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Contents

Form Factors for Seagoing Ships from Model Experiments on Deep Water*.

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Summary

The present paper deals with the determination of form factors for a series of seagoing ships (CB = 0.55 to 0.85) based on the results of towing tests with models on deep water. The evaluation of the experimental data to determine the form factors and the results are discussed.

Particular attention is paid to select appropriate Froude number ranges for the evaluation. Moreover, the influence of an inaccurate estimated form factor on the prediction of the total resistance of the ship is investigated.

The form factor of the ship "Lucy Ashton" is derived from measured model resistances and, in order to verify this form factor, ship resistances will be predicted by applying the form factor method. The results will be compared with published experimental data of full scale tests.

1. Introduction

Shipyards and owners expect a reliable estimation of the resistance and the horsepower of a new ship during the design phase. That is why a universally valid and accepted method should be available. The pure theoretical prediction based on modern mathematical models still have not any significance for the practice. Experiments on original conditions with the full sized ship are extremely expensive and, of course, presuppose the finish of the actual ship's body. Therefore, the usual methods of resistance estimation are based on experiments with geometrically similar models and physical laws, by which the test results will be extrapolated on the full scale ship.

The extrapolation will be carried out mostly by using the classical Froude's method or, at least since the 15th ITTC 1978 [1], by using the form factor method. In both methods, the total resistance is composed of a part dependent on the Reynolds number with reference to the skin friction coefficient of the smooth flat plate (friction line of the ITTC 1957, [2]) and of a part dependent on the Froude number. While the method of Froude represents the former viscous resistance only by the mentioned frictionline, the form factor method contains additionally a form-caused viscous component. The latter is supposed to be proportional to the frictional coefficient of the flat plate, as proposed by Hughes [3]. The constant of proportionality is a geometrically dependent and called form factor. The explicity consideration of the shape should make allowance for the real three dimensional characteristics of the flow around the ship's hull. Therefore, when applying the form factor method, a more reasonable extrapolation of model test results can be expected. Form factors are determined for a multitude of different ships [4]. The arising problems like scatter of the derive form factors [5] and the problems in the course the translation of model resistances to the full sized ship [6] are also considered. In the present work, form factors of a ship's series with block coefficients varied from CB = 0.55 to 0.85 are derived from model test results on deep water, which have been carried out by the Hamburgische-Schiffbau-Versuchsanstalt (HSVA). The procedure to determine the form factors will be discussed and the results will be compared with data of publised empirical formulas. Moreover, the effect of the form factor on the estimation of the ship resistance will be investigated.

2. Determination of ship resistances according to the form factormethod.

The total resistance coefficient of a ship is expressed in the form factor method [1] by

$$C_{T,S} = C_{FO,S} \cdot (1+k) \,..\, C_{R,S} + C_A + C_{AA} \quad \text{(1a)}$$

where k represent the form factor, once introduced by Hughes [3]. If the geometrical similarity betweenthe model and the ship is in force, the form factor may be interpreted as a constant. C_A defines an empirical coefficient, which allows for the roughness of the wetted ship's hull, and C_{AA} the coefficient of the air or wind resistance.

Assuming a perfect smooth surface and neglecting wind effects, the total resistance coefficient of the model is given by

$$C_{T,M} = C_{FO,M} \cdot (1+k) \,..\, C_{R,M} \quad \text{(1b)}$$

As in the Froud's method the friction coefficients $C_{FO,S}$ and $C_{FO,M}$ are determined by way of calculation, whereas the ITTC-formula [2] for the drag coefficient of a two-dimensional turbulent flow over a flat plate.

$$C_{FO} = 0.075 / (\log R - 2)^2 \quad \text{(2)}$$

is used. The coefficients of the residuary resistances $C_{R,S}$ and $C_{R,M}$ are defined Fn - dependent in the sense of coefficients of the wavemaking resistance and the tests with the geometrically similar model will be performed considering Froude's law of similarity. Then, the residuary resistance coefficients of the ship and of the model can be equated

$$C_{R,S} = C_{R,M} \quad \text{(3)}$$

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and determined from rearranging of eq.(1b)

$$C_{R,M} = C_{T,M} - C_{FO,M}\,(1+k) \quad (4)$$

with the data $C_{T,M}$ and $C_{FO,M}$ of the model experiments. As explained later on, also the form factor k will be determined by an evaluation of the model test results.

The pros and cons of the Froude's method and of the form factor method as well as suggestions for improvement and their consequences are discussed in detail in the literatures [6], [7].

