AN APPROXIMATE METHOD FOR CALCULATION OF RESISTANCE AND TRIM OF THE PLANING HULLS

by D. Radojcic

Ship Science Report No. 23

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UNIVERSITY OF SOUTHAMPTON

DEPARTMENT OF SHIP SCIENCE

FACULTY OF ENGINEERING AND APPLIED SCIENCE

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Abstract

A mathematical model is presented for predicting the resistance and trim angle of bare stepless planing hulls in calm water. Volume Froude numbers covered are 1 to 3.5 for resistance and 1 to 4 for trim angle. The predictive technique is established by regression analysis of data of systematic Series 62 (with deadrise angle of 12.5° and 25°) and Series 65. The mathematical model is a function of four hull form and loading parameters (loading coefficient (area coefficient), ratio of length to beam, longitudinal center of gravity location, deadrise angle) and section shape. The method presented makes it possible to estimate the resistance of planing hulls in the early stage of design and is sutable for programming.

This paper has been submitted to the SNAME Symposium on Powerboats - Recreational and Commercial, Miami, 19th and 20th February 1985.

Introduction

Besides by the model tests, the resistance of a bare stepless planing hull form in the calm water can be determined mainly in the following two ways:

- by means of empirically derived equations, among which those of Savitsky (1) are the most frequently used, and
- by use of systematic series results.

It is the objective of this paper to derive a mathematical model for calculating resistance, trim angle, wetted area, and length of wetted area of planing hull forms by use of regression analysis applied to the systematic series results.

The intention of the paper is to anable a small craft designer to evaluate resistance and trim angle; to perform a parametric study of planing hull forms in the preliminary design stage and then to choose the best variant amongst those considered. The mathematical expressions obtained can be easily programmed, which further facilitates prediction and optimization.

An aproach similar to the one employed here was previously used in (2), but regression equations, number of cases, etc. are quite diferent. However, for better in-depth understanding, reference (2) should be considered as a companion paper.

Previous Regression Analyses Conserning Resistance of a Small Craft

The application of regression analysis to ship data is very well shown in Farlie-Clarke's paper (3), which could serve as a textbook. In it, among other things, is given an extensive review of regression analalysis of ship data.

Two papers conserning the application of regression analysis for calculating the resistance of small craft should be mentioned, too.

The first one, written by Mercier and Savitsky (4), deals with the calculation of the total resistance of transom-stern craft in the non-planing range, specifically for volume Froude numbers between 1 and 2. The predictive technique is established by regression analysis of the resistance data of seven transom-stern hull series (NPL, Nordstrom, De Groot, SSPA, Series 64, Series 63, and Series 62). It should be noticed that of all systematic series mentioned only one - Series 62 - is hard chine form.

The second paper was presentewd by Jin Ping-zong et al. (5) and deals with the calculation of the residuary resistance of round bilge displacement hulls over a speed range of Froude numbers between 0.4 and 1.0.

Available Systematic Series of Planing Hull Forms

Only a few of the systematic series of planing hull forms have been published. These are:

- Series EMB 50 (6)
- Series TMB 62 (7)
- Series NSRDC 65 (8)(9)
- Series BK and MBK (10)
- Series 62-DUT* with 25^0 deadrise angle (11)

However, the Series EMB 50 is out of date. The results of the Series BK and MBK are not available in the original form (some results are released in monograph (10)).

Practically, the results of only three remaining systematic series can be used for the regression analysis.

Series 65 consists of two groups of models — 65-A and 65-B. Series 65-A hulls are with narrow and shallow transom and as such, are not suitable for the modern stepless planing hulls, so they were omitted too.

The original presentation of the remaining series were different (different hull form parameters were used, some models were fixed-to-trim and some were free-to-trim, etc.). With the help of NSRDC Report 3544 (12) the results of Series 62-DUT were transformed to the unique basis, as was done with original Series 62 and 65 results and one model named DL-62-A (Davidson Laboratory model, originated from model 4667-1) in the NSRDC Report 4307 (13).

In the Report 4307 the tow force was applied horizontally through CG for various displacements, each for C_a=0 and 0.0004. The parameters R/Δ, τ, $S/\nabla^{2/3}$, L_c/L_p, and L_k/L_p were presented as a function of two form parameters (LCG/L_p and $L_p/\nabla^{1/3}$) for $F_{n\nabla}$=1 to 4.

Hull Form and Hull Loading Parameters Used for Regression Analysis

Based on E. Clement's papers (14) and (15), the following four hull form and hull loading parameters were selected:

- loading coefficient (area coefficient) - $A_p/\nabla^{2/3}$
- ratio of length to beam - L_p/B_{pa}
- longitudinal centre of gravity location - LCG/L_p
- deadrise angle at 50% of L_p - β_x

However, the multitude of different loading conditions for all of 27 models of accepted series made it necessary to narow the working space (number of observed cases) to the recomended range and to treat it with a view to the preliminary design stage

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requirements. Otherwise, the accuracy of the prediction in the early design stage would be diminished, although the working space would be broader.

After the elimination (same constraints as in (2)) there remained 15 models with 98 different loading conditions (unfortunatelly only 52 for F_{nv}=3.5 and 33 for F_{nv}=4.0). These are the models given in Table 1 and Figure 1. Lines and body plans of accepted hulls are given in Figure 2.

The accepted four hull form parameters covered the ranges:

- $4.25 < A_p/\nabla^{2/3} < 9.50$
- $30.0 < 100 \cdot LCG/L_p < 44.8$
- $2.36 < L_p/B_{pa} < 6.73$
- $13.0^o < \beta_x < 37.4^o$

The data used for the derivation of the regression coefficients, (most of them taken from Report 4307) hold good for Δ=100000 lb =45.36 t in a sea water 15°C (59°F), ν=1.1907·10^{-6} m^2/s (1.2817 10^{-5} ft^2/s), ρ=1026 kg/m^3 (1.9905 lb/ft^3), and ATTC-1947 friction coefficients with C_a=0.

Regression Analysis

The analysis of the data was carried out with the aid of microcomputer Apple II+. The program used for the selection of the "best subset" was Stepwise Multiple Regression (16) (based on Biomedical Package Series). However, the stepwise procedure was not followed strictly because it was felt that it was necessary to obtain the overall best mathematical model — for F_{nv} range 1 to 4 — and not only for discrete values of F_{nv} (1.00, 1.25, 1.50, 1.75, 2.00, 2.50, 3.00, 3.50, and 4.00). Therefore, in selection of the best subset the following parameters were varied:

- F to enter and F to remove values
- number of cases (outliers were discharded)
- number of variables
- variables themselves

This was done for all four dependant variables (R/Δ, τ, $S/\nabla^{2/3}$, and L/L_p). For instance, for R/Δ more than 140 subsets were tried before the final one was choosen.

The principal four hull form parameters were transformed into another set of variables rangigng from -1 to +1. These new variables, which subsequently were used throughout regression analysis, are as follow:

$$x_1 = (A_p/\nabla^{2/3} - 6.875)/2.625$$
$$x_2 = (100(LCG/L_p) - 37.4)/7.4$$
$$x_3 = (L_p/B_{pa} - 4.545)/2.185$$
$$x_4 = (\beta_x - 25.2)/12.2$$

	MODEL	L_p (m)	A_p (m^2)	B_{pa} (m)	B_{pt} (m)	B_{px} (m)	L_p/B_{pa}	L_p/B_{px}	B_{px}/B_{pa}	B_{pt}/B_{px}	$\circ A_p/L_p$	β_{II} (°)	β_t (°)
65-B	5237	1.8721	1.1009	0.5880	0.7925	0.7980	3.18	2.35	1.36	0.99	0.397	21.2	16.3
	5240	1.8721	0.7785	0.4151	0.5602	0.5645	4.50	3.32	1.36	0.99	0.397	21.2	16.3
	5239	2.6478	1.1009	0.4157	0.5602	0.5645	6.36	4.69	1.36	0.99	0.397	21.2	16.3
	5186	1.8721	0.7785	0.4157	0.5602	0.5645	4.50	3.32	1.36	0.99	0.397	28.7	22.5
	5184	1.8721	0.5500	0.2941	0.3962	0.3990	6.36	4.69	1.36	0.99	0.397	28.7	22.5
	5236	1.8721	0.5500	0.2941	0.3962	0.3990	6.36	4.69	1.36	0.99	0.397	37.4	30.4
TMB 62	4665	1.1924	0.6011	0.5041	0.4770	0.5962	2.36	2.00	1.18	0.80	0.475	13.0	12.5
	4666	1.8248	0.9030	0.4947	0.4225	0.5962	3.69	3.06	1.21	0.71	0.482	13.0	12.5
	4667-1	2.4384	1.1892	0.4877	0.3810	0.5962	5.00	4.09	1.22	0.64	0.488	13.0	12.5
	4668	2.4384	0.8844	0.3627	0.2847	0.4435	6.72	5.50	1.22	0.64	0.488	13.0	12.5
	DL-62-A	0.9126	0.2211	0.2423	0.2920	0.2981	3.77	3.06	1.23	0.98	0.424	20.0	13.0
62-DUT	186	1.0000	0.4297	0.4297	0.4000	0.5000	2.37	2.00	1.16	0.80	0.471	25.0	25.0
	187	1.2500	0.4277	0.3422	0.2900	0.4080	3.65	3.06	1.19	0.71	0.479	25.0	25.0
	188	1.5000	0.4500	0.3000	0.2350	0.3670	5.00	4.09	1.22	0.64	0.488	25.0	25.0
	189	1.5000	0.3347	0.2230	0.1750	0.2730	6.73	5.49	1.22	0.64	0.488	25.0	25.0

