A COMPUTERIZATION OF SERIES 60
RESISTANCE AND SELF-PROPULSION MODEL TESTS
by
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May 19, 1967

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Accepted by ______________________________
Chairman, Departmental Committee on Graduate Students

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Arthur P. Amesse

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ABSTRACT

The Series 60 resistance and self-propulsion model test results are represented by curve fitting methods which result in functions containing Chebyshev polynomials. The accuracy of the curve fitting method is discussed, and the range of validity of the functions is presented.

A computer program for the calculation of EHP and SHP for single-screw merchant ships with hull proportions falling within the range of the Series 60 is discussed in detail. Several examples in the use of the program are presented.

It is concluded that estimates of EHP and SHP can be calculated to within a tolerance in the neighborhood of 1% on the average, and with great certainty, to within a tolerance of less than 3% for any given speed.

Thesis Supervisor: Philip Mandel

Title: Professor of Naval Architecture

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B	Beam in feet
B/H	Beam - draft ratio
C_b	Block coefficient
C_f	Frictional resistance coefficient (ATTC)
C'_f	Frictional resistance coefficient (ITTC)
ΔC_f	Frictional ship correlation factor
C_m	Midship area coefficient
C_p	Prismatic coefficient
C_t	Total resistance coefficient
EHP	Effective or tow rope horsepower
H	Draft in feet
L	Length between perpendiculars (LBP) in feet
LCB	Longitudinal center of buoyancy
LWL	Length on designed waterline in feet
L/B	Length - beam ratio
PC	Propulsive coefficient (EHP/SHP)
R	Resistance in pounds
Re	Reynolds number
S	Wetted surface area in square feet
SHP	Shaft horsepower
V	Speed in knots
V_s	Speed in feet per second
$V/\sqrt{LWL}$	Speed - length ratio
Δ	Displacement in long tons

∇	Volume of displacement in cubic feet
ν	Kinematic viscosity in ft.^{2}/second
ρ	Density of water in lb. sec^2/ft.^{4}
⊗	Midpoint of length between perpendiculars

I. INTRODUCTION

1. Foreword

The determination of the required horsepower necessary to fulfill the speed requirements of a new ship design is one of the many problems which faces the naval architect in the early stages of ship design. He must have some way of knowing what effect various choices of size, proportions, and fullness of the ship will have on the power required to propel the ship at the speeds he desires.

In determining this power requirement, the naval architect can draw upon his past experience in ship design and the results of specific isolated model tests which are published periodically in the various technical journals of the profession.

However, the results of experiments conducted on families of models, in which the different design parameters are varied systematically, are the naval architects' most valuable sources of reference in estimating the power required for his new design. The result of these tests are usually expressed in the form of design charts from which the naval architect, using interpolation techniques where necessary, can calculate the power requirements for a number of combinations of design parameters, and thereby make an intelligent choice of the best combination of parameters to give minimum power with due consideration for the other limitations of his design conditions. The Series 60 is such a family of models designed to aid the naval architect in the estimation of power requirements for single-screw merchant ships.

2. The Series 60 Model Tests

The research on Series 60 was carried out at the David Taylor Model Basin (DTMB) of the United States Navy. Experiments were conducted as part

of the Bureau of Ships Fundamental Hydromechanics Research Program during the years 1948 to 1960. The results were published in a series of papers presented before the Society of Naval Architects and Marine Engineers, and a final report, incorporating all of the information contained in the interim reports was published in July of 1963.(1)*

After a survey of current practice in the shipbuilding industry to ensure, as far as possible, that the series would cover the normal range of proportions of modern ships, proportions were chosen for five parent models of the Series 60. These proportions are listed in Table I below.

TABLE I

Hull Proportions for Five Parent Models of Series 60

Model No.	4210	4218	4221	4213	4214
C_b	.60	.65	.70	.75	.80
L/B	7.50	7.25	7.00	6.75	6.50
B/H	2.50	2.50	2.50	2.50	2.50
$\Delta/(L/100)^3$	122.0	141.4	163.4	188.2	216.5
$L/\nabla^{1/3}$	6.165	5.869	5.593	5.335	5.092
LCB as % of L from ⊗ BP	1.5 aft	1.54 aft	0.55 aft	1.5 fwd	2.5 fwd

For any one block coefficient and LCB position, a total of nine models were tested in which the L/B and B/H ratios were varied, for a total of forty-five models. To cover the general spread of L/B, B/H, and $\Delta/(L/100)^3$ for

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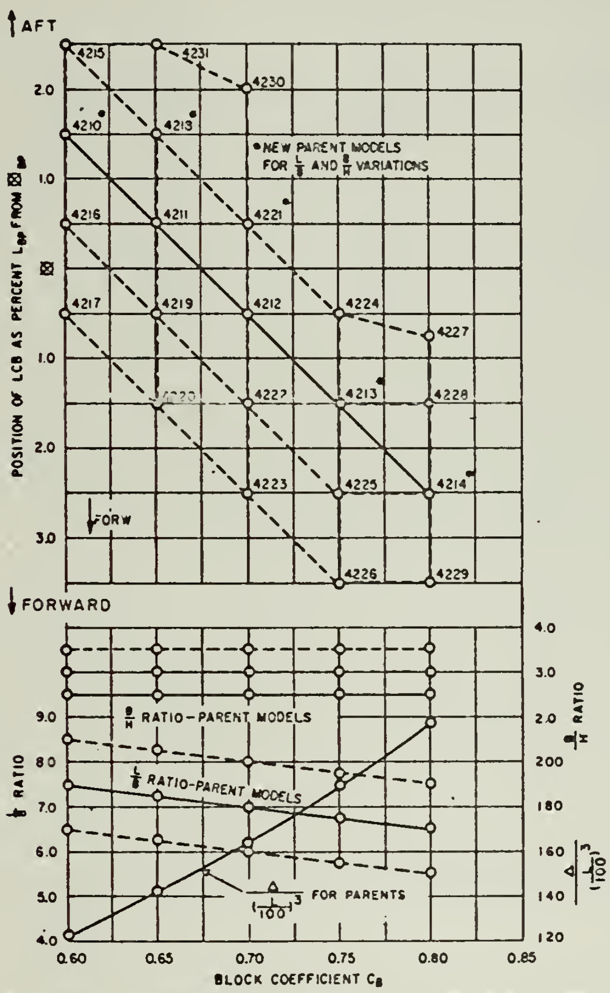
* Numbered references throughout the text are listed on page 44.

existing designs and the possible variation in LCB position, a grid was adopted as shown by the dotted lines in Figure I.

FIGURE I *

Variation of Proportions with C_b for Series 60 Models

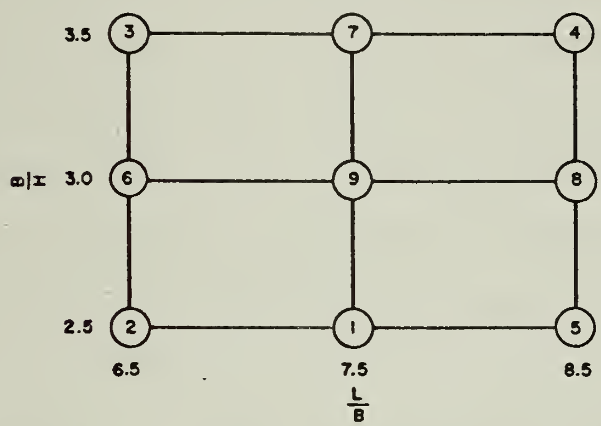


* From reference (1), page II-3

The pattern for a typical case (C_b = .60) is shown in Figure II.

FIGURE II *

Typical Variation of L/B and B/H Ratios for a Given Value of C_b



The midship section of the models had no deadrise in accordance with current practice. The relationship between C_m and C_p for the Series 60 is as follows:

$$C_m = 0.0857\ C_p + .925$$

And, since $C_b = C_p \times C_m$

$$C_b = 0.0857\ C_p^2 + .925\ C_p \qquad (1)$$

LWL for the Series 60 hull forms is related to L by the following simple formula:

$$LWL = \frac{406.75 \times L}{400.} \qquad (2)$$

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* From reference (1), page II-3

The results of the Series 60 resistance tests are presented in the form of easy to use design charts, and in numerical point-by-point form in tables..

Values of total resistive coefficient (C_t) for forty-five ships of length between perpendiculars of 400 feet, and varying values of C_b, L/B, and B/H are presented in Tables B-1 through B-45 of reference (1). Utilizing the Froude assumption that the total resistance can be divided into two parts, the skin friction of an "equivalent plank" and the residuary resistance, the values of C_t include a skin friction coefficient (C_f) calculated for salt water at 59°F in accordance with the American Towing Tank Conference (ATTC) 1947 line*, and an additional allowance for ship correlation (ΔC_f) of + 0.0004 as recommended by the ATTC 1947. Methods for scaling the values of C_t for an arbitrary ship length will be discussed in Chapter IV.

Values of propulsive coefficient (PC or EHP/SHP) for forty-five ships of length between perpendiculars of 600 feet, and varying values of C_b, L/B, and B/H are also presented in Tables B-1 through B-45 of reference (1). Unlike the values of C_t, the propulsion data can not be corrected for variation in ship length. The choice of a 600 foot ship to illustrate the propulsion tests was made principally because it was considered more representative of modern ships than the 400 foot length chosen for the resistance presentation.** The propulsion data presented was obtained using a standard propeller diameter equal to 0.70 of the designed load draft.

Data for the effect of variation of LCB position on power requirements is by no means complete. Corrections to total resistance for variation of

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* Also known as the Schoenher line.

** Reference (1), page VII-4.

LCB position for five values of C_b are presented in Tables 49 through 53 in reference (1), with only four or five different positions of LCB noted.

Although the propulsive data is presented for ships of 600 foot length, if the designer adopts the lines of Series 60, the position of LCB as used in the parent forms, and a propeller having the standard ratio of diameter to draft of 0.7, he can make a very accurate estimate of both the EHP and SHP of a ship for any particular selection of L, B, H, and Δ.

3. Previous Work in Series 60 Computerization

The development of a computer program for estimating EHP using the Series 60 results was first attempted by D. Khoushy in 1962.[2] This attempt represented the Series 60 by curve fitting methods to some extent e.g. wetted surface, but it relied exclusively on interpolative methods for C_t which are both cumbersome to program and highly consumptive of computer storage space*. Furthermore, the large amount of storage space required in this type of program made it unsuitable for use as an EHP or SHP subroutine in a larger program. It also should be noted that an interpolative scheme is not very efficient since the test results are not presented in a uniform manner, i.e. at low values of C_b models were tested up to a $V/\sqrt{LWL}$ of 1.10 whereas the higher values of C_b were tested up to a $V/\sqrt{LWL}$ of 0.80. This problem was avoided in the Khoushy work by discarding a large amount of Series 60 data in the low and high ranges of $V/\sqrt{LWL}$.

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* The storage of approximately 6000 numbers is required for the Series 60.

Therefore, it was decided that curve fitting would be the most advantageous method of representing the Series 60 model test results in a computer program.

4. The Curve Fitting Approach

The curve fitting approach for representing the Series 60 results is very desirable since once a function is found, which represents the given data, one knows the error he can expect in predicting EHP and SHP using these derived functions. The fitting of curves through the Series 60 resistance data was started in early 1966 by T. M. Pitidis-Poutous. The basic theory of the curve fitting method employed was developed in reference (3) in 1965 with the mathematical derivation of ships lines being the focus of attention. This curve fitting method, as it applies to the representation of the Series 60 resistance data and its extension to represent the propulsion results for this work, is described in Chapter II.

II. DESCRIPTION OF CURVE FITTING METHODS USED FOR THE SERIES 60

The theory of the curve fitting methods used for representing the Series 60 model test results stated herein is largely adopted from reference (4).

Since the chart reading methods of the Series 60 are not suitable for computerization, it was decided to fit curves through the numerical results presented for C_t and PC (or EHP/SHP) in Tables B-1 through B-45 of reference (1).

In the Series 60, both C_t and PC are functions of four independent variables, i.e. $V/\sqrt{LWL}$, C_b, L/B, and B/H. Thus, either C_t or PC can be represented by an equation of the form:

$$Y = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{n=1}^{N} a_{nkji} \, \Phi_i\left(\frac{L}{B}\right) \Psi_j\left(\frac{B}{H}\right) X_k(C_b) \, \Omega_n\left(\frac{V}{\sqrt{LWL}}\right) \qquad (3)$$

and the problem reduces to determining the matrix of coefficients $[a_{nkji}]$ from the given data. If the coordinate functions Φ, Ψ, X, and Ω are taken as ordinary polynomials, the above expression becomes

$$Y = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{n=1}^{N} a_{nkji} \left(\frac{L}{B}\right)^{i-1} \left(\frac{B}{H}\right)^{j-1} (C_b)^{k-1} \left(\frac{V}{\sqrt{LWL}}\right)^{n-1}$$

It can be shown that there are certain advantages to be gained if the coordinate functions are taken as the Chebyshev polynomials, with no additional complications.* The independent variables $V/\sqrt{LWL}$, C_b, L/B,

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* See reference (5).

and B/H can be normalized in the range of -1 to +1 by the equations given in Table II, and the corresponding symbols used for the original, normalized, and computer program variables are given in Table III. The equations of Table II were derived on the basis of the limits of the Series 60 model tests.

Stipulations on the maximum powers I, J, K, and N, to be used in equation (3) are determined by the amount of data available from the Series 60 results. For example, each model was tested for three different values of B/H and L/B, therefore I and J must be equal to or less than 3. Models were tested for five different values of C_b, therefore K must be equal to or less than 5. Thus, the number of terms in the equation will be equal to or less than 45N. The value of N cannot be arrived at in the same way as I, J, and K, since each model was tested for twenty to thirty different values of $V/\sqrt{LWL}$, differing from model to model. If we assume, for the moment, that N = 10 would be adequate, we see that the determination of the coefficients a_{nkji} would involve the solution of 450 linear algebraic equations. This is virtually impossible, both from the numerical and computer storage points of view.

