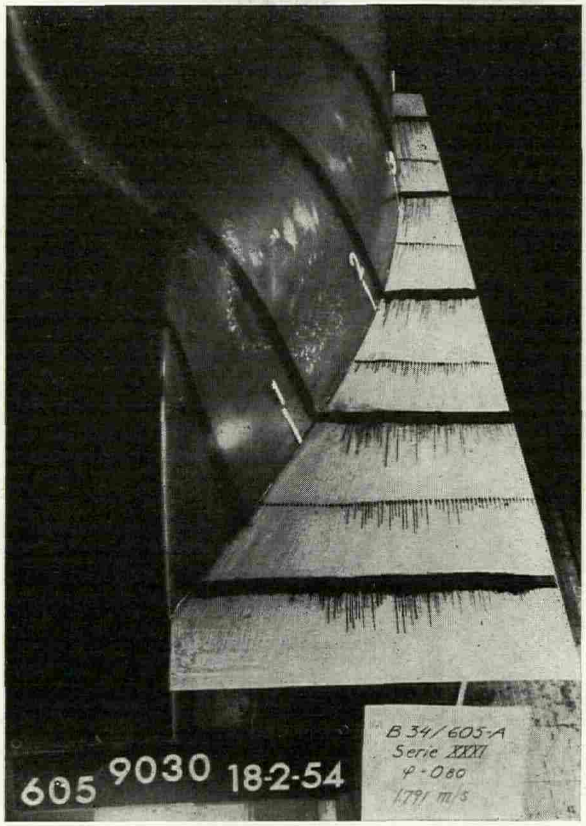


Fig. 13. Model No. 605. After-Body and Plate.
Streamlines at $v = 1.8$ m/sec.

The lower picture in Fig. 12 shows the after-body of the double model. It is evident from this photograph that very few paint streamlines were formed abaft Station No. 2. This may indicate that flow separation took place in this region.

The plate on the after-body, which was mentioned above, can be seen in horizontal projection in the lower part of Fig. 12. (It is the cause of the heavy shadow on the lower half of the model in this photograph.) The plate is shown as seen obliquely from above in Fig. 13 and this photograph also indicates that some flow separation occurred abaft Station No. $1\frac{1}{2}$ or $1\frac{1}{4}$. In this region, the wet paint was not disturbed from its original position, at least not close to the surface of the model.

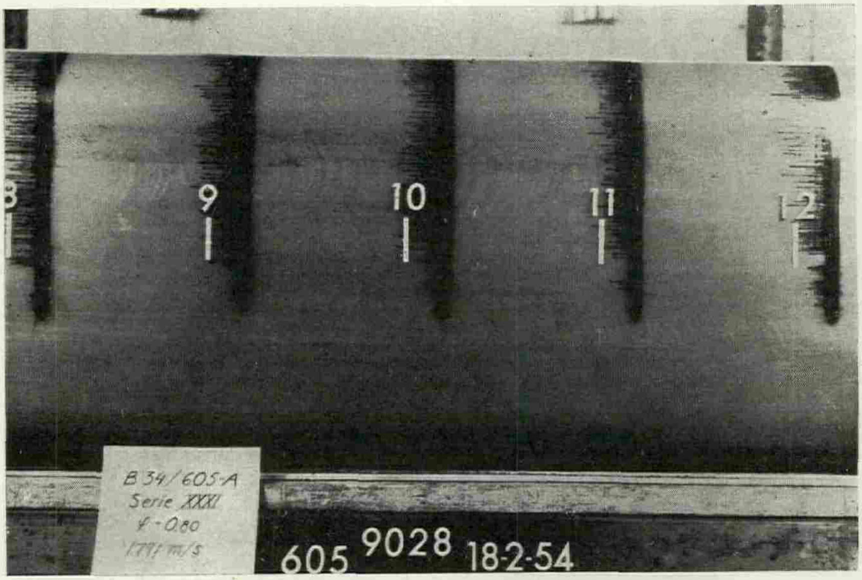


Fig. 14. Model No. 605. Parallel Middle Body.
Streamlines at $v = 1.8$ m/sec.

