AN ANALYSIS OF THE SERIES 60 RESULTS

PART I

ANALYSIS OF FORMS AND RESISTANCE RESULTS

by

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Abstract.

The Series 60 results are analytically analysed in order to achieve its ultimate objectives in a computer program form. All form coefficients are analytically related to the basic parameters. The offsets are analytically expressed in terms of the entrance and run prismatic coefficients. An analytical curve fitting method and regression analysis are used to express the dependent resistance coefficients at different speed coefficients, in terms of the independently varied hull parameters. The polynomial function contiaining all interaction terms, based on regression analysis, is shown to be the best among others considered. The function is discussed and the assumptions involved are clearly indicated.

I. Introduction.

The Series 60 consists of 62 models, tested at D. T. M. B., in which the main dimensional ratios, block coefficient and longitudinal centre of buoyancy are varied systematically. The range of variation of each hull parameter is carefully chosen and falls within the normal range of design practice. The design of geomatrically related parent forms of the Series 60[1, 2] provides continuity regarding the shape of sections, and offers many advantages over the former methods of deriving a methodical series from a single parent form [8], and from some independently designed parent forms [9, 10]. The distribution of the tested models at each CB is shown by a three-dimensional representation in Figure 1 which clearly indicates the discontinuity in the L/B - L. C. B. and $B/_T$ - L. C. B. directions. An overall graphical representation is made [7], but with the electronic computers becoming more popular, it is necessary to develope the analytical representation.

The objectives of this analysis are:

1. To obtain analytical expressions for the calculation of the form coefficients and the offsets of any intermediate design.
2. To obtain a rational analytical expression for the calculation of the resistance coefficients, which can be utilized for the following:

a. Estimation of the resistance of any intermediate form
b. Estimation of the effect on resistance of variation in the hull parameters, and suggestion of optimum combinations, if any.
c. Comparison with individual model results for the relative superiority of the resistance quality.
d. Comparison with the results of analyses of other series in order to investigate the effect of variations in parameters which are not identical [11].

II. Analytical representation of the form coefficients.

All form coefficients are related to the basic parameters either linearly or quadratically. The coefficients of the straight lines or the second degree polynomials are determined either exactly or by the method of least squares depending upon the number of data points.

1. The midship section coefficient "CM".

The CM - CB relation is shown in Figure 2, and is given by:

$$CM = 0.08 \times CB + 0.93 \qquad (1)$$

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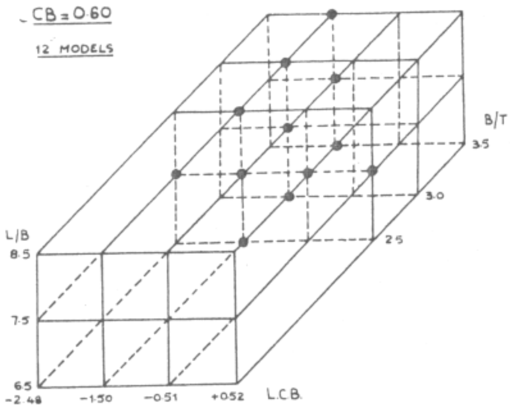
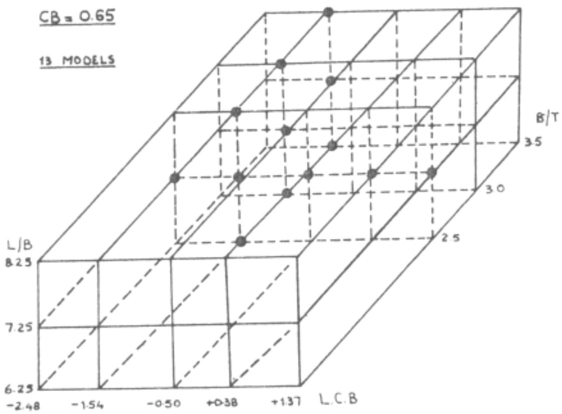
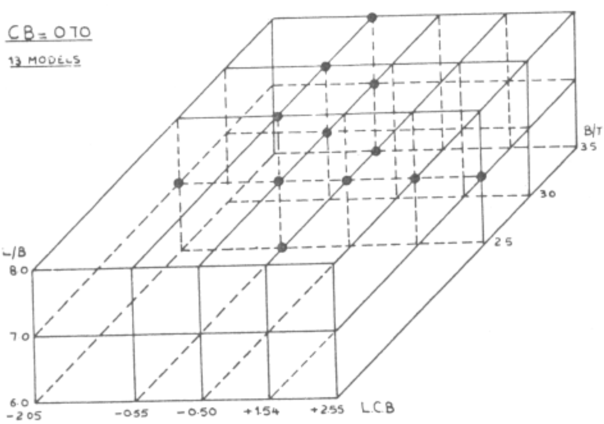
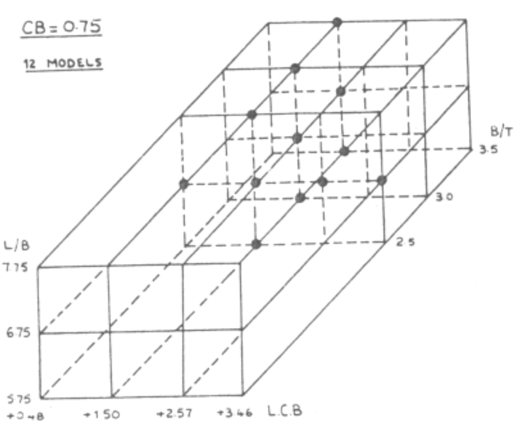








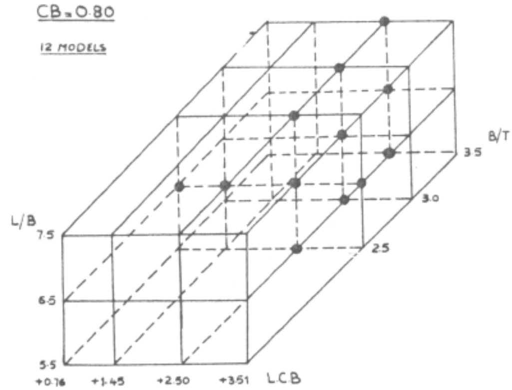


Figure 1.

The midship section is designed to have a circular bilge without a rise of floor, in which case the bilge radius R is given by:

$$R = \sqrt{\frac{BxT\,(1-CM)}{0.4292}} \tag{2}$$

2. The length of parallel middle body "L.P.M.B.".

The L.P.M.B. is a function of CB only, and their relation is shown in Figure 3 , and is given by:

(i) For CB = 0.60 to 0.70

$$L.P.M.B. = LBP\,(3.402 - 11.55 \times CB + 9.80 \times CB^2) \tag{3}$$

(ii) For CB = 0.70 to 0.80

$$L.P.M.B. = LBP\,(1.81 \times CB - 1.148) \tag{4}$$

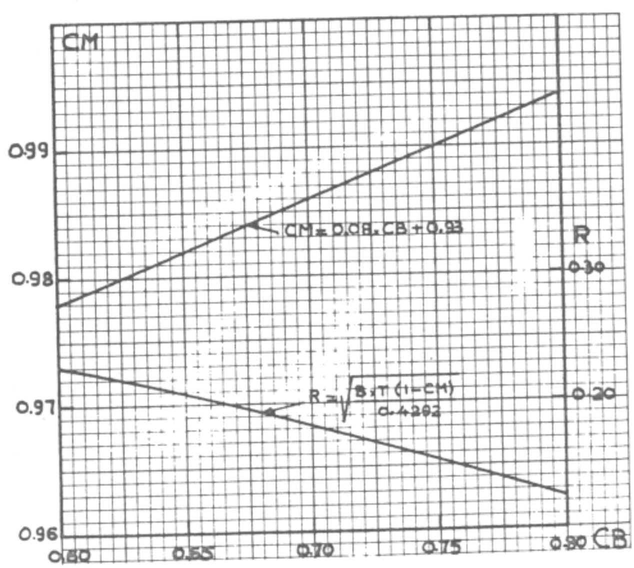


Figure 2.