These considerations prohibited the use of a direct, 4-parameter fit, and indicated the necessity of a step-by-step technique.

Using the symbols for the normalized variables as defined in Table III, equation (3) becomes:

$$Y = \sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} \sum_{n}^{N} a_{nkji} \; \Phi_i(\mu) \Psi_j(\gamma) X_k(x) \Omega_n(v)$$

or

$$Y = \sum_{n=1}^{N} \sum_{\ell=1}^{L} A_{n\ell} \; F_\ell(\mu, \gamma, x) \; \Omega_n(v) \qquad (4)$$

TABLE II

Equations for Normalizing Independent Variables in Series 60 Range

$$v = 2.5 \frac{V}{\sqrt{LWL}} - 1.875 \quad ; \quad \frac{V}{\sqrt{LWL}} = 0.4v + 0.75$$

$$u = \frac{L/B - 7.0}{1.5} \quad ; \quad \frac{L}{B} = 1.5u + 7.0$$

$$z = 2.0 \frac{B}{H} - 6.0 \quad ; \quad \frac{B}{H} = 0.5z + 3.0$$

$$x = 10.0\ C_b - 7.0 \quad ; \quad C_b = 0.1x + 0.7$$

TABLE III

Correspondence of Original, Normalized, and Computer Program Symbols

Original Symbol	C_t	PC	C_b	B/H	L/B	$V/\sqrt{LWL}$
Normalized Symbol	Y	Y	x	z	u	v
Computer Symbol	CTM	PCM	CB	BH	BL	VL

where: $\ell = j + J(i-1) + IJ(k-1)$

and $F_\ell = \Phi_i(u)\,\Psi_j(z)\,X_k(x)$

The above substitutions reduce the four-dimensional matrix "a" to a two-dimensional matrix "A", which is easier for computations, and defines the problem more appropriately for the method to be used. For given values of u, z, and x, equation (4) can be written as:

$$Y_p = \sum_{n=1}^{N} C_{pn}\,\Omega_n(v) \qquad (5)$$

with

$$C_{pn} = \sum_{\ell=1}^{L} A_{n\ell}\,F_\ell(u, z, x) \qquad (6)$$

Equation (5) represents the variation of Y with respect to v for the p^{th} model, and the N coefficients (C_{pn}, n = 1, N) can be evaluated from the data in Tables B-1 through B-45 of reference (1), using the least-squares criterion:

$$\sum_i \left\{ (Y_p)_i - \sum_{n=1}^{N} C_{pn}\,\Omega_n(v_i) \right\}^2 = \text{MINIMUM}$$

by differentiating partially with respect to the unknown coefficients.

All models were fitted in this fashion, and the resulting equation for each model was evaluated at intermediate values in order to ensure that the polynomial had no undesired oscillations. In fitting the curves for C_t, it was found that a reasonably good fit was obtained with N = 10 (corresponding to a 9th order polynomial) and since this is rather high, the possibility of introducing a suitable weighting function was explored. Therefore, the fittings were repeated with the following two alternative

weighting functions assigned to C_t:

$$Y = \left(C_t \times 10^3\right)\left(V/\sqrt{LWL}\right)^3$$

$$Y = \left(C_t \times 10^3\right) / \left(V/\sqrt{LWL}\right)^2$$

The last alternative was found to give the best fit with N = 10 for most models. Going from N = 10 to N = 11, the maximum error experienced in $C_t \times 10^3$ only decreased from .025 to .024 for Table B-1 of reference (1).

Having obtained matrix $[C_{pn}]$ corresponding to equation (5) with p = 45 (number of models), matrix $[A_{nl}]$ was obtained by exact fit, i.e. L = 45. It should be mentioned here that a certain amount of regression could also be tried on this step of fitting, and this was actually attempted, but without success. The reason is that, although it might be possible to obtain a good fit for C_t or PC at a constant value of $V/\sqrt{LWL}$ with L less than 45, it does not follow that such a fitting could be applied successfully to the coefficients of the C_t - $V/\sqrt{LWL}$ equation (i.e. C_{pn}). Thus, direct 4-parameter fitting of the data could have produced an equation with less error and less terms, if it were possible numerically.

The values of PC were fitted in the same manner described above, but no weighting function was used.

The final equations obtained are as follows:

$$\frac{C_t \times 10^3}{\left(V/\sqrt{LWL}\right)^2} = \sum_{n=1}^{10} \sum_{l=1}^{45} A_{nl}\, F_l(\mu, \zeta, x)\, T_{n-1}(v) \qquad (7)$$

$$PC = \frac{EHP}{SHP} = \sum_{n=1}^{10} \sum_{l=1}^{45} B_{nl}\, F_l(\mu, \zeta, x)\, T_{n-1}(v) \qquad (8)$$

where

$$F_\ell = T_{i-1}(u)\, T_{j-1}(z)\, T_{k-1}(x)$$

$$\ell = j + 3(i-1) + 9(k-1)$$

$$T_p = p^{th} \text{ Chebyshev Polynomial}$$

The elements of the matrices $[A_{nl}]$ and $[B_{nl}]$ are read in as data in the main program, and are listed in Appendix A. These matrices form a compact computational package of 900 numbers for the calculation of C_t (400 ft. ship) and PC (600 ft. ship).

No attempt was made at fitting curves through the data for correction to total resistance due to variation of LCB position. The inadequacy of the data presented, as well as the erratic nature in which it behaves with $V/\sqrt{LWL}$, precluded the use of the curve fitting methods described above.

III. RESULTS OF CURVE FITTING METHODS USED AND RANGE OF VALIDITY

The results of the curve fitting methods used for C_t and PC were first tested by reproducing the data contained in Tables B-1 through B-45, i.e. for the forty-five models of the Series 60. The results of this test are presented in Table IV, where the maximum error, in percent, experienced in C_t and PC is noted for each of the forty-five models.

The maximum error experienced in C_t was 2.740% for the parent model 4218. The maximum error experienced in PC was 2.030% for model 4276. Although these figures appear prohibitive at first glance, it should be emphasized that these are the maximum errors experienced for any given model, and they occur at only one value of $V/\sqrt{LWL}$. The errors at other values of $V/\sqrt{LWL}$ for any given model are well under 1% in the great majority of cases. In fact, as can be seen from Table IV, the maximum errors experienced in C_t and PC for any given model are well below 1% in most cases. To illustrate this point further, plots of C_t versus $V/\sqrt{LWL}$ are presented in Figures III through VII, and plots of PC (or EHP/SHP) versus $V/\sqrt{LWL}$ are presented in Figures VIII through XII, for the five parent models of the Series 60. In these plots, the solid line represents the value of C_t and PC as calculated from equations (7) and (8) respectively, and the points represent the value at that $V/\sqrt{LWL}$ presented in the tables of reference (1), which are in error enough to be visually discernable on the scale used in making the plots. It is further noted that Figure IV represents the worst case experienced in fitting either C_t or PC.

As a second test, equations (7) and (8) were evaluated by generating 125 interpolate and extrapolate models, especially concentrating on

TABLE IV

Maximum % Errors Experienced in C_t and PC for the 45 Models of the Series 60

Series 60 Table No.	Model No.	C_b	L/B	B/H	Max. % Error in C_t	Max % Error in PC
B-1	4240	.60	6.5	2.5	.578	.853
B-2*	4210	.60	7.5	2.5	1.230	.648
B-3	4267	.65	8.25	2.5	1.515	.672
B-4	4264	.65	6.25	2.5	.340	.616
B-5*	4218	.65	7.25	2.5	2.740	.298
B-6	4243	.60	8.5	2.5	.701	.696
B-7	4244	.70	6.0	2.5	.531	.248
B-8*	4221	.70	7.0	2.5	.370	.402
B-9	4247	.70	8.0	2.5	.282	.552
B-10	4268	.75	5.75	2.5	.819	.386
B-11*	4213	.75	6.75	2.5	.824	.697
B-12	4271	.75	7.75	2.5	1.045	.682
B-13	4248	.80	5.5	2.5	.191	.372
B-14*	4214	.80	6.5	2.5	.381	.134
B-15	4215	.80	7.5	2.5	.243	.394
B-16	4252	.60	6.5	3.0	.885	.437
B-17	4255	.60	7.5	3.0	.714	.393
B-18	4254	.60	8.5	3.0	.477	1.261
B-19	4272	.65	6.25	3.0	.602	.529
B-20	4275	.65	7.25	3.0	.405	.446
B-21	4274	.65	8.25	3.0	.600	.516
B-22	4256	.70	6.0	3.0	.175	.277
B-23	4259	.70	7.0	3.0	.134	.590
B-24	4258	.70	8.0	3.0	.278	.573
B-25	4276	.75	5.75	3.0	.528	2.030
B-26	4279	.75	6.75	3.0	1.331	1.430
B-27	4278	.75	7.75	3.0	.923	.591
B-28	4260	.80	5.5	3.0	.248	.517
B-29	4263	.80	6.5	3.0	.166	.129
B-30	4262	.80	7.5	3.0	.082	.284
B-31	4241	.60	6.5	3.5	.541	.449
B-32	4253	.60	7.5	3.5	.411	.878
B-33	4242	.60	8.5	3.5	.459	.906
B-34	4265	.65	6.25	3.5	.634	.537
B-35	4273	.65	7.25	3.5	.418	.349
B-36	4266	.65	8.25	3.5	.493	.664
B-37	4245	.70	6.0	3.5	.203	.443
B-38	4257	.70	7.0	3.5	.435	.452
B-39	4246	.70	8.0	3.5	.312	.544
B-40	4269	.75	5.75	3.5	.223	.598
B-41	4277	.75	6.75	3.5	.506	.581
B-42	4270	.75	7.75	3.5	.919	1.275
B-43	4249	.80	5.5	3.5	.192	.542
B-44	4261	.80	6.5	3.5	.191	.577
B-45	4250	.80	7.5	3.5	.118	.303