3. Determination of the form factors

In this work, form factors for a series of merchant ships will be derived from results of systematical model towing tests. The experiments have been carried out by Chirila [8] in the large towing tank of the HSVA. Additionally, the form factor of the ship "Lucy Ashton" will be determined, for which measured resistances exist not only from geosim tests, but also from experiments with the full scale ship [9]. Thus, by applying of the form factor method, the opportunity is presented to check the form factor derived from the model test results and to verify predicted ship resistances. The experiments with the models have been carried out in the National Physical Laboratory Teddington, and the measurings with the ship in the bay Gare Loch, Glasgow, in 1950.

3.1 Description of the models

Table (1) shows the data of the investigated HSVA-models. The surface of the wooden model bodies was coated with laquer and, to promote turbulent flow, stripes of sandpaper was fixed at positions given in Table (1).

The data of the "Lucy Ashton" and its 20ft-model, are listed in Table (2). The model was made in wax and had a demonstrable smooth surface. For the purpose of turbulence stimulation, a trip-wire (diameter 0.91 mm) was mounted in a distance to the bow of 5% of the model length. The ship itself had a painting corresponding to the standard service condition. Hereby, a mean height of equivalent sand roughness of Ks = 0.096 mm results.

3.2 Completion and conditions of the trials.

All experimental results considered in the following sections originated from trials which have been carried out with design draft. The investigated Froude number ranges are included in the Tables (1) and (2). During the course of the trials, the models could freely trim and sag. Further informations about the flow conditions in the HSVA-tests are not available.

Supplementary experimental investigations with the "Lucy Ashton" - models [9] without trip-wire showed, that the model resistances were changed by 1% at the most. Thus, effects of laminar flow can be almost excluded.

The experiments with the full scale ship have been performed on a straight route (l=1 mile). During the runs, the speed of the ship and the thrust of the driving airscrews have been measured several times. Subsequently, the measured values were averaged and tidal effects as well as effects caused by variable displacement due to the fuel consumption and by different rudder positions were eliminated.

Furthermore, wind measurements during the runs of the ship and separate model experiments in a wind tunnel have been made, from which the wind resistances could estimated, these were substracted from the measured total resistances. Finally, the results were converted to a reference temperature of 15 C.

A detailed description of the models and of the experiments can be found in the cited literatures.

3.3 Evaluation procedure to determine the form factors.

In order to determine the form factors from the model test results (C_T, C_{FO} and F_n), the residuary resistance coefficient in eq.(1b) will be replaced by a speed-dependent formulation. According to Huges [3], this can be realized at low and medium Froude numbers by employing the equation

$$C_W = y \cdot F_n^N \quad (5)$$

of the wavemaking resistance coefficient [10]. As results of theoretical investigations [11], [12], the exponent of the Froude number varies between N = 4 and 6. Values in this range have been used also in determinations of form factors [3], [13], [14].

According to the ITTC 1981 [5], the range of application in form factor determinations is restricted to 0.12-0.14 $\leqslant$ Fn $\geqslant$ 0.20-0.22, whereat the lower limit laminar flow effects should be avoided. As reported in [13], eq.(5) can also be applied in cases of ship with fully forms.

In confirmity with the graphic method of Prohaska [14], the equation

$$C_T / C_{F0} - 1 = k + y \cdot F_n^N \; / \, C_{F0} \quad (6)$$

is taken as a basis for the further evaluation. The determination of the values of k, y and N will be carried out by the gaussian least squares method. They were considered as the mean unknown constants of a fitting function. A computarized calculation procedure was prepared to carry out this task with the case of a given exponent N is also allowed.

In order to make the regression calculations not doubtful because of single, highly scattering measured values and with regard to a selection of suitable speed ranges, beforehand the rest data are figured in the for $(C_T - C_{F0})/C_{F0}$ against the Froude number, fig. 1, and the courses are examined. The curves of the HSVA-models show throughout smooth courses. However, the data of the "Lucy Ashton" -model compries irregularities and 3 values in the range $Fn < 0.3$ will be excluded from the regression analysis.

Besides, concave courses should generally be expected for exponents $N > 1$ according to eq.(6). Both criterions are met in the case of "Lucy Ashton", possibly for the HSVA-model No.2 too. But, when inspecting the values of the other HSVA-models, almost linear courses in the lower Froude number range can be seen, whereat elongationsof the curves result in negative form factors.

Furthermore, a slight convex curvature can be observed in the case of model No.6 at low Froude numbers. This considerations allow the conclusion, that the flow was not fully turbulent in the experiments at low speeds with the models No.1 and No.3 to No.6. Therefore, the lower limit of the Froude number range in the determination of the form factors of these models need possibly a shifting above the limit suggested by the ITTC 1981 ($Fnu = 0.12 - 0.14$). Since in the cases of model No.1 and No.2 measuring values exist only for $F_n > 0.18$, the ITTC-recommendation anyway cannot be effective for these models.