Table 1 - Hull characteristics of chosen models

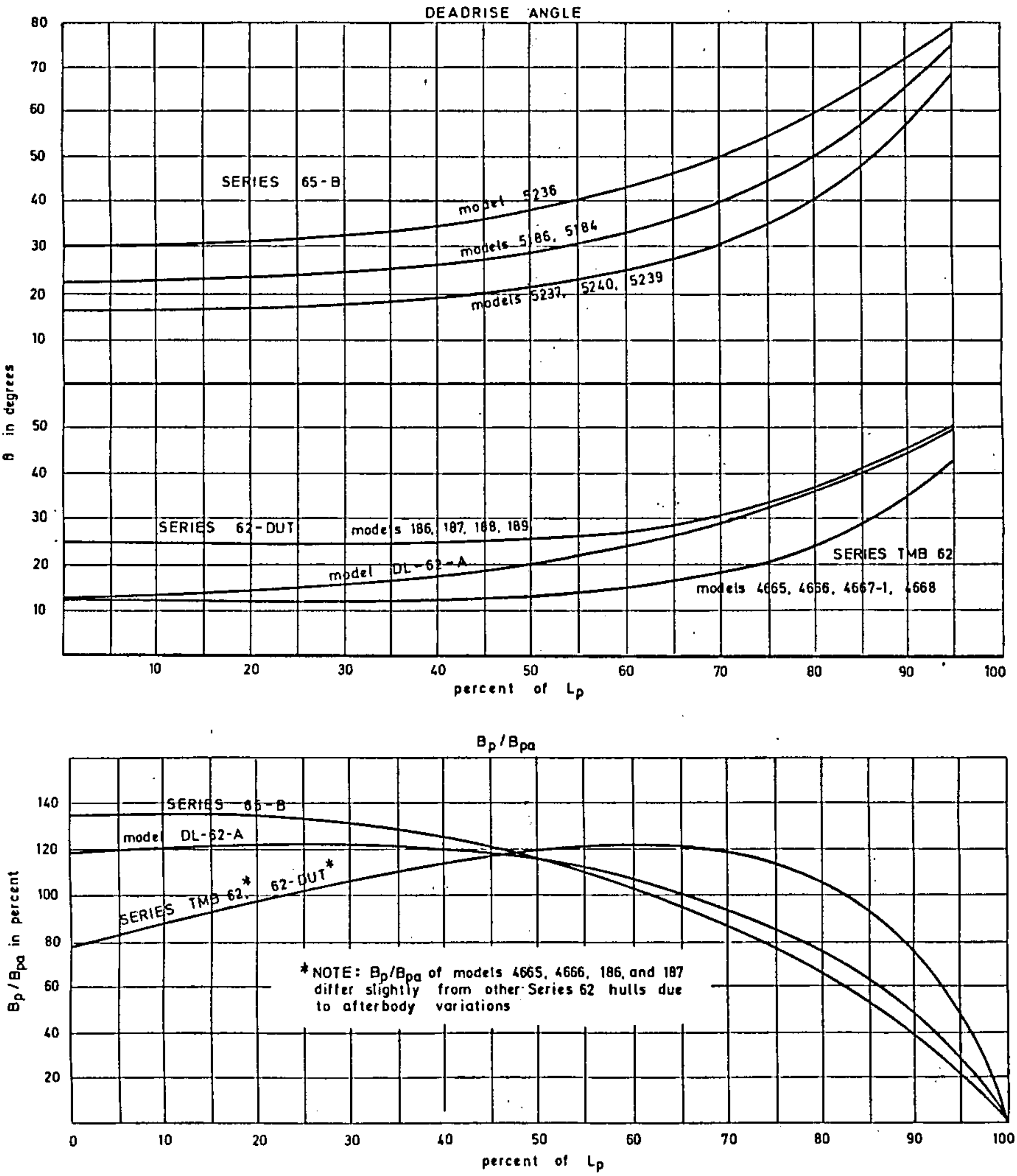

Figure 1 - Form characteristic curves of chosen models

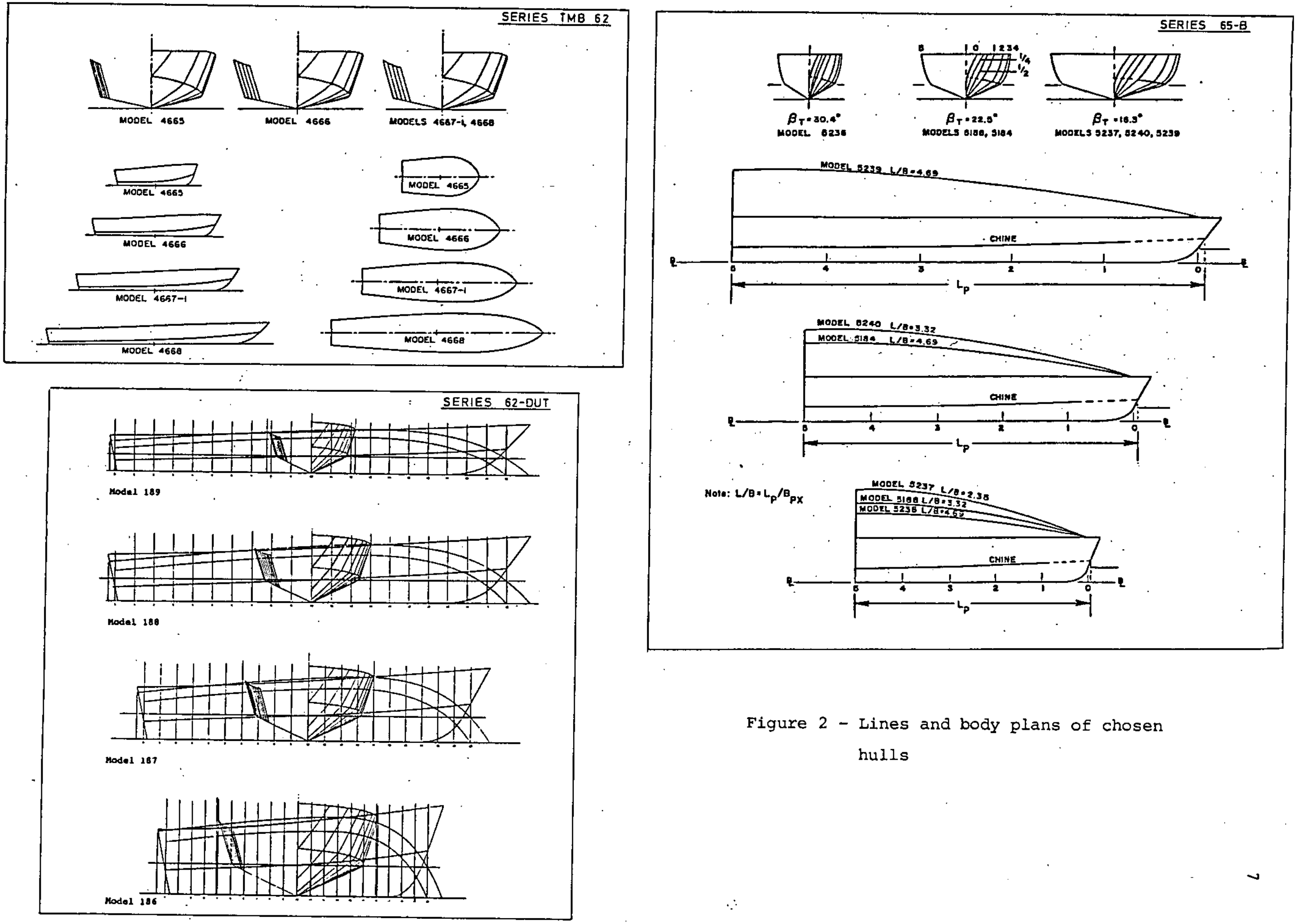

Figure 2 - Lines and body plans of chosen hulls

Mathematical Models for Calculation of Resistance, Trim Angle, Wetted Surface, and Mean Length of Wetted Surface

The same mathematical model was taken for all four answers, and that is a polynomial equation. Other forms were tried as well (multiplicative, exponential, reciprocial model, etc.), but there were not enough reasons for rejecting the polynomial form in all four cases.

The initial polynomial equation, to which subsequently the least square curve fitting was applied, had 27 terms, i.e.

$$
\begin{aligned}
Y = {} & b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_1x_2 + b_6x_1x_3 \\
& + b_7x_1x_4 + b_8x_2x_3 + b_9x_2x_4 + b_{10}x_3x_4 + b_{11}x_1^2 \\
& + b_{12}x_2^2 + b_{13}x_3^2 + b_{14}x_4^2 + b_{15}x_1x_2^2 + b_{16}x_1x_3^2 \\
& + b_{17}x_1x_4^2 + b_{18}x_2x_1^2 + b_{19}x_2x_3^2 + b_{20}x_2x_4^2 \\
& + b_{21}x_3x_1^2 + b_{22}x_3x_2^2 + b_{23}x_3x_4^2 + b_{24}x_4x_1^2 \\
& + b_{25}x_4x_2^2 + b_{26}x_4x_3^2
\end{aligned}
$$

where $Y=\tau$ ("a" regression coefficients), $Y=R/\Delta$ ("b" regression coefficients), $Y=S/\nabla^{2/3}$ ("c" regression coefficients), and $Y=L/L_p$ ("d" regression coefficients).

Also, from now on $x_5=x_1x_2$, $x_6=x_1x_3$, . . . $x_{26}=x_4x_3^2$.

However, for R/Δ and τ it was necessary to introduce one "dummy" variable "z" which forms two distinct groups of data — z=1 for Series 65-B and z=0 for the rest of the data used (Series DMB 62, Model 62-A, and Series 62-DUT). The mathematical model included one extra term in this case

$$Y=b_0+b_z+b_1x_1+b_2x_2+ \; . \; . \; . \; +b_{26}x_{26}.$$

The final mathematical model for R/Δ and τ is actually the same for all cases, it differs only in the constant term b_0.

This distinctive separation into two groups actually acts as a fifth variable and should be taken as a section shape only, and should not be confused with hull characteristics. In other words, all models of Series 62 (TMB 62, 62-A, and 62-DUT) have similar section shape which for one section, more or less, can be defined with three points connected with straight lines. However, for

Series 65-B, which looks very much like semi-displacement series, there is slight curvature of section shape on sides. Also, the chine does not exist in fore part of 65-B's hulls for about 20% of L_p (Figure 2).

The results, which were obtained with the use of "z variable", are in complete agreement with those published in (10). It should be noted that the importance of section shape, according to (10), is of greater importance than the four parameters ($A_p/\nabla^{2/3}$, LCG/L_p, L_p/B_{pa}, β_{M}) used in the current paper. However, according to (14) and (15) section shape is not of great significance.

In a previous similar paper by the author (2), this fact was not realised and regression equations were carried out differently.

In Appendix I and Appendix II regression coefficients are given for τ and R/Δ, respectively. The magnitude of each coefficient is given for descrete values of $F_{n\nabla}$, as well as in the polynomial form which can be used for calculation of regression coefficients for intermediate values of $F_{n\nabla}$.

It was felt to be more correct to do the interpolation of coefficients for calculation of intermediate values, rather than interpolation of the final answer.

For displacements other than 100000 lb it was necessary to evaluate the regression coefficients of the wetted surface and the mean length of the wetted surface.

However, it should be pointed out that the exact value of $S/\nabla^{2/3}$ and L/L_p are not of great importance for the calculation of the resistance for the displacements other than 100000 lb.

Appendix III and IV give regression coefficients for $S/\nabla^{2/3}$ and L/L_p, respectively, in a format similar to coefficients for τ and R/Δ.

It should be noted that the mathematical model for the calculation of R/Δ holds good only for $F_{n\nabla}$ range 1 to 3.50, while for τ, $S/\nabla^{2/3}$, and L/L_p for $F_{n\nabla}$ range 1 to 4 (although values of $F_{n\nabla}>3.50$ or even greater than 3.00 should be avoided since number of cases for these $F_{n\nabla}$ values were only 33 ($F_{n\nabla}=4.00$) and 52 ($F_{n\nabla}=3.50$)).

All diagrams and calculation of fitted polynomials in Appendices I to IV were done with a help of program "Curve Fitter" (17).

The confidience interval of fitted polynomials of the regression coefficients were within 95%.

Boundaries of Applicability

The mathematical model presented may only be used to predict the performance of a new planing hull whose characteristics are similar to the data underlying its derivation. First of all, the distribution of the principal four parameters should be as shown in Appendix V (for F_{nv}=3.50 and 4.00 the range is narrower).

The rest of the hull characteristics and parameters which were not used in developing the performance equations should also be within the range of values covered by the data (Table 1).

However, the new design may have any combination of the hull characteristics of the data considered, which turnes out to be one of the most atractive features of the regression analysis.

Quality of Fitted Equations - Control Information

Some of the important statistics or quality of fitted equations or control information, for discrete F_{nv} values (output of Stepwise Multiple Regression program) are given in Appendix VI.

Control information for fitted polynomials of regression coefficients (output of Curve Fitter program) are given in Appendix VII.

Finally, the degree of agreement for resistance between the test data and the results calculated by proposed mathematical model for eight ad hoc chosen cases, is given in Appendix VIII. The comparison is rather satisfactory.

Conclusions

Recent SNAME Transaction paper (18) under headings "Summary and Conclusions" suggests:

"Addition of a module which will use the NSRDC Series 62 and 65 hull data as an alternative to the present module".

This is exactly what is given here and that is a new mathematical model for predicting the performance of the stepless planing hull forms in calm water. Relatively wide speed range of applicability should be pointed out — F_{nv}=1 to 3.50 (to 4.00 for τ). The model proposed can be easily programmed which further facilitates prediction and optimization in preliminary design stage.