The flow close to the model was evidently relatively symmetrical about the waterline plane (plane of symmetry). This is shown by Fig. 12 and also by Fig. 14; the latter illustrates the middle-body of the model.

From what has been said above regarding the results of the streamline test, it is clear that there is reason to suspect that some separation of flow took place on the after-body of the fullest model. However, no attempt has been made to correct the recorded values given earlier in this paper in the light of the streamline test observations.

Appendix 2

Primary Results

Model No. 563, 1 mm Tripwire at Stn. 19	Starting Time	v m/sec.	R kg
Date 18th June 53, Watertemp. = 16.6° C	8.00	0.207	0.0522
	8.00	0.220	0.0541
	8.40	0.242	0.0728
	8.40	0.271	0.0813
	9.15	0.297	0.0949
	9.15	0.320	0.107
	9.40	0.346	0.127
	10.20	0.374	0.151
	10.20	0.400	0.178
	10.45	0.495	0.268
	11.05	0.597	0.379
	11.35	0.700	0.513
	12.00	0.811	0.686
	12.20	0.901	0.828
	13.25	1.000	1.022
	13.45	0.448	0.214
	14.05	0.553	0.333
	14.25	0.651	0.449
	14.50	0.753	0.587
	15.10	0.851	0.735

Model No. 564, 1 mm Tripwire at Stn. 19	Starting Time	v m/sec.	R kg
Date 11th May 53, Watertemp. = 13.6° C	10.55	0.201	0.0348
	11.30	0.222	0.0427
	11.30	0.247	0.0495
	12.05	0.276	0.0607
	12.05	0.298	0.0702
	13.35	0.349	0.0965
	13.35	0.406	0.124
	14.00	0.448	0.151
	14.20	0.496	0.198
	14.35	0.551	0.263
	14.50	0.599	0.316
	15.05	0.650	0.372
	15.20	0.802	0.552
	15.40	0.948	0.752
	16.00	1.103	1.011
	16.20	1.205	1.184
Date 30th July 53, Watertemp. = 17.4° C	10.15	1.147	1.08
	10.30	1.201	1.17
	10.45	1.297	1.35
	11.00	1.403	1.60
	11.20	1.502	1.85
	11.40	1.603	2.18
	12.00	1.702	2.45
	12.20	1.728	2.52
	13.30	1.810	3.13
	13.50	1.900	3.60
	14.10	2.009	3.78
	14.30	2.108	4.20
	14.50	2.310	6.20
	15.15	2.510	7.51
	15.40	2.192	4.95

Model No. 586
No Turbulence Device

Date	Starting Time	v m/sec.	R kg
23rd Sept. 53 15.4° C	16.45	0.206	0.0784
	16.45	0.251	0.103
Date 24th Sept. 53 Watertemp. = 15.4° C	9.45	0.229	0.0930
	9.45	0.280	0.121
	11.20	0.302	0.149
	11.20	0.332	0.200
	11.25	0.359	0.226
	12.15	0.387	0.238
	12.15	0.412	0.285
	14.20	0.466	0.332
	14.20	0.511	0.392
	15.30	0.565	0.465
	15.30	0.614	0.525
	16.00	0.665	0.644
25th Sept. 53 15.5° C	12.05	0.596	0.517
	12.05	0.645	0.594
	13.35	0.389	0.227
	13.35	0.442	0.291
	14.10	0.291	0.124
	14.10	0.314	0.146
	14.10	0.338	0.202
Date 26th Sept. 53 Watertemp. = 15.4° C	8.40	0.718	0.75
	9.00	0.748	0.82
	9.00	0.801	0.91
	9.25	0.906	1.13
	9.25	1.003	1.36
	10.15	1.224	1.95
	10.35	1.423	2.57
	10.55	1.617	3.30
	11.20	1.822	4.20
	11.50	2.003	5.36
	12.15	2.272	7.42
	12.35	2.520	8.79
	12.55	2.751	10.10
28th Sept. 53 15.3° C	8.50	2.100	5.75
	9.15	2.940	11.58
	9.40	3.207	14.47
	10.20	3.461	19.15
	10.45	2.651	9.38
	11.10	2.385	8.11