* Denotes parent model

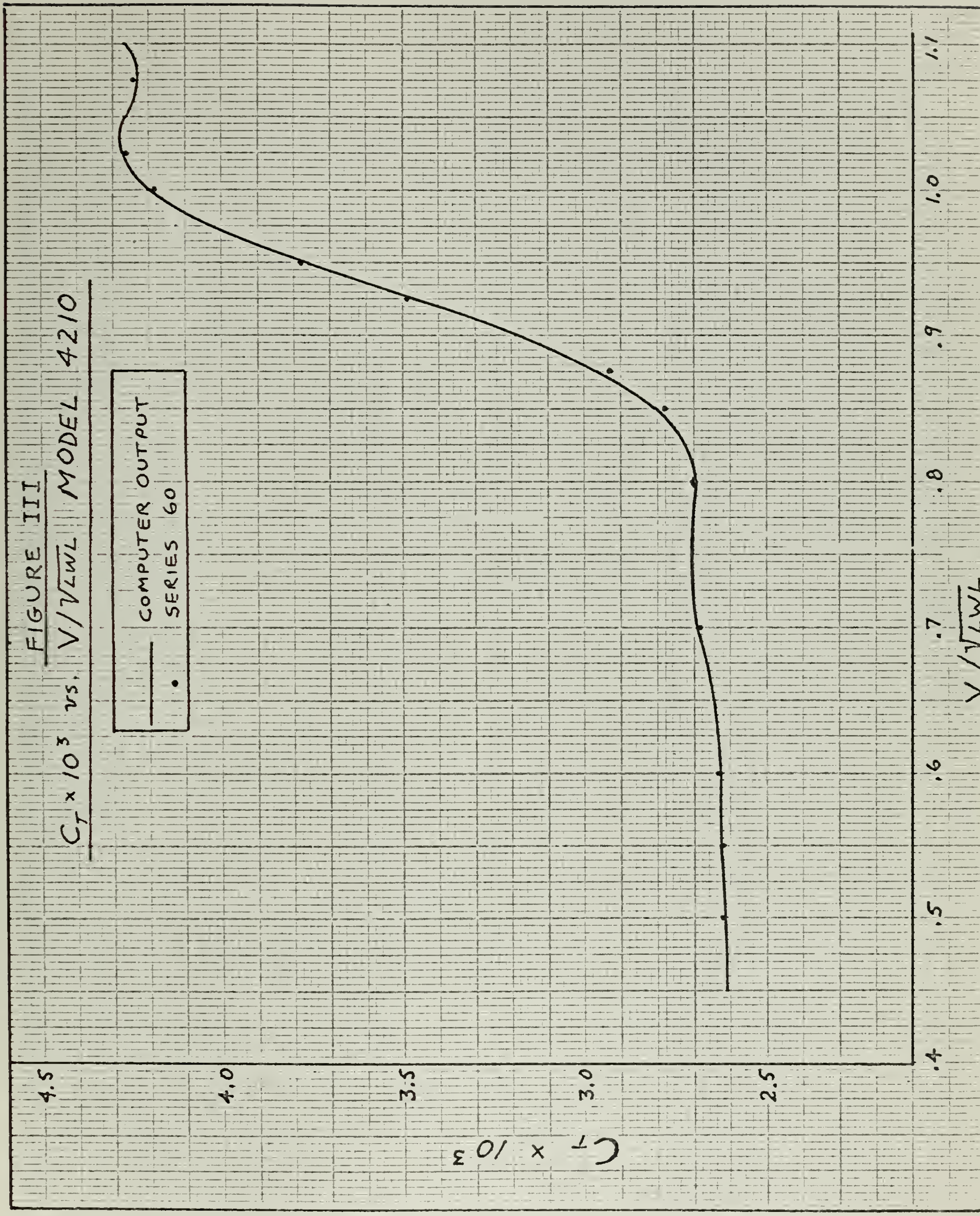


FIGURE III

$C_T \times 10^3$ vs. $V/\sqrt{LWL}$ MODEL 4210

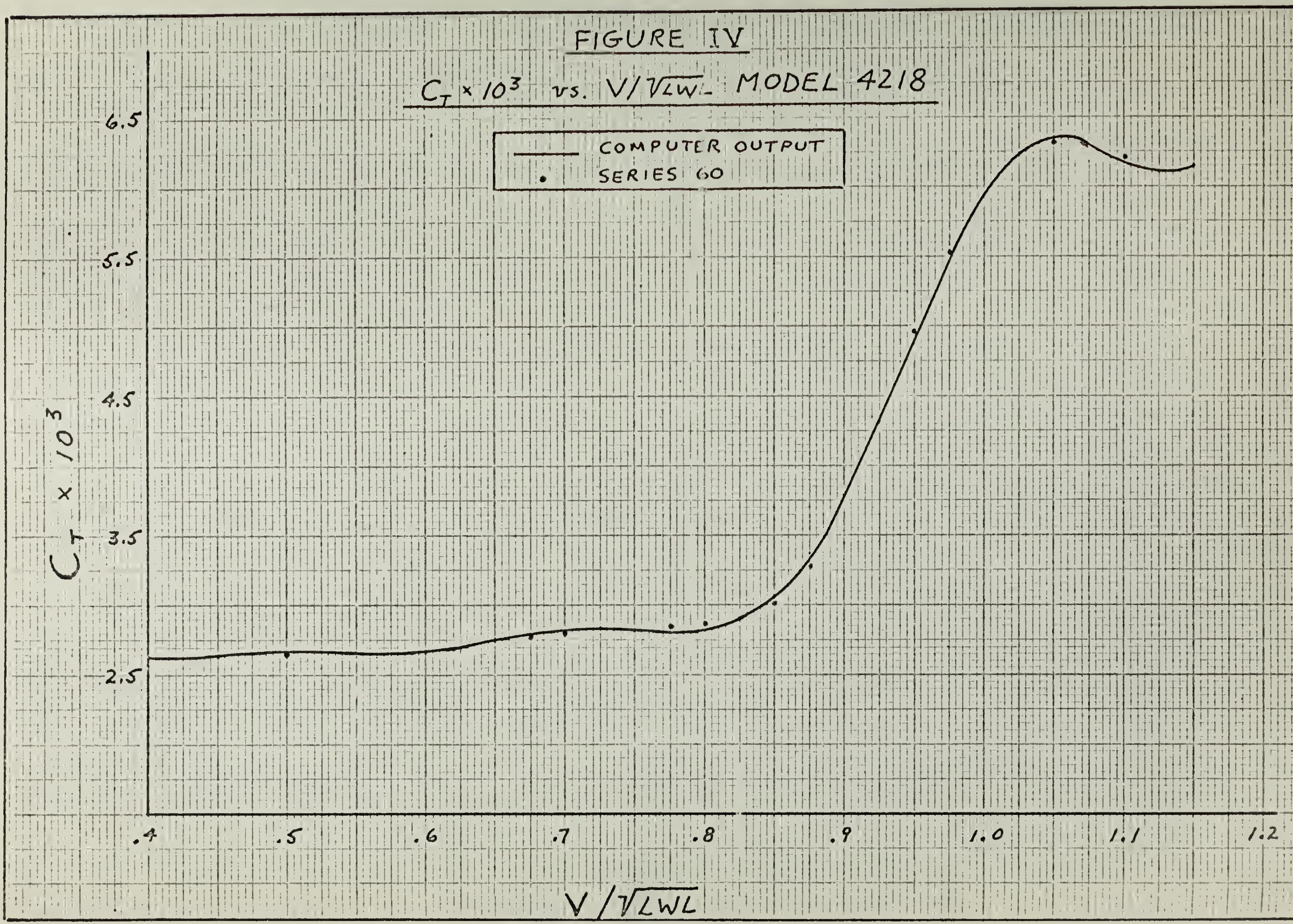


FIGURE IV
$C_T \times 10^3$ vs. $V/\sqrt{L_{WL}}$ - MODEL 4218
COMPUTER OUTPUT
SERIES 60
6.5
5.5
4.5
3.5
2.5
$C_T \times 10^3$
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
$V/\sqrt{LWL}$

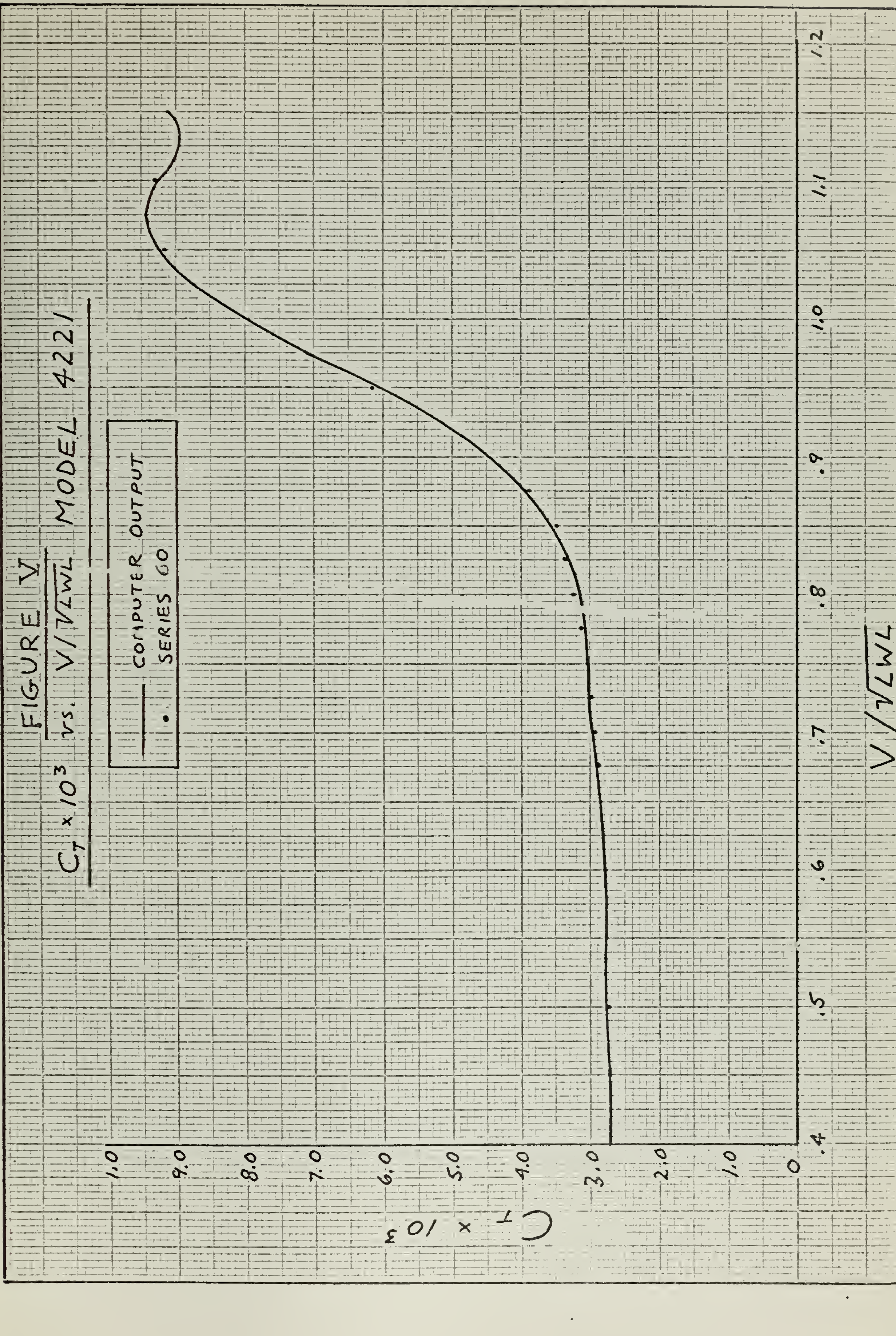


FIGURE V
$C_T \times 10^3$ vs. $V/\sqrt{LWL}$ MODEL 4221
— COMPUTER OUTPUT
• SERIES 60
1.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
$V/\sqrt{LWL}$
$C_T \times 10^3$

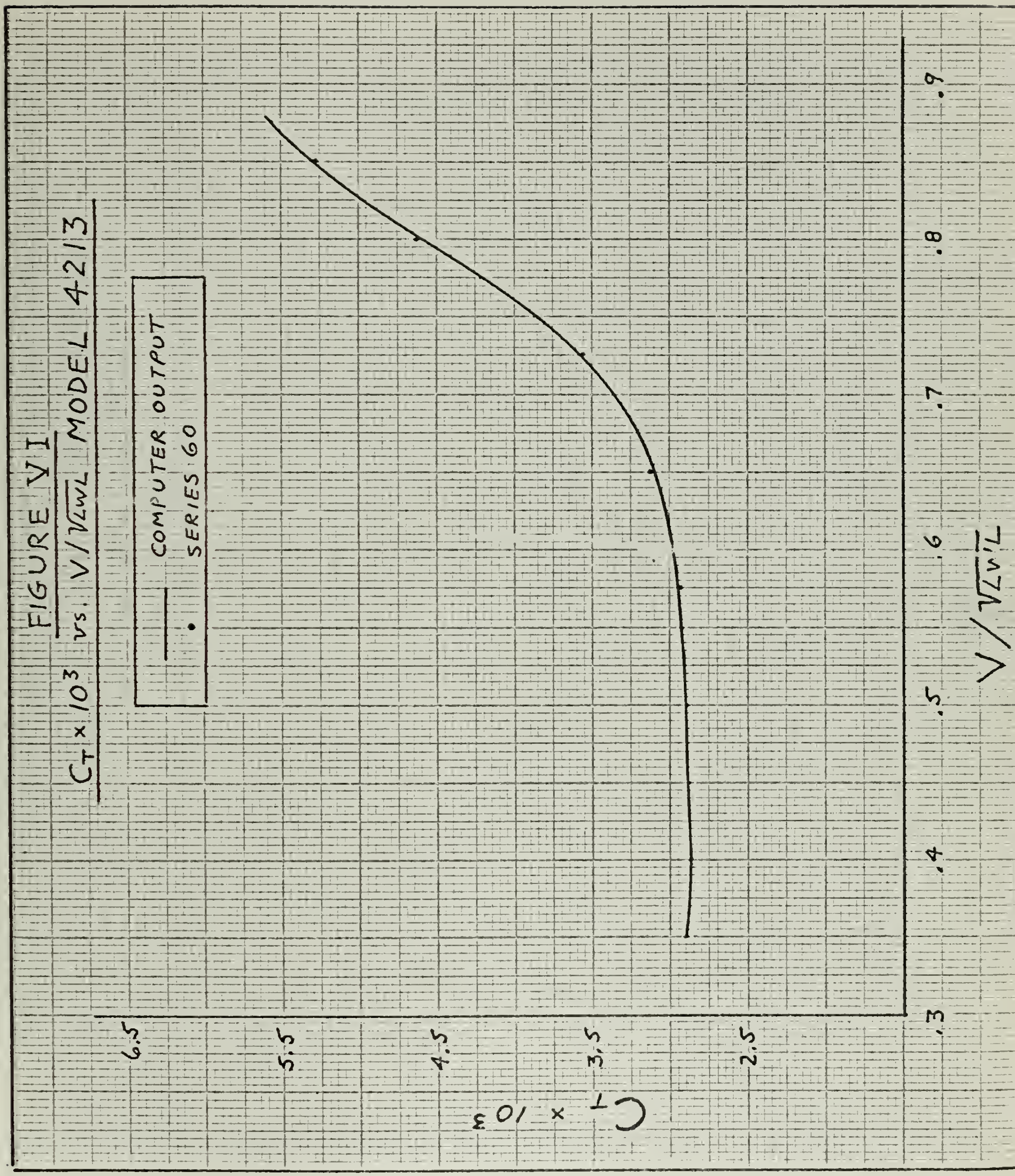


FIGURE VI

$C_T \times 10^3$ vs. $V/\sqrt{L_{WL}}$ MODEL 4213

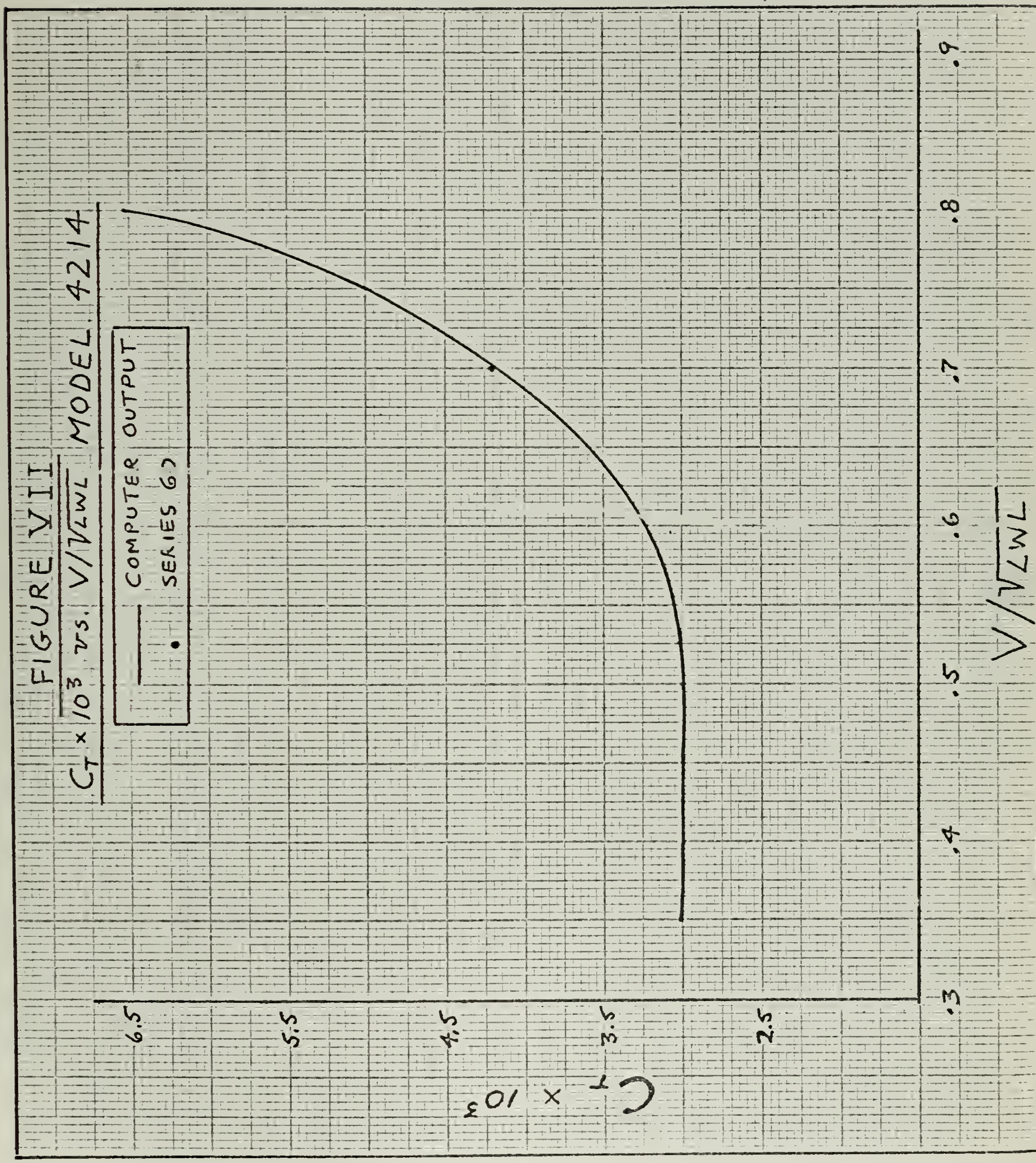


FIGURE VII
$C_T \times 10^3$ vs. $V/\sqrt{LWL}$ MODEL 4214
COMPUTER OUTPUT
SERIES 62
6.5
5.5
4.5
3.5
2.5
$C_T \times 10^3$
.3
.4
.5
.6
.7
.8
.9
$V/\sqrt{LWL}$