The upper Froude number concerning the range of validity of eq.(5) resp. eq.(6) cannot further examined by analysing Fig.(1). But the steep courses at high speeds indicate an altered behaviour of the wavemaking resistance, which is not representable by constant values of y and N in eq.(5) over the whole Froude number range. In the cases of model No.1 and No.2 again, the recommendation of the ITTC ($F_{n0} = 0.20 - 0.22$) cannot be taken as a basis due to the measuring range.

3.4 Results and discussions

In the first regression calculations, the Froude number limits are varied between $F_{nu} = 0.12$ to 0.14 and $F_{n0} = 0.20$ bis 0.22 as far as the measuring ranges allow. In addition, exponents of $N = 4$, 5 or 6 are supposed in eq.(5) for the wavemaking resistance coefficient. These variations result in form factor values which show a relative strong scatter.

From this particularly affected are the models, which corresponding to the analysis of fig.1 presumably have been towed under imperfect turbulent flow conditions. When setting the lower limit to $F_{nu} = 0.12$ and the upper to $F_{n0} = 0.20$ or less, partly negative form factors result. To conducta further assessment of these facts, figures are prepared according to the graphical method of Prohaska. For example, fig.(2) shows the given date of model No.3 and the fitting line determined with $F_{nu} = 0.12$, $F_{n0} = 0.22$ and $N = 4$.

The related experimental CT-data form a weakly marked S-shape, which is directed downwards at low Froude numbers and which indicates likewise effects of laminar flow. Obviously, the latter is the reason for the relative small value of form factor of $k = 0.0971$ (model No.3) and for the negative values mentioned above. Moreover, the quality of the regression analysis is not satisfactory in the range $0.12 \leqslant Fn \geqslant 0.22$.

In order to find reasonable results, all further regression calculations are carried out with a systematic variation of the Froude number limits in larger ranges. The constants k, y and N of eq.(6) are determined in each case by the best approximation.

Subsequently, the calculated form factors are plotted against the current limits Fno and Fnu of the actual considered range of evaluation. Hereby the idea is followed, that the existence of a straight fitting line in the sense of Prohaska's method will be expressed by specific shapes of the graphs. When approaching the correct Froude number limits and especially within these limts, the k-curves should show horizontal parts which should be easily to identify.

The form factors of model No.3 are plotted in fig.(3a) and fig.(3b) against the lower and the upper Froude number limit, while the other limit of the two is applied as a parameter. But, both figures do not clearly reveal the expected features. This is essentially explainable by the S-shaped courses of the C_T/C_{F0} - values, as shown in fig.(2).

Therefore, parts of the curves will be approximately considered horizontal tangents. Moreover, the condition shall be met, that the k-values do not vary strongly when the parameters Fno & Fnu change. In the present example, the ranges of k $= 0.127$ to 0.19, $F_{nu} = 0.15$ to 0.18 and $F_{n0} = 0.21$ to 0.24 are ascertained.

Graphs of the same kind as well as similar large scatter ranges of the form factors and of the Froude number limits are found for the HSVA-models No.1, No.5 and No.6. However, the corresponding plots for the HSVA-model No.2 and No.4 show a different appearance without clearly identifiable indications for the envisaged evaluation. The results of these two models can only be estimated for the present.

The curves of the "Lucy Ashton"-model are represented in the fig.(4a) and fig.(4b). Fig.(4a) shows long-drawn flat courses in the range $F_{nu} = 0.09$ to 0.15. Nevertheless, the form factor can not be specified moer pvecisly than than $k = 0.038$ to 0.058 due to *the fluctuations of the measuring values in the interesting Froude number range $F_{n0} < 0.28$. The Froude number limits agree approximately with the recommendation of the ITTC 1981.*

Since the regression calculations yield simultaneously the exponent of the Froude number in eq.(5), also the N-values respectively the ranges of the N- values are known.

The upper part of Table (3) represents the determined data of the form factors and of the exponents N for all models. With respect to the arithmetical mean value, the form factors show a scatter range of about + 10% to + 21%. But in all cases, the quality of the regression analysis within the accompanying Froude number limits is quite good.

A reduction of the determined data ranges can be done with the help of plots according to the method of Prohaska by applying additional conditions for the measuring values which lie outside of the actual considered Froude number range Fnu < Fn < Fno. For the purpose of data reduction, the following assumptions are used:

1- the measured resistance coefficients in the range $F_n < F_{nu}$ shall be affected by laminar flow and therefore the C_T/C_{FO} -values in question should lie below the fitting line;

2- the resistance coefficients in the range Fn > Fno shall be influenced by an unacceptable increase of the wave making resistance and accordingly the corresponding C_T / C_{F0}- values should lie above the fitting line.