The proposed model may be used together with other performance prediction methods available (for F_{nv}=1-2 Reference (4), for higher F_{nv} values Savitsky's equations (1), etc.).

For the derivation of the regression equations, data of modern planing hull forms were used rather than prismatic forms.

Only four (plus section shape) hull form and loading parameters were used, already accepted in planing hull form design practice.

Step-by-step calculation procedure is given in Appendix IX.

Acknowledgments

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NOMENCLATURE

A_p - Projected planing-bottom area

$\oplus A_p$ - Distance of centroid of A_p forward of transom

B_p - Breadth over chines

B_{pa} - Mean breadth over chines - A_p/L_p

B_{pt} - Breadth over chines at transom

B_{px} - Maximum breadth over chines

β_M - Deadrise angle at 50% L_p, in degrees

β_t - Deadrise angle at transom

β_x - Deadrise angle at B_{px}

C_a - Correlation (roughness, etc.) allowance coefficient

C_f - Specific frictional resistance

Δ - Craft displacement at rest, in tons

∇ - Craft displaced volume at rest, in m^3

$F_{n\nabla}$ - Volume froude number - $v/\sqrt{g \cdot \nabla^{1/3}}$

g - Acceleration of gravity, 9.807 m/s^2

L_c - Projected wetted chine length

L_k - Projected wetted keel length

L_p - Projected chine length

L_s - Projected mean wetted length of a craft (ship, boat)

L_m - Projected mean wetted length of a model (Δ_m=100000 lb)

LCG - Longitudinal center of gravity location, measured from the transom

R - Total resistance

Re - Reynold's number - $(v \cdot L)/\nu$

S - Wetted surface

τ - Trim angle of planing area

v - Speed, in m/s

w - Specific weight of water

λ - Linear ratio, ship to model

ρ - Density of water, 1026 kg/m^3 (salt w.)

ν - Kynematic viscosity, $1.1907 \cdot 10^{-6}$ m^2/s

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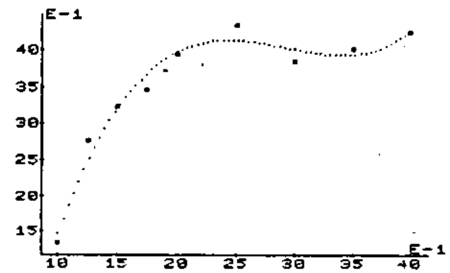
APPENDIX 1 - Regression coefficients for dynamic trim estimate equation (τ)



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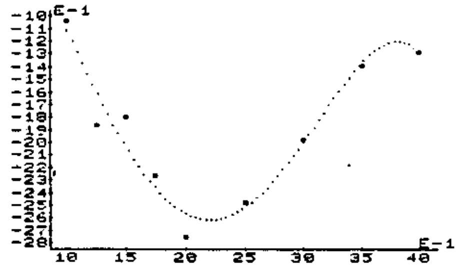
1 DEGREE COEFFICIENT = 11.1179363
2 DEGREE COEFFICIENT = -3.91539417
3 DEGREE COEFFICIENT = .447110286

#	$X=F_{nv}$	$Y=a_0$
1	1	1.33336293
2	1.25	2.75105083
3	1.5	3.20994172
4	1.75	3.4636892
5	2	3.93382114
6	2.5	4.33912398
7	3	3.84085312
8	3.5	4.02473013
9	4	4.24066972



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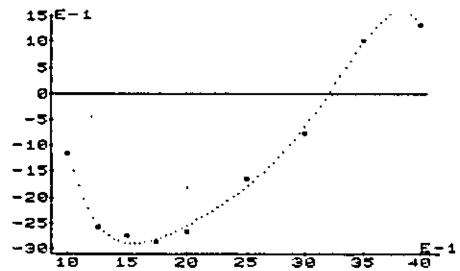
4 DEGREE COEFFICIENT = -.184171879

#	$X=F_{nv}$	$Y=a_1$
1	1	-1.03702812
2	1.25	-1.86276316
3	1.5	-1.79648922
4	1.75	-2.26844448
5	2	-2.75880036
6	2.5	-2.48144444
7	3	-1.97280091
8	3.5	-1.38826006
9	4	-1.28313404



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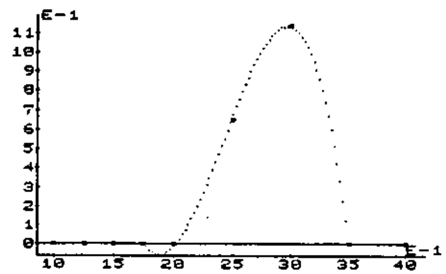
4 DEGREE COEFFICIENT = 5.71966848
5 DEGREE COEFFICIENT = -.458053536

#	$X=F_{nv}$	$Y=a_3$
1	1	-1.15780847
2	1.25	-2.57565899
3	1.5	-2.73103753
4	1.75	-2.8789717
5	2	-2.67156966
6	2.5	-1.63892185
7	3	-.759729025
8	3.5	1.02117918
9	4	1.33437093



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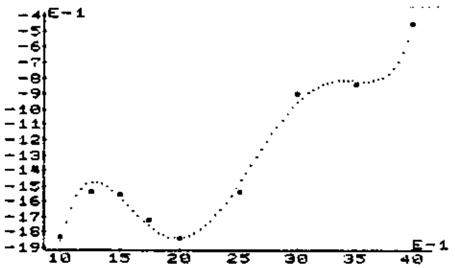
2 DEGREE COEFFICIENT = 13.4700017
3 DEGREE COEFFICIENT = -1.85063407

#	$X=F_{nv}$	$Y=a_z$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	.644809301
7	3	1.13525183
8	3.5	0
9	4	0

IF $F_{nv} <= 2.00$ AND $F_{nv} >= 3.50$ THEN $a_z = 0$



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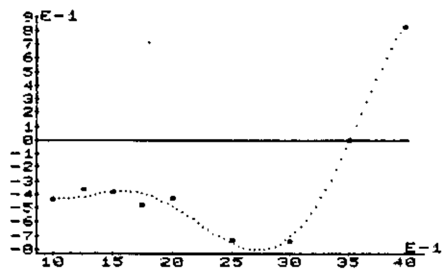
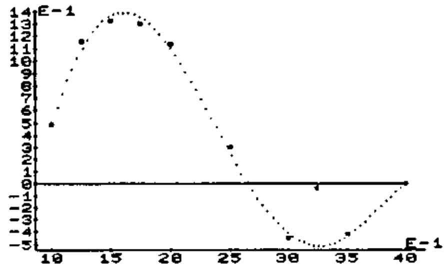
4 DEGREE COEFFICIENT = -4.74304608
5 DEGREE COEFFICIENT = .370242529

#	$X=F_{nv}$	$Y=a_2$
1	1	-1.83432596
2	1.25	-1.53407422
3	1.5	-1.55056152
4	1.75	-1.72094149
5	2	-1.84237867
6	2.5	-1.53976972
7	3	-.900498766
8	3.5	-.839419231
9	4	-.44692903



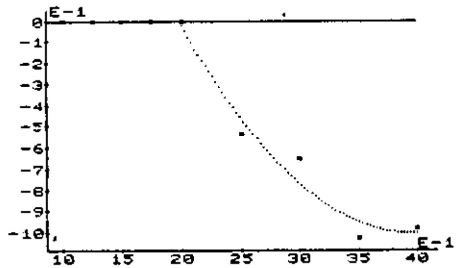
0 DEGREE COEFFICIENT = 5.4198155
1 DEGREE COEFFICIENT = -16.8178875
2 DEGREE COEFFICIENT = 18.0888154
3 DEGREE COEFFICIENT = -8.99396205
4 DEGREE COEFFICIENT = 2.05291989
5 DEGREE COEFFICIENT = -.172527414

#	$X=F_{nv}$	$Y=a_\zeta$
1	1	-.442475664
2	1.25	-.366031002
3	1.5	-.385272217
4	1.75	-.481950649
5	2	-.428069255
6	2.5	-.731979745
7	3	-.747782977
8	3.5	0
9	4	.831585316



0 DEGREE COEFFICIENT = -2.9852334
1 DEGREE COEFFICIENT = 1.52396453
2 DEGREE COEFFICIENT = 5.6057755
3 DEGREE COEFFICIENT = -4.84633227
4 DEGREE COEFFICIENT = 1.32444878
5 DEGREE COEFFICIENT = -.118840578

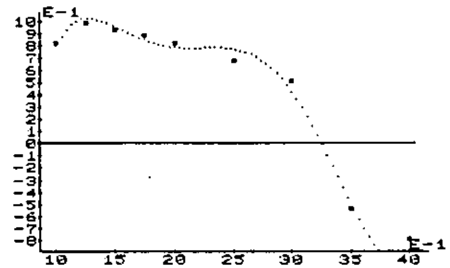
#	$X=F_{nv}$	$Y=a_6$
1	1	.482224303
2	1.25	1.14962838
3	1.5	1.32316858
4	1.75	1.30002617
5	2	1.13565883
6	2.5	.302119572
7	3	-.454155325
8	3.5	-.413090914
9	4	0



0 DEGREE COEFFICIENT = 3.03387463
1 DEGREE COEFFICIENT = -2.04535626
2 DEGREE COEFFICIENT = .259200284

#	$X=F_{nv}$	$Y=a_9$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	-.538710349
7	3	-.652023523
8	3.5	-1.0269636
9	4	-.981259789

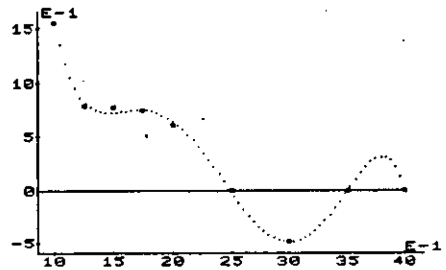
IF $F_{nv} \leq 2.00$ THEN $a_9 = 0$



0 DEGREE COEFFICIENT = -14.4207844
1 DEGREE COEFFICIENT = 39.3509741
2 DEGREE COEFFICIENT = -38.1560267
3 DEGREE COEFFICIENT = 17.5549224
4 DEGREE COEFFICIENT = -3.84805203
5 DEGREE COEFFICIENT = .320604451

#	$X=F_{nv}$	$Y=a_{12}$
1	1	.817052435
2	1.25	.990261998
3	1.5	.933987B3
4	1.75	.891951401
5	2	.820895405
6	2.5	.67384787
7	3	.508175897
8	3.5	-.531880853
9	4	-.794749289

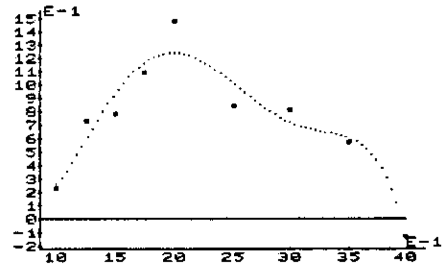
IF $a_{12} \leq -0.8$ THEN $a_{12} = -0.8$



0 DEGREE COEFFICIENT = 34.293556
1 DEGREE COEFFICIENT = -81.5686451
2 DEGREE COEFFICIENT = 76.1356274
3 DEGREE COEFFICIENT = -33.8801755
4 DEGREE COEFFICIENT = 7.14598861
5 DEGREE COEFFICIENT = -.573468136

