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A bare hull resistance prediction method derived from the results of the Delft Systematic Yacht Hull Series extended to higher speeds

by

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A BARE HULL RESISTANCE PREDICTION METHOD DERIVED FROM THE RESULTS OF THE DELFT SYSTEMATIC YACHT HULL SERIES EXTENDED TO HIGHER SPEEDS

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SUMMARY

The present paper reports on the various methods of the prediction of residuary resistance over the years and provides an improved formulation for the calculation of the residuary resistance. Also the influence of the variation of the overhang on the residuary resistance will be discussed shortly.

1. INTRODUCTION

Since 1975 several regression based polynomial expressions have been presented to enable the assessment of the (bare hull) residuary resistance of a sailing yacht all using the database obtained from the results of the Delft Systematic Yacht Hull Series (DSYHS).

This DSYHS is presumably the largest consistent systematic series of yacht hulls tested up to now. At present it consists of some 70 different systematically derived models all tested in a consistent measurement setup and measurement procedure at the Delft Shiphydromechanics Laboratory of the Delft University of Technology in the Netherlands. Also the elaboration procedures etc. have all been kept the same within the DSYHS over all the years and if they were changed these changes have been applied to all the models in the DSYHS. This could imply retesting a large part of the models.

The DSYHS experiments started in 1973 and the execution of Gerritsma's initial idea for the Series was at the beginning a joint initiative of Professor Jelle Gerritsma from Delft University and Professors Nick Newman and Justin Kerwin from Massachusetts Institute of Technology in Boston, USA. The prime aim of Gerritsma was to develop a design tool for designers using the newly arising possibilities of the Velocity Prediction Programs (VPP) and Kerwin and Newman were more interested in using the VPP results for handicap purposes in the framework of what became later known as HMS and ultimately the IMS.

Over the years since 1973 considerable changes in yacht design did take place and, as a matter of fact, are still taking place. The shape of the hulls and appendages, displacement and stability, rig layouts, the demands of the designers and the users, as well as the obtainable speeds with sailing yachts have changed, just to name a few.

So a need is constantly present to adjust or update the results in the database, which are used for the regression formulations inside the Velocity Prediction Program.
In the present report the developments in the prediction of the upright resistance of the sailing yacht hull over the years will be highlighted and the newest additions to the prediction methods to accommodate the recent changes in the sailing yacht design will presented.

2. UPRIGHT RESIDUARY RESISTANCE PREDICTION METHODS DEVELOPMENT SINCE 1973

Several formulations for the prediction of the residuary resistance of a sailing yacht have been developed since the beginning of the Delft Systematic Yacht Hull Series. The range of hull parameters included in these formulations as well as the speed range in which they were applicable depended on the number of available models tests of the DSYHS available at that particular time. A short overview:

2.1 J KERWIN (1975)

The first one was presented by J. Kerwin e.a. from MIT, Ref [1], in the framework of the Irwin Pratt Handicapping Project in 1975. It was developed for speeds up to Froude number 0.45 only and its formulation was based on the results of the first 9 models of Series 1 of the DSYHS. The parent hull of this Series 1 within the DSYHS was derived in a combined effort by Gerritsma, Newman and Kerwin and originated from the famous Standfast 43 design from Frans Maas at Breskens, The Netherlands. The typical hull shape of this parent hull design is depicted in Figure 1.

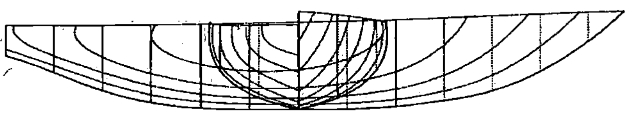

Figure 1: Linesplan of parent hull series 1 (Sysser 1)

Their formulation read:

$$\text{(1.1)} \qquad \frac{Rrh}{\Delta}\cdot 10^5 = a_1 \cdot \left(\frac{B}{Tc}\right)^{a_2} \cdot \frac{c_v}{\sqrt{{c_v}^2 + a_3}}$$

In which:

$$\text{(1.2)} \qquad c_v = \frac{\nabla}{L^3}\cdot 10^3$$

Basically their formulation had as prime parameters the Length to Displacement ratio and the Beam to Draft ratio of the hull under consideration, being the prime parameters varied within the small subseries of 9 models of Series 1 tested at that time.

2.2 GERRITSMA, VERSLUIS & ONNINK (1981)

The second formulation derived from the DSYHS results for the residuary resistance was developed by Gerritsma, Versluis and Onnink in 1981, Ref [2], and was also up to speeds equivalent to Fn = 0.45, the typical speed range in which the models were tested at that time. It used the results of the first 21 models of the DSYHS, the complete so-called Series 1. All models in Series 1 are derived from the same parent model as depicted in Figure 1.

Thanks to the significant larger number of models with a considerable wider range of varied hull parameters now available they were capable to take considerably more hull form parameters in the regression formula than the previous formulation from Kerwin.