A great number of potential solutions of the regression calculations, which are taken into account in the upper part of Table (3), can be excluded by the mentioned conditions. When forming mean values of the remaining results, the scatter ranges of the form factors reduce approximately to the half.

The resulting form factors and exponents N as well as the Froude number limits finally selected during this evaluation are given in the lower part of Table (3). Fig.5 illustrates an example of the Prohaska-plot for the HSVA-model No.3 with k = 0.161 and N = 7.

The Froude number limits of the HSVA-models show almost a clear dependence on the block coefficient Table (3). Both, the lower Froude number Fnu (model No.2 excluded) and the upper Froude number Fno are shifted towards smaller values with increasing C_B.

The exponents N of the Froude number in the eq.(5) of the wave making resistance coefficient do not lie exactly in the range N = 4 to 6, which has been used many times for form factor determinations [3], [13], [14], but they are comparable to the exponents given in [5]. The latter work deals with the determination of form factors for the "Victory"-deosim, where values of N = 2.6 to 7.1 has been found dependent on the model size.

For the purpose of examination, the results of the present investigation are compared with form factors calculated by the empirical formulas of Watanabe [15], ITTC 1972 [16], Holtrop [17], Wright [18] and Granville [19] (see also [14]).

Fig.6 shows the comparison, where the term $C_B/(L_{WL}/B)\sqrt{B/T})^2$ was selected for the abscissa according to the parameter of the formula of Watanabe and that of the ITTC 1972. In contrast to a pure CB-dependent sequence, now the HSVA-model No.2 ($C_B = 0.65$) is close to the model No.6 ($C_B = 0.85$) and the "Lucy Ashton" -model ($C_B = 0.685$) is placed before the HSVA-model No.1 ($C_B = 0.55$). It should be noted, that this changed sequence corresponds to a sorting after the reciprocal length/displacement ratio.

The values of the empirical equations form a widespread band, in which the form factors of the present ship models fit well. Only the form factor of the HSVA-model No.6 with the lowest length/ displacement ratio is positioned a little above average.

Disregarding this model, a good agreement can be stated with the formulas of Watanabe and of the ITTC 1972 concerning not only the dependence on the form parameters, but also concerning the level when comparing with the mean values of both empirical equations. Considering all models, the lowest mean deviation follows when comparing with data of Wright's formula.

4. Effect of the form factor on the total ship resistance.

First, the impact of the scatter of the form factors on the estimated ship resistances will be investigated. For this purpose, the definition of the relative error

$$\Delta C_{T,S} = (C_{T,S\,x} - C_{T,S}) / C_{T,S}$$

appears recommendable. $C_{T,S}$ represents the base case, namely the total resistance coefficient determined with the mean form factor k of the scatter range, whereas the resistance coefficient C_{T,S_x} is related to a differing form factor kx. Inserting eq.(1a), (3) and (4), the relative deviation can be expressed by

$$\Delta C_{T,S} = \frac{k(1-k_x/k)\,(C_{F0,M} - C_{F0,S})}{C_{T,M} - (1+k)\,.\,(C_{F0,M} - C_{F0,S}) + C_A + C_{AA}} \quad (7)$$

This equation shows, that the form factor method forecasts too high ship resistances when too small value of form factors which results to an inaccurate evaluation of the model test results.

Since the difference of the frictional resistance coefficients $C_{F0,M}$ -C_{F0} increases with decreasing Reynolds number, one should pay special attention *to the low speed range. In this connection, also the model scale is of imprtance. The smaller the model size, the larger the differences of the C_{FO}-values and consequently, the greater the eventuality of defects due to incorrect form factors. Moreover $\Delta C_{T,S}$ is influenced by the level of the k-value with the tendency, that in cases of high form factors greater errors may be expected. Eq.(7) indicates further, that the relative deviation $\Delta C_{T,S}$ decreases in cases of high coefficients C_A and C_{AA}.*

In a numerical evaluation of eq.(7), the greatest possible errors of the predicted ship resistances have been determined by using the data $C_A = 0$ and $C_{AA} = 0$. The results show, that the reduction of the scatter range of the form factors from maximal +20% to maximal +10% (see section 3.4) lowers the maximal possible error of $C_{T,S}$ by about 50%. When applying the form factors given in the lower part of Table (3), the resistances of the full scale ships of the HSVA-series are affected by an uncertainty of maximum +1.2% (model No.1) to +2.6% (model No.6). The uncertainty in the ship resistance forecast for the "Lucy Ashton" amounts maximal +0.33%.