Model No. 586
1 mm Tripwire at Stn. 19

Date	Starting Time	v m/sec.	R kg
Date 30th Sept. 53 Watertemp. = 15.4° C	9.45	0.200	0.0839
	9.45	0.244	0.119
	10.50	0.301	0.164
	10.50	0.348	0.226
	11.25	0.404	0.256
	11.25	0.448	0.332
	12.00	0.498	0.414
	12.00	0.548	0.515
	13.30	0.599	0.626
	13.30	0.648	0.724
	14.00	0.700	0.821
	15.05	0.775	0.994
	15.30	0.726	0.881
	15.55	0.676	0.768
	16.20	0.575	0.591
	16.20	0.623	0.657
Date 1st Oct. 53 Watertemp. = 15.4° C	8.45	0.745	0.927
	9.05	0.804	1.076
	9.05	0.895	1.308
	9.30	1.001	1.63
	9.30	1.098	1.92
	10.10	1.201	2.27
	10.25	1.304	2.64
	10.40	1.406	3.01
	11.00	1.506	3.43
	11.20	1.606	3.87
	11.35	1.709	4.37
	11.55	1.809	4.88
	12.15	1.910	5.38
	13.25	2.010	5.98
	13.45	2.110	6.67
	14.05	2.208	7.51
	14.25	2.319	8.45
	14.45	2.428	9.17
	15.10	2.510	9.63
	15.30	2.650	10.34
	15.50	2.783	11.12
	16.10	2.970	12.72
	16.35	3.176	15.05

Model No. 586 3 mm Tripwire at Stn. 19			
	Starting Time	v m/sec.	R kg
Date 18th Nov. 53 Watertemp. = 13.7° C	11.35	0.246	0.133
	12.05	0.301	0.190
	12.05	0.348	0.280
	13.30	0.407	0.307
	13.30	0.447	0.400
	14.05	0.497	0.460
	14.05	0.550	0.570
	14.35	0.596	0.665
	14.35	0.647	0.756
	15.05	0.703	0.883
	16.00	0.348	0.270
	16.00	0.406	0.320
	16.35	0.449	0.379
	16.35	0.496	0.461
Date 19th Nov. 53 Watertemp. = 13.6° C	11.00	0.700	0.88
	11.00	0.748	0.99
	11.20	0.804	1.12
	11.40	0.898	1.37
	11.40	0.998	1.67
	11.55	1.101	2.00
	12.10	1.203	2.32
	13.25	1.309	2.73
	13.40	1.403	3.10
	13.55	1.505	3.52
	14.15	1.608	3.98
	14.35	1.706	4.47
	14.55	1.812	5.03
	15.15	1.913	5.58
	15.35	1.998	6.05

Model No. 605 1 mm Tripwire at Stn. 19			
	Starting Time	v m/sec.	R kg
Date 20th Jan. 54 Watertemp. = 13.1° C	9.20	0.197	0.159
	10.15	0.301	0.324
	10.50	0.406	0.526
	11.15	0.504	0.793
	11.35	0.604	1.172
	12.00	0.527	0.860
	12.25	0.562	0.997
Date 20th Jan. 54 Watertemp. = 13.1° C	14.20	0.655	1.38
	14.45	0.697	1.61
	14.45	0.753	1.79
	15.10	0.797	2.01
	15.10	0.852	2.27
	15.30	0.894	2.47
	15.30	0.947	2.74
	15.50	0.988	2.96
	16.05	1.050	3.33
	16.20	1.105	3.64
	16.35	1.160	3.98
Date 21st Jan. 54 Watertemp. = 12.9° C	8.40	1.155	3.97
	9.00	1.199	4.26
	9.15	1.243	4.51
	9.30	1.297	4.90
	10.10	1.339	5.25
	10.50	1.390	5.62
	11.10	1.454	6.12
	11.30	1.504	6.48
	11.45	1.552	6.87
	12.05	1.608	7.32
	12.25	1.653	7.79
	13.25	1.701	8.32
	13.45	1.789	9.12
	14.05	1.996	11.39