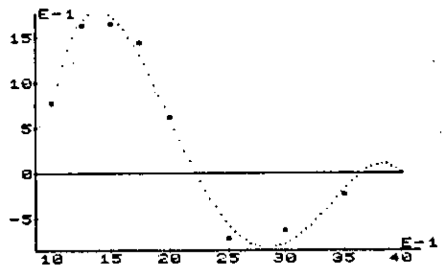
#	$X=F_{nv}$	$Y=a_8$
1	1	1.5602212
2	1.25	.783089411
3	1.5	.771596878
4	1.75	.744953767
5	2	.606752914
6	2.5	0
7	3	-.488988706
8	3.5	0
9	4	0

IF $F_{nv} \geq 350$ THEN $a_8 = 0$



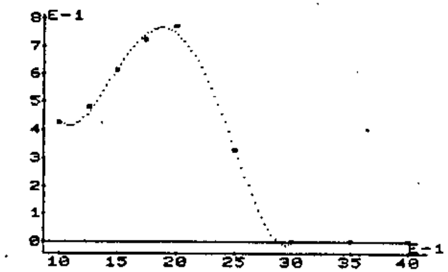
0 DEGREE COEFFICIENT = 6.51201707
1 DEGREE COEFFICIENT = -20.5921328
2 DEGREE COEFFICIENT = 23.6517009
3 DEGREE COEFFICIENT = -11.7257026
4 DEGREE COEFFICIENT = 2.6400682
5 DEGREE COEFFICIENT = -.222775269

#	$X=F_{nv}$	$Y=a_{11}$
1	1	.231294929
2	1.25	.727889502
3	1.5	.781132304
4	1.75	1.08787427
5	2	1.48532225
6	2.5	.835768857
7	3	.815710588
8	3.5	.570996313
9	4	-.13408536



0 DEGREE COEFFICIENT = -21.6469813
1 DEGREE COEFFICIENT = 45.2206538
2 DEGREE COEFFICIENT = -30.0967147
3 DEGREE COEFFICIENT = 8.01428353
4 DEGREE COEFFICIENT = -.744581638

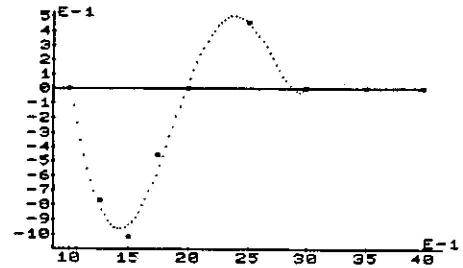
#	$X=F_{nv}$	$Y=a_{13}$
1	1	.777216966
2	1.25	1.63732229
3	1.5	1.66100134
4	1.75	1.45160997
5	2	.619358807
6	2.5	-.732243325
7	3	-.630496484
8	3.5	-.243713956
9	4	0



#	$X=F_{nv}$	$Y=a_{14}$
1	1	.420958093
2	1.25	.480768508
3	1.5	.611615595
4	1.75	.722073092
5	2	.773466947
6	2.5	.329024632
7	3	0
8	3.5	0
9	4	0

0 DEGREE COEFFICIENT = 7.04288049
1 DEGREE COEFFICIENT = -17.030063
2 DEGREE COEFFICIENT = 15.3143485
3 DEGREE COEFFICIENT = -5.61339313
4 DEGREE COEFFICIENT = .713314478

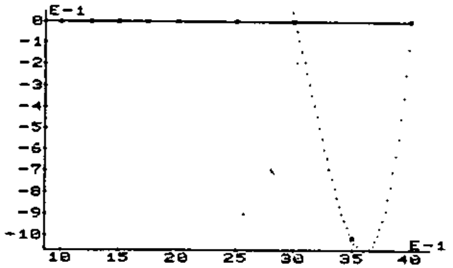
IF $F_{nv} >= 2.90$ THEN $a_{14} = 0$



#	$X=F_{nv}$	$Y=a_{16}$
1	1	0
2	1.25	-.766193801
3	1.5	-1.02118319
4	1.75	-.457751471
5	2	0
6	2.5	.460667698
7	3	0
8	3.5	0
9	4	0

0 DEGREE COEFFICIENT = .020905644
1 DEGREE COEFFICIENT = 21.381973
2 DEGREE COEFFICIENT = -46.7355148
3 DEGREE COEFFICIENT = 35.1550349
4 DEGREE COEFFICIENT = -11.0612294
5 DEGREE COEFFICIENT = 1.24784672

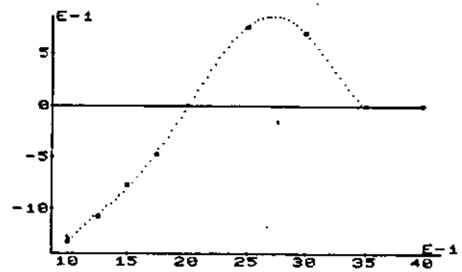
IF $F_{nv} >= 2.90$ THEN $a_{16} = 0$



#	$X=F_{nv}$	$Y=a_{18}$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	0
7	3	0
8	3.5	-1.01829318
9	4	0

0 DEGREE COEFFICIENT = -122.166228
1 DEGREE COEFFICIENT = 120.130734
2 DEGREE COEFFICIENT = -38.6863526
3 DEGREE COEFFICIENT = 4.07226397

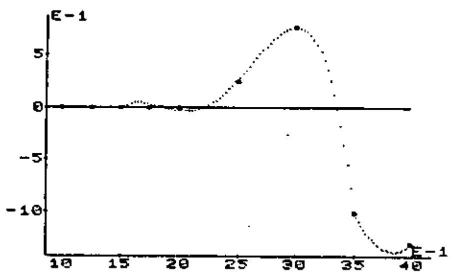
IF $F_{nv} <= 3.00$ THEN $a_{18} = 0$



#	$X=F_{nv}$	$Y=a_{19}$
1	1	-1.31998028
2	1.25	-1.06647051
3	1.5	-.759307742
4	1.75	-.464885898
5	2	0
6	2.5	.74883439
7	3	.686296711
8	3.5	0
9	4	0

0 DEGREE COEFFICIENT = -12.0728215
1 DEGREE COEFFICIENT = 30.0365433
2 DEGREE COEFFICIENT = -32.8541844
3 DEGREE COEFFICIENT = 17.5042737
4 DEGREE COEFFICIENT = -4.33856452
5 DEGREE COEFFICIENT = .399774159

IF $F_{nv} >= 3.50$ THEN $a_{19} = 0$



#	$X=F_{nv}$	$Y=a_{23}$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	.242369481
7	3	.778293938
8	3.5	-1.01220609
9	4	-1.31954182

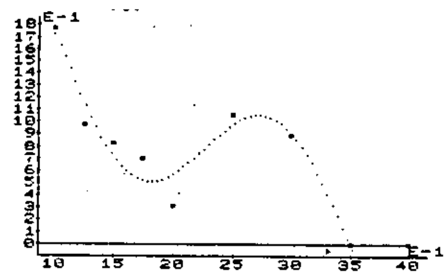
IF $F_{nv} <= 2.20$ THEN $a_{23} = 0$

$F_{nv} = 2.20 - 3.50$

0 DEGREE COEFFICIENT = -33.6958479
1 DEGREE COEFFICIENT = 65.7673982
2 DEGREE COEFFICIENT = -46.9575384
3 DEGREE COEFFICIENT = 14.4914087
4 DEGREE COEFFICIENT = -1.62326062

$F_{nv} = 3.50 - 4.00$

0 DEGREE COEFFICIENT = 45.6207381
1 DEGREE COEFFICIENT = -24.4672185
2 DEGREE COEFFICIENT = 3.18371365

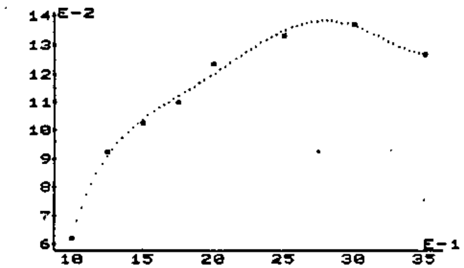


#	$X=F_{nv}$	$Y=a_{25}$
1	1	1.77654067
2	1.25	.985105727
3	1.5	.827274025
4	1.75	.700907514
5	2	.315896151
6	2.5	1.05978194
7	3	.898469077
8	3.5	0
9	4	0

0 DEGREE COEFFICIENT = -4.29258375
1 DEGREE COEFFICIENT = 24.2841156
2 DEGREE COEFFICIENT = -31.7618165
3 DEGREE COEFFICIENT = 17.3198433
4 DEGREE COEFFICIENT = -4.19504127
5 DEGREE COEFFICIENT = .371878483

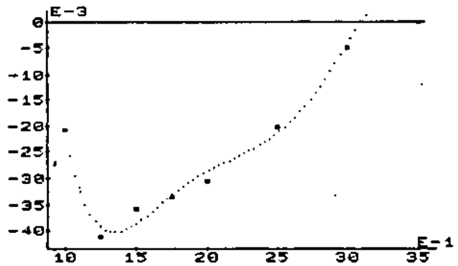
IF $F_{nv} >= 3.50$ THEN $a_{25} = 0$

APPENDIX 2 - Regression coefficients for resistance estimating equation (R/Δ)



#	$X = F_{nv}$	$Y = b_0$
1	1	.0616665941
2	1.25	.0921846034
3	1.5	.10261366
4	1.75	.109972881
5	2	.123424208
6	2.5	.133447525
7	3	.137380334
8	3.5	.127100469

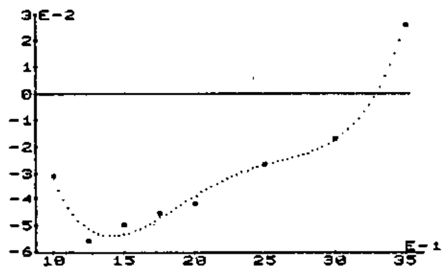
0 DEGREE COEFFICIENT = -.68060853
1 DEGREE COEFFICIENT = 1.76822681
2 DEGREE COEFFICIENT = -1.60390433
3 DEGREE COEFFICIENT = .723710042
4 DEGREE COEFFICIENT = -.158752596
5 DEGREE COEFFICIENT = .0134431117



#	$X = F_{nv}$	$Y = b_1$
1	1	-.020685586
2	1.25	-.0413523864
3	1.5	-.0358178764
4	1.75	-.0336868303
5	2	-.0303952276
6	2.5	-.0203340848
7	3	-4.86717548E-03
8	3.5	0

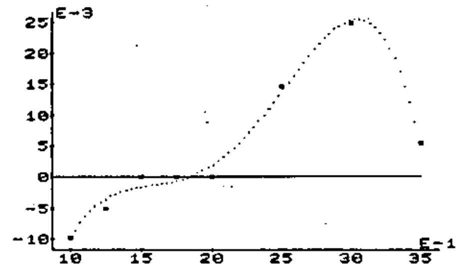
IF $b_1 > 0$ THEN $b_1 = 0$

0 DEGREE COEFFICIENT = .91528052
1 DEGREE COEFFICIENT = -2.38372611
2 DEGREE COEFFICIENT = 2.2938749
3 DEGREE COEFFICIENT = -1.06661552
4 DEGREE COEFFICIENT = .241232679
5 DEGREE COEFFICIENT = -.0212123476



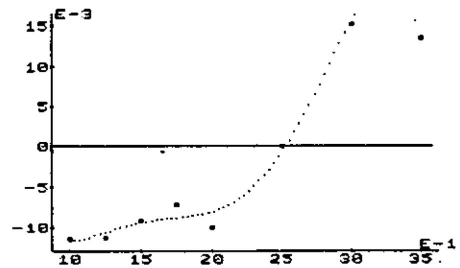
#	$X = F_{nv}$	$Y = b_3$
1	1	-.0310235083
2	1.25	-.0563088688
3	1.5	-.0498193425
4	1.75	-.045332873
5	2	-.042124873
6	2.5	-.0267461175
7	3	-.017212295
8	3.5	.0259263377