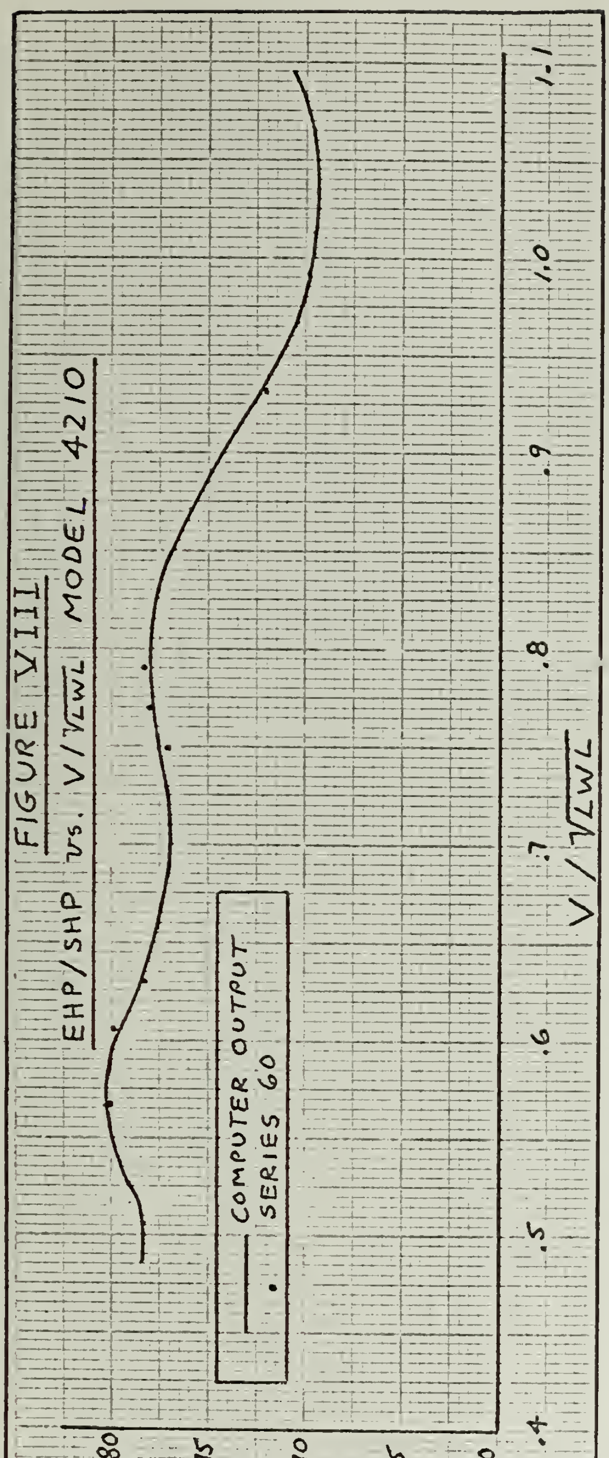


FIGURE VIII
EHP/SHP vs. V/√LWL MODEL 4210

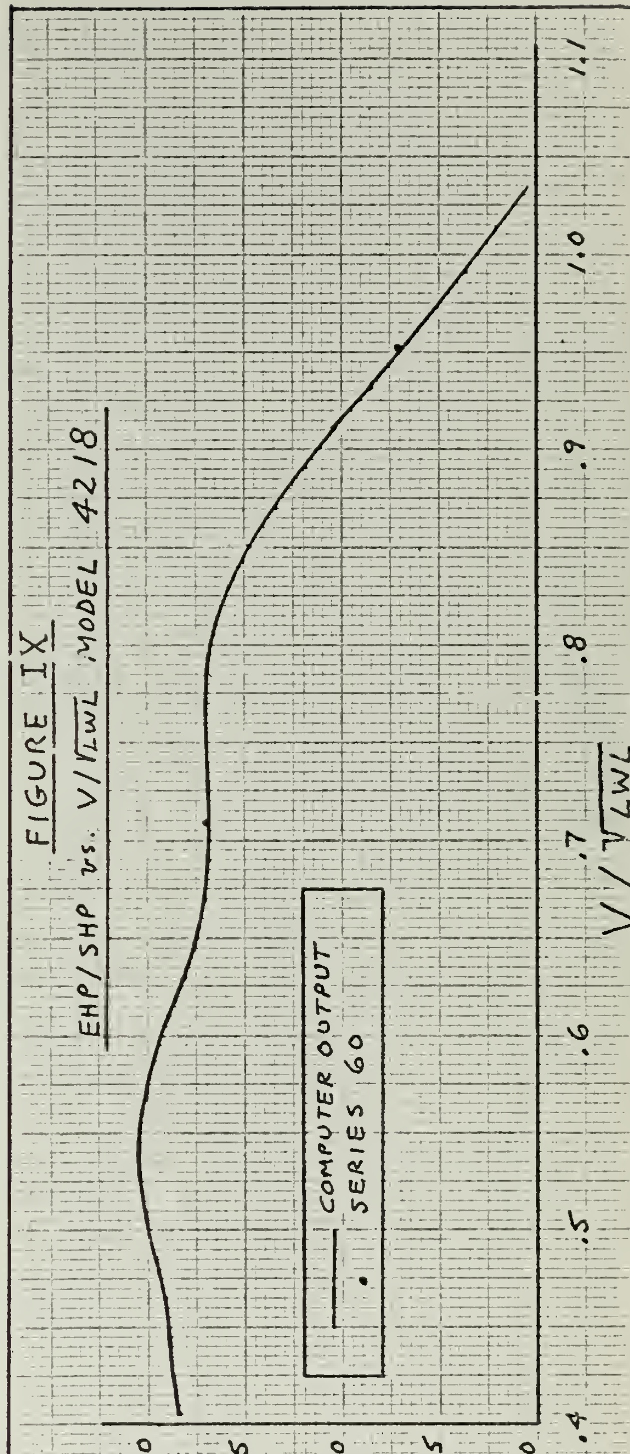


FIGURE IX
EHP/SHP vs. V/√LWL MODEL 4218

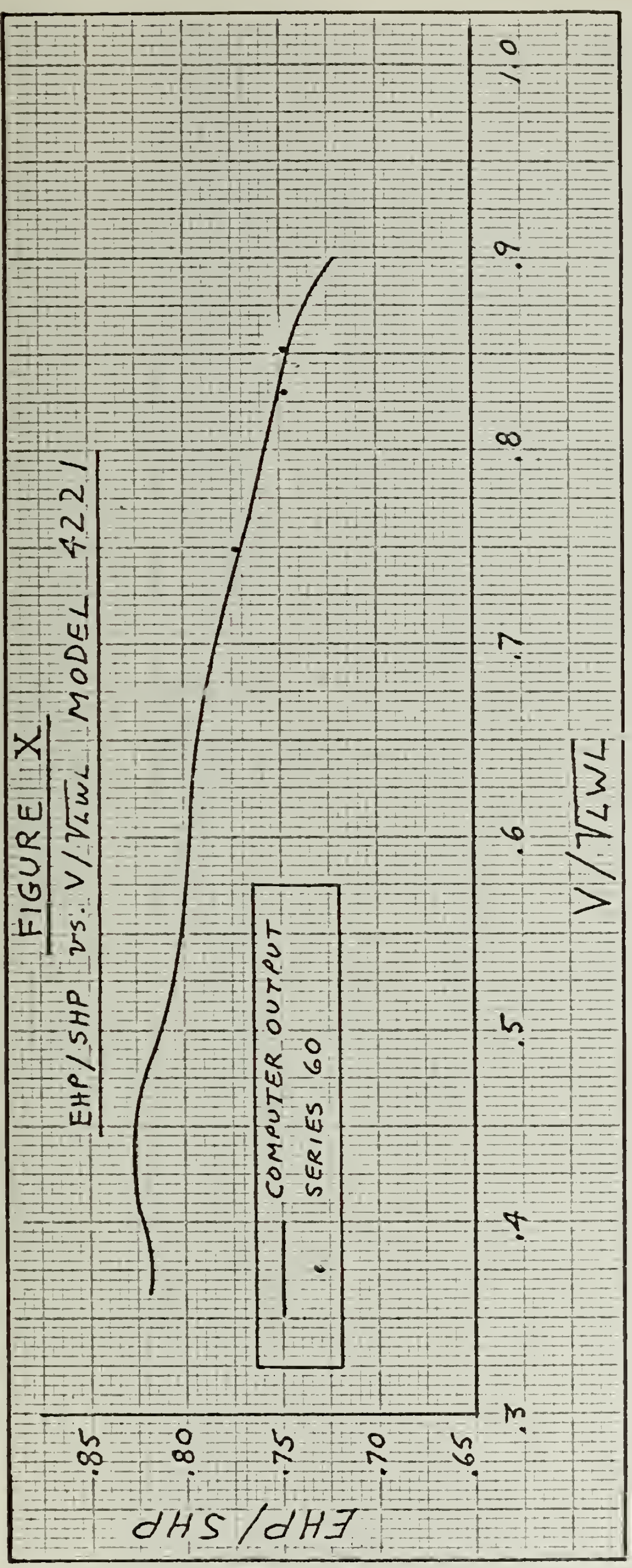


FIGURE X
EHP/SHP vs. V/√LWL MODEL 4221
COMPUTER OUTPUT
SERIES 60
EHP/SHP
.85
.80
.75
.70
.65
.3
.4
.5
.6
.7
.8
.9
1.0
V/√LWL

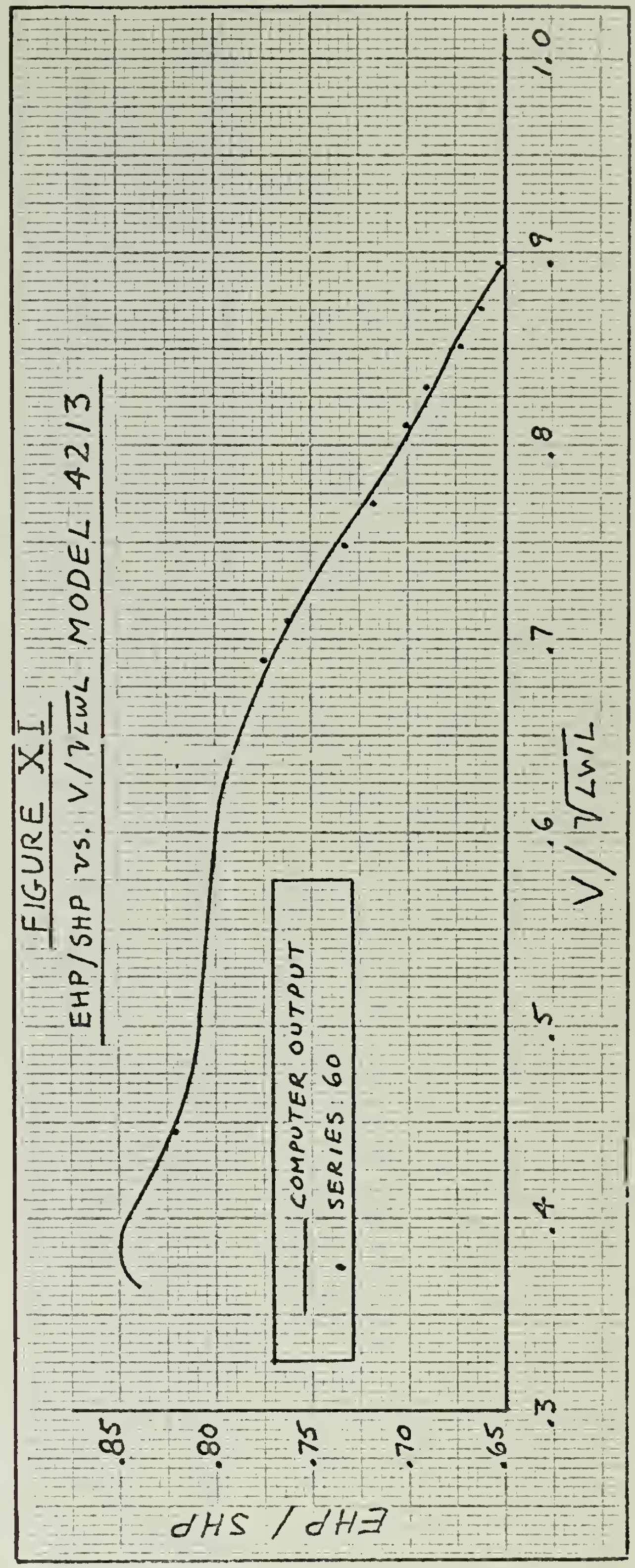


FIGURE XI
EHP/SHP vs. V/√LWL MODEL 4213
COMPUTER OUTPUT
SERIES 60
EHP/SHP
.85
.80
.75
.70
.65
.3
.4
.5
.6
.7
.8
.9
1.0
V/√LWL