Model No. 561 1 mm Tripwire at Stn. 19			
	Starting Time	v m/sec.	R kg
Date 16th June 53 Watertemp. = 16.7° C	12.00	0.201	0.0345
	12.00	0.224	0.0399
	13.40	0.247	0.0491
	13.40	0.274	0.0694
	14.15	0.300	0.0918
	14.15	0.322	0.109
	14.40	0.348	0.128
	15.15	0.376	0.150
	15.15	0.402	0.170
	15.45	0.496	0.253
Date 17th June 53 Watertemp. = 16.7° C	8.25	0.602	0.348
	8.45	0.702	0.458
	9.10	0.804	0.578
	9.30	0.900	0.713
	10.10	1.001	0.900
	10.30	1.102	1.088
	10.55	0.450	0.190
	11.15	0.552	0.277
	11.35	0.650	0.385
	12.00	0.756	0.525

Model No. 562 1 mm Tripwire at Stn. 19			
	Starting Time	v m/sec.	R kg
Date 7th May 53 Watertemp. = 13.7° C	12.05	0.202	0.0270
	13.45	0.225	0.0305
	13.45	0.248	0.0367
	14.15	0.273	0.0490
	14.15	0.297	0.0570
	14.50	0.322	0.0790
	14.50	0.348	0.105
	15.20	0.375	0.118
	15.20	0.401	0.134
	15.50	0.449	0.162
	16.05	0.497	0.207
	16.25	0.552	0.256
Date 8th May 53 Watertemp. = 13.8° C	8.40	0.598	0.294
	9.05	0.648	0.346
	9.30	0.697	0.394
	10.20	0.748	0.449
	10.40	0.804	0.508
	11.00	0.848	0.568
	11.25	0.901	0.632
	11.45	0.949	0.697
	12.05	1.002	0.768
	12.25	1.049	0.828
	13.40	1.106	0.927
	14.00	1.152	1.004
	14.20	1.202	1.086
	15.00	0.332	0.0905
	15.00	0.362	0.109
	15.30	0.424	0.149
	15.50	0.475	0.188
	16.15	0.524	0.231
Date 3rd Aug. 53 Watertemp. = 17.0° C	8.50	1.143	0.97
	9.20	1.193	1.07
	9.20	1.294	1.22
	9.40	1.398	1.42
	10.10	1.504	1.63
	10.30	1.600	1.84
	10.50	1.725	2.10
	11.10	1.699	2.05
	11.30	1.800	2.31
	11.50	1.900	2.56
	12.15	2.000	2.80
	13.25	2.101	3.12
	13.45	2.199	3.45
	14.05	2.300	3.78
	14.25	2.410	4.09
	14.50	2.510	4.39

Model No. 350

3 mm Tripwire at Stn. 19

	Starting Time	v	R
		m/sec.	kg
$B/T = 6.00$			
Date 27th Jan. 54, Watertemp. = 13.0° C	9.45	0.141	0.0215
	9.45	0.163	0.0333
	10.40	0.195	0.0407
	10.40	0.217	0.0556
	11.10	0.243	0.0645
	11.10	0.274	0.0832
	11.45	0.299	0.0982
	11.45	0.321	0.116
	12.05	0.347	0.134
	12.25	0.377	0.155
	13.30	0.403	0.178
	13.50	0.450	0.217
	14.15	0.500	0.259
	14.40	0.554	0.311
	15.00	0.602	0.366
	15.20	0.647	0.419
	15.50	0.708	0.508
	16.15	0.758	0.575
	16.35	0.808	0.649
28th Jan. 54, 12.8° C	8.25	0.853	0.705
	8.45	0.902	0.790
	9.05	0.576	0.342
	9.30	0.522	0.284
	10.15	0.474	0.237
	10.35	0.427	0.193
$B/T = 4.00$			
11th Jan. 54, 12.6° C	15.00	0.142	0.0299
	15.00	0.167	0.0441
	15.45	0.204	0.0603
	15.45	0.227	0.0759
	16.15	0.244	0.0849
	16.40	0.277	0.109
12th Jan. 54, 12.8° C.	8.45	0.297	0.117
	9.10	0.322	0.139
	9.35	0.349	0.163
	10.15	0.374	0.182
	10.40	0.399	0.209
	11.00	0.449	0.261