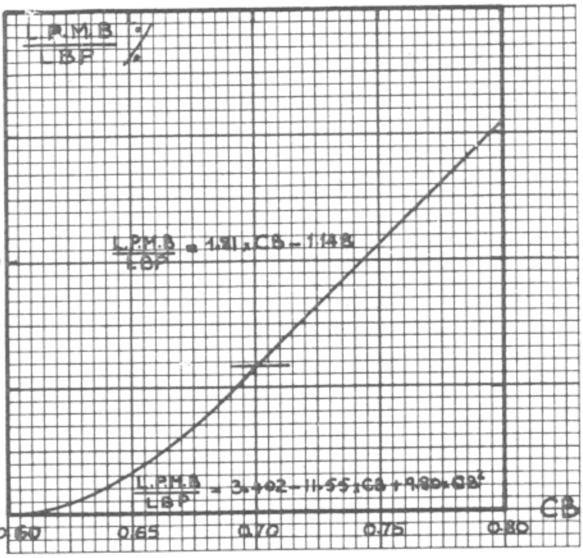


Figure 3.

3. The length of entrance "L.E.".

The L. E. is a function of both CB and L. C. B., and their relation is shown in Figure 4, and is given by:

$$L.E. = LBP\,[a - b\,(LCB)] \quad (5)$$

where a and b are quadratic functions in CB as follows:

(i) For CB = 0.60 to 0.70

$$a = -1.3201 + 6.3692 \times CB - 5.5586 \times CB^2 \quad (6)$$

$$b = +0.3973 + 1.3116 \times CB + 1.0823 \times CB^2 \quad (7)$$

(ii) For CB = 0.70 to 0.80

$$a = +0.9803 - 0.6424 \times CB - 0.2368 \times CB^2 \quad (8)$$

$$b = +0.0531 - 0.1172 \times CB + 0.0786 \times CB^2 \quad (9)$$

The length of run 'L.R.' is given by

$$L.R. = LBP - L.P.M.B. - L.E. \quad (10)$$

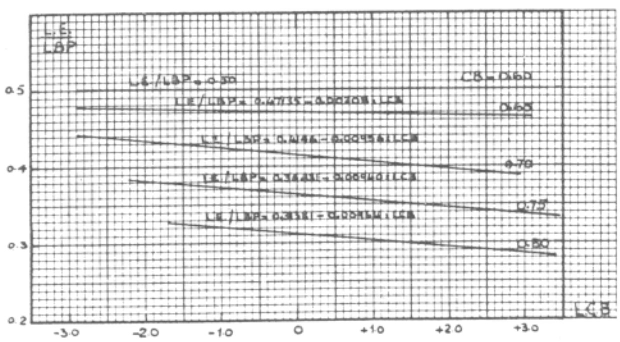


Figure 4.

4. The entrance and run prismatic coefficients "CPE" and "CPR".

The difference (CPE - CPR) rather than the ratio (CPE/CPR) as used in the original analysis [7]. is related to L. C. B. for different CB as shown in Figure 5. This representation has the advantage of a linear relationship between (CPE - CPR) and L. C. B. The CPE and CPR can be calculated from the following expressions:

$$CPR = [CP \times LBP - L.P.M.B. - m \times L.E. \times L.C.B. - C1 \times L.E.]/L.E. + L.R. \quad (11)$$

$$CPE = C1 + CPR + m \times L.C.B. \quad (12)$$

where C1 and m are quadratic functions of CB as follows:

(i) For CB = 0.60 to 0.70

$$C1 = -0.0908 + 0.6100 \times CB - 0.7596 \times CB^2 \quad (13)$$

$$m = -0.1548 + 0.7136 \times CB - 0.6327 \times CB^2 \quad (14)$$

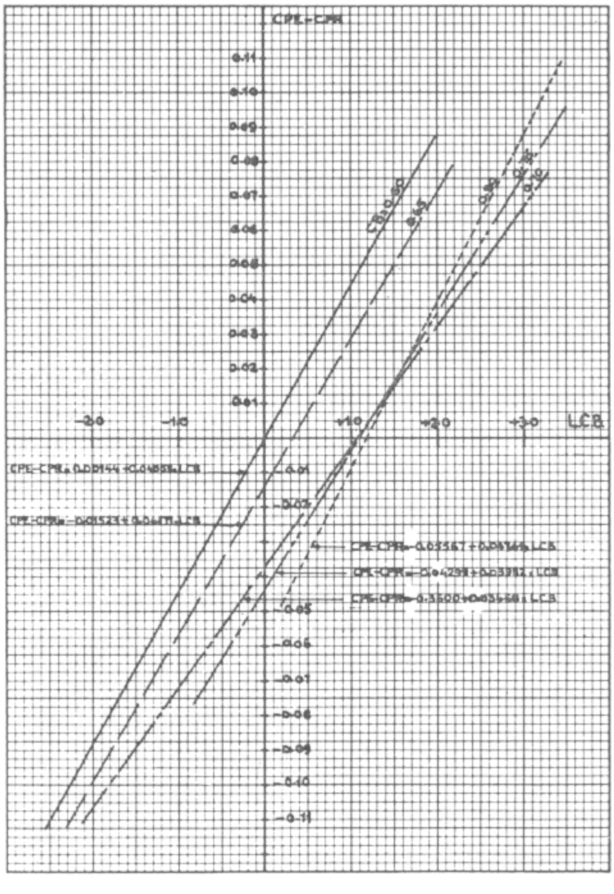


Figure 5.

(ii) For CB = 0.70 to 0.80

$$C1 = -0.5466 + 1.5372 \times CB - 1.1539 \times CB^2 \tag{15}$$

$$m = +0.2297 - 0.6321 \times CB + 0.5051 \times CB^2 \tag{16}$$

The CPF and CPA can be calculated from the following relations:

$$CPF = 2[CPE \times L.E. + LBP/2 - L.E.] / LBP \tag{17}$$

$$CPA = 2[CPA \times L.R. + LBP/2 - L.R.] / LBP \tag{18}$$

Plotting of (CPF - CPA) to the bare of L. C. B. is shown in Figure 6 to give one straight line for all CB, the equation of which is given by:

$$CPF - CPA = 0.895 \times L.C.B. \tag{19}$$

The estimation of CPF and CPA using equation (19) agrees very well with that equations (17) and (18).

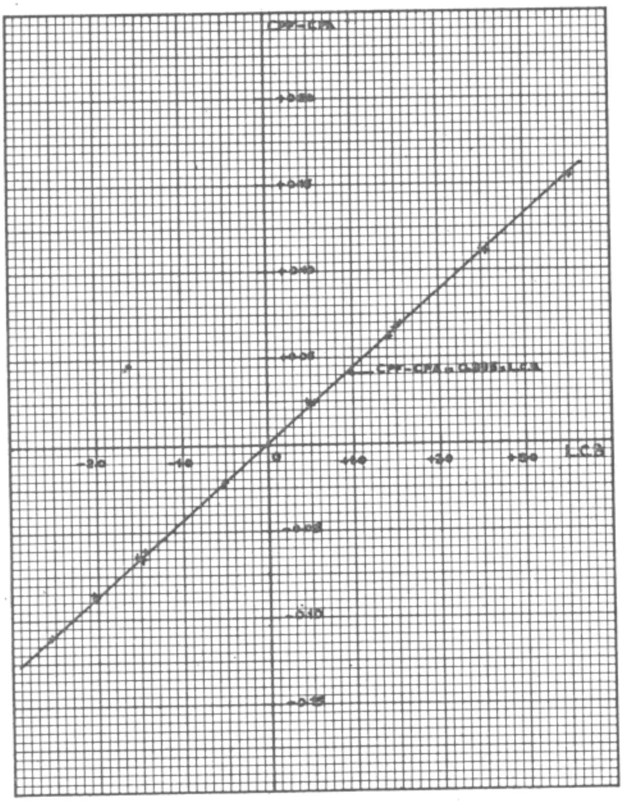


Figure 6.