0 DEGREE COEFFICIENT = .454783404
1 DEGREE COEFFICIENT = -1.02858934
2 DEGREE COEFFICIENT = .741564782
3 DEGREE COEFFICIENT = -.225316353
4 DEGREE COEFFICIENT = .0249735883



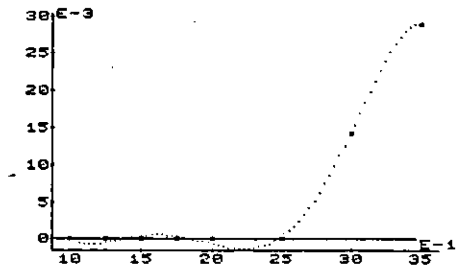
#	$X = F_{nv}$	$Y = b_2$
1	1	-9.90906073E-03
2	1.25	-4.99868341E-03
3	1.5	0
4	1.75	0
5	2	0
6	2.5	.0146274254
7	3	.024863472
8	3.5	5.41199618E-03

0 DEGREE COEFFICIENT = -.21082981
1 DEGREE COEFFICIENT = .451243114
2 DEGREE COEFFICIENT = -.358866778
3 DEGREE COEFFICIENT = .123150714
4 DEGREE COEFFICIENT = -.0149746614



#	$X = F_{nv}$	$Y = b_2$
1	1	-.0115942836
2	1.25	-.0113336247
3	1.5	-9.27630558E-03
4	1.75	-7.21881832E-03
5	2	-9.96893019E-03
6	2.5	0
7	3	.0151752974
8	3.5	.0134467009

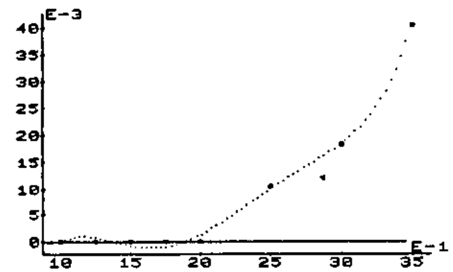
0 DEGREE COEFFICIENT = .0988434074
1 DEGREE COEFFICIENT = -.358791111
2 DEGREE COEFFICIENT = .440163502
3 DEGREE COEFFICIENT = -.254720105
4 DEGREE COEFFICIENT = .0699444179
5 DEGREE COEFFICIENT = -7.2285748E-03



#	$X = F_{nv}$	$Y = b_4$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	0
7	3	.014291177
8	3.5	.0290017347

IF $F_{nv} <= 2.50$ THEN $b_4 = 0$

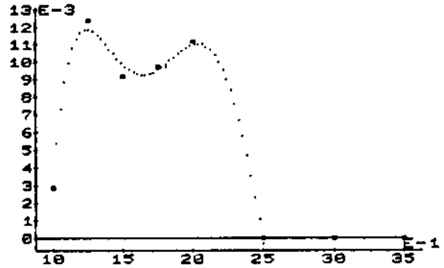
0 DEGREE COEFFICIENT = .208217904
1 DEGREE COEFFICIENT = -.60583501
2 DEGREE COEFFICIENT = .671318048
3 DEGREE COEFFICIENT = -.353381553
4 DEGREE COEFFICIENT = .0881187183
5 DEGREE COEFFICIENT = -8.29085106E-03



#	$X = F_{nv}$	$Y = b_5$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	.010282334
7	3	.0181133506
8	3.5	.0405533942

IF $F_{nv} <= 1.90$ THEN $b_5 = 0$

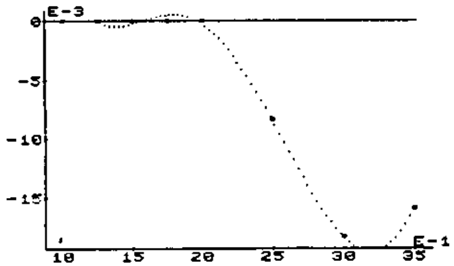
0 DEGREE COEFFICIENT = -.250024001
1 DEGREE COEFFICIENT = .703461468
2 DEGREE COEFFICIENT = -.748551226
3 DEGREE COEFFICIENT = .37644997
4 DEGREE COEFFICIENT = -.0898368641
5 DEGREE COEFFICIENT = 8.26140102E-03



#	$X = F_{nv}$	$Y = b_8$
1	1	2.86041182E-03
2	1.25	.012382611
3	1.5	9.14594633E-03
4	1.75	9.66438792E-03
5	2	.0110891014
6	2.5	0
7	3	0
8	3.5	0

IF $F_{nv} >= 2.50$ THEN $b_8 = 0$

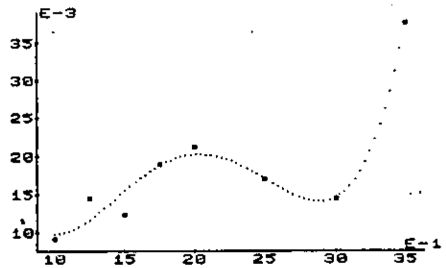
0 DEGREE COEFFICIENT = -1.22078063
1 DEGREE COEFFICIENT = 3.56870936
2 DEGREE COEFFICIENT = -4.02286588
3 DEGREE COEFFICIENT = 2.20383963
4 DEGREE COEFFICIENT = -.586467769
5 DEGREE COEFFICIENT = .0605788125



#	$X = F_{nv}$	$Y = b_{10}$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	-8.38569728E-03
7	3	-.0183147381
8	3.5	-.0158474283

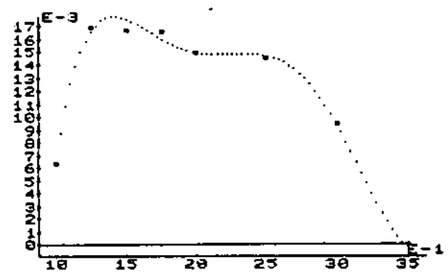
IF $F_{nv} <= 2.00$ THEN $b_{10} = 0$

0 DEGREE COEFFICIENT = .307419954
1 DEGREE COEFFICIENT = -.732807256
2 DEGREE COEFFICIENT = .660268664
3 DEGREE COEFFICIENT = -.278422142
4 DEGREE COEFFICIENT = .0544250149
5 DEGREE COEFFICIENT = -3.95367066E-03



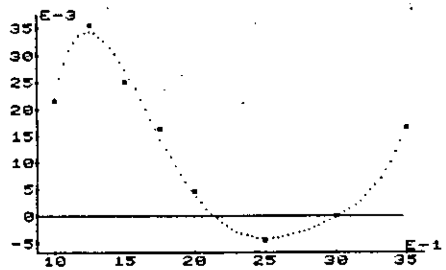
#	$X = F_{nv}$	$Y = b_{11}$
1	1	9.05674168E-03
2	1.25	.0144867723
3	1.5	.0123726747
4	1.75	.01881432
5	2	.0211418461
6	2.5	.0169507733
7	3	.014404704
8	3.5	.0376868178

0 DEGREE COEFFICIENT = .107738054
1 DEGREE COEFFICIENT = -.257834193
2 DEGREE COEFFICIENT = .234480033
3 DEGREE COEFFICIENT = -.0852493653
4 DEGREE COEFFICIENT = .0107621929



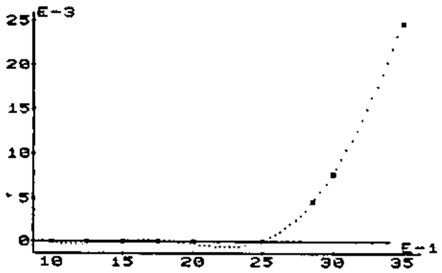
#	$X = F_{nv}$	$Y = b_{12}$
1	1	6.30047106E-03
2	1.25	.0169821234
3	1.5	.0167040604
4	1.75	.0166689502
5	2	.0149862636
6	2.5	.0145372715
7	3	9.4842147E-03
8	3.5	0

0 DEGREE COEFFICIENT = -.432187321
1 DEGREE COEFFICIENT = 1.09140177
2 DEGREE COEFFICIENT = -1.02271579
3 DEGREE COEFFICIENT = .462439089
4 DEGREE COEFFICIENT = -.101090895
5 DEGREE COEFFICIENT = 8.53633259E-03



#	$X = F_{nv}$	$Y = b_{13}$
1	1	.0215370341
2	1.25	.0357083554
3	1.5	.0249751241
4	1.75	.0161092665
5	2	4.50582797E-03
6	2.5	-4.53941144E-03
7	3	0
8	3.5	.0163508162

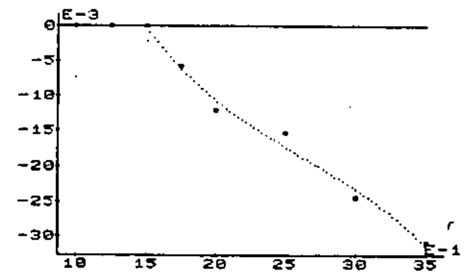
0 DEGREE COEFFICIENT = -.802401508
1 DEGREE COEFFICIENT = 2.05404065
2 DEGREE COEFFICIENT = -1.89219525
3 DEGREE COEFFICIENT = .819187137
4 DEGREE COEFFICIENT = -.170697515
5 DEGREE COEFFICIENT = .0139021933



0 DEGREE COEFFICIENT = .0725533921
1 DEGREE COEFFICIENT = -.207868472
2 DEGREE COEFFICIENT = .225405554
3 DEGREE COEFFICIENT = -.115037564
4 DEGREE COEFFICIENT = .0274049915
5 DEGREE COEFFICIENT = -2.40233736E-03

#	$X=F_{nv}$	$Y=b_{14}$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	0
6	2.5	0
7	3	7.65336527E-03
8	3.5	.024700557

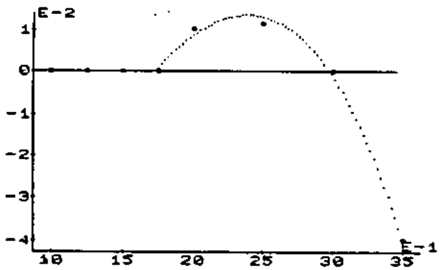
IF $F_{nv} <= 2.50$ THEN $b_{14} = 0$



0 DEGREE COEFFICIENT = .0837900649
1 DEGREE COEFFICIENT = -.0944281902
2 DEGREE COEFFICIENT = .0316357144
3 DEGREE COEFFICIENT = -4.01703279E-03

#	$X=F_{nv}$	$Y=b_{17}$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	-5.8492448E-03
5	2	-.0121337289
6	2.5	-.0153905511
7	3	-.0244844078
8	3.5	-.0310924864

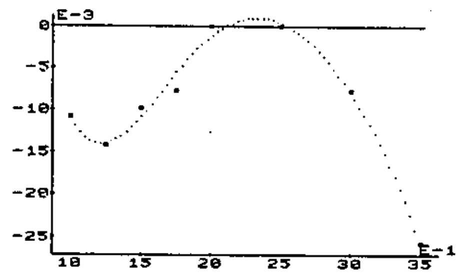
IF $F_{nv} <= 1.50$ THEN $b_{17} = 0$



0 DEGREE COEFFICIENT = -.0963084704
1 DEGREE COEFFICIENT = .051716079
2 DEGREE COEFFICIENT = .0144287668
3 DEGREE COEFFICIENT = -7.02458471E-03