	Starting Time	v	R
		m/sec.	kg
$B/T = 4.00$			
Date 12th Jan. 54, Watertemp. = 12.8° C	11.25	0.501	0.319
	11.50	0.556	0.387
	12.15	0.600	0.442
	13.25	0.652	0.520
	13.45	0.703	0.598
	14.05	0.757	0.686
	14.25	0.807	0.765
	14.50	0.858	0.858
	15.10	0.904	0.947
	15.35	0.527	0.350
	15.55	0.481	0.296
	16.15	0.437	0.248
$B/T = 2.00$			
Date 28th Jan. 54, Watertemp. = 12.8° C	12.25	0.149	0.0474
	12.25	0.172	0.0627
	13.45	0.200	0.0834
	13.45	0.224	0.109
	14.10	0.247	0.127
	14.35	0.277	0.156
	14.55	0.300	0.183
	15.20	0.327	0.214
	15.45	0.349	0.244
	16.10	0.379	0.285
	16.25	0.404	0.321
Date 29th Jan. 54, Watertemp. = 12.6° C	9.40	0.398	0.316
	10.15	0.448	0.387
	10.40	0.498	0.472
	11.00	0.553	0.557
	11.20	0.603	0.658
	11.40	0.658	0.766
	12.00	0.707	0.882
	12.20	0.758	1.001
	13.30	0.813	1.177
	13.55	0.856	1.274
	14.20	0.908	1.418
	14.45	0.432	0.348
	15.10	0.478	0.432
	15.35	0.522	0.498
	16.00	0.578	0.620

Model No. 590
1 mm Tripwire at Stn. 19

	Starting Time	v m/sec.	R kg
Date 4th Feb. 54, Watertemp. = 12.6° C	9.30	0.299	0.124
	10.20	0.350	0.165
	10.40	0.406	0.219
	11.00	0.450	0.270
	11.20	0.504	0.343
	11.45	0.552	0.416
	12.05	0.604	0.502
	12.25	0.652	0.596
	13.30	0.705	0.693
	13.50	0.756	0.780
	14.15	0.806	0.879
	14.40	0.852	0.971
	15.05	0.906	1.084
	15.25	0.953	1.201
	15.45	1.000	1.309
	16.05	0.919	1.119
	16.25	0.882	1.040

Model No. 582
1 mm Tripwire at Stn. 19

	Starting Time	v m/sec.	R kg
Date 5th Feb. 54, Watertemp. = 12.7° C	9.40	0.295	0.194
	10.25	0.348	0.268
	10.50	0.402	0.347
	11.10	0.452	0.436
	11.30	0.502	0.519
	11.50	0.553	0.636
	12.15	0.601	0.764
	13.30	0.654	0.908
	13.50	0.704	1.037
	14.10	0.752	1.163
	14.35	0.803	1.321
	14.55	0.780	1.251
	15.20	0.718	1.058
	15.40	0.671	0.932
	16.00	0.619	0.786
	16.20	0.580	0.700

Model No. 614
1 mm Tripwire at Stn. 19

	Starting Time	v m/sec.	R kg
10th Feb. 54, 12.5° C	16.25	0.296	0.185
	16.50	0.346	0.247
Date 11th Feb. 54, Watertemp. = 12.5° C	9.00	0.400	0.321
	9.25	0.446	0.403
	10.15	0.498	0.506
	10.40	0.550	0.608
	11.00	0.602	0.728
	11.25	0.651	0.840
	11.50	0.706	0.989
	12.15	0.756	1.100
	13.30	0.812	1.286
	13.50	0.835	1.347
	14.10	0.777	1.172
	14.35	0.725	1.030