5. The waterplane area coefficients "CWF" and "CWA".

The CWF and CPF are linearly related, whereas CWA and CPA are quadratically related as

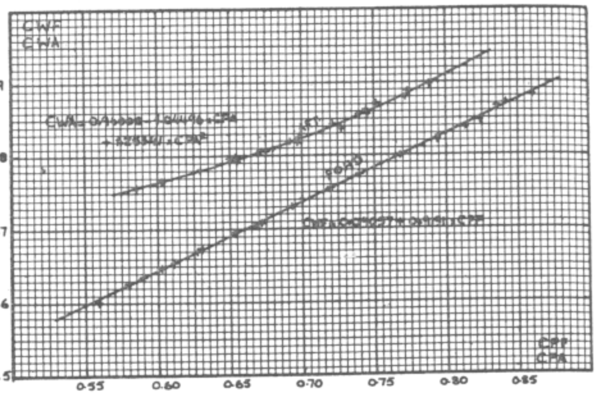


Figure 7.

shown in Figure 7. The relations are given by:

$$CWF = 0.09057 + 0.9191 \times CPF \tag{20}$$

$$CWA = 0.94008 - 1.04496 \times CPA + 1.25341 \times CPA^2 \tag{21}$$

These relations correspond to moderate U-shaped sections forward and moderate V-shaped sections aft [11].

6. The moment of inertia coefficient "CIT".

The CIT and CW are linearly related as shown in Figure 8. The relation is given by:

$$CIT = 1.417 \times CW - 0.460 \tag{22}$$

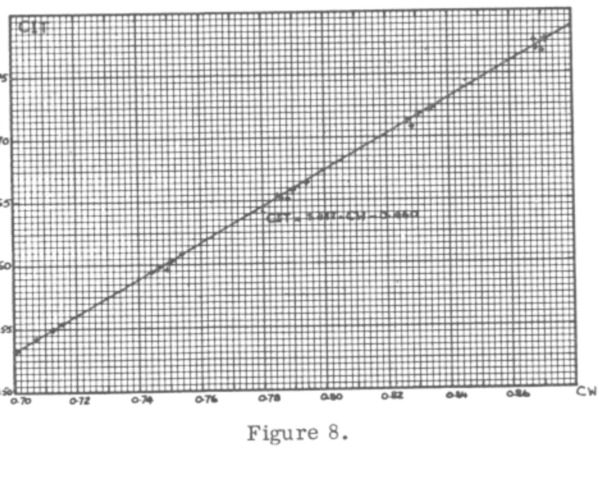
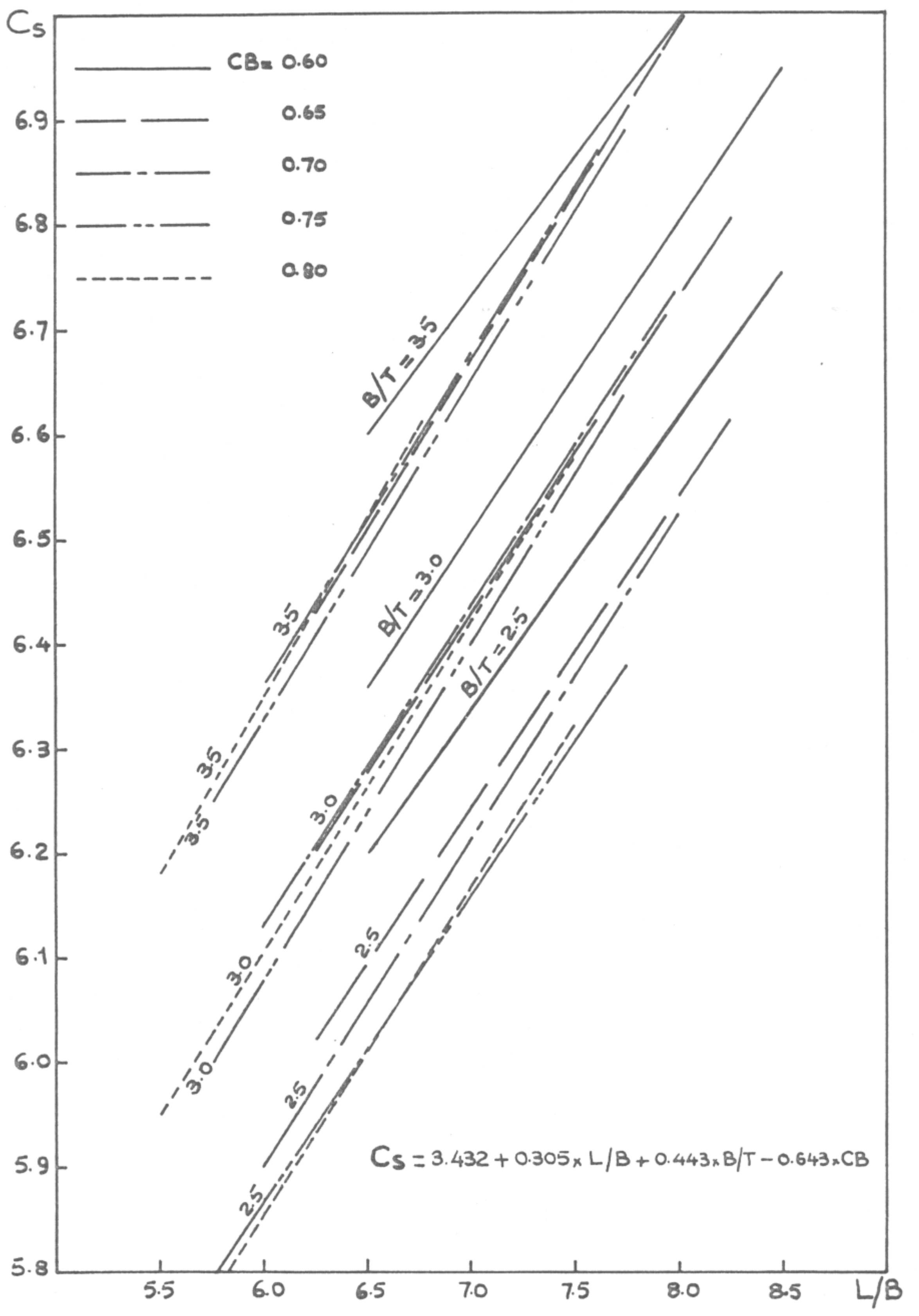


Figure 8.

7. The wetted surfacecoefficient "W.S.C.".

The effect on the W. S. C. of variation in L. C. B. in negligibly small. The W. S. C. is shown in Figure 9 to vary linearly with $L/_B$. Similar representation shows that the W. S. C. varies nearly linearly with both $B/_T$ and CB without any inter-



Cs
CB= 0.60
0.65
0.70
0.75
0.80
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
B/T = 3.5
B/T = 3.0
B/T = 2.5
3.5
3.0
2.5
Cs = 3.432 + 0.305 x L/B + 0.443 x B/T − 0.643 x CB
5.5
6.0
6.5
7.0
7.5
8.0
8.5
L/B

Figure 9

dependency. The W.S.C. is given by:

$$W.S.C. = 3.432 + 0.305\,(L/B) + 0.443\,(B/T) - 0.643\,(CB) \qquad (23)$$

The coefficients are determined by the method of least squares, and the standard error is 0.55%.

III. Analytical representation of the offsets.

The published curves from which the sectional area curve and the offsets can be obtained are staged at their inflection points, and each part is expressed, either linearly or quadratically, in terms of the entrance and run prismatic coefficients. The coefficients for each is determined by the method of least squares, and the standard error seldom exceeded 0.002. As an example, for the 0.25 WL, the station 5 in the entrance (EW35) is given by:

For $CPE \leq 0.65$

$$EW35 = +0.37238 - 0.98664 \times CPE + 2.34265 \times CPE^2.$$

for $0.73 \leq CPE > 0.65$

$$EW35 = -3.23525 + 10.24156 \times CPE - 6.39606 \times CPE^2.$$

for $CPE > 0.73$

$$EW35 = -0.26332 + 0.78095 \times CPE.$$

and the run (RW35) is given by:

for $CPR \leq 0.67$

$$RW35 = -0.95875 + 2.475 \times CPR.$$

for $CPR > 0.67$

$$RW35 = -5.02782 + 15.17191 \times CPR - 9.88045 \times CPR^2.$$

The outlined method is preferred to the method in which every curve is represented by an n^{th} degree polynomial, because of the existance of straight lines within the curves and the poor agreement obtained regarding both the values and the position of the inflection points [11].