Their formulation read:

$$\begin{aligned}\frac{Rr}{\Delta c}\cdot 10^3 &= A_0 + A_1\cdot Cp + A_2\cdot Cp^2 + \\ &+A_3\cdot LCB + A_4\cdot LCB^2 + \\ &+A_5\cdot\frac{Bwl}{Tc} + A_6\cdot\frac{Lwl}{\nabla c^{1/3}}\end{aligned} \tag{1.3}$$

In Series 1 the hull parameters varied were : the Beam to Draft ratio, the Length to Displacement ratio, the prismatic coefficient Cp and the Longitudinal position of the Center of Buoyancy LCB, so these were also the parameters used in the regression.

2.3 GERRITSMA & KEUNING (1987)

In 1987 Gerritsma and Keuning presented two different expressions based on now Series1 and a new series of models i.e. the Series 2 of the DSYHS, Ref [3]. This Series 2 was derived from a new parent model introduced in the DSYHS which was designed by Cees van Tongeren of Van der Stadt and Partners at Zaandam, The Netherlands. The lines of this new parent model are depicted in Figure 2. The aim was to use models which in shape followed the developments in the design of sailing yachts of that time more closely.

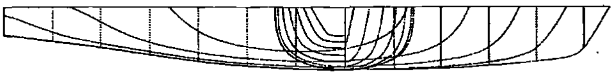

Figure 2: Linesplan of parent hull series 2 and 3 (Sysser 25)

After the introduction of this new parent model into the Delft Systematic Yacht Hull Series it became possible to attain much higher speeds than was possible therefore. This higher attainable speed followed the actual developments in the yachting scene of the new era more closely. The new models of Series 2 of the DSYHS were now tested to speeds equivalent to a Froude number of Fn = 0.60. This led to two different expressions for the residuary resistance: one for speeds up to a Froude number Fn = 0.45 using the entire available model range from Series 1 and 2 and one for the higher speed range, i.e. 0.475 < Fn < 0.75 using only Series 2. The shapes of the two newly developed polynomial expressions became quite different from each other because some typical high speed terms, known to be of importance from experiences in the planing boat world, were now introduced in the polynomial expression for the higher speeds, which were not used in the lower speed range expression, and also because the number of models available in the Series 2 was limited to only 8. Unfortunately this caused some discontinuities in the predicted resistance at the Froude number of 0.45, i.e. in the area of the overlap between the two formulations This discontinuity had to be smoothened artificially to make their use in the Velocity Prediction Program environment feasible.

The two expressions now read:

For speed range 0.125 < Fn < 0.450

$$\begin{aligned}\frac{Rr}{\Delta c}\cdot 10^3 &= a_0 + a_1\cdot Cp + a_2\cdot LCB + \\ &+a_3\cdot\frac{Bwl}{Tc} + a_4\cdot\frac{Lwl}{\nabla c^{1/3}} + \\ &+a_5\cdot Cp^2 + a_6\cdot Cp\cdot\frac{Lwl}{\nabla c^{1/3}} + \\ &+a_7\cdot LCB^2 + a_8\cdot\left(\frac{Lwl}{\nabla c^{1/3}}\right)^2 + \\ &+a_9\cdot\left(\frac{Lwl}{\nabla c^{1/3}}\right)^3\end{aligned} \tag{1.4}$$

And for the higher speed range, i.e. 0.475 < Fn < 0.75

$$\begin{aligned}\frac{Rr}{\Delta c}\cdot 10^3 &= c_0 + c_1\cdot\frac{Lwl}{Bwl} + c_2\cdot\frac{Aw}{\nabla c^{2/3}} + \\ &+c_3\cdot LCB + c_4\cdot\left(\frac{Lwl}{Bwl}\right)^2 + \\ &+c_5\cdot\frac{Lwl}{Bwl}\left(\frac{Aw}{\nabla c^{2/3}}\right)^3\end{aligned} \tag{1.5}$$

The most striking difference with the previous low speed range polynomial is found in the coupling between the prismatic coefficient Cp and the Length to Displacement ratio and the higher order terms of the Length to

Displacement ratio. In the high speed expression all kind of new parameters were used originating from the planing boat world, such as the "loading factor", i.e. the ratio between the waterplane area and the weight of the ship and also the length to beam ratio.

2.4 KEUNING, VERSLUIS, ONNINK & VAN GULLIK (1996) AND KEUNING & SONNENBERG (1998)

Till that time all these presented expressions assessed the residuary resistance of the hull of the sailing yacht including the resistance of the keel and rudder, as fitted on all models throughout the entire Delft Systematic Yacht Hull Series.

This standard keel and rudder design originated from the Standfast design used for the parent hull of the Series 1 and therefore followed the design philosophy of the beginning of the 1970's. The trend towards much more efficient keels and rudders with higher aspect ratio made this automatic inclusion of this standard keel and rudder in the resistance unrealistic, and therefore the use of these formulations unattractive.