Finally, resistance coefficients $C_{T,S}$ will be predicted for the ship "Lucy Ashton" by applying the form factor method with the averaged form factor k=0.046 (Table(3)). The calculated coefficients will be compared with the results of the full scale tests. Since the wind resistance coefficients have been already subtracted from the measuring values [9], the prediction needs for completeness only the definition of C_A. The ITTC 1978 [1] recommends the calculation by equation

$$C_A = 10^{-3} \cdot (105 (Ks/L_{WL})^{1/3} - 0.64) \quad (8)$$

With a height of roughness of $Ks = 150.10^{-6}$ m. From this follows $C_A = 8.10^{-4}$, whereas the measured mean height of roughness $Ks = 96.10^{-6}$ m [9] result in $C_A = 6.10^{-4}$.

The comparison of the ship resistance coefficients is illustrated in fig.(7) not only for a roughness allowance of $C_A = 8.10^{-4}$, but also for the frequently used value of $C_A = 2.10^{-4}$, but also for the frequently used value of $C_A = 2.10^{-4}$ and for $C_A = 0$. Throughout good agreement can be recognized when contrasting the measured data and the coefficients predicted with $C_A = 2.10^{-4}$. The maximum differences amount +2.7%-4.5%, where the highest difference of -4.5% occurs only in the Froude number range of Fn=0.27 to 0.31. The use of the roughness allowance CA=8.10-4 results in too high resistance coefficients (+10% to +29%).

The comparison in fig.7 shows, that the form factor method is quite suitable for ship resistance estimations. However, not only the form factor, but also the roughness allowance should be ascertained by reliable means.

5. Conclusion

In this study, form factors are derived from model test results on deep water for a series of seagoing ships with different block coefficients The determination procedure is described and discussed, especially with respect to the Froude number range selected for the evaluations. The latter is proved to be C_B - dependent in the present investigation.

The evaluation of the measuring values indicates clearly, that the turbulent flow conditions should be maintained with great care during the model experiments.

The determined form factors show a systematica dependence on the ship's form parameter C_B, L/B and B/T or alternative on the length/displacement ratio $L/\forall^{1/3}$. This dependency as well as the form factors themselves are compatible with well known empirical form factor formulas.

In each considered case, the form factor could not be determined without a certain scatter. Hence, mean values have been defined within the scatter range. The resulting uncertainty of the form factors related to the mean value amounts +10% at the most. Hereby results an uncertainty of the predicted ship resistances of maximal +2.6%.

Additionally, the form factor of the "Lucy Ashton" is determined from model test results. Furthermore, total ship resistance coefficients are predicted by the form factor method and compared with published data from full scale trials. A good agreement can be stated, which still requires a suitable roughness allowance.

Symbols:

A_M	Midship section area
B	Breadth of shipof model
C_A	Roughness allowance
C_{AA}	Coefficient of air or wind resistance
C_B	Block coefficient, $C_B = \forall/(L_{BP}.B.T)$
C_{FO}	Coefficient of the frictional resistance according to ITTC 1957
C_P	Prismatic coefficient, $C_R = \forall / (A_M.L_{BP})$
C_R	Coefficient of the residuary resistance in the form factor method. $C_R = C_T - (1+k)/C_{F0}$
C_T	Coefficient of the total resistance C∀ Length/displacement ration, $CV = L_{BP}/\forall^{1/3}$
C_W	Coefficient of the wave resistance
F_n	Froude number, $Fn = U_o\sqrt{g/L_{BP}}$
k	Form factor
Ks	Equivalent sand grain size

N	*Exponent of the Froude number*
R_n	*Reynolds number*, $R_n = U_o \cdot L_{BP}/\nu$
S	*Wetted surface*
T	*Design draft*
U_o	*Speed of model or ship*
$\forall$	*Volume of displacementy*
y	*Factor in eq.(5) for CW*
t	*kinematic viscosity of water*
λ	*Scale factor*

Indices

o,u	*Upper and lower limit of the Froude number range for the determination of the form factor*
M	*Model*
S	*Ship*
x	*Variation of k in eq.(7)*

Model Nr.	1	2	3	4	5	6
HSVA-Nr	1696	2253	1249	1124	1241	1947A
L_{PP} m	6,417	7,381	6,095	6,096	6,096	7,5901
L_{WL} m	6,699	7,536	6,248	6,213	6,213	7,803
B m	0,9875	1,1429	0,9467	0,8238	0,8351	1,1499
T m	0,3688	0,4643	0,3603	0,3582	0,3408	0,4260
$\forall$ m^3	1,2768	2,6064	1,3030	1,3482	1,3895	3,1592
S m^2	7,460	11,374	7,273	7,576	7,698	13,3311
A_M m^2	0,3551	0,5310	0,3004	0,2925	0,2817	0,4877
L/B	6,500	6,327	7,200	7,400	7,300	6,601
B/T	2,678	2,613	2,350	3,300	2,450	2,699
C_B	0,564	0,652	0,701	0,750	0,801	0,850
C_P	0,560	0,665	0,711	0,757	0,809	0,851
$C\forall$	5,915	5,363	5,582	5,518	5,463	5,173
X_P , L %	-0,92	-1,53	0,07	1,00	2,53	2,25
λ	24	21	22,5	25	35	33,33
Abrasive paper at station	9,75 +7,5	9,75	9,5 +8	9,5 +8	9,5 +8	9,75
Fn During the testes	0,185 to 0,318	0,198 to 0,290	0,112 to 0,252	0,106 to 0,228	0,112 to 0,219	0,124 to 0,186