A computer program is prepared using the aforementioned relations, the input data are LBP, B, T, Δ and L.C.B., and the output are the form coefficients, the offsets and the sectional area curve ordinates.

IV. Analysis of the resistance results.

The CR-$V/\sqrt{LWL}$ system of presentation is used because it satisfies the final objectives of this analysis [11,12]. The CR400 values are obtained from the published Ⓒ$_{400}$ values [7], and they correspond to extrapolation from the model size of 20 ft. to the 400 ft. ship using Froude method of extrapolation together with Schoenherr friction line plus an addition of 0.0004 for the ship model correlation coefficient. The following methods are considered:

1. A curve fitting method.

This method is somewhat similar to the one used in the original analysis [7], but the results are presented in an analytical form. At each $V/\sqrt{LWL}$, the resistance equation is built up as follows:

a. For each CB, L.C.B. and L/B:

$$CR_{400} = A_1 + A_2\,(B/T) + A_3\,(B/T)^2 \qquad (24)$$

The A coefficients are determined exactly using the values corresponding to the three tested B/T ratios.

b. For each CB and L.C.B. each of the A coefficients is quadratically expressed in terms of L/B.

$$Ai = a1i + a2i\,(L/B) + a3i\,(L/B)^2 \qquad (25)$$

Hence, substituting in equation (24):

$$CR_{400} = a11 + a21(L/B) + a31(L/B)^2 + a12(B/T) + a22\,(L/B)(B/T) + a32\,(L/B)^2(B/T) + a13(B/T)^2 + a23\,(L/B)(B/T)^2 + a33\,(L/B)^2(B/T)^2 \qquad (26)$$

c. For each CB, the CR - L.C.B. relation is assumed quadratic

$$CR_{400} = C1 + C2\,(LCB) + C3\,(LCB)^2 \qquad (26)$$

The C coefficients are determined by the method of least squares.

It is necessary to assume that the rate of change of CR with respect to L.C.B. is independent of L/B and B/T, but depends only upon CB. This is because of the discontinuity at each block coefficient referred to before. The consequence of this assumption is that optimum L.C.B. positions for a given CB is independent of L/B and B/T. However, in this particular application, the effect on the optimum L.C.B. of variation in CB carries in itself the effect of variation in L/B, because for each CB forms of varying L.C.B. have different $L/_B$ ratios. The same assumption is used in the original analysis [7] as well as in others [9,13], and is discussed in full details [11,12] and shown to be invalidated by many experimental results [14,15,16].

Variation in CR due to changes in L.C.B. position from that adopted for tests of varying $L/_B$ and $B/_T$ (LCBt) is expressed as a correction in the form of $C2\,(LCB - LCBt) + C3\,(LCB^2 - LCBt^2)$. Hence, for each CB the resistance equation is written as:

$$\begin{aligned}CR_{400} = {} & [a11 - C2 \times LCBt - C3 \times LCBt^2] + \\ & a21(L/_B) + a31(L/_B)^2 + \\ & a12(B/_T) + a22\,(L/_B)\,(B/_T) + \\ & a32\,(L/_B)^2\,(B/_T) + a13(B/_T)^2 + \\ & a23\,(L/_B)\,(B/_T)^2 + a33\,(L/_B)^2\,(B/_T)^2 + \\ & C2\,(LCB) + C3\,(LCB)^2 \qquad (27)\end{aligned}$$

d. Variation of each of the above coefficients with CB is assumed quadratic for the two ranges CB = 0.60 to 0.70 and 0.70 to 0.80, in which case the data of 0.70 block coefficient are presented in the equation for each range. Hence, the resistance equation for every CB range is given by:

$$\begin{aligned}CR_{400} = {} & A01 + A02\,(CB) + A03\,(CB)^2 + \\ & A11(L/_B) + A12\,(L/_B)(CB) + \\ & A13\,(L/_B)(CB)^2 + A21\,(L/_B)^2 + \\ & A22\,(L/_B)^2(CB) + A23\,(L/_B)^2(CB)^2 + \\ & A31\,(B/_T) + A32\,(B/_T)(CB) + \\ & A33\,(B/_T)(CB)^2 + A41\,(L/_B)(B/_T) + \\ & A42\,(L/_B)(B/_T)(CB) + \\ & A43\,(L/_B)(B/_T)(CB)^2 + \\ & A51\,(L/_B)^2(B/_T) + \\ & A52\,(L/_B)^2(B/_T)(CB) + \\ & A53\,(L/_B)^2(B/_T)(CB)^2 + A61\,(B/_T)^2 + \\ & A62\,(B/_T)^2(CB) + A63\,(B/_T)^2(CB)^2 + \\ & A71\,(L/_B)(B/_T)^2 + \\ & A72\,(L/_B)(B/_T)^2(CB) + \\ & A73\,(L/_B)(B/_T)^2(CB)^2 + \\ & A81\,(L/_B)^2(B/_T)^2 + \\ & A82\,(L/_B)^2(B/_T)^2(CB) + \\ & A83\,(L/_B)^2(B/_T)^2(CB)^2 + \\ & A91\,(LCB) + A92\,(LCB)(CB) + \\ & A93\,(LCB)(CB)^2 + A101(LCB)^2 + \\ & A102(LCB)^2(CB) + \\ & A103(LCB)^2(CB)^2 \qquad (28)\end{aligned}$$

The range of estimations of CR is as follows:

For $CB \leq 0.70$ $V/\sqrt{LWL} = 0.60$ to 0.90

For $CB \geq 0.70$ $V/\sqrt{LWL} = 0.50$ to 0.80

Hence, for $V/\sqrt{LWL} = 0.60$ to 0.80, and for the whole range of CB, the resistance equation consists of 66 terms, whereas for other $V/\sqrt{LWL}$ it contains 33 terms. The CR values are calculated for the tested forms using equation (28), and as should be expected from a curve fitting process, the agreement is excellent.

2. Regression analysis.

Regression analysis has been successfully applied to data of random forms [17,18], and data of related forms [11,12]. Independency of the varied parameters is shown in Figure 16, and the suggested limits are indicated to avoid any extrapolation. Several resistance equations are tested, and in each case independency of each term is checked by plotting it against the rest. This is because, the excistence of a dependent term, while it may improve the estimation, it would give a small order of importance to that term as well as to the term on which it depends. Thus the relative order of importance of each term cannot be evaluated as well as optimum values of this dependent term because the relation between its optimum and the term on which it depends would carry in itself the relation already excisting between these two terms. The presence of cross-coupling terms is essential as they take into account the interaction between the different hull parameters. The number of terms in the regression equation is largely governed by the number of data points available, which are given in the following table.

$V/\sqrt{LWL}$	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90
No. of data points	40	40	67	67	67	67	67	54	41
CB range	0.70-0.80		0.60-0.80					0.60-0.75	0.60-0.70