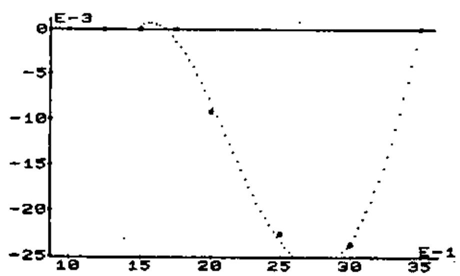
#	$X=F_{nv}$	$Y=b_{18}$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	.0102507011
6	2.5	.0117938074
7	3	0
8	3.5	-.0399586552

IF $F_{nv} <= 1.75$ THEN $b_{18} = 0$



0 DEGREE COEFFICIENT = .239891152
1 DEGREE COEFFICIENT = -.613376388
2 DEGREE COEFFICIENT = .546363655
3 DEGREE COEFFICIENT = -.223775671
4 DEGREE COEFFICIENT = .0435805114
5 DEGREE COEFFICIENT = -3.34563196E-03

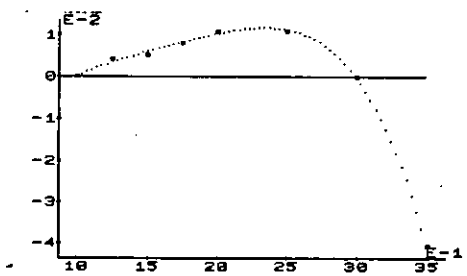
#	$X=F_{nv}$	$Y=b_{19}$
1	1	-.01066115
2	1.25	-.0142674181
3	1.5	-9.70227307E-03
4	1.75	-7.76785648E-03
5	2	0
6	2.5	0
7	3	-7.78078997E-03
8	3.5	-.0257532507



0 DEGREE COEFFICIENT = -.42568354
1 DEGREE COEFFICIENT = .737069771
2 DEGREE COEFFICIENT = -.44134888
3 DEGREE COEFFICIENT = .1056215
4 DEGREE COEFFICIENT = -8.50381909E-03

#	$X=F_{nv}$	$Y=b_{20}$
1	1	0
2	1.25	0
3	1.5	0
4	1.75	0
5	2	-9.27554913E-03
6	2.5	-.0226544525
7	3	-.0238970116
8	3.5	0

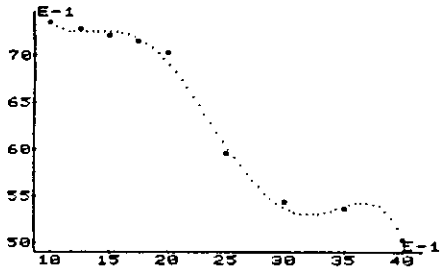
IF $F_{nv} <= 1.70$ THEN $b_{20} = 0$



0 DEGREE COEFFICIENT = -.0445653975
1 DEGREE COEFFICIENT = .0959537263
2 DEGREE COEFFICIENT = -.0779070336
3 DEGREE COEFFICIENT = .0316037524
4 DEGREE COEFFICIENT = -4.88289898E-03

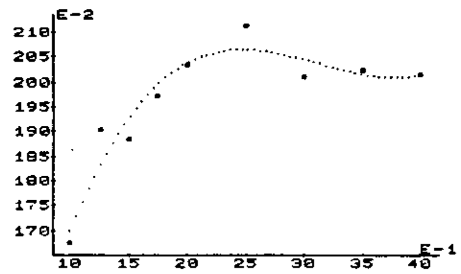
#	$X=F_{nv}$	$Y=b_{23}$
1	1	0
2	1.25	4.17371449E-03
3	1.5	5.35018099E-03
4	1.75	7.98569283E-03
5	2	.0111539215
6	2.5	.0111671159
7	3	0
8	3.5	-.040826501

APPENDIX 3 - Regression coefficients for wetted area estimate equation ($S/\nabla^{2/3}$)



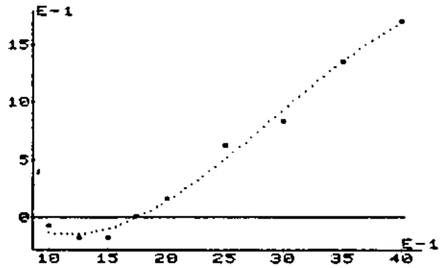
#	$X=F_{n\nabla}$	$Y=c_0$
1	1	7.35972955
2	1.25	7.28287556
3	1.5	7.20829266
4	1.75	7.15098528
5	2	7.01829675
6	2.5	5.95292073
7	3	5.43200915
8	3.5	5.36244782
9	4	5.0278817

0 DEGREE COEFFICIENT = 21.0720651
1 DEGREE COEFFICIENT = -37.5722652
2 DEGREE COEFFICIENT = 38.7068186
3 DEGREE COEFFICIENT = -18.6410796
4 DEGREE COEFFICIENT = 4.1462388
5 DEGREE COEFFICIENT = -.345191372



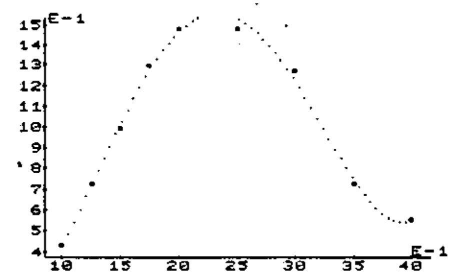
#	$X=F_{n\nabla}$	$Y=c_1$
1	1	1.67293911
2	1.25	1.90314231
3	1.5	1.88377274
4	1.75	1.97128608
5	2	2.03566157
6	2.5	2.11515615
7	3	2.00972331
8	3.5	2.02278043
9	4	2.01557671

0 DEGREE COEFFICIENT = .724907898
1 DEGREE COEFFICIENT = 1.38743421
2 DEGREE COEFFICIENT = -.464556174
3 DEGREE COEFFICIENT = .0495796924



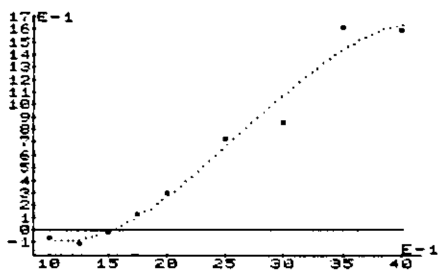
#	$X=F_{n\nabla}$	$Y=c_2$
1	1	-.0719307963
2	1.25	-.177743433
3	1.5	-.177568134
4	1.75	.0146232208
5	2	.160293315
6	2.5	.628621015
7	3	.838019739
8	3.5	1.34709626
9	4	1.70218866

0 DEGREE COEFFICIENT = .698083098
1 DEGREE COEFFICIENT = -1.56103568
2 DEGREE COEFFICIENT = .830587372
3 DEGREE COEFFICIENT = -.0946387432



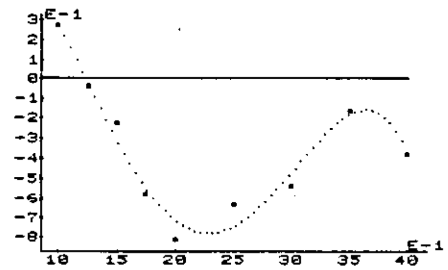
#	$X=F_{n\nabla}$	$Y=c_3$
1	1	.428001565
2	1.25	.725644452
3	1.5	.994301034
4	1.75	1.29217163
5	2	1.47999022
6	2.5	1.47732914
7	3	1.26920476
8	3.5	.722796533
9	4	.556450741

0 DEGREE COEFFICIENT = .837716092
1 DEGREE COEFFICIENT = -2.91976793
2 DEGREE COEFFICIENT = 3.70288321
3 DEGREE COEFFICIENT = -1.33988494
4 DEGREE COEFFICIENT = .148044921



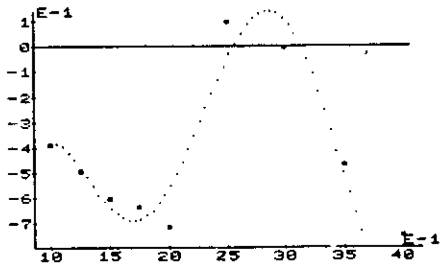
#	$X=F_{n\nabla}$	$Y=c_4$
1	1	-.0605586162
2	1.25	-.112506159
3	1.5	-.0273415228
4	1.75	.130287856
5	2	.298053799
6	2.5	.728083736
7	3	.858963177
8	3.5	1.61946479
9	4	1.58873964

0 DEGREE COEFFICIENT = .771477951
1 DEGREE COEFFICIENT = -1.68759472
2 DEGREE COEFFICIENT = .958549828
3 DEGREE COEFFICIENT = -.120600635



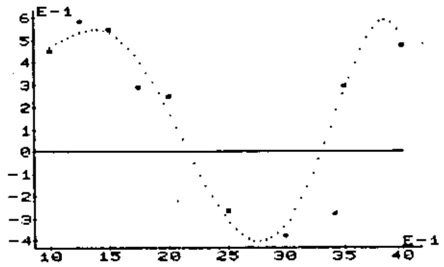
#	$X=F_{n\nabla}$	$Y=c_{12}$
1	1	.274735849
2	1.25	-.0396800436
3	1.5	-.228363996
4	1.75	-.58283712
5	2	-.813679314
6	2.5	-.633937835
7	3	-.538713231
8	3.5	-.166247945
9	4	-.377306991

0 DEGREE COEFFICIENT = .257990396
1 DEGREE COEFFICIENT = 2.18906325
2 DEGREE COEFFICIENT = -3.29567695
3 DEGREE COEFFICIENT = 1.28098211
4 DEGREE COEFFICIENT = -.150947518



#	$X=F_{nv}$	$Y=c_{13}$
1	1	-.389153909
2	1.25.	-.492790524
3	1.5	-.604027624
4	1.75	-.637934141
5	2	-.712616902
6	2.5	.0980372526
7	3	-3.52813341E-03
8	3.5	-.469343355
9	4	-.747949486

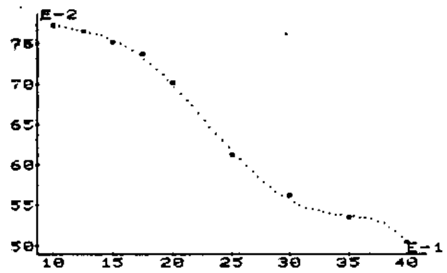
0 DEGREE COEFFICIENT = -11.2344614
1 DEGREE COEFFICIENT = 31.8255001
2 DEGREE COEFFICIENT = -34.536869
3 DEGREE COEFFICIENT = 17.1331198
4 DEGREE COEFFICIENT = -3.90632068
5 DEGREE COEFFICIENT = .331328007



#	$X=F_{nv}$	$Y=c_{19}$
1	1	.449769352
2	1.25	.584691008
3	1.5	.545012026
4	1.75	.286942075
5	2	.247044475
6	2.5	-.264839768
7	3	-.383009916
8	3.5	.295878267
9	4	.476005743

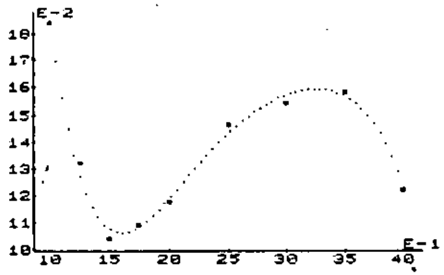
0 DEGREE COEFFICIENT = 4.25441629
1 DEGREE COEFFICIENT = -12.9327684
2 DEGREE COEFFICIENT = 16.1160621
3 DEGREE COEFFICIENT = -9.00400032
4 DEGREE COEFFICIENT = 2.23896166
5 DEGREE COEFFICIENT = -.201970547

APPENDIX 4 - Regression coefficients for mean length of wetted area estimate equation (L/L_p)