(Table 1) Main dimensions and form parameter of HSVA Models (non-dimensionally values are determined with LPP)

	Locy Ashton 20 ft-model	Lucy Ashton Ship
Remarks	with Turbulant producer	sharp seams red - oxide paint
L_{WL} m	6,096	58,0644
B m	0,67391	6,41909
T m on perpendicularship	0,14880 0,16383	1,417332 156058
V m^3	0,44728	386,52500
S m^2	4,46027	404,59274
A_M m^2	0,10481	9,508
L/B	9,045	
B/T	4,212	
C_B	0,685	
C_P	0,705	
$C\forall$	7,97108	
X_p / L %	-1,956	
λ	9,525	1,00
Fn During the tests	0,0818 to 0,3354	0,1301 to 0,3244

(Table 2) Main dimensions and form parameter of model and the ship "Lucy Ashton" (non-dimensionally values are determined with LWL the average draft / 17/)

Model Nr	1	2	3	4	5	6	L. A.
HSVA-Nr	1696	2253	1249	1124	1241	1947A	20 ft
C_B	0,546	0,650	0,701	0,750	0,801	0,850	0,685
Range of the form factor (k)	0,127 to 0,166	0,167 to 0,228	0,127 to 0,190	0,120 to 0,183	0,147 to 0,178	0,245 to 0,314	0,038 to 0,058
Range of the Exponent N	4,012 to 7,930	2,870 to 3,800	6,100 to 10,800	3,60 to 6,62	6,87 to 9,84	4,04 to 10,60	3,600 to 4,4400
Scatter of (k) values in %	± 13,3	± 15,4	± 18,1	± 20,8	± 9,5	± 12,1	± 20,8
			3,9				
Fn Lower limits	0,200 ± 0,01	0,210 ± 0,01	0,180 ±0,015	0,150 ±0,01	0,140 ±0,01	0,140 ±0,015	0,138 ±0,02
Fn Upper limits	0,280 ±0,015	0,250 ±0,01	0,230 ±0,015	0,195 ±0,01	0,215 ±0,01	0,180 ±0,01	0,235 ±0,015
Form factor (K)	0,133	0,198	0,161	0,166	0,162	0,277	0,047
Exponent	N	4,6	3,3	7,0	5,4	7,8	5,9

(Table 3) Estimation of the Form factors, Exponents of the wave resistance coefficient, and the Froude-Nr.values.

Model Nr	1	2	3	4	5	6	L.A.
Mean (k)	0,133	0,198	0,161	0,166	0,162	0,277	0,046
	From factor variation k ± 10%						
$\Delta C_{T,S}$ in %	C_A = 0						
	±1,2	±1,3	±1,5	±1,6	±1,8	±2,6	±0,33
	CA = 2. 10^{-4} .						
$\Delta C_{T,S}$ in %	±1,1	±1,2	±1,3	±1,4	±1,6	±2,4	±0,3
	10^{+4}						
$\Delta C_{T,S}$ in %	. C A(	A c-cording	to ITTC'78 /1/)			3,86	3,92
	4,33						
3,98	2,34						
2,88	8,01	±0,9	±1,1	±1,2	±1,2	±1,5	±2,3
±0,25	From factor variations k ±20 %						
	$\Delta C_{T,S}$	in %	C_A = 0		+2,3	+2,5	+2,8
+3,1 +3,6 +5,2		CA = 2. 10-4	$\Delta C_{T,S}$ in %			+2,1	+2,4
+0,7	+2,6	+2,8	+3,2	+4,7	+0,6		

(Table 4) Variations of the total resistance coefficients as a function of form factors.