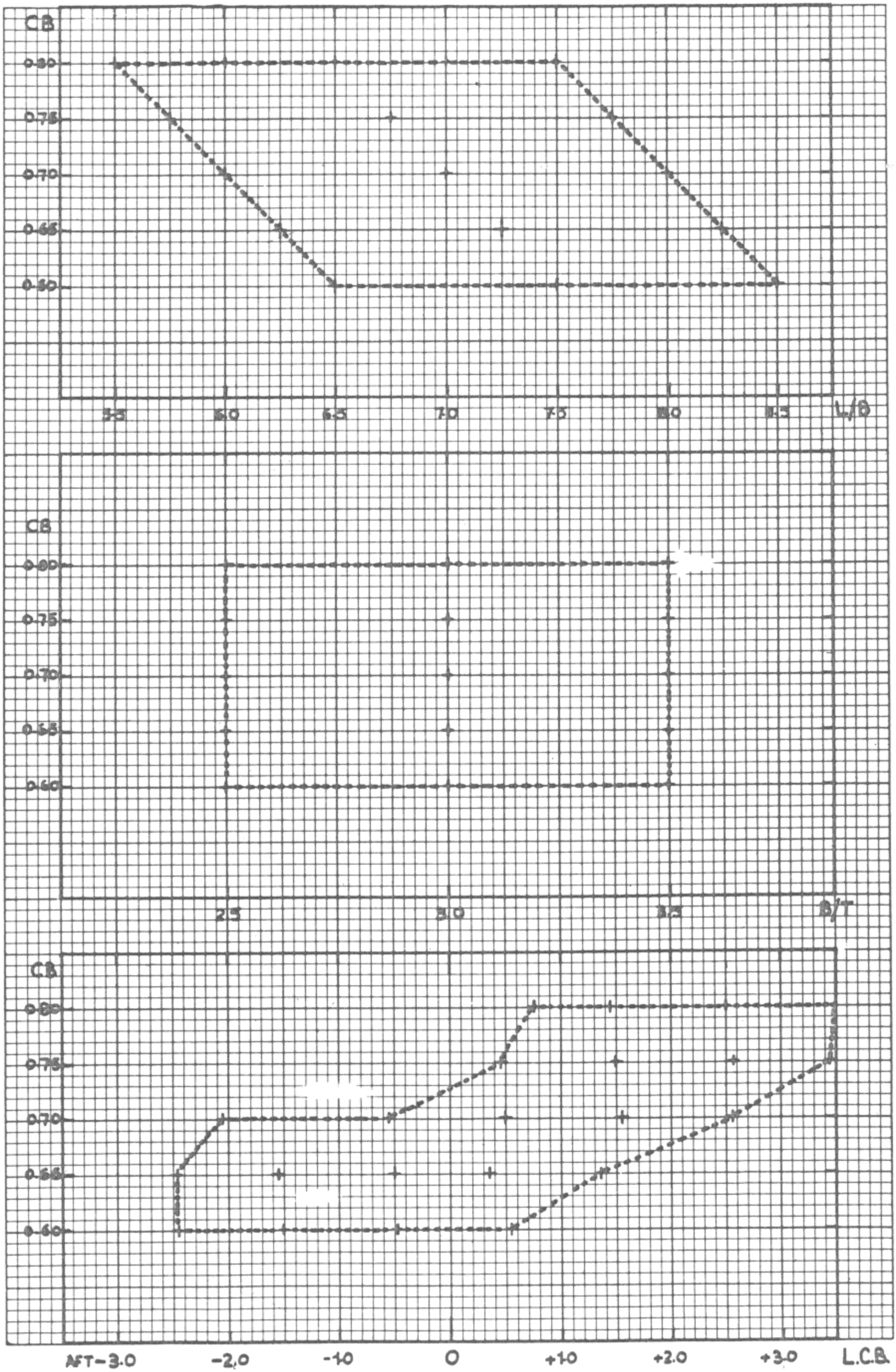

CB
0.80
0.75
0.70
0.65
0.60
5.5
6.0
6.5
7.0
7.5
8.0
8.5
L/B
CB
0.80
0.75
0.70
0.65
0.60
2.5
3.0
3.5
B/T
CB
0.80
0.75
0.70
0.65
0.60
AFT-3.0
-2.0
-1.0
0
+1.0
+2.0
+3.0
L.C.B.

Figure 10.

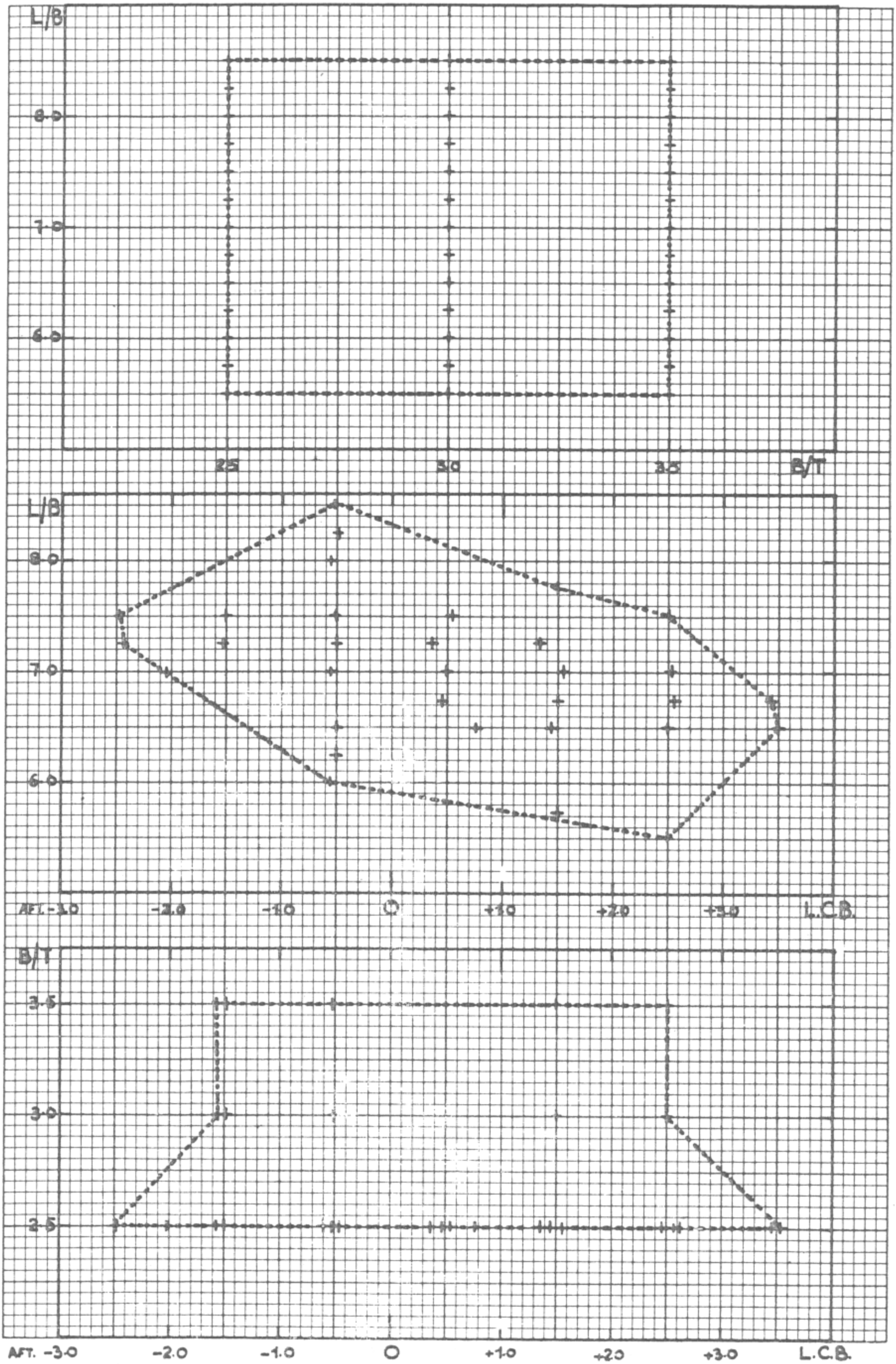


Figure 10 cont.

For each of the assumed regression equation. the hull parameters as well as their cross-coupling terms are transferred into another set of variables having the same range. This avoids very small or very large coefficients. and facilitates the evaluation of the relative order of importance of each term. The following functions are considered:

a. The power function.

The following power function - which is an extension of the Mumford indices method [13], containing CB and LCB togheter with cross-coupling terms between all parameters - is considered.

$$CR_{400\,(V/\sqrt{LWL})} = a \times (L/_B)^{n2} \times (B/_T)^{n3} \times (CB)^{n4} \times (LCB)^{n5} \times [(L/_B)(B/_T)]^{n6} \times [(L/_B)(CB)]^{n7} \times [(L/_B)(LCB)]^{n8} \times [(B/_T)(CB)]^{n9} \times [(B/_T)(LCB)]^{n10} \times [(CB)(LCB)]^{n11}. \quad (29)$$

This is transferred to a linear form by taking logarithms for both sides. The formal parameters and the cross-coupling terms are transferred into another set of variables each ranging from + 1 to + 10 so that their logarithmic values vary from 0 to + 1. The n coefficients are determined using the theory of minimal variance with respect to log CR.

The above equation may thought to be reduced to the following form

$$CR_{400\,(V/\sqrt{LWL}} = A \times (L/_B)^{N2} \times (B/_T)^{N3} \times (CB)^{N4} \times (LCB)^{N5} \quad (30)$$

In fact, and on statistical basis they differ because the introduction of the independent cross-coupling terms in equation (29) is equivalent to introducing new parameters to take into account the possibility of interaction. The standard error of estimate of equation (30) is much higher than that of equation (29), and the agreement with test results is far much worse.

b. The polynomial function.