To deal with this challenge, Keuning, Onnink, Versluis and Van Gullik, Ref [4], presented in 1996 for the first time an extensive new expression for the residuary resistance of the unappended or so called "bare" hull (i.e. without keel and rudder).

This new formulation was based on the results obtained from the upright resistance tests with the models of Series 1, 2, 3 and 4 of the Delft Systematic Yacht Hull Series and covered the speed range from Froude number Fn = 0.10 to Fn = 0.60.

The Series 3 was introduced in the DSYHS to cover the possible use of the results for rather light more extreme designs than previously possible and to also be able to cover smaller more dinghy type designs. The parent model of Series 3 was similar to that of Series 2.

The parent model of Series 4 was introduced into the DSYHS with the aid of Jim Teeters working with the Sparkman & Stephens design office at that time. It was introduced because it resembled more closely the design trend at that time visible in the contemporary IMS fleet, one of the users of the DSYHS database. The lines of this model are depicted in Figure 3.

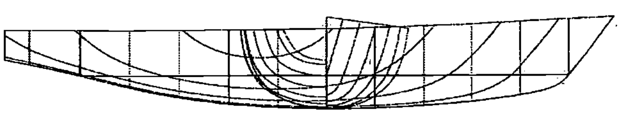

Figure 3: Linesplan of parent hull series 4 (Sysser 44)

In order to be able to do this in principle all the hulls within the Series 1 to 4 had to be retested for their upright resistance without keel and rudder. This has been carried out in the Delft Shiphydromechanics Laboratory between 1992 and 1996 but not with all the models. In total some 34 out of the total of 50 of the models within the DSYHS have been retested without appendages fitted. In principle all the tests have been carried out with a maximum speed corresponding to Fn = 0.60 at that time.

In order to be able to calculate the total resistance of the yacht additional formulations had now to be developed to assess the resistance of the keel and rudder, which resistance components now had to be added to the bare hull resistance to yield the total resistance. These formulations were presented in 1997 by Keuning and Binkhorst Ref [5] and in 1998 by Keuning and Sonnenberg in Ref [6].

The new residuary resistance formulations for the bare hull derived now read:

(1.6)

$$\frac{Rrh}{\nabla c \cdot \rho \cdot g} = a_0 + \begin{pmatrix} a_1 \cdot \dfrac{LCB_{fpp}}{Lwl} + a_2 \cdot Cp + \\ a_3 \cdot \dfrac{\nabla c^{2/3}}{Aw} + a_4 \cdot \dfrac{Bwl}{Lwl} + \\ a_5 \cdot \dfrac{\nabla c^{2/3}}{Sc} + a_6 \cdot \dfrac{LCB_{fpp}}{LCF_{fpp}} + \\ a_7 \cdot \left(\dfrac{LCB_{fpp}}{Lwl} \right)^2 + a_8 \cdot Cp^2 \end{pmatrix} \cdot \frac{\nabla c^{1/3}}{Lwl}$$

In which:

Rrh	Residual resistance of the bare hull	N
∇c	Volume of displacement of canoe body	m^3
ρ	Density of water	kg/m^3
g	Gravitational acceleration	m/s^2
Lwl	Length of waterline	m
Bwl	Beam of waterline	m
LCB_{fpp}	Longitudinal position centre of buoyancy to forward perpendicular	m
LCF_{fpp}	Longitudinal position centre of flotation to forward perpendicular	m
Cp	Prismatic coefficient	-
Aw	Waterplane area at zero speed	m^2
Sc	Wetted surface area	m^2

The formulation for the bare hull resistance as presented in Ref [4] and Ref [6] were applicable to speeds up to Froude number Fn = 0.60. The maximum speed for which it is applicable was lower than the maximum speed possible with the previous high speed formulation derived using Series 2, but this reduction was necessary because also the models of Series 1 were included in the regression. Most of these models could not obtain these high speeds due to over-excessive wave making during the tests.

The most striking differences with the previous formulations were:

- one expression for the entire speed range using the same data base, so no "connection" problems between the two different expressions
- all parameters have been coupled with the length displacement ratio to make them "weight dependent"
- the LCB-LCF separation introduced for higher speeds to incorporate effects of trim at speed
- the beam to draft ratio of the hull was replaced by the relation between the wetted surface and the displacement, which was considered to be a less sensitive parameter with respect to possible "exploitation".

As a new addition to the formulations for the residuary resistance Keuning and Sonnenberg, Ref [6], introduced into the DSYHS database the change (increase) of the residuary resistance of the hull due to the forward or bow down trim of the yacht at speed. This trim is caused by the pitching moment introduced by the sail driving force high up in the rig.

3. THE PRESENT FORMULATION

3.1 ADDITIONS TO THE DSYHS DATABASE

Since the latest update in 1998 some considerable additions have been made again to the DSYHS database. These additions to the DSYHS have been made over the last decade to deal with some special issues, which will be shortly summarized below:

1) The more recent and new developments in the design of sailing yachts since the last published version of the regression results in 1998 were quite significant and still led to an ever increasing speed potential of the newer designs, making the possibility to carry out speed predictions at higher Froude numbers desirable.