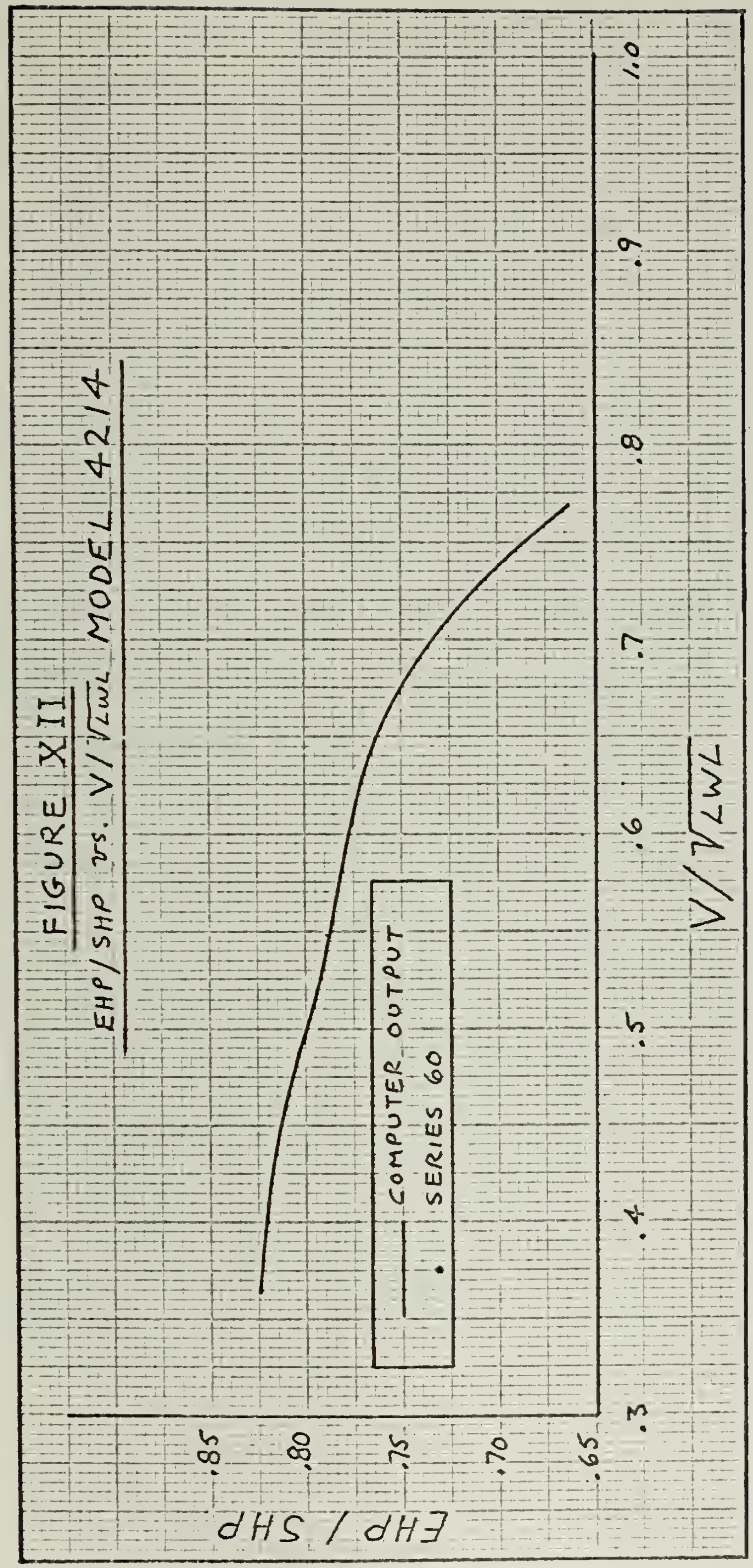


FIGURE XII
EHP/SHP vs. V/√LWL MODEL 4214
.85
.80
.75
.70
.65
EHP / SHP
.3
.4
.5
.6
.7
.8
.9
1.0
V/√LWL
COMPUTER OUTPUT
SERIES 60

intermediate values of the five Cb's used for the Series 60 models. This was done in order to determine the range of validity of these equations with respect to their four independent variables. It should be emphasized that the ranges of validity determined below are not just a result of the inadequacies of the curve fitting methods used; they are very much a result of the limits of the Series 60 model tests themselves and the range of data made available in reference (1).

The data presented in reference (1) is based on the use of three values of B/H, i.e. 2.5, 3.0, and 3.5. Since equations (7) and (8) rely on a second order interpolation scheme in B/H, which is the method suggested in reference (1) when using the design charts, there should be no discrepancies caused by this variable. It is also expected that a limited amount of extrapolation is possible in B/H.*

Similarly, there should be no discrepancies due to L/B since equations (7) and (8) rely on a second order interpolation scheme for this variable, which is also the method used by DTMB in the preparation of the Series 60 design charts. However, as can be readily seen from Figure I, there are limits (imposed by the proportions of the Series 60 models) on the range of interpolation possible in L/B. The range of interpolation in L/B is a function of C_b and can be expressed as follows:

$$(L/B)_{min} = 5.5 + \frac{8.0 - 10\, C_b}{2} \qquad (9)$$

$$(L/B)_{max} = 7.5 + \frac{8.0 - 10\, C_b}{2} \qquad (10)$$

* See example of the ship SCHUYLER OTIS BLAND in Chapter V.

A small amount of extrapolation beyond these limits should not cause trouble.

In producing the Series 60 design charts, a third order interpolation in C_b was used by DTMB. In equations (7) and (8) a fourth order interpolative scheme for C_b is used, which could produce slight discrepancies in interpolation and extrapolation. It is recommended that the program be used only in the range of $C_b = 0.60$ to 0.80.

The Series 60 model tests impose definite limits on the range of $V/\sqrt{LWL}$ permissible. For example, in testing equations (7) and (8) with the 125 models mentioned above, it was found that with $C_b = 0.775$, $B/H = 3.0$, and $L/B = 7.0$, the values of C_t and PC given by equations (7) and (8) dropped off sharply at $V/\sqrt{LWL} = .925$ and even went negative at $V/\sqrt{LWL} = .950$. This is understandable since at these values of $V/\sqrt{LWL}$ we are outside the range of results given by the Series 60 tests. Therefore, to avoid occurrences of this nature, a "trap" has been built into the EHP-SHP program described in Chapter IV, which puts limits on the value of $V/\sqrt{LWL}$ allowed, depending upon the value of C_b. These limits are presented in Table V.

TABLE V

Limits of $V/\sqrt{LWL}$ Allowed by Program

Range of C_b	$(V/\sqrt{LWL})_{min}$	$(V/\sqrt{LWL})_{max}$
$.600 \leq C_b \leq .612$	.45	1.10
$.612 < C_b \leq .625$	.45	.90
$.625 < C_b \leq .725$	.40	.90
$.725 < C_b \leq .775$	.35	.875
$.775 < C_b \leq .800$	.35	.800

Within the ranges of independent variables stipulated above, one can expect values of C_t and PC from equations (7) and (8) to agree with the published results of Series 60 to within 1%, with consistent reliability .

IV. DESCRIPTION OF THE EHP-SHP COMPUTER PROGRAM FOR SERIES 60

The program for calculating EHP and SHP using the Series 60 model test results was written in the FORTRAN IV language. A flow chart for the program, a listing of the FORTRAN statements, and the 900 elements of the matrices $[A_{nl}]$ and $[B_{nl}]$ mentioned in Chapter II are included in Appendix A. The following is a general description of the methods of calculation used. Detailed instructions for the use of the program are contained in Appendix C.

1. Inputs

First the elements of matrices $[A_{nl}]$ and $[B_{nl}]$ are read in as data. The number of ships to be calculated (NJOBS) and an identifying alphameric statement is then read. It takes three cards to describe each ship to be calculated. The first card describes the input mode (INOPT) for the ship to be calculated. The operator is afforded an option of one of two possible input modes for each ship.

a. Mode I

Entry is made with L, B, H, C_b, V_{max}, V_{min}, $V_{increment}$, ΔC_f, Position of LCB from ⊗, S, φ, and kinematic viscosity.

b. Mode II

Entry is made with L, B/H, Δ, C_p, V_{max}, V_{min}, $V_{increment}$, ΔC_f, Position of LCB from ⊗, S, φ, and kinematic viscosity.

2. Calculation of needed parameters

Using the input information, the program then calculates the remaining parameters required for executing the remainder of the program. For example, if the entry is made using Mode I, the program calculates Δ, B/H, C_p using equation (1), the Series 60 equivalent LWL using equation (2), the volume of

displacement ∇ , midship coefficient C_m, and L/B.

3. Normalizing hull proportion parameters

The program calculates the normalized hull proportion parameters for L/B, B/H, and C_b using the equations in Table II.

4. Trap to make sure $V/\sqrt{LWL}$ is within range of model test

The program calculates $V/\sqrt{LWL}$ maximum and minimum and ensures that these values are within the range of validity given in Table V. If they are not, the program alters V_{min} and V_{max} accordingly, until they are within the range.

5. Calculation of number of increments in V to be calculated

Using V_{max}, V_{min}, and $V_{increment}$, the number of different speeds (m) at which EHP and SHP are desired is calculated. There is a maximum of 100 different speeds allowed for each ship. If this number exceeds 100, the program keeps doubling $V_{increment}$ until "m" is 100 or less. If the operator desires EHP-SHP information for only one speed, m is set at one.

6. Calculation of V's, $V/\sqrt{LWL}$'s and normalizing $V/\sqrt{LWL}$

The V's and $V/\sqrt{LWL}$'s are calculated based on the V_{min} , $V_{increment}$ LWL, and m calculated above. The $V/\sqrt{LWL}$'s are then normalized using the equation in Table II. If $V_{max} = V_{min}$ and $V_{increment} = 0.$, only one speed is used.

7. Calculation of C_t for a 400 foot ship and PC for a 600 foot ship

The C_t for a ship of L = 400 ft. (C_{tM}) and PC for a ship of L = 600 ft. are calculated for each $V/\sqrt{LWL}$ using the normalized parameters determined above, and equations (7) and (8) respectively. Subroutine CEF* is used to

* See program listing in Appendix A.

evaluate the Chebyshev Polynomials for these equations.

8. <u>Calculation of C_f for a 400 foot ship and C_f for a ship of length L</u>

The Reynolds Numbers (Re) for the L = 400 ft. ship (Re_M) and for the ship of length L (Re_S) are calculated for each $V/\sqrt{LWL}$ by using equations (11) and (12).

$$Re_M{}^{*} = \frac{406.75 \times v_s}{1.2817 \times 10^{-5}} \tag{11}$$

$$Re_S = \frac{LWL \times v_s}{\nu} \tag{12}$$

The C_f's for the 400 ft. ship (C_{f_M}) and ship of length L (C_{f_S}) are calculated using the ATTC 1947 correlation line given in equation (13).

$$C_f^{-.5} = 4.132 \log_{10} (Re \times C_f) \tag{13}$$

In the calculation of the C_f's, it is necessary for the program to use an iteration process, since C_f appears on both sides of equation (13). The initial estimate for this process is made by using the equation for the International Towing Tank Conference (ITTC) line, equation (14).

$$C_f' = \frac{0.075}{(\log_{10} Re - 2)^2} \tag{14}$$

Equation (13) is recycled for 50 times, or until the C_f values converge to within a tolerance of 5.0×10^{-7}. Although this should not occur, if formula (13) does not converge, the program prints the error signal

---

* Note that LWL = 406.75 for a ship of 400 ft. length between perpendiculars, and that kinematic viscosity is for salt water at 59°F.

"SCHOENHER NO CONVERGE" with the speed at which the trouble was experienced.

9. Calculation of wetted surface (S) if not input

Ideally, the wetted surface (S), in square feet, is fed into the computer as input. However, if the wetted surface is not known at that time, the program will calculate an approximate wetted surface using equation (15).

$$S = 2.654 \; (L/B)^{.329} \; (B/H)^{.208} \; (C_b)^{-.0609} \; (\nabla)^{.666} \qquad (15)$$

This equation for approximating wetted surface for the Series 60 was developed by D. Khoushy in reference (2). This formula was tested extensively and compared to the contours for wetted surface calculation, Figures B-124 through B-126, in reference (1). It was found that this formula adequately represents the wetted surface contours of the Series 60, with the maximum error rarely exceeding 1.2%. Since wetted surface is a factor in calculating resistance, EHP and SHP, if wetted surface is not an input parameter to the program, one can expect errors in EHP and SHP due to the use of equation (15), in addition to the errors to be expected due to the use of equations (7) and (8) as discussed in Chapter III.

10. Calculation of C_t for the ship of length L, R, EHP, and SHP

The C_t for the ship of length L, (C_{t_S}), is calculated using equation (16).

$$C_{t_S} = C_{t_M} - C_{f_M} - 0.0004 + C_{f_S} + \Delta C_f \qquad (16)$$

Then the remaining calculations are trivial, namely:

$$R = 1/2 \rho S v_s^2 C_{t_S}$$

$$EHP = \frac{R v_s}{550}$$

$$SHP = \frac{EHP}{PC}$$

where PC is for a ship of L = 600 ft.