This is the same type of function used by Doust [17, 18] and by the author [11, 12]. The degree of the polynomial is limited to the second order. The following polynomial functions are tested:

(i) $$CR_{400\,(V/\sqrt{LWL})} = a1 + a2\,(L/_B) + a3\,(B/_T) + a4\,(CB) + a5\,(LCB) + a6\,(L/_B)^2 + a7\,(B/_T)^2 + a8\,(CB)^2 + a9\,(LCB)^2 + a10\,(L/_B)(B/_T) + a11\,(L/_B)(CB) + a13\,(B/_T)(CB) + a15\,(CB)(LCB) \quad (31)$$

This equation assumes that the rate of change of CR with respect to L. C. B. is independent of the main dimensional ratios.

(ii) $$CR_{400\,(V/\sqrt{LWL})} = a1 + a2\,(L/_B) + a3\,(B/_T) + a4\,(CB) + a5\,(LCB) + a6\,(L/_B)^2 + a7\,(B/_T)^2 + a8\,(CB)^2 + a9\,(LCB)^2 + a10\,(L/_B)(B/_T) + a11\,(L/_B)(CB) + a12\,(L/_B)(LCB) + a13\,(B/_T)(CB) + a14\,(B/_T)(LCB) + a15\,(CB)(LCB) \quad (32)$$

This equation eliminates the above assumption by introducing the cross-coupling terms $(L/_B)$ (LCB) and $(B/_T)(LCB)$.

(iii) $$CR_{400\,(V/\sqrt{LWL})} = a1 + a2\,(L/_B) + a3\,(B/_T) + a4\,(CB) + a5\,(LCB) + a6\,(L/_B)^2 + a7\,(B/_T)^2 + a8\,(CB)^2 + a9\,(LCB)^2 + a10\,(L/_B)(B/_T) + a11\,(L/_B)(CB) + a12\,(L/_B)(LCB) + a13\,(B/_T)(CB) + a14\,(B/_T)(LCB) + a15\,(CB)(LCB) + a16\,(LCB)(CB)^2 \quad (33)$$

These polynomial equations are transformed in the following linear form

$$Y_{400\,(V/\sqrt{LWL})} = a1\,x1 + a2\,x2 + a3\,x3 + a4\,x4 + \ldots \ldots\ldots\, ai\,xi + \ldots\ldots + a16\,x16$$

Where the x variable is the normalized value of the corresponding term in the regression equation. The ranges of the parameters are as follows:

L/B = 5.5 to 8.5
B/T = 2.5 to 3.5
CB = 0.60 to 0.80
LCB = -2.48 to +3.51
CR_{400} = 9.013 to 25.688

Hence, the normalized X variables are as follows:

X1 = 1	X2 = 2 (L/B - 7)/3
X3 = 2 (B/T - 3)	X4 = 10(CB - 0.7)
X5 = (LCB - 0.515)/2.995	X6 = $X2^2$
X7 = $X3^2$	X8 = $X4^2$
X9 = $X5^2$	X10 = X2 X3
X11 = X2 X4	X12 = X2 X5
X13 = X3 X4	X14 = X3 X5
X15 = X4 X5	X16 = X5 $X4^2$

Y400 = (CR400 - 17.3505)/8.3375

The a coefficients are determined according to the theory of minimal variance with respect to CR.

Considerations of minimum standard errors, best correlations with test results and best agreement with optimum L.C.B. position, show that equation (33) is the best among others considered, and hence considered to represent the standard of performance of the series 60. The 'a' coefficients are given in Table 1. and the relative order of importance of each term is shown in Table 2, which indicates the significance of the cross-coupling terms (L/B) (LCB) and (B/T)(LCB). This again confirms the existence of a measurable interaction between L.C.B. and main dimensional ratios. Figure 11 shows the good agreement obtained between the L.C.B. ranges calculated from the experimental results and those calculated using the derivative of the regression equation

$$\text{Opt. } X5\ (V/\sqrt{LWL}) = \frac{-a5 - a12\,X2 - a14\,X3 - a15\,X4 - a16\,X8}{2\,a9}$$

Two computer program are prepared based on equation (33), the first to calculate the CR at different $V/\sqrt{LWL}$ for any intermediate combination of LBP. B.T. Δ and L.C.B. and the second to calculate the optimum L.C.B. and CR at different $V/\sqrt{LWL}$ for any intermediate combination of LBP. T.B. Δ and V.

V. Comments on the regression equation representing the standard of performance of the Series 60.

1. Assumptions involved in the equation.

For all $V/\sqrt{LWL}$ considered, the regression equation assumes the following

a. CR varies quadratically with each hull parameter, and hence it can show an optimum value for each, if any.

b. The rate of change of CR with respect to L/B, B/T and CB varies linearly with each of the others, whereas the rate of change of CR with respect to L.C.B. varies linearly with L/B and B/T but quadratically with CB.

2. The effect on ship resistance of the varied parameters.

This can be directly seen from Tables 1 and 2. However, if the effect of terms which has values less than the standard error is neglected, then the effect on CR of variations in the parameters can be summarized as follows:

a. For all $V/\sqrt{LWL}$ considered, CR increases as L/B is increased. The rate of change of CR with respect to L/B increases as L/B, B/T and CB are increased, and as L.C.B. is moved forward. Variation in L/B ratio has a relatively large effect on CR.

b. For all $V/\sqrt{LWL}$ considered, CR increases as B/T is increased. The rate of change of CR with respect to B/T varies by a negligible amount as B/T is changed, but increases as CB is increased and as L.C.B. is moved forward. Variation in B/T ratio has a relatively small effect on CR.

c. For all $V/\sqrt{LWL}$ considered, CR increases as CB is increased. The rate of change of CR with respect to CB increases as CB is increased, and as the L.C.B. is moved aft up to $V/\sqrt{LWL}$ of 0.6 after which it increases as the L.C.B. is moved forward. Variation in CB has a relatively large effect on CR particularly at $V/\sqrt{LWL}$ higher than 0.65.

Table 1

Regression coefficients of equation (33)

coeff. \ $V/\sqrt{LWL}$	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90
a1	-0.8244	-0.8249	-0.8278	-0.7970	-0.7562	-0.6619	-0.5200	-0.3570	-0.0267
a2	+0.1906	+0.1865	+0.2050	+0.2332	+0.2496	+0.2607	+0.3185	+0.3528	+0.1333
a3	+0.1164	+0.1133	+0.1042	+0.1116	+0.1221	+0.1298	+0.1302	+0.1533	+0.1015
a4	-0.0519	+0.0060	+0.0832	+0.1075	+0.1494	+0.2603	+0.5236	+0.5455	+0.4568
a5	+0.0057	-0.0109	-0.0451	-0.0165	+0.0472	+0.1491	+0.2289	+0.4001	+0.4677
a6	+0.0072	+0.0198	+0.0211	+0.0172	+0.0216	+0.0361	-0.0017	-0.0027	+0.0181
a7	-0.0052	-0.0036	+0.0067	+0.0068	+0.0064	+0.0033	-0.0023	-0.0025	+0.0175
a8	+0.1134	+0.1109	+0.0933	+0.1041	+0.1585	+0.1859	+0.2930	+0.2579	+0.0506
a9	+0.0670	+0.0917	+0.0708	+0.0826	+0.1428	+0.1562	+0.1742	+0.1861	+0.1558
a10	+0.0483	+0.0510	+0.0400	+0.0409	+0.0414	+0.0403	+0.0368	+0.0118	+0.0279
a11	-0.1276	-0.0745	-0.0729	-0.0879	-0.0744	-0.0636	-0.1171	-0.1500	-0.0988
a12	+0.1125	+0.0971	+0.1269	+0.1882	+0.2115	+0.2289	+0.3315	+0.4253	+0.0834
a13	-0.0481	-0.0213	+0.0232	+0.0265	+0.0188	+0.0103	+0.0132	-0.0068	-0.0151
a14	+0.0372	+0.0206	-0.0105	-0.0049	+0.0135	+0.0378	+0.0190	+0.0789	+0.0582
a15	-0.0954	-0.1924	-0.0855	-0.0189	+0.0018	+0.0793	+0.1247	+0.2562	+0.3376
a16	-0.0629	+0.0108	+0.0036	+0.0581	+0.0884	+0.0671	-0.0053	+0.0601	+0.1429
S.E	0.025	0.026	0.025	0.026	0.025	0.029	0.043	0.035	0.022