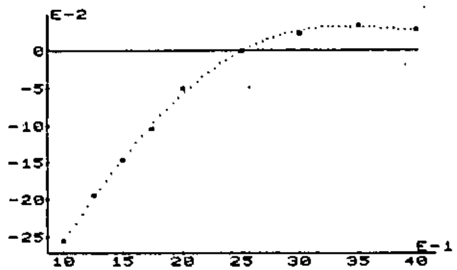
#	$X=F_{nv}$	$Y=d_0$
1	1	.774181444
2	1.25	.76501529
3	1.5	.752199079
4	1.75	.736158069
5	2	.701285196
6	2.5	.612134312
7	3	.562070943
8	3.5	.53520799
9	4	.504833828

0 DEGREE COEFFICIENT = 1.18626298
1 DEGREE COEFFICIENT = -1.22960745
2 DEGREE COEFFICIENT = 1.40323299
3 DEGREE COEFFICIENT = -.74864824
4 DEGREE COEFFICIENT = .17758175
5 DEGREE COEFFICIENT = -.0153931385



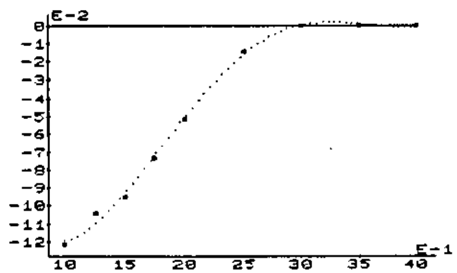
#	$X=F_{nv}$	$Y=d_2$
1	1	.18434727
2	1.25	.131685832
3	1.5	.103753254
4	1.75	.109122364
5	2	.117522448
6	2.5	.146181863
7	3	.15420571
8	3.5	.158171096
9	4	.122109443

0 DEGREE COEFFICIENT = 1.38306901
1 DEGREE COEFFICIENT = -2.53395056
2 DEGREE COEFFICIENT = 1.91972946
3 DEGREE COEFFICIENT = -.700233537
4 DEGREE COEFFICIENT = .12606393
5 DEGREE COEFFICIENT = -9.0800932E-03



#	$X=F_{nv}$	$Y=d_4$
1	1	-.255697366
2	1.25	-.19439791
3	1.5	-.14539163
4	1.75	-.105031037
5	2	-.0503398627
6	2.5	0
7	3	.0238449353
8	3.5	.0346133551
9	4	.0276896874

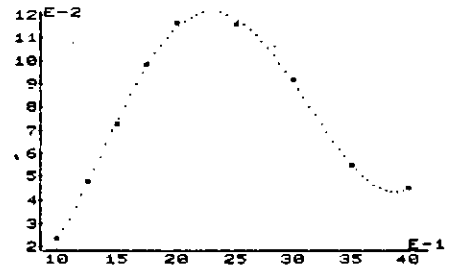
0 DEGREE COEFFICIENT = -.486707657
1 DEGREE COEFFICIENT = .196621987
2 DEGREE COEFFICIENT = .0703241364
3 DEGREE COEFFICIENT = -.039534813
4 DEGREE COEFFICIENT = 4.4276266E-03



#	$X=F_{nv}$	$Y=d_1$
1	1	-.121840305
2	1.25	-.104177618
3	1.5	-.0948155086
4	1.75	-.0733662127
5	2	-.0513349044
6	2.5	-.0142502515
7	3	0
8	3.5	0
9	4	0

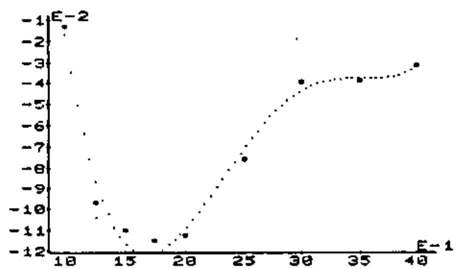
IF $F_{nv} > 3.00$ THEN $d_1 = 0$

0 DEGREE COEFFICIENT = .0200515847
1 DEGREE COEFFICIENT = -.368249845
2 DEGREE COEFFICIENT = .306887634
3 DEGREE COEFFICIENT = -.0863977359
4 DEGREE COEFFICIENT = 8.09343529E-03



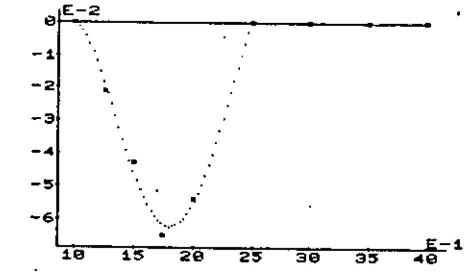
#	$X=F_{nv}$	$Y=d_3$
1	1	.0233926715
2	1.25	.0477575032
3	1.5	.0726234456
4	1.75	.0979617313
5	2	.116865457
6	2.5	.116217714
7	3	.092023116
8	3.5	.0545998233
9	4	.0447722719

0 DEGREE COEFFICIENT = .228560719
1 DEGREE COEFFICIENT = -.69308823
2 DEGREE COEFFICIENT = .744838057
3 DEGREE COEFFICIENT = -.3065356
4 DEGREE COEFFICIENT = .052958298
5 DEGREE COEFFICIENT = -3.19139083E-03



#	$X=F_{nv}$	$Y=d_7$
1	1	-.0129073048
2	1.25	-.0967228615
3	1.5	-.110057193
4	1.75	-.11534376
5	2	-.112835707
6	2.5	-.0758100715
7	3	-.0392880659
8	3.5	-.0387325274
9	4	-.0313665268

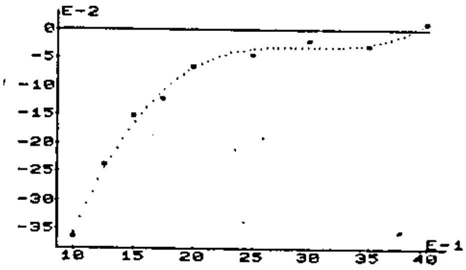
0 DEGREE COEFFICIENT = .956768932
1 DEGREE COEFFICIENT = -1.7810837
2 DEGREE COEFFICIENT = 1.03355053
3 DEGREE COEFFICIENT = -.247128773
4 DEGREE COEFFICIENT = .0211541158



#	$X=F_{nv}$	$Y=d_{13}$
1	1	0
2	1.25	-.0208250274
3	1.5	-.0426510579
4	1.75	-.064896565
5	2	-.0540418978
6	2.5	0
7	3	0
8	3.5	0
9	4	0

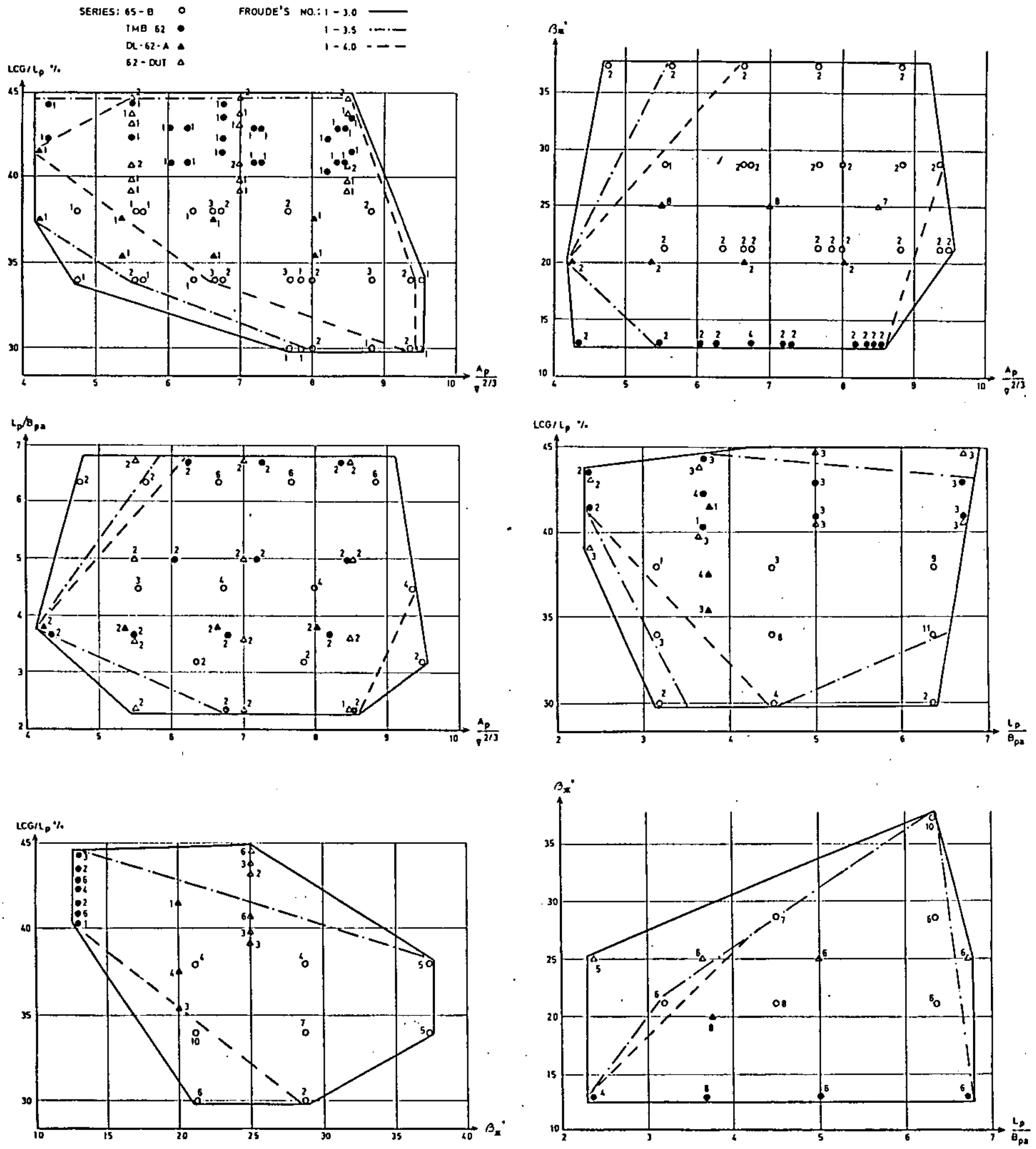
0 DEGREE COEFFICIENT = -.85944128
1 DEGREE COEFFICIENT = 2.40506332
2 DEGREE COEFFICIENT = -2.34465891
3 DEGREE COEFFICIENT = .925669864
4 DEGREE COEFFICIENT = -.127042768

IF $F_{nv} >= 2.50$ THEN $d_{13}=0$



#	$X=F_{nv}$	$Y=d_{20}$
1	1	-.364729515
2	1.25	-.238998683
3	1.5	-.151585478
4	1.75	-.121441717
5	2	-.0668215214
6	2.5	-.0442671874
7	3	-.0184440973
8	3.5	-.0292923551
9	4	.0119770906

0 DEGREE COEFFICIENT = -1.15077799
1 DEGREE COEFFICIENT = 1.13214392
2 DEGREE COEFFICIENT = -.380681632
3 DEGREE COEFFICIENT = .0425840763