11. Calculation of LCB position from ⊗ as a percentage of L

The LCB position from ⊗ as a percentage of length between perpendiculars is calculated and presented in the output. It should be remembered here that corrections to R, EHP, and SHP for variation in LCB position from those of the parent model hull forms are not built into the program. Graphs for assistance in making these corrections, based on Tables 49 through 53 of reference (1), are included in Appendix B. The LCB position from ⊗ as a percentage of length between perpendiculars is calculated for entry to these graphs.

12. Output

The output for each ship calculated includes C_b, L/B, B/H, C_p, Cm, length between perpendiculars (LBP) in feet, LWL in feet, B in feet, H in feet, displacement (DISP) in tons, volume of displacement (VOL) in cubic feet, wetted surface (WSURF) in square feet, ΔC_f, water density ρ in $\frac{lb.\ sec^2}{ft.^4}$, kinematic viscosity (GNU) in $\frac{ft^2}{sec}$, LCB position as a percentage of LBP, and a tabulation of V, $V/\sqrt{LWL}$, R, EHP, PC, and SHP for each speed requested in the input. A statement is printed under this tabulation which reminds the user that the values are not corrected for variation in LCB position as explained above.

V. EXAMPLES IN USE OF THE EHP-SHP COMPUTER PROGRAM FOR KNOWN SHIPS

The final EHP-SHP computer program was tested with the parameters of six ships whose EHP-SHP characteristics are known. As a first test, the Series 60 equivalent of the ship SCHUYLER OTIS BLAND was chosen, since this was the ship used in Appendix D of reference (1) in illustrating a numerical example of the use of the Series 60 charts. It was also chosen since it illustrates the ability of the program to interpolate for intermdeiate values of C_b (0.651) and L/B (6.82) and to extrapolate outside the range of the Series 60 in B/H (2.444).

As a second test, the five parent models of the Series 60, with L = 600 feet, were chosen since complete information on their EHP and SHP behavior is presented in Tables 27 through 31 in reference (1), and they cover a variety of hull proportion combinations.

The results of these tests are discussed below.

1. Test using the ship SCHUYLER OTIS BLAND

As a first test on this ship, input Mode I was used with the wetted surface area of 39994.0 square feet as input. As a result, the computer output, Table VI, for EHP was a measure of the accuracy of equation (7). In comparing the computer program's EHP results with those resulting from the hand calculations carried out in Table D-3 of reference (1), it was found that the maximum error experienced in EHP was + 2.70% at $V/\sqrt{LWL}$ = .85, while the average error experienced was + 1.19% . Although the average error of 1.19% is fairly gratifying, the maximum error certainly is not. However, referring to Table IV again we see that in using the hull proportions of the SCHUYLER OTIS BLAND we place ourselves in the neighborhood of parent model

TABLE VI

Computer Output SCHUYLER OTIS BLAND, Wetted Surface as Input

```
9   TEST RUN OF EHP SHP PROGRAM

CB= 0.651    L/B= 6.818    B/H= 2.444    CP= 0.662    CM= 0.983
LBP=  450.00 FT    LWL=  457.59 FT    B=   66.00 FT    H=   27.00 FT
DISP=  14915.33 TONS    VOL=   522036.56 FT**3    WSURF=  39994.00 FT**2
DELTA CF= 0.0004000    RHO= 1.9904995 LB*SEC**2/FT**4    GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.000 PERCENT OF LBP AFT OF AMIDSHIPS.
```

V (KTS)	V/RTLWL	R (LBS)	EHP (HP)	PC	SHP (HP)
8.557	0.4000	22159.35	582.26	0.9302	625.96
9.627	0.4500	28125.36	831.44	0.8091	1027.57
10.697	0.5001	35482.00	1165.50	0.8185	1423.90
11.767	0.5501	42740.56	1544.35	0.8333	1853.22
12.837	0.6001	51097.96	2014.23	0.8228	2448.00
13.907	0.6501	61709.68	2635.29	0.8023	3284.84
14.977	0.7001	73426.81	3376.92	0.7907	4270.78
16.047	0.7502	84243.62	4151.18	0.7901	5254.16
17.117	0.8002	96300.19	5051.69	0.7853	6433.36
18.187	0.8502	119834.44	6692.43	0.7663	8732.97
19.257	0.9002	169401.37	10017.20	0.7270	13779.42

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***

TABLE VII

Computer Output SCHUYLER OTIS BLAND, No Wetted Surface as Input

```
9   TEST RUN OF EHP SHP PROGRAM

CB= 0.651   L/B= 6.818   B/H= 2.444   CP= 0.662   CM= 0.983
LBP=  450.00 FT   LWL=  457.59 FT   B=   66.00 FT   H=   27.00 FT
DISP=  14915.33 TONS   VOL=   522036.56 FT**3   WSURF=  39651.54 FT**2
DELTA CF= 0.0004000   RHO= 1.9904995 LB*SEC**2/FT**4   GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.000 PERCENT OF LBP AFT OF AMIDSHIPS.
```

V (KTS)	V/RTLWL	R (LBS)	EHP (HP)	PC	SHP (HP)
8.557	0.4000	21967.97	577.21	0.9303	620.46
9.627	0.4500	27881.64	824.20	0.8091	1018.61
10.697	0.5000	35175.26	1155.37	0.8185	1411.55
11.767	0.5501	42371.59	1530.97	0.8333	1837.16
12.837	0.6001	50656.73	1996.77	0.8228	2426.76
13.907	0.6501	61176.62	2612.44	0.8023	3256.33
14.977	0.7001	72793.44	3347.69	0.7907	4233.30
16.047	0.7501	83518.00	4115.31	0.7901	5208.77
17.117	0.8002	95469.56	5017.90	0.7868	6377.68
18.187	0.8502	116794.31	6634.18	0.7664	8656.82
19.257	0.9002	157924.62	9929.66	0.7270	13658.64

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***

TABLE VIII

Computer Output Model 4210, L = 600 ft.

9 TEST RUN OF EHP SHP PROGRAM

CB= 0.600   L/B= 7.500   B/H= 2.500   CP= 0.613   CM= 0.979
LBP= 600.00 FT   LWL= 610.12 FT   B= 80.00 FT   H= 32.00 FT
DISP= 26331.41 TONS   VOL= 921599.31 FT**3   WSURF= 60320.19 FT**2
DELTA CF= 0.0004000   RHO= 1.9904995 LB*SEC**2/FT**4   GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.500 PERCENT OF LBP AFT OF AMIDSHIPS.

V (KTS)	V/RTLWL	R (LBS)	EHP (HP)	PC	SHP (HP)
12.000	0.4858	62025.71	2285.57	0.7862	2907.00
12.500	0.5061	67855.12	2604.56	0.7833	3325.19
13.000	0.5263	73815.69	2946.68	0.7912	3724.31
13.500	0.5465	79717.31	3304.66	0.7992	4135.09
14.000	0.5668	85594.62	3679.73	0.8026	4584.66
14.500	0.5870	91624.31	4079.62	0.8008	5094.66
15.000	0.6073	98030.37	4515.36	0.7949	5680.24
15.500	0.6275	104992.00	4997.23	0.7872	6348.00
16.000	0.6478	112576.31	5531.05	0.7797	7093.68
16.500	0.6680	120707.19	6115.87	0.7740	7901.46
17.000	0.6882	129181.81	6743.59	0.7710	8746.97
17.500	0.7085	137729.56	7401.27	0.7706	9604.01
18.000	0.7287	146107.69	8075.82	0.7725	10454.11
18.500	0.7490	154215.00	8760.71	0.7755	11296.42
19.000	0.7692	162197.37	9463.21	0.7735	12155.68
19.500	0.7895	170521.37	10210.68	0.7802	13087.20
20.000	0.8097	179986.12	11053.76	0.7796	14177.99
20.500	0.8299	191659.50	12064.95	0.7762	15543.65
21.000	0.8502	206724.00	13330.65	0.7697	17319.16
21.500	0.8704	226244.75	14935.82	0.7605	19641.54
22.000	0.8907	250868.19	16949.00	0.7492	22622.29
22.500	0.9109	280542.37	19339.96	0.7370	26310.78
23.000	0.9311	314607.50	22219.70	0.7248	30654.70
23.500	0.9514	350943.06	25324.78	0.7139	35472.14
24.000	0.9716	387053.87	28524.88	0.7051	40455.93
24.500	0.9919	420074.31	31603.34	0.6988	45227.64
25.000	1.0121	447651.25	34365.35	0.6950	49444.45
25.500	1.0324	468923.75	36718.37	0.6937	52932.97
26.000	1.0526	485422.50	38755.58	0.6946	55799.49

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***

TABLE IX

Computer Output Model 4218, L = 600 ft.

```
9  TEST RUN OF EHP SHP PROGRAM

CB= 0.650   L/B= 7.250   B/H= 2.500   CP= 0.661   CM= 0.983
LBP=  600.00 FT   LWL=  610.12 FT   B=   82.76 FT   H=   33.10 FT
DISP=  30526.83 TONS   VOL=  1068438.00 FT**3   WSURF=  65503.41 FT**2
DELTA CF= 0.0004000   RHO= 1.9904995 LB*SEC**2/FT**4   GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.540 PERCENT OF LBP AFT OF AMIDSHIPS.
```

V (KTS)	V/RTLWL	R (LBS)	EHP (HP)	PC	SHP (HP)
10.000	0.4048	47318.60	1453.02	0.7839	1853.58
10.500	0.4251	51747.85	1668.49	0.7872	2119.64
11.000	0.4453	57288.19	1935.08	0.7883	2454.88
11.500	0.4656	63346.29	2236.97	0.7913	2827.09
12.000	0.4858	69503.19	2561.10	0.7961	3217.10
12.500	0.5061	75544.25	2899.70	0.8011	3619.82
13.000	0.5263	81491.25	3253.09	0.8044	4044.36
13.500	0.5465	87522.87	3628.24	0.8048	4508.37
14.000	0.5668	93916.31	4037.48	0.8020	5034.02
14.500	0.5870	100951.62	4494.92	0.7966	5642.37
15.000	0.6073	108825.12	5012.58	0.7896	6347.98
15.500	0.6275	117583.12	5596.52	0.7823	7153.75
16.000	0.6478	127093.69	6244.32	0.7759	8047.86
16.500	0.6680	137064.75	6944.66	0.7712	9004.46
17.000	0.6882	147110.37	7679.50	0.7688	9989.56
17.500	0.7085	156860.44	8429.32	0.7683	10971.77
18.000	0.7287	166098.00	9180.75	0.7692	11935.77
18.500	0.7490	174904.00	9936.02	0.7705	12895.72
19.000	0.7692	183779.56	10722.39	0.7711	13906.07
19.500	0.7895	193720.06	11599.79	0.7698	15069.05
20.000	0.8097	206208.75	12664.21	0.7658	16537.93
20.500	0.8299	223114.19	14045.61	0.7585	18515.80
21.000	0.8502	240476.62	15894.11	0.7481	21246.88
21.500	0.8704	278195.69	18366.65	0.7348	24996.67
22.000	0.8907	319643.37	21593.82	0.7194	30016.61

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***

TABLE X

Computer Output Model 4221, L = 600 ft.

9 TEST RUN OF EHP SHP PROGRAM

CB= 0.700 L/B= 7.000 B/H= 2.500 CP= 0.709 CM= 0.987
LBP= 600.00 FT LWL= 616.12 FT B= 85.71 FT H= 34.29 FT
DISP= 35265.23 TONS VOL= 1234282.00 FT**3 WSURF= 70961.75 FT**2
DELTA CF= 0.0004000 RHO= 1.9904995 LB*SEC**2/FT**4 GNU= 0.128169995E-04 FT**2/SEC
LCB IS 0.550 PERCENT OF LBP AFT OF AMIDSHIPS.

V (KTS)	V/RTLWL	R (LBS)	EHP (HP)	PC	SHP (HP)
10.000	0.4048	52995.75	1627.35	0.8240	1974.99
10.500	0.4251	58169.74	1875.55	0.8276	2266.24
11.000	0.4453	64292.62	2171.67	0.8271	2625.62
11.500	0.4656	70977.81	2506.46	0.8231	3045.03
12.000	0.4858	77922.75	2871.35	0.8173	3513.22
12.500	0.5061	84933.81	3260.10	0.8112	4018.77
13.000	0.5263	91980.87	3671.82	0.8060	4555.54
13.500	0.5465	99147.75	4110.15	0.8022	5123.81
14.000	0.5668	106616.44	4583.45	0.7996	5731.94
14.500	0.5870	114609.50	5103.05	0.7980	6394.65
15.000	0.6073	123332.25	5680.79	0.7968	7129.89
15.500	0.6275	132919.12	6326.45	0.7953	7954.70
16.000	0.6478	143397.69	7045.36	0.7933	8881.52
16.500	0.6680	154681.19	7837.23	0.7904	9915.67
17.000	0.6882	166596.19	8696.71	0.7867	11055.37
17.500	0.7085	178947.19	9616.21	0.7822	12294.52
18.000	0.7287	191616.94	10591.25	0.7771	13629.15
18.500	0.7490	204693.38	11628.31	0.7717	15068.03
19.000	0.7692	218605.00	12754.25	0.7662	16645.63
19.500	0.7895	234246.88	14026.51	0.7608	18437.24
20.000	0.8097	253066.56	15541.90	0.7555	20573.02
20.500	0.8299	277086.56	17442.57	0.7502	23249.56
21.000	0.8502	308829.37	19914.94	0.7448	26738.90
21.500	0.8704	351123.19	23181.37	0.7382	31400.77
22.000	0.8907	406778.25	27480.31	0.7285	37721.46

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***

TABLE XI

Computer Output Model 4213, L = 600 ft.

9 TEST RUN OF EHP SHP PROGRAM

CB= 0.750 L/B= 6.750 B/H= 2.500 CP= 0.757 CM= 0.991
LBP= 600.00 FT LWL= 610.12 FT B= 88.89 FT H= 35.56 FT
DISP= 40634.83 TONS VOL= 1422218.00 FT**3 WSURF= 76735.56 FT**2
DELTA CF= 0.000400 RHO= 1.9904995 LB*SEC**2/FT**4 GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.500 PERCENT OF LBP FWD OF AMIDSHIPS.