However the number of models that were actually towed in the towing tank to the higher speeds, in order to be able to increase the speed range in which the formulations were applicable, was in 1998 still limited to around 30. So this number could ideally still be increased to improve the accuracy of the resistance predictions at the higher speeds. In the last years quite a few of the models of the DSYHS have been retested and towed up to the highest speed possible given the physical restrictions of both the measurement setup and the models. With increasing speed to Froude numbers above Fn = 0.60 the wave making of a number of the models became so excessive that further testing became impossible. This was in particular true for models in the Series 1. It should be realized however that when this happened the total resistance of the yacht under consideration also became so excessively high that it was, is and will remain very unlikely that actual sailing yachts close to those design characteristics would ever be capable of achieving such high speeds in reality in particular in the true wind speed range generally applied in the VPP. However to improve the accuracy of the predictions based on the DSYHS database it is of importance to go as far as feasible in order to keep for each Froude number used in the regression the size of the database as similar as possible.

2) This high resistance - high speed limitation became in particular evident with the tests carried out with the longitudinal sail force moment applied during the tests. With increasing resistance, this trimming moment also became excessively high causing in the above mentioned situations the bow down trim of the model to become so large that the freeboard forward became too small to carry out the tests safely. The trimmed condition tests were therefore often more restricted due to the aforementioned physical restrictions than the tests without trimming moment applied.

3) A new series of models was added with a pronounced variation of the mid-ship section area coefficient Cm. Due to the nature of the transformation method of the lines plan of the various models used in the DSYHS to derive the various lines plans from the parent hulls the mid-ship area coefficient changes are quite small within each of the series. Between the different parent models however there is a difference. So these models were added and numbered as models #60, #61, #62 and #63, i.e. the Series 6 of the DSYHS. The parent model of this Series 6 is the same as the parent model used for the USSAM systematic series models as tested in the USA.

4) In particular the larger yachts or maxi's and mega yachts tend to have larger L/B ratio's in combination with also high $L/\Delta^{1/3}$ ratio's than available at that time (1998) within the DSYHS data base. A limited number of models with these characteristics have therefore been tested in the DSYHS and are numbered as Series 7, i.e. models #71, #72 and #73. These models were derived from the same parent model as Series 2 and Series 3. For these models the L/B ratio was 5.0, 5.8 and 5.0 respectively combined with the $L/\Delta^{1/3}$ ratio equal to 6.0, 7.0 and 8.0.

An overview of the parameters of the models presently in the DSYHS database is presented in Table 1. These additions to the DSYHS database have been implemented and used for the new regressions carried out in the framework of the present report. By doing so the effects of the aforementioned shortcomings of the regressions derived from the 1998 DSYHS database are lessened.

The new regressions are carried out using slightly different formulations compared to the 1998 reports.