Range of variation of accepted four principal
hull form parameters

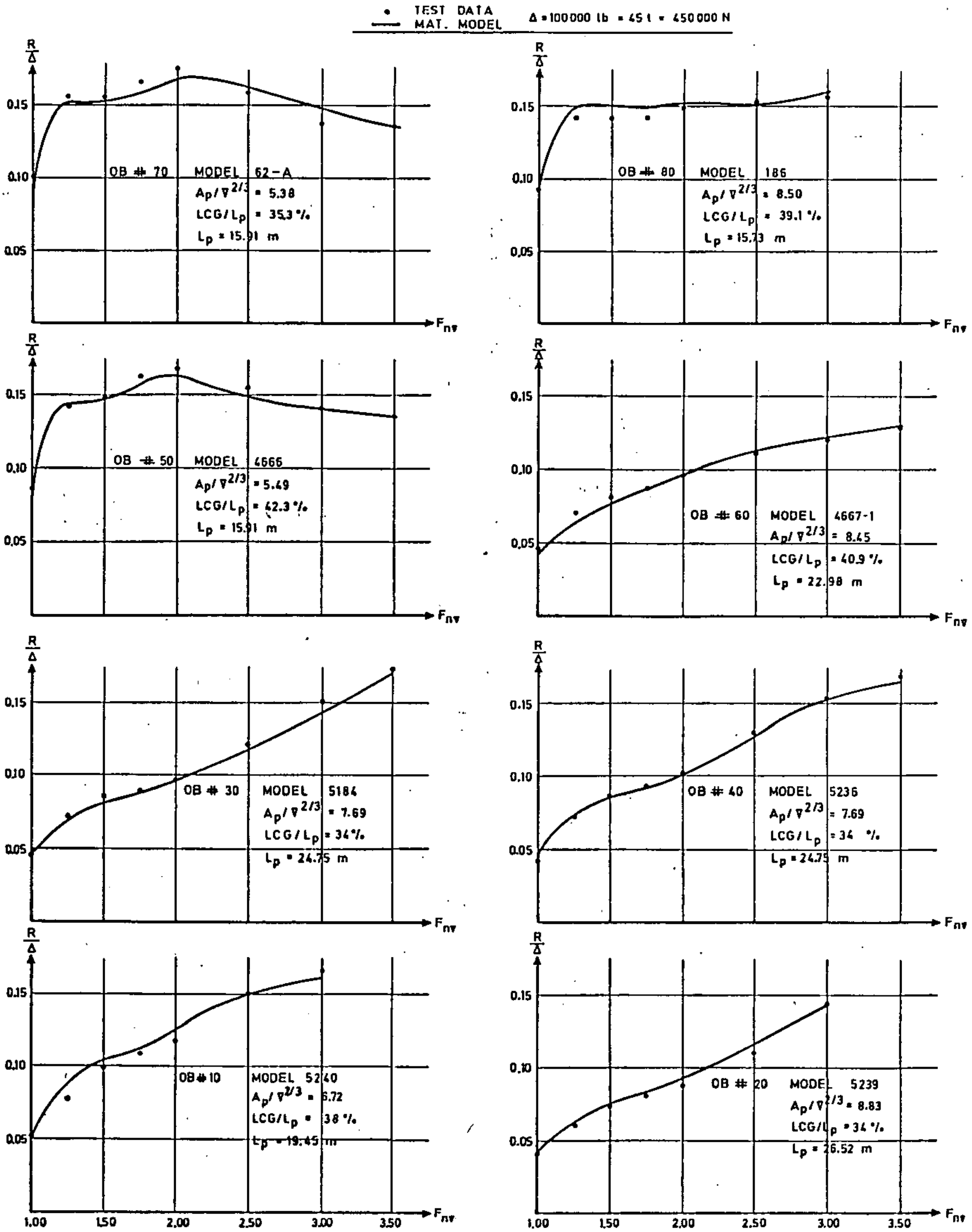
APPENDIX VI

Control Information

n — number of cases
k — number of predicted variables
R^2 — multiple R squared (coef. of determination)
s — standard error of est.
D.F. — degrees of freedom
F — F-test (F ratio)

F_{nv}	1.00	1.25	1.50	1.75	2.00	2.50	3.00	3.50	4.00
dynamic trim – τ									
n	95	94	94	94	94	95	94	51	33
k	12	13	13	13	11	15	14	10	8
R^2	95.20	97.69	96.79	96.90	96.91	97.31	96.09	96.34	96.33
s	0.3116	0.2904	0.3466	0.3726	0.3885	0.3067	0.2833	0.1449	0.1844
D.F.	82	80	80	80	82	79	79	40	24
F	135.39	260.59	185.83	192.60	233.56	190.82	138.50	105.32	78.67
resistance – R/Δ									
n	96	95	95	93	92	92	92	48	-
k	9	10	9	10	11	12	13	13	-
R^2	96.74	98.19	97.79	96.12	95.70	94.82	90.43	97.79	-
$s \cdot 10^3$	4.3131	5.6215	5.0736	6.4351	7.0991	5.2511	6.0267	3.5451	-
D.F.	86	84	85	82	80	79	78	34	-
F	283.16	455.95	418.78	203.18	161.76	120.46	56.67	115.63	-
wetted area – $S/V^{2/3}$									
n	97	98	97	98	97	97	97	51	33
k	7	7	7	7	7	7	7	7	7
R^2	83.58	87.84	87.21	87.11	85.97	89.51	88.30	94.68	97.04
s	0.4295	0.4242	0.4678	0.5285	0.6041	0.5663	0.5567	0.3743	0.2551
D.F.	89	90	89	90	89	89	89	43	25
F	64.73	92.87	86.68	86.86	77.88	108.52	95.94	109.34	117.04
length of wetted area – L/L_p									
n	95	95	96	98	96	96	96	51	32
k	6	7	7	7	7	5	5	5	5
R^2	86.72	86.23	83.64	79.59	82.88	88.50	92.92	91.99	79.26
$s \cdot 10^2$	6.209	4.988	4.731	5.093	4.663	4.014	2.897	2.548	3.057
D.F.	88	87	88	90	88	90	90	45	26
F	95.80	77.83	64.28	50.14	60.86	138.52	236.40	103.40	19.88

COEF. No.	τ-"a" coef. R^2 % std. error	R/Δ-"b" coef. R^2 % std. error	$S/\nabla^{2/3}$-"c" coef. R^2 % std. error	L/L_p-"d" coef. R^2 % srd. error
0	96.9 0.212	99.5 $3.37 \cdot 10^{-3}$	99.7 0.093	99.9 $5.68 \cdot 10^{-3}$
z	100.0 0.022	98.9 $1.78 \cdot 10^{-3}$	-	-
1	93.1 0.213	99.0 $2.82 \cdot 10^{-3}$	90.6 0.050	99.7 $3.53 \cdot 10^{-3}$
2	99.5 0.058	99.1 $1.92 \cdot 10^{-3}$	99.1 0.085	99.0 $4.20 \cdot 10^{-3}$
3	99.6 0.176	98.8 $4.30 \cdot 10^{-3}$	99.5 0.042	99.8 $2.28 \cdot 10^{-3}$
4	99.1 0.075	99.9 $6.40 \cdot 10^{-4}$	97.5 0.136	99.9 $5.83 \cdot 10^{-3}$
5	-	99.8 $1.32 \cdot 10^{-3}$	-	-
6	99.7 0.066	97.8 $1.94 \cdot 10^{-3}$	-	-
7	-	-	-	98.0 $8.01 \cdot 10^{-3}$
8	99.9 0.024	-	-	-
9	96.1 0.116	-	-	-
10	-	99.9 $4.73 \cdot 10^{-4}$	-	-
11	91.2 0.226	96.5 $2.50 \cdot 10^{-3}$	-	-
12	99.4 0.085	99.6 $6.99 \cdot 10^{-4}$	96.1 0.095	-
13	98.7 0.153	99.3 $2.10 \cdot 10^{-3}$	91.4 0.144	99.2 $5.48 \cdot 10^{-3}$
14	99.5 0.031	100.0 $2.66 \cdot 10^{-4}$	-	-
15	-	-	-	-
16	98.8 0.136	-	-	-
17	-	98.8 $1.96 \cdot 10^{-3}$	-	-
18	100.0 $8.20 \cdot 10^{-3}$	99.6 $2.59 \cdot 10^{-3}$	-	-
19	100.0 0.026	98.4 $1.93 \cdot 10^{-3}$	97.2 0.094	-
20	-	99.5 $1.84 \cdot 10^{-3}$	-	99.3 0.012
21	-	-	-	-
22	-	-	-	-
23	99.9 0.043	99.9 $7.69 \cdot 10^{-4}$	-	-
24	-	-	-	-
25	94.2 0.222	-	-	-
26	-	-	-	-



Comparison of resistance of proposed mathematical model with results of measurements for eight ad hoc chosen hulls

APPENDIX IX

Step-by-Step Calculation Procedure

The calculation procedure for a proposed (new) hull in the initial design stage should be as follows:

1. Principal hull form parameters should be calculated ($A_p/\nabla^{2/3}$, LCG/L_p, L_p/B_{pa}, β_M).

2. Check if the above parameters are within the range given in Appendix V.

3. Calculate principal four independent variables (x_1, x_2, x_3, and x_4).

4. Calculate the other independent variables (x_5 to x_{26}).

5. Multiply them with the coresponding regression coefficients given in Appendices I, II, III, and IV.
   For the intermidiate Froude numbers one can calculate the regression coefficients using polynomial expresions.

6. At this point one should select which series (65 or 62) is most appropriate to the new design's section shape. If it is the Series 65 then value of b_z and a_z should be added/subtracted from constant term b_0 and a_0, respectively.

7. Addition of terms gives values for various Froude numbers for τ, $(R/\Delta)_{100000}$, $S/\nabla^{2/3}$, and L/L_p.

Fairing should be applied if necessary.
If the mass of the new design is approximately 100000 lb ≃ 450000 N ≃ 45 t, terminate the calculation procedure. Otherwise go to 8.

8. The scale ratio should be calculated according to (14)

   $(\Delta_m = 100000 \text{ lb} = 45.36 \text{ t}, \quad \rho_m = 104.6 \text{ kg}\cdot\text{s}^2/\text{m}^4)$

   $$\lambda = \sqrt[3]{\frac{\Delta_s}{\Delta_m}\cdot\frac{\rho_m}{\rho_s}} = \sqrt[3]{\frac{\Delta_s}{\rho_s}\cdot 2.3}\,, \quad \Delta_s \text{ in tons, } \rho_s \text{ in kgs}^2/\text{m}^4$$

9. Calculate the length of the model as $L_{pm} = L_p/\lambda$. Then calculate the mean length of wetted area for each Froude number of model and of proposed new design as

   $$L_m = \left(\frac{L}{L_p}\right)\cdot L_{pm}, \quad L_s = \left(\frac{L}{L_p}\right)\cdot L_p.$$

10. Calculate Re value

    $$\text{for model} \quad Re_m = \frac{5.885\cdot F_{n\nabla}\cdot L_m}{1.1907\cdot 10^{-6}} = L_m\cdot F_{n\nabla}\cdot 4.9423\cdot 10^6$$

    $$\text{for new design} \quad Re_s = \frac{L_s\cdot F_{n\nabla}\cdot\sqrt{g\cdot\nabla^{1/3}}}{\nu}$$

11. Schoenherr's friction coefficients should be calculated for the model as $(C_f)_{100000} = f(F_{n\nabla})$, and for the new design as $C_f' = f(F_{n\nabla})$ which need not be Schoenherr's. Correlation coefficient C_a may be applied if desired.

12. Calculate the new design's R/Δ according to the relation givenen in (4)

    $$\frac{R}{\Delta} = \left(\frac{R}{\Delta}\right)_{100000} + ((C_f' + C_a) - (C_f)_{100000})\cdot\frac{1}{2}\cdot\frac{S}{\nabla^{2/3}}\cdot F_{n\nabla}^{\,2}$$

Note should be taken that the results apply only to the conditions which are equivalent to those in Report 4307 (towing tank conditions, tow force horizontal through CG, etc.).