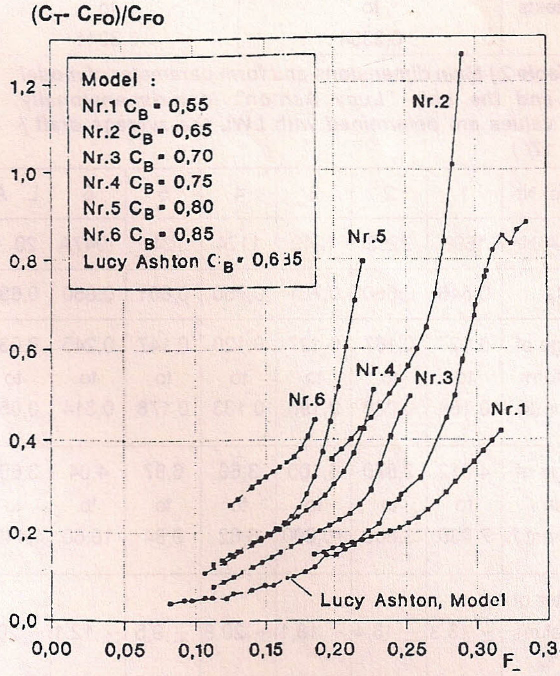

Fig.1 Relative differences of the measured total resistance to the C_{FO}

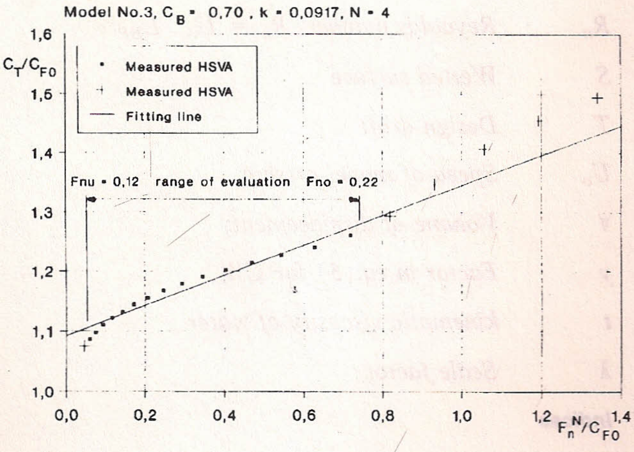

Fig.2 Determination of the form factor according to Prohaska.

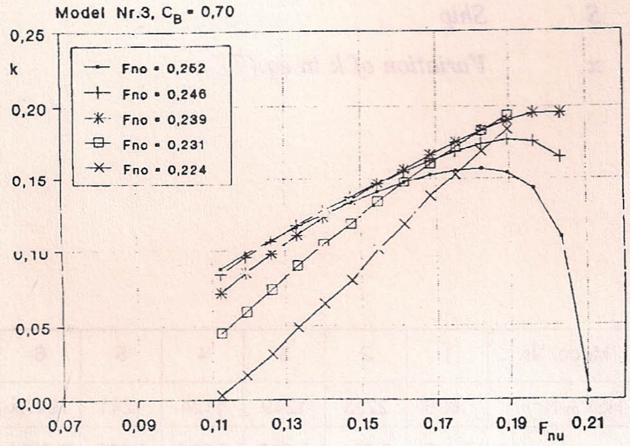

Fig.3a Form factors as a function of the lower limits of Froud-number.

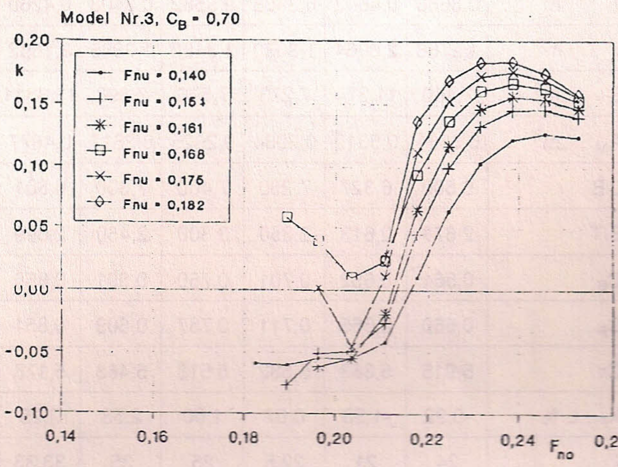

Fig.3b. Form factor as a function of the upper limits of Froud-number

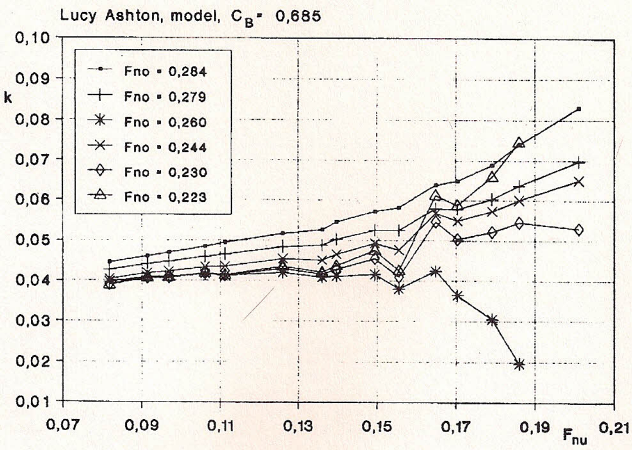

Fig.4a. Form factor as a function of the lower limits of Froude-number.