Series	Sysser	$\frac{LCB_{fpp}}{Lwl}$	Cp	$\frac{\nabla c^{2/3}}{Aw}$	$\frac{Bwl}{Lwl}$	$\frac{LCB_{fpp}}{LCF_{fpp}}$	$\frac{\nabla c^{1/3}}{Lwl}$	Cm	$\frac{Bwl}{Tc}$
Series 1	1	0.523	0.564	0.201	0.317	0.980	0.21	0.646	3.99
	2	0.523	0.567	0.230	0.276	0.981	0.21	0.646	3.04
	3	0.523	0.572	0.173	0.364	0.981	0.21	0.647	5.35
	4	0.523	0.568	0.195	0.285	0.980	0.20	0.646	3.95
	5	0.524	0.559	0.212	0.364	0.981	0.23	0.647	3.96
	6	0.524	0.561	0.244	0.317	0.981	0.23	0.646	2.98
	7	0.523	0.561	0.174	0.317	0.980	0.19	0.646	4.95
	8	0.524	0.586	0.203	0.305	0.983	0.21	0.647	3.84
	9	0.522	0.546	0.199	0.328	0.979	0.21	0.646	4.13
	10	0.500	0.564	0.199	0.317	0.963	0.21	0.646	3.99
	11	0.550	0.565	0.203	0.317	1.000	0.21	0.646	3.99
	12	0.500	0.564	0.194	0.285	0.963	0.20	0.647	3.94
	13	0.550	0.564	0.198	0.285	1.000	0.20	0.646	3.94
	14	0.523	0.529	0.205	0.285	0.978	0.20	0.646	3.69
	15	0.523	0.530	0.212	0.316	0.978	0.21	0.646	3.68
	16	0.523	0.529	0.255	0.317	0.978	0.23	0.646	2.81
	17	0.500	0.598	0.191	0.317	0.966	0.21	0.647	4.24
	18	0.550	0.599	0.194	0.317	1.002	0.21	0.647	4.24
	19	0.500	0.530	0.208	0.317	0.960	0.21	0.646	3.75
	20	0.550	0.530	0.212	0.317	0.998	0.21	0.646	3.75
	21	0.523	0.598	0.188	0.285	0.983	0.20	0.647	4.17
	22	0.523	0.599	0.202	0.366	0.983	0.23	0.647	4.23
Series 2	23	0.519	0.547	0.206	0.288	0.938	0.20	0.721	4.09
	24	0.521	0.543	0.109	0.286	0.933	0.14	0.739	10.96
	25	0.520	0.548	0.165	0.250	0.936	0.17	0.727	5.39
	26	0.521	0.543	0.093	0.250	0.924	0.13	0.749	12.91
	27	0.519	0.546	0.265	0.222	0.939	0.20	0.724	2.46
	28	0.521	0.544	0.137	0.222	0.930	0.14	0.736	6.75
Series 3	29	0.546	0.549	0.106	0.250	0.947	0.13	0.751	10.87
	30	0.546	0.549	0.141	0.250	0.946	0.15	0.751	7.08
	31	0.545	0.548	0.082	0.250	0.943	0.12	0.752	15.82
	32	0.521	0.549	0.104	0.250	0.927	0.13	0.751	10.87
	33	0.566	0.549	0.108	0.250	0.963	0.13	0.751	10.87
	34	0.544	0.522	0.110	0.250	0.945	0.13	0.757	10.37
	35	0.545	0.580	0.103	0.250	0.946	0.13	0.758	11.47
	36	0.544	0.551	0.108	0.250	0.949	0.13	0.707	10.16
	37	0.544	0.552	0.110	0.250	0.956	0.13	0.657	9.43
	38	0.545	0.547	0.079	0.333	0.942	0.13	0.755	19.38
	39	0.546	0.549	0.133	0.200	0.948	0.13	0.753	6.97
	41	0.582	0.540	0.175	0.250	0.977	0.17	0.741	5.21
Series 4	42	0.533	0.554	0.224	0.301	0.945	0.21	0.711	3.71
	43	0.533	0.553	0.167	0.359	0.943	0.20	0.712	6.29
	44	0.533	0.554	0.200	0.301	0.947	0.20	0.712	4.42
	45	0.533	0.554	0.252	0.240	0.947	0.20	0.711	2.79
	46	0.533	0.553	0.172	0.301	0.947	0.19	0.712	5.57
	47	0.560	0.548	0.159	0.300	0.959	0.18	0.749	6.04
	48	0.507	0.557	0.164	0.300	0.920	0.18	0.725	5.80
	49	0.563	0.566	0.157	0.298	0.964	0.18	0.743	6.31
	50	0.579	0.539	0.159	0.300	0.979	0.18	0.777	6.34
Series 6	60	0.546	0.541	0.158	0.256	0.955	0.17	0.747	5.74
	61	0.546	0.542	0.149	0.269	0.952	0.17	0.790	6.70
	62	0.545	0.541	0.167	0.243	0.958	0.17	0.676	4.71
Series 7	71	0.560	0.519	0.218	0.200	0.969	0.17	0.754	3.39
	72	0.560	0.521	0.146	0.170	0.971	0.13	0.745	5.67
	73	0.561	0.521	0.159	0.200	0.967	0.14	0.757	5.41

Table 1: Parameters of the models used in the regression for the present formulation

Extensive variations have been investigated for their applicability, fit and robustness and although it is very difficult to define "the best", a final selection has been made. The number of models now available for the regression to obtain the resistance polynomial of the residuary resistance of the bare hull at the different Froude numbers now is :

- 47 models for speeds up to and equal to Fn = 0.60
- 34 models for Fn = 0.65
- 30 models for Fn = 0.70
- 23 models for Fn = 0.75

The new formulation for the untrimmed upright residuary resistance of the bare hull reads:

(1.7)

$$\frac{Rrh}{\nabla c \cdot \rho \cdot g} = a_0 + \left(\begin{array}{l} a_1 \cdot \dfrac{LCB_{fpp}}{Lwl} + a_2 \cdot Cp + \\ a_3 \cdot \dfrac{\nabla c^{2/3}}{Aw} + a_4 \cdot \dfrac{Bwl}{Lwl} + \\ a_5 \cdot \dfrac{LCB_{fpp}}{LCF_{fpp}} + a_6 \cdot \dfrac{Bwl}{Tc} \\ + a_7 \cdot Cm \end{array} \right) \cdot \frac{\nabla c^{1/3}}{Lwl}$$

In which:

Rrh	Residual resistance of the bare hull	N
∇c	Volume of displacement of canoe body	m^3
ρ	Density of water	kg/m^3
g	Gravitational acceleration	m/s^2
Lwl	Length of waterline	m
Bwl	Beam of waterline	m
Tc	Draft of canoe body	m
LCB_{fpp}	Longitudinal position centre of buoyancy to forward perpendicular	m
LCF_{fpp}	Longitudinal position centre of flotation to forward perpendicular	m
Cp	Prismatic coefficient	-
Aw	Waterplane area at zero speed	m^2
Cm	Midship section coefficient	-

In which the coefficients have been determined using least square methods. They are presented in Table 2.