V (KTS)	V/RTLWL	R (LBS)	EHP (HP)	PC	SHP (HP)
10.000	0.4048	60930.57	1871.01	0.8431	2219.11
10.500	0.4251	67217.81	2167.28	0.8325	2603.49
11.000	0.4453	73817.31	2493.40	0.8227	3030.66
11.500	0.4656	80747.50	2851.47	0.8156	3496.06
12.000	0.4858	88073.56	3245.40	0.8111	4001.34
12.500	0.5061	95858.06	3679.42	0.8084	4551.76
13.000	0.5263	104177.25	4158.70	0.8066	5155.83
13.500	0.5465	113068.50	4687.23	0.8051	5821.81
14.000	0.5668	122559.50	5268.85	0.8034	6558.30
14.500	0.5870	132694.56	5908.29	0.8011	7375.62
15.000	0.6073	143584.62	6613.63	0.7979	8289.30
15.500	0.6275	155464.94	7399.55	0.7935	9324.85
16.000	0.6478	168750.25	8290.97	0.7879	10523.30
16.500	0.6680	184053.75	9325.70	0.7807	11945.74
17.000	0.6882	202198.56	10555.24	0.7718	13675.62
17.500	0.7085	224087.81	12041.96	0.7614	15816.23
18.000	0.7287	250609.75	13851.97	0.7495	18481.37
18.500	0.7490	282410.19	16043.28	0.7367	21778.01
19.000	0.7692	319660.56	18650.21	0.7234	25780.09
19.500	0.7895	361652.31	21667.42	0.7104	30499.04
20.000	0.8097	407692.94	25038.27	0.6982	35862.39
20.500	0.8299	455225.00	28656.37	0.6869	41720.00
21.000	0.8502	502299.00	32390.80	0.6762	47903.32
21.500	0.8704	547560.62	36159.28	0.6650	54359.84

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***

TABLE XII

Computer Output Model 4214, L = 600 ft.

9 TEST RUN OF EHP SHP PROGRAM

CB= 0.800   L/B= 6.500   B/H= 2.500   CP= 0.804   CM= 0.995
LBP= 600.00 FT   LWL= 610.12 FT   B= 92.31 FT   H= 30.92 FT
DISP= 46742.03 TONS   VOL= 1635970.00 FT**3   WSURF= 82869.75 FT**2
DELTA CF= 0.0004000   RHO= 1.9904995 LB*SEC**2/FT**4   GNU= 0.128169995E-04 FT**2/SEC
LCB IS 2.500 PERCENT OF LBP FWD OF AMIDSHIPS.

V (KTS)	V/RTLWL	R (LBS)	EHP (HP)	PC	SHP (HP)
9.000	0.3644	55512.29	1534.17	0.8240	1861.83
9.500	0.3846	61758.31	1801.61	0.8234	2188.12
10.000	0.4048	68416.94	2100.90	0.8210	2559.06
10.500	0.4251	75455.37	2432.88	0.8176	2975.81
11.000	0.4453	82871.31	2799.23	0.8133	3441.86
11.500	0.4656	90683.81	3202.35	0.8083	3961.83
12.000	0.4858	98942.81	3645.91	0.8029	4541.12
12.500	0.5061	107720.87	4134.76	0.7974	5185.47
13.000	0.5263	117135.81	4677.79	0.7922	5904.72
13.500	0.5465	127568.44	5288.32	0.7876	6714.32
14.000	0.5668	139260.75	5986.64	0.7836	7640.30
14.500	0.5870	152772.94	6802.29	0.7798	8722.90
15.000	0.6073	168731.44	7771.92	0.7758	10018.46
15.500	0.6275	187810.87	8939.09	0.7707	11599.04
16.000	0.6478	210635.69	10345.67	0.7638	13549.25
16.500	0.6680	237661.06	12042.58	0.7545	15962.04
17.000	0.6882	269223.06	14054.34	0.7422	18936.35
17.500	0.7085	305488.94	16416.28	0.7268	22585.79
18.000	0.7287	347016.56	19180.68	0.7085	27072.04
18.500	0.7490	395596.62	22473.23	0.6874	32692.44
19.000	0.7692	455781.69	26592.64	0.6637	40067.29

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***

TABLE XIII

Maximum and Average % Errors in EHP and SHP for 5 Parent Models, L = 600 ft.

Model No.	% Error in EHP		% Error in SHP	
	Max.	Avg.	Max.	Avg.
4210	1.48	.49	1.43	.57
4218	2.12	.74	2.10	.90
4221	2.32	.93	2.25	.99
4213	1.44	.79	1.51	.82
4214	.915	.32	1.13	.34

4218 where the maximum error of 2.74% was experienced in the test of equation (7).

The SCHUYLER OTIS BLAND was also tested without wetted surface as input. The results of this run are presented in Table VII. We can see that the wetted surface calculated by equation (15), 39651.54 square feet, is in error by -.858%. The error in the calculation of wetted surface area tends to reduce the error in EHP in this instance.

One must keep in mind that we are comparing computer output with values derived from hand calculations, in which design charts were read with an unknown accuracy.

2. <u>Test using the five parent models of Series 60 with L = 600 feet</u>

The results of the computer run with the five parent models of Series 60 with L = 600 feet are presented in Tables VIII through XII. In these cases, the wetted surface area of the ships was calculated by equation (15), since it was not known. The maximum and average percent errors in EHP and SHP experienced in this test are presented in Table XIII. Although at some points the errors exceeded 2%, in no case did the average error exceed 1%. These errors are probably due mainly to the innacuracy of the equation used for wetted surface area.

VI. CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of tests run to date, one can conclude that the EHP-SHP computer program presented herein can be relied upon to estimate the EHP-SHP requirements of single-screw merchant ships, falling within the range of hull proportions of the Series 60, to a tolerance in the neighborhood of 1% on the average, and with great certainty, to within a tolerance of less than 3% for any given speed.

The weak link in the EHP-SHP program appears to be the calculation of wetted surface area. It is recommended that the representation of the Series 60 wetted surface contours be further investigated, to determine whether equation (15) can be modified and improved.

It is further recommended that the elements of matrices $[A_{nl}]$ and $[B_{nl}]$ be punched in the form of FORTRAN data statements, and included in the body of the main program. This will greatly facilitate its conversion to a subroutine for inclusion in a larger program if it were so desired.

It is also recommended that the program be extensively tested with existing ships, to further determine its accuracy.

VII. REFERENCES

(1) Todd, F. H., "Series 60 Methodical Experiments With Models of Single-Screw Merchant Ships", David Taylor Model Basin Report 1712, July 1963.

(2) Khoushy, D., "A Method of Estimating EHP From Standard Series Model Testing Results", M.I.T. Department of Naval Architecture and Marine Engineering Report, February 1962.

(3) Pitidis-Poutous, T. M., "The Mathematical Derivation of Preliminary Ship Lines", M.I.T. Department of Naval Architecture and Marine Engineering Report 65-3, February 1965.

(4) Pitidis-Poutous, T. M., "The Computerization of Series 60 Resistance and Propulsion Experiments", M.I.T. Department of Naval Architecture and Marine Engineering Report, May 1967.

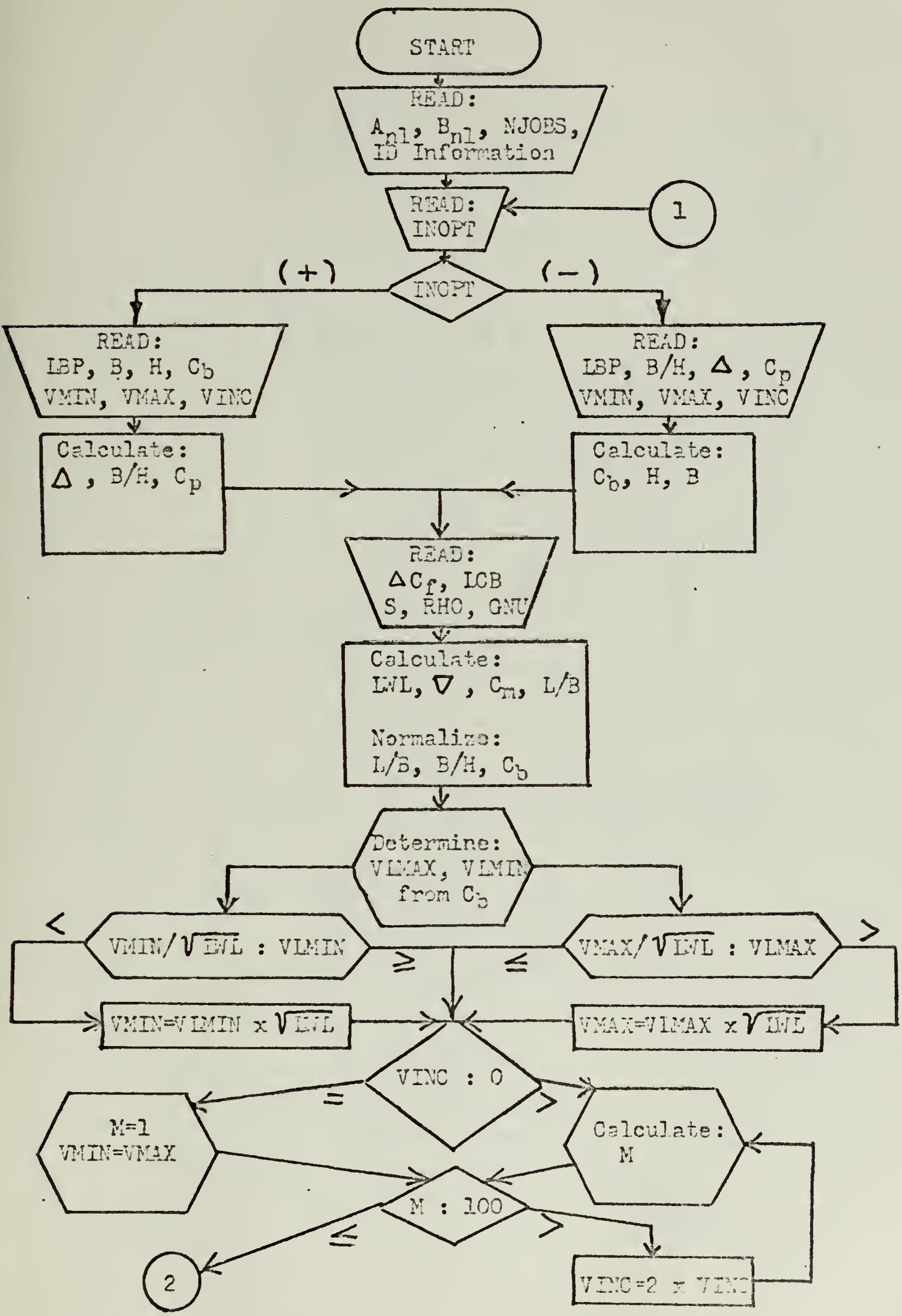
(5) Hildebrand, F. B., "Introduction to Numerical Analysis", McGraw-Hill Book Company, 1956.

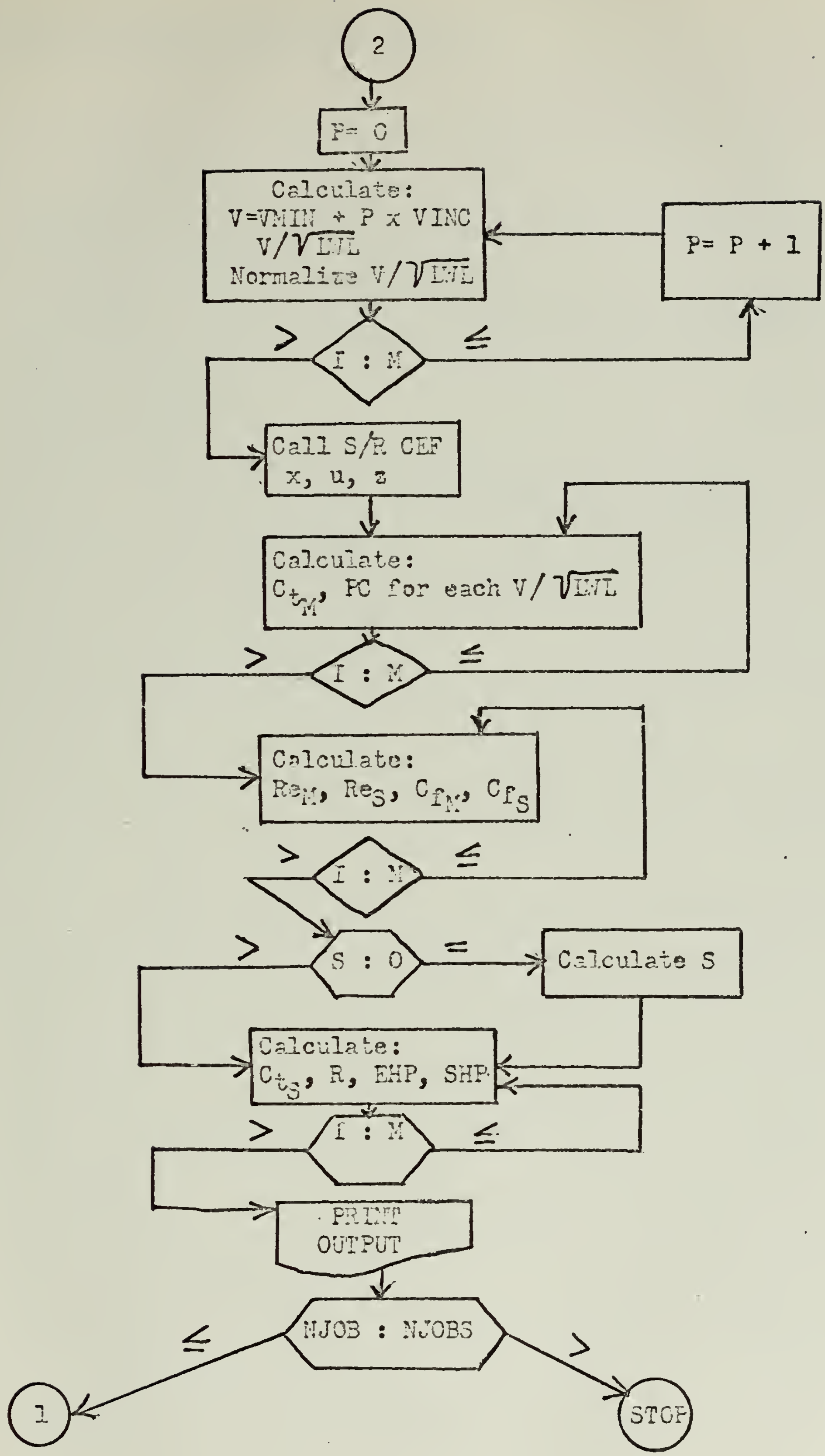
VIII. APPENDIX

APPENDIX A

PROGRAM LISTINGS

1. Flow Chart for EHP-SHP Program.





2
P= 0
Calculate:
V=VMIN + P x VINC
V/√LWL
Normalize V/√LWL
P= P + 1
I : M
>
≤
Call S/R CEF
x, u, z
Calculate:
C_tM, PC for each V/√LWL
I : M
>
≤
Calculate:
Re_M, Re_S, C_fM, C_fS
I : M
>
≤
S : 0
>
=
Calculate S
Calculate:
C_tS, R, EHP, SHP
I : M
>
≤
PRINT
OUTPUT
NJOB : NJOBS
≤
>
1
STOP