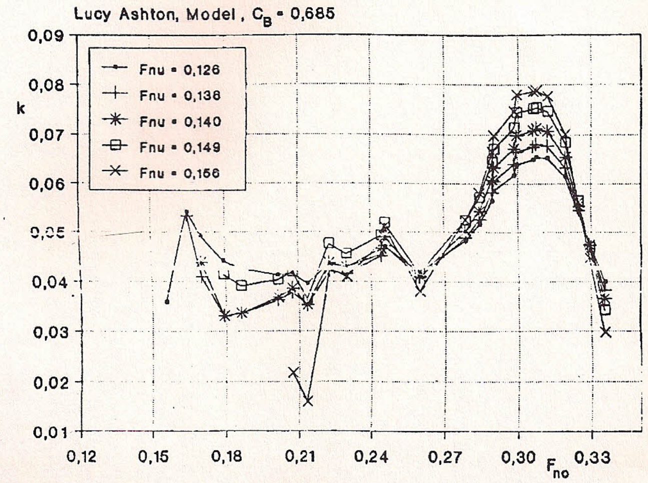

Fig.4b Form factor as a function of the upper limits of Froude-number

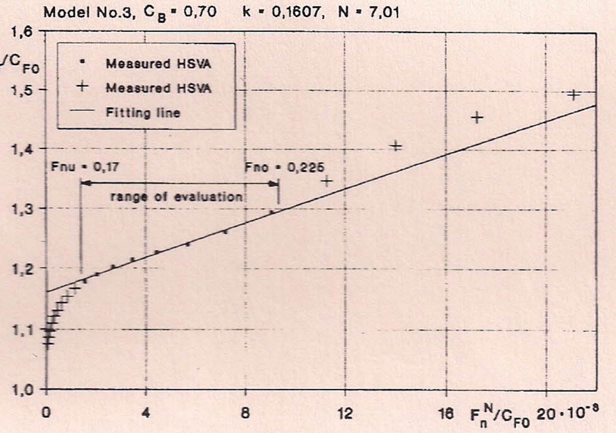

Fig. 5 : Form factor according to Prohaska

Fig.5 Determination of the form factor according to Prohaska.

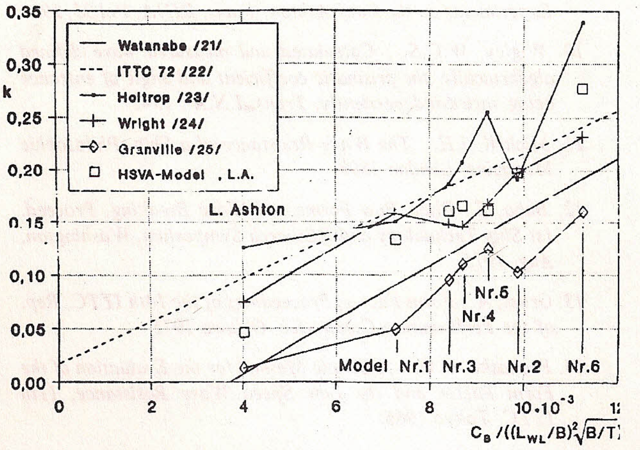

Fig.6 Comparison between calculated form factors and the empirical equations.

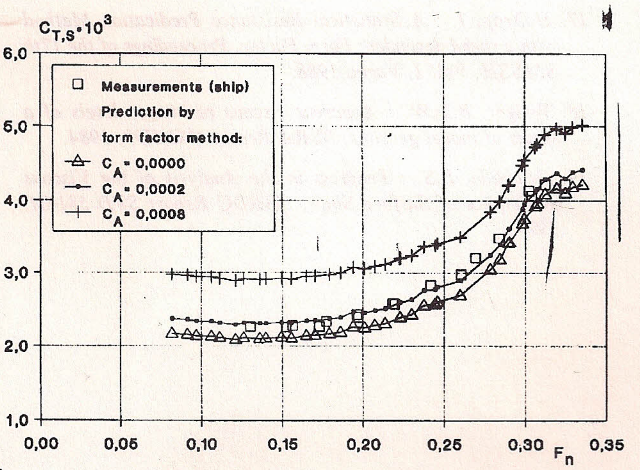

Fig.7 coefficient of Total resistance "Lucy Ashton"

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