The most noticeable changes when compared with the 1998 formulations are:

- The B/T ratio has been re-established at the cost of the wetted area versus displacement ratio as introduced in 1998 because at present we aim at the use of the formulations as a designer tool, so exploitation of parameters is not an issue as it is when they are used for handicap purposes.
- The mid-ship section area coefficient has been introduced in the regression. It is considered to be of importance both in the lower and the higher speeds range.
- The higher order terms for the prismatic coefficient Cp and the LCB have been disregarded. Originally these were introduced for establishing an optimum value for both Cp and LCB within the range of the series. These higher order terms however made the robustness and stability of the results obtained with the formulations smaller in those cases in which a resistance prediction has to be made (slightly) outside the parameter range covered by the models of the DSYHS.

The results of the new regression have been compared against the database. The R-squared value of the regression for speeds above Fn = 0.35 is between 0.98 and 0.995 which is considered to be good.

Some of the selected results for the sake of comparisons are depicted in the Figures 5 to 9 in which the resistance prediction of models in the DSYHS is compared with the measured results. Please note that in some cases the prediction exceeds the speed range covered by the experiments. In general the comparison is good.

Fn	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
a_0	-0.0005	-0.0003	-0.0002	-0.0009	-0.0026	-0.0064	-0.0218	-0.0388	-0.0347	-0.0361	0.0008	0.0108	0.1023
a_1	0.0023	0.0059	-0.0156	0.0016	-0.0567	-0.4034	-0.5261	-0.5986	-0.4764	0.0037	0.3728	-0.1238	0.7726
a_2	-0.0086	-0.0064	0.0031	0.0337	0.0446	-0.1250	-0.2945	-0.3038	-0.2361	-0.2960	-0.3667	-0.2026	0.5040
a_3	-0.0015	0.0070	-0.0021	-0.0285	-0.1091	0.0273	0.2485	0.6033	0.8726	0.9661	1.3957	1.1282	1.7867
a_4	0.0061	0.0014	-0.0070	-0.0367	-0.0707	-0.1341	-0.2428	-0.0430	0.4219	0.6123	1.0343	1.1836	2.1934
a_5	0.0010	0.0013	0.0148	0.0218	0.0914	0.3578	0.6293	0.8332	0.8990	0.7534	0.3230	0.4973	-1.5479
a_6	0.0001	0.0005	0.0010	0.0015	0.0021	0.0045	0.0081	0.0106	0.0096	0.0100	0.0072	0.0038	-0.0115
a_7	0.0052	-0.0020	-0.0043	-0.0172	-0.0078	0.1115	0.2086	0.1336	-0.2272	-0.3352	-0.4632	-0.4477	-0.0977

Table 2: The coefficients for the polynomial for the untrimmed upright residuary resistance of the bare hull