Table 2

Relative order of importance of the regression coefficients

$V/\sqrt{LWL}$	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90
1	a1	a1	a1	a1	a1	a1	a4	a4	a5
2	a2	a15	a2	a2	a2	a2	a1	a12	a4
3	a11	a2	a12	a12	a12	a4	a12	a5	a15
4	a3	a3	a3	a3	a8	a12	a2	a1	a9
5	a8	a8	a8	a4	a4	a8	a8	a2	a16
6	a12	a12	a15	a8	a9	a9	a5	a8	a2
7	a15	a9	a4	a11	a3	a5	a9	a15	a3
8	a9	a11	a11	a9	a16	a3	a3	a9	a11
9	a16	a10	a9	a16	a11	a15	a15	a3	a12
10	a4	a13	a5	a10	a5	a16	a11	a11	a14
11	a10	a14	a10	a13	a10	a11	a10	a14	a8
12	a13	a6	a13	a6	a6	a10	a14	a16	a10
13	a14	a5	a6	a5	a13	a6	a13	a10	a1
14	a6	a16	a14	a15	a14	a14	a16	a13	a6
15	a5	a4	a7	a7	a7	a13	a7	a6	a7
16	a7	a7	a16	a14	a15	a7	a6	a7	a13

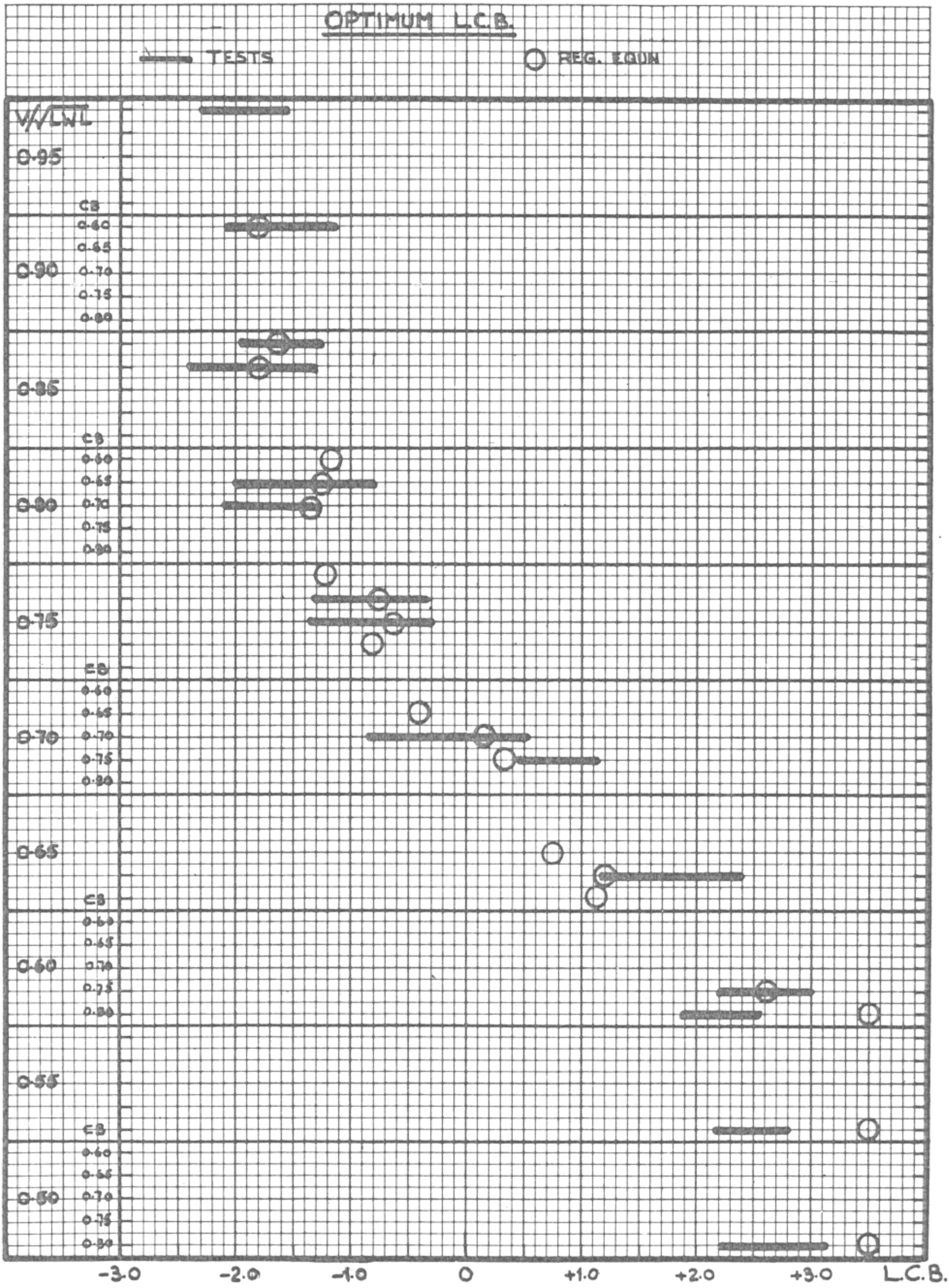

OPTIMUM L.C.B.
TESTS
REG. EQUN
V/√LWL
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
CB
0.60
0.65
0.70
0.75
0.80
-3.0
-2.0
-1.0
0
+1.0
+2.0
+3.0
L.C.B.

Figure 11.

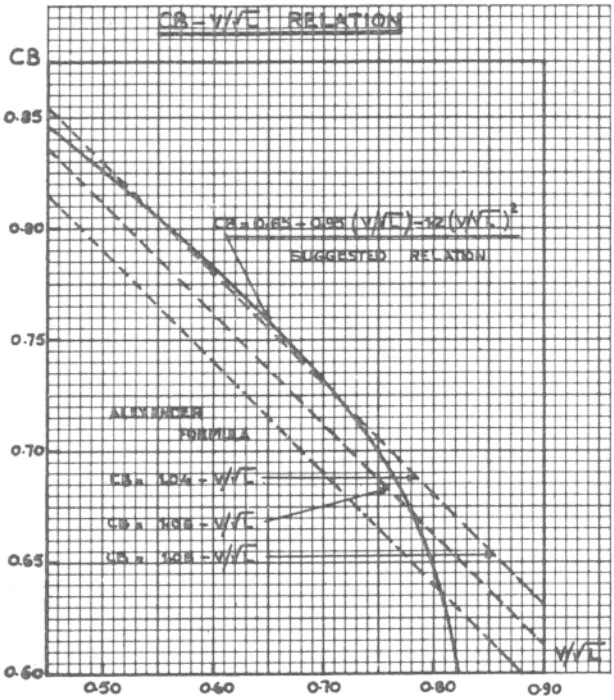


Figure 12.