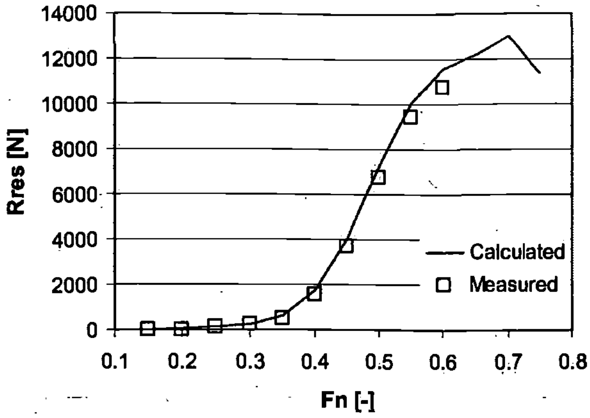

Figure 5: Residuary resistance measured and calculated for Sysser 1

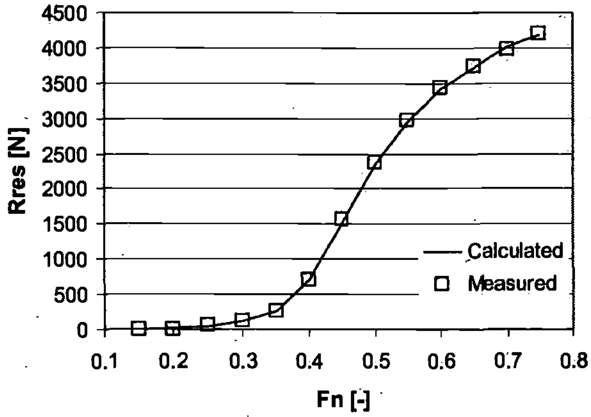

Figure 6: Residuary resistance measured and calculated for Sysser 25

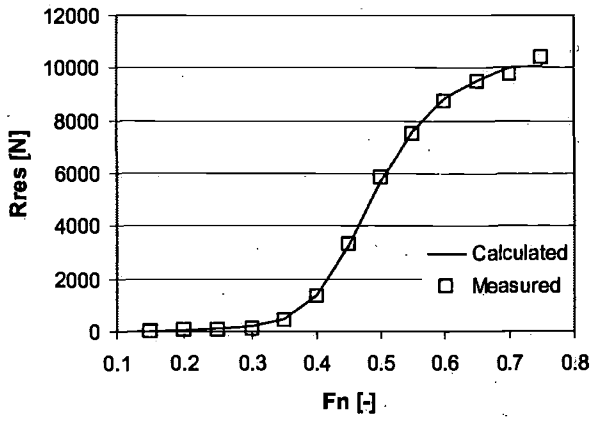

Figure 7: Residuary resistance measured and calculated for Sysser 44

In addition a comparison has been made with two models not belonging to the DSYHS. These models, which have been tested in the Delft towing tank (model #329 and #366), have been used often for validation. The particulars of these models are presented in the Table 3. The resistance comparison is depicted in the Figures 10 and 11. In general the comparison is considered to be good.

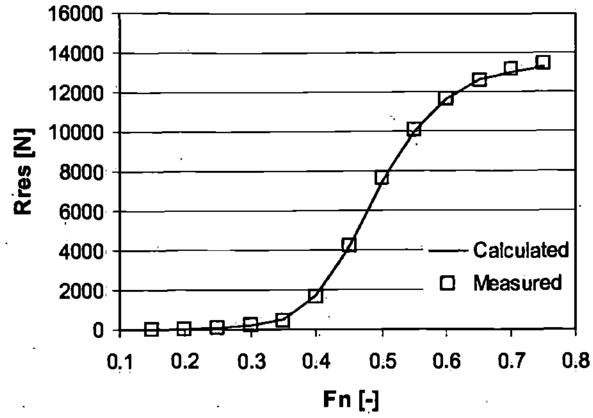

Figure 8: Residuary resistance measured and calculated for Sysser 42

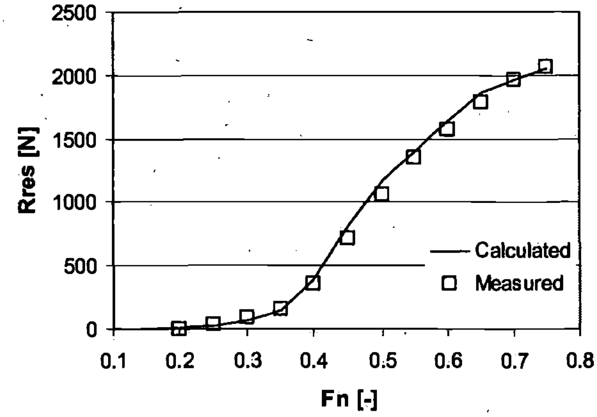

Figure 9: Residuary resistance measured and calculated for Sysser 73

Model		329	366
Lwl	m	10:00	10.00
Bwl	m	2.21	1.74
Tc	m	0.46	0.58
∇c	m^3	3.44	3.44
Aw	m^2	14.46	11.49
LCB_{fpp}	m	5.50	5.50
LCF_{fpp}	m	5.64	5.64
Cp	-	0.53	0.53
Cm	-	0.64	0.64

Table 3: Particulars models 329 and 366

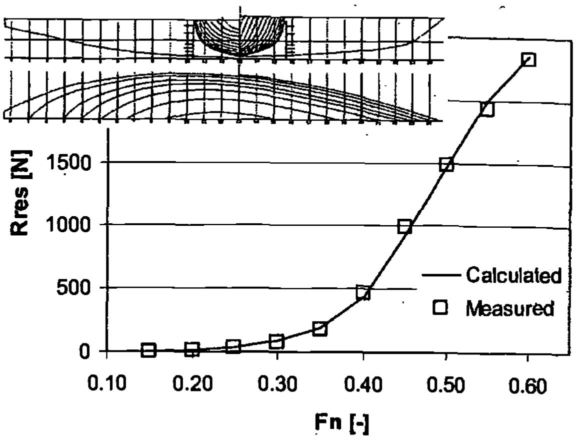

Figure 10: Linesplan and residual resistance model 329

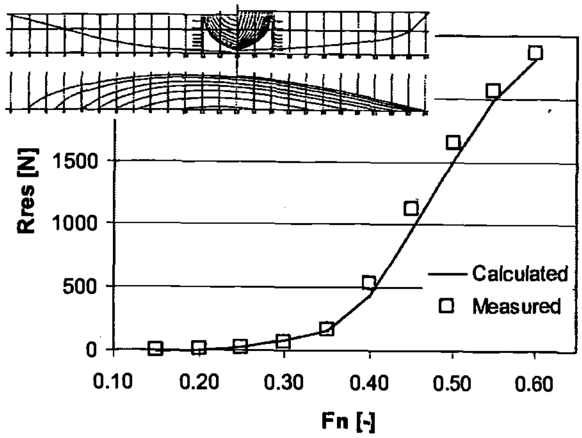

Figure 11: Linesplan + residual resistance model 366

4. INFLUENCE OF OVERHANGS

Another aspect regarding the applicability of the results of the DSYHS to a wider range of yacht designs is the desire to take into account the effect of the overhang aft.