Based on this analysis and a similar one for the B.S.R.A. Series, the following formula is suggested for the determination of a suitable block coefficient corresponding the design $V/\sqrt{LWL}$ in the range 0.50 to 0.80.

$$CB = 0.65 + 0.95\,(V/\sqrt{L}) - 1.2\,(V/\sqrt{L})^2 \qquad (35)$$

This relation is shown in Figure 12 together with the Alexander Formula with different constant term.

d. For every $V/\sqrt{LWL}$ considered, there is an optimum L.C.B. given by

$$\text{Opt. } LCB_{(V/\sqrt{LWL})} = 0.515 + 2.995x$$

$$\left(\frac{-a5 - a12\,X2 - a14\,X3 - a15\,X4 - a16\,X8}{2\,a9}\right)$$

The optimum L.C.B. tends to move aft as $L/_B$ is increased, which is the same trend measured on the coaster series [15]. The effect on the optimum L.C.B. of variations in $B/_T$ is negligibly small. For $V/\sqrt{LWL}$ up to 0.60, it tends to move forward as CB is increased, whereas for higher $V/\sqrt{LWL}$ it tends to move aft as CB is increased. For a given form, it tends to move aft as $V/\sqrt{LWL}$ is increased. However, a deviation from the suggested optimum of 0.4%L up to $V/\sqrt{LWL}$ of 0.65 and of 0.25%L for higher $V/\sqrt{LWL}$ has a small effect on CR. As the variation in $B/_T$ leads only to change in draft and has a small effect on the location of the optimum L.C.B., and since variation in $L/_B$ leads to changes in both beam and draft and has a large effect on the location of the optimum L.C.B., it is probable to conclude that variation in the beam affects the location of the optimum L.C.B. whereas the draft has a negligible effect. This is contrary to Bocler's conclusions [14]. Figure 13 gives the optimum L.C.B. positions for the Series 60 forms as suggested from this analysis at every $V/\sqrt{LWL}$ for the corresponding suitable combination of CB and $L/_B$ at a representative value of $B/_T$ of 2.5 and clearly reflects the aforementioned remarks.

Concluding remarks.

This analysis brought more confidence in using regression analysis with the resistance data of related forms. Regression analysis offers a full control over the assumptions to be used. The ultimate objectives of the series 60 are programmed using the analytical expressions arrived at in this analysis. A solved example is given in reference [19], and clearly indicates the procedure of the above-mentioned programs.

Acknowledgements.

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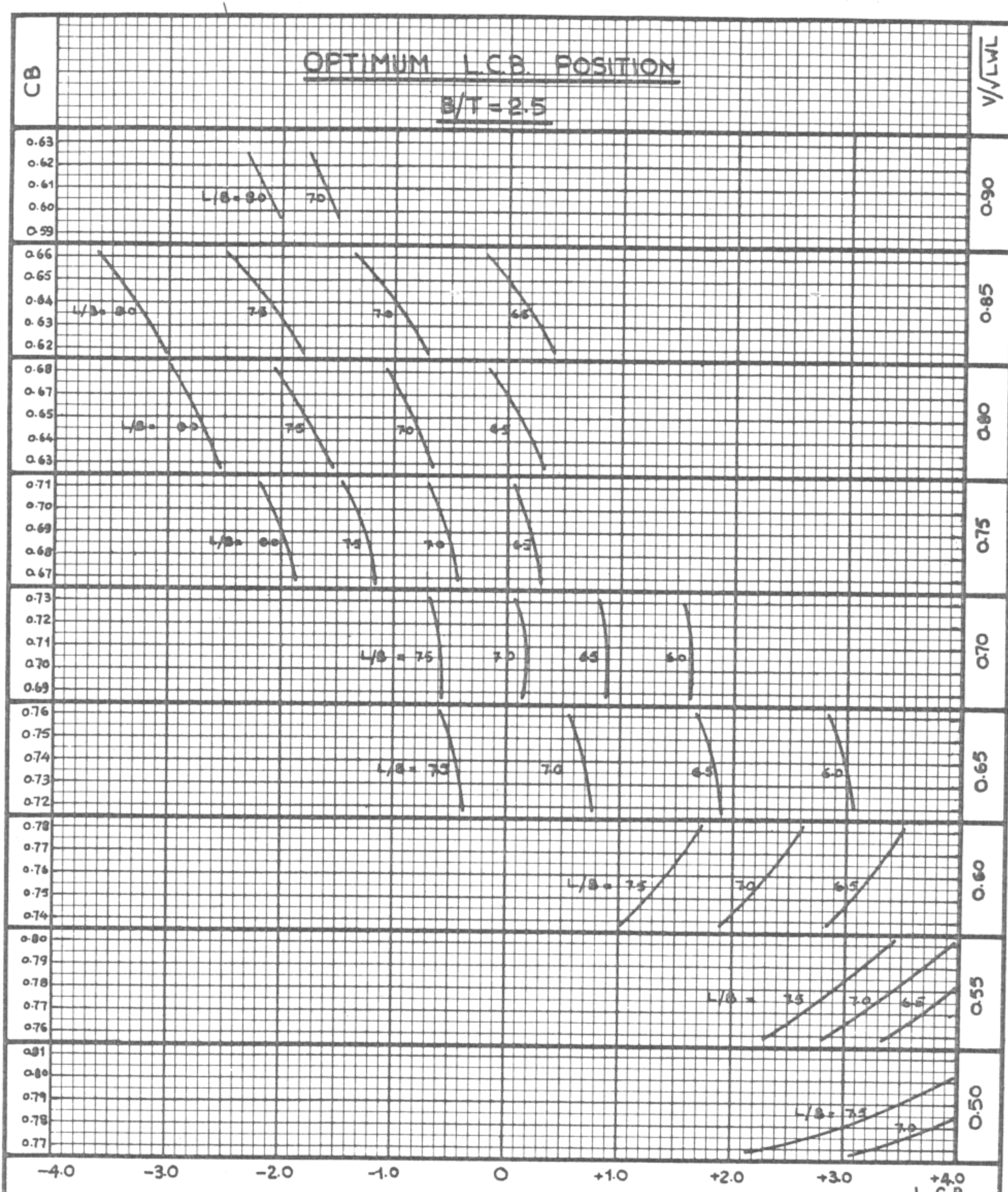
OPTIMUM L.C.B. POSITION
B/T = 2.5
CB
V/√LWL
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
L/B = 8.0
7.5
7.0
6.5
6.0
-4.0
-3.0
-2.0
-1.0
0
+1.0
+2.0
+3.0
+4.0
L.C.B

Figure 13.

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Nomenclature.

LBP or L	Lenght between perpendiculars.
LWL	Lenght on the designed load waterline.
B	Moulded beam.
T	Moulded draft.
Δ	Displacement in tons.
∇	Volume of displacement.
$CB = \frac{\nabla}{LBP x B x T}$	Block coefficient.
AM	Midship section area.
$CM = \frac{AM}{B x T}$	Midship section area coefficient.
$CP = \frac{\nabla}{AM x LBP}$	Prismatic coefficient.
CPF	Prismatic coefficient of the forward body.
CPA	Prismatic coefficient of the after body.
CPE	Prismatic coefficient of the entrance.
CPR	Prismatic coefficient of the run.
R	Bilge radius.
AW	Area of the load waterplane.
$CW = \frac{AW}{LBP x B}$	Waterplane area coefficient.
CWF	Waterplane area coefficient of the forward body.
CWA	Waterplane area coefficient of the after body.
IT	Transverse moment of inertia of the load waterplane.
CIT	Transverse inertia coefficient.
$BM_T = \frac{IT}{\nabla}$	Transverse metacentric radius.
L.C.B.	Position of the longitudinal centre of buoyancy expressed as a fraction percentage of LBP from amidships. positive when forward and negative when aft.
L.P.M.B.	Length of parallel middle body.
L.E.	Length of entrance.
L.R.	Length of run.
LBP/B or $L/_B$	Length-breadth ratio.
$B/_T$	Breadth-draft ratio.
W.S.	Wetted surface.

$W.S.C. = \dfrac{W.S}{\nabla^{2/3}}$ Wetted surface coefficient.

R_T Total resistance.

V Speed in knots.

ν Speed in ft/sec.

$C = \dfrac{2938 \times RT}{\Delta^{2/3} \times V^2}$ R.E. Froude total resistance coefficient, where R_T is in tons.

$CR = \dfrac{RT \times LBP}{\Delta \times V^2}$ Total resistance coefficient, where R_T is in 1b.

$CR = 2.4938 \times \text{©} \times LBP/\nabla^{1/3} =$

$= 99.181 \times LBP/\nabla^{1/3} \times W.S.C. \times C_T$

$C_T = \dfrac{RT}{\frac{1}{2}\rho S \nu^2}$ Total resistance coefficients where R_T is in 1b.

$V/\sqrt{LWL}$ Speed-lenght ratio based on LWL

Other symbols are defined as they occur.

R_T [lb] 1 lb ≙ 0,454 kg

LBP [ft] 1 ft ≙ 0.305 m

Δ [t] ~~1 tons ≙ 907,185 kg~~

V [kn] 1 kn ≙ 0,5144 m/s