The models of the DSYHS all have a standardized overhang length aft in the order of 17.5 % of the waterline length. Many actual designs have either smaller or no overhang at all. The influence of overhangs is known of course for a long time and some research has already been reported on this issue.

For instance in the 1980's Gerritsma shortened the overhang on the parent model of Series 1 of the DSYHS in two consecutive steps, reducing the overhang with 50% and 100%. The result was that the overall effect on the upright resistance was rather small. This was largely due however to the very shape of the Series 1 hulls as well as to the speed range in which the DSYHS models were tested in that period, namely from Fn=0.125 to Fn=0.45. The larger differences however occur at the higher speeds.

Andy Claughton of Wolfson Unit in Southampton carried out a similar experiment with one more contemporary model in the 1990's and found a more noticeable resistance increase with shorter overhangs.

The lack of systematic data on this issue led the Shiphydromechanics Department to carrying out a dedicated experiment on 4 different models of the DSYHS to determine the effect of overhang aft on the upright resistance. The aim is to be able to formulate some kind of generally applicable correction for the upright resistance with regard to the overhang length.

The models used for this experiment were model #23, model #27, model #42 and model #47. The main particulars of these models can be found in Table 1. A selection of hull shape parameters has been sought which were considered to have an important effect on overhang resistance so that an appropriate correction could be formulated.

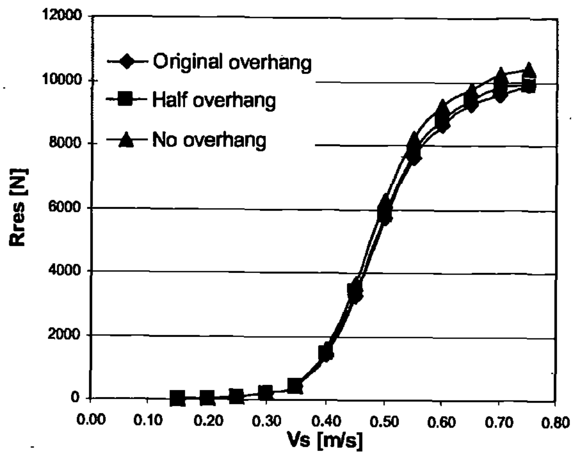

Figure 12: Influence of overhang for Sysser 23 on residuary resistance

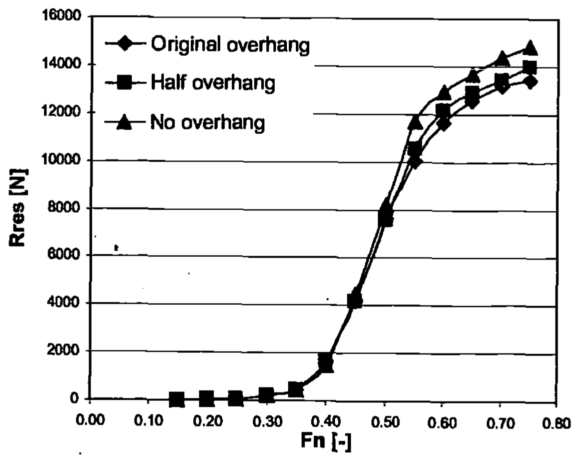

Figure 13: Influence of overhang for Sysser 42 on residuary resistance

The overhangs of the models have been shortened in two steps, i.e. 50% shorter and 100% shorter. Because a slightly different measurement set up was used than commonly used in the DSYHS set up also the full overhang has been retested, because in the end only the resistance difference between the various modifications is of interest for the formulation of the correction.

The results of the tests are presented in the Figures 12 and 13 in which the residuary resistance is depicted for two of the four models with the three different overhang lengths.

As may be seen from these results there is a noticeable resistance increase with shorter overhang. The difference between 100% overhang and 50% overhang for the Series 2 models is much smaller than the difference between the 50% and 0 % overhang. This trend is also present with the models of Series 4. Further comparing the different models there appears to be a significant relation between the change in resistance and the draft or beam to draft ratio of the hull under consideration.

At present no final result of a generally applicable correction is available ready for publication but it is the target of the research in the nearest foreseeable future.

5. CONCLUSIONS

With the present formulations for the untrimmed upright residuary resistance of the bare hull, a robust formulation has been found which is valid for a wide range of parametric variations and a wide range of Froude numbers.

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7. AUTHORS' BIOGRAPHIES

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