2. Listing of EHP-SHP program and S/R CEF

```
C     PROGRAM TO CALC EHP,SHP USING SERIES 60 MODEL TEST RESULTS
      DIMENSION A(10,45),B(10,45)
      DIMENSION VS(100),VL(100),V(100),AVL(10),BVL(10),PHI(10)
      DIMENSION PSI(10),CHI(10),VPHI(10),CTM(100),PCM(100),CFS(100)
      DIMENSION CFM(100),CTS(100),R(100),EHP(100),SHP(100),QQ(20)
    1 FORMAT (5F16.7)
    2 FORMAT (I4,19A4)
    3 FORMAT (7F10.2)
    4 FORMAT (4F10.6,E10.6)
    5 FORMAT (28H SCHOENHER NO CONVERGE.   VS=,F6.3)
    6 FORMAT (4HOCB=, F6.3, 2X, 5H L/B=,F6.3,2X,5H B/H=,F6.3,2X,4H CP=,
     1F6.3,2X,4H CM=,F6.3)
    7 FORMAT (5H LBP=,F8.2,3H FT,2X,5H LWL=,F8.2,3H FT,2X,3H B=,
     1F8.2,3H FT,2X,3H H=,F8.2,3H FT)
    8 FORMAT ( 6H DISP=,F10.2,5H TONS,2X,5H VOL=,F12.2,6H FT**3,2X,
     17H WSURF=,F10.2,6H FT**2)
    9 FORMAT (1H0,2X,7HV (KTS),3X,7HV/RTLWL,6X,7HR (LBS),5X,8HEHP (HP),
     14X,2HPC,7X,8HSHP (HP))
   10 FORMAT (F9.3,F10.4,F14.2,F13.2,F8.4,F13.2)
  500 FORMAT (7H LCB IS,F6.3,33H PERCENT OF LBP AFT OF AMIDSHIPS.)
  501 FORMAT (21H LCB IS AT AMIDSHIPS.)
  502 FORMAT (7H LCB IS,F6.3,33H PERCENT OF LBP FWD OF AMIDSHIPS.)
  503 FORMAT (I4)
  504 FORMAT (1H1,I4,19A4)
  505 FORMAT (10H DELTA CF=,F10.7,2X,5H RHO=,F10.7,16H LB*SEC**2/FT**4,
     12X, 5H GNU=,E16.9,10H FT**2/SEC)
  506 FORMAT (74H0 *** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATIO
     1OF LCB POSITION ***)
C     READ COEFF OF POL FOR CTM AND PCM
      DO 200 N=1,10
      READ (5,1) (A(N,L),L=1,45)
  200 CONTINUE
      DO 201 N=1,10
      READ (5,1) (B(N,L),L=1,45)
  201 CONTINUE
C     READ NUMBER OF SHIPS AND ID INFO
      READ (5,2) NJOBS, (QQ(L),L=1,19)
      DO 1000 NJOB=1,NJOBS
C     READ INPUT AND CALC NEEDED PARAMETERS FOR SHIP
      READ (5,503) INOPT
      IF (INOPT) 900,900,901
  900 READ(5,3) XLBP, BH, DEL,CP,VMIN,VMAX,VINC
      CB=.0557*(CP)**2 + .925*CP
      H=SQRT((35.*DEL)/(CB*XLBP*BH))
      BM=BH*H
      GO TO 903
  901 READ(5,3) XLBP, BM, H, CB, VMIN, VMAX, VINC
      DEL=CB*XLBP*BM*H/35.
```

```
      BH=BM/H
      CP=(-.925 + SQRT(.925**2 + 4.*.0375*CB))/(2.*.0375)
  903 READ (5,4)DCF,XLCB,WSURF,RHO,GNU
      XLWL=406.75*XLBP/400.
      VOL=35.*DEL
      CM=CB/CP
      BL=XLBP/BM
C     NORMALIZE PARAMETERS
  600 U=(-7.0 + BL)/1.5
      Z=-6.0 + 2.0*BH
      X=-7.0 + 10.0*CB
C     TRAP TO MAKE SURE VL IS WITHIN RANGE OF MODEL TEST RESULTS
      IF (CB.GE.0.60.AND.CB.LE.0.612) GO TO 800
      IF (CB.GT.0.612.AND.CB.LE.0.625) GO TO 801
      IF (CB.GT.0.625.AND.CB.LE.0.725) GO TO 802
      IF (CB.GT.0.725.AND.CB.LE.0.775) GO TO 803
      IF (CB.GT.0.775.AND.CB.LE.0.800) GO TO 804
  800 VLMIN=.45
      VLMAX=1.1
      GO TO 11
  801 VLMIN=.45
      VLMAX=.90
      GO TO 11
  802 VLMIN=.40
      VLMAX=.90
      GO TO 11
  803 VLMIN=.35
      VLMAX=.875
      GO TO 11
  804 VLMIN=.35
      VLMAX=.80
   11 IF (VMIN/(XLWL**.5)-VLMIN)12,13,13
   12 VMIN=VLMIN*(XLWL**.5)
   13 IF (VLMAX-VMAX/(XLWL**.5))14,15,15
   14 VMAX=VLMAX*(XLWL**.5)
C     CALC OF M. IF VINC=0.,M=1 THROUGHOUT PROGRAM
   15 IF (VINC.GT.0.) GO TO 16
      M=1
      VMIN=VMAX
      GO TO 20
   16 VM=(VMAX-VMIN)/VINC + 0.5
      M=VM
      M=M + 1
C     MAKE SURE M NOT GREATER THAN 100
      IF (M.LE.100) GO TO 20
      VINC=2.0*VINC
      GO TO 15
C     CALC OF SHIPS V, V OVER RT LWL, NORMALIZE V OVER RT LWL
```

```
20 P=0.0
   DO 30 I=1,M
   VS(I)=VMIN + P*VINC
   VL(I)=VS(I)/(XLWL**.5)
   V(I)=2.5*VL(I)-1.875
   P=P+1.0
30 CONTINUE
C     CALC OF CT'S AND PC'S FOR 400 FT MODEL
   CALL CEF(5,X,CHI)
   CALL CEF(3,U,PHI)
   CALL CEF(3,Z,PSI)
   DO 32 N=1,10
   AVL(N)=0.0
   BVL(N)=0.0
32 CONTINUE
   DO 35 K=1,5
   DO 35 I=1,3
   DO 35 J=1,3
   L=J + 3*(I-1) + 9*(K-1)
   DO 35 N=1,10
   AVL(N)=AVL(N)+A(N,L)*PHI(J)*PSI(I)*CHI(K)
   BVL(N)=BVL(N)+B(N,L)*PHI(J)*PSI(I)*CHI(K)
35 CONTINUE
   DO 40 IM=1,M
   CALL CEF(10,V(IM),VPHI)
   CTM(IM)=0.0
   PCM(IM)=0.0
   DO 36 N=1,10
   CTM(IM)=CTM(IM)+AVL(N)*VPHI(N)
36 PCM(IM)=PCM(IM)+BVL(N)*VPHI(N)
   CTM(IM)=CTM(IM)*VL(IM)*VL(IM)*0.001
40 CONTINUE
C     CALC OF CF'S FOR 400 FT MODEL AND OUR SHIP LENGTH
   DO 50 I=1,M
   REM=(VS(I)*1.6889*406.75)/(1.2817E-05)
   RES=(VS(I)*1.6889*XLWL)/(CNU)
   CFM(I)=0.075/(((ALOG(REM)/2.3025851)-2.0)**2)
   CFS(I)=0.075/(((ALOG(RES)/2.3025851)-2.0)**2)
   DO 45 K=1,50
   DUMMY=CFM(I)
   BOGUS=CFS(I)
   CFM(I)=(2.3025851/(4.132*ALOG(REM*CFM(I))))**2
   CFS(I)=(2.3025851/(4.132*ALOG(RES*CFS(I))))**2
   IF(ABS(DUMMY-CFM(I))-5.0E-07)41,41,45
41 IF(ABS(BOGUS-CFS(I))-5.0E-07)50,50,45
45 CONTINUE
   WRITE (6,5) VS(I)
50 CONTINUE
```

```
C     CALC OF WSURF IF NOT GIVEN
      IF (WSURF.GT.0.) GO TO 52
      WSURF=2.654*(BL**.329)*(BH**.206)*(1./CB**.0609)*(VOL**.666)
C     CALC OF OUTPUT
   52 DO 60 I=1,M
      CTS(I)=CTM(I)-CFM(I)-0.0004+CFS(I)+DCF
      R(I)=0.5*RHO*WSURF*((VS(I)*1.6889)**2)*CTS(I)
      EHP(I)=(R(I)*VS(I)*1.6889)/550.
      SHP(I)=EHP(I)/PCM(I)
   60 CONTINUE
      WRITE (6,504) NJOBS, (QQ(L),L=1,19)
      WRITE (6,6) CB,BL,BH,CP,CM
      WRITE (6,7) XLBP,XLWL,BM,H
      WRITE (6,8) DEL, VOL, WSURF
      WRITE (6,505) DCF,RHO,GNU
C     CALC POSIT OF LCB AS PERCENT LBP
      PLCB=ABS(XLCB*100./XLBP)
      IF(XLCB)300,301,302
  300 WRITE (6,500) PLCB
      GO TO 80
  301 WRITE (6,501)
      GO TO 80
  302 WRITE (6,502) PLCB
   80 WRITE (6,9)
      DO 70 I=1,M
      WRITE (6,10) VS(I),VL(I),R(I),EHP(I),PCM(I),SHP(I)
   70 CONTINUE
      WRITE (6,506)
 1000 CONTINUE
      STOP
      END.
```

```
      SUBROUTINE CEF(IQ,U,CEV)
      DIMENSION CEV(10)
      CEV(1)=1.
      CEV(2)=U
      DO 1 I=3,IQ
    1 CEV(I)=2.*U*CEV(I-1)-CEV(I-2)
      RETURN
      END
```

3. Listing of the elements of matrices $\left[A_{nl}\right]$ and $\left[B_{nl}\right]$

14.5496749	.5716764	-8.2847855	-3.8561125	-1.7527813
-4.2498243	3.6124631	6.9628193	9.5129474	-.1362346
3.0622852	-10.7471809	-1.9325106	-1.8457452	-1.9138988
3.4111510	6.6729977	8.6686578	10.9422909	-1.1619693
5.1626700	-12.7457705	3.8944108	-20.6135871	.2975470
-3.1337792	-1.5805094	-4.1246761	-4.3190157	9.2565368
2.6226676	4.1792587	2.9804134	-3.7988752	-7.7339188
-9.5670892	-18.9723346	-2.0663788	1.4384205	17.0297606
-.1651251	26.2876034	-3.7946664	-5.4386603	-8.5539843
2.0543374	6.0696035	-14.7957796	-8.0446357	-5.2953234
-9.6466057	6.6879889	15.2288588	19.5549841	3.3218863
10.0803037	-18.7150843	-5.4674808	-8.7203598	-4.4610978
7.4975004	16.6380384	19.5020454	21.5180669	1.3053365
11.7528948	-25.7646174	4.4902981	-41.6621118	.4519087
-1.9336088	-.7903185	-4.0614309	-6.6258063	19.3319943
3.2480401	5.8423042	4.0355520	-6.4192246	-12.6607876
-16.1050329	-36.8042016	-1.8150560	3.9613633	31.8206713
-1.4036943	50.2369723	-6.9833475	-8.3405252	-15.8904130
15.6760455	10.4243429	-10.1061479	-8.8934225	-9.5402666
-9.6399064	6.2720277	17.9089139	20.2862217	6.1209267
21.5296779	-9.4334426	-9.5180357	-16.4130535	-9.0837952
6.9852836	25.4480231	24.0250919	27.9649415	8.6855114
15.5010594	-26.4746642	-3.9946576	-40.3662152	1.8919065
6.7128025	5.8870946	.3066370	.2028761	21.0287769
-.5120574	.0038713	.3865842	-4.5718835	-3.4520131
-9.9060216	-29.2158365	1.1079659	5.6389875	24.9728816
-3.3926241	41.8341432	-4.8893459	-3.6825050	-11.5304912
9.6277839	16.2365427	-4.7057711	-9.1724963	-12.4285052
-10.1977649	4.9444501	19.3510261	19.8452249	14.4467354
30.3299296	-1.1930575	-12.6853125	-24.2127221	-10.9986560
6.9635317	31.6147134	27.1034150	29.7396600	16.3621583
18.0186410	-25.0731938	-11.5984603	-37.1239061	2.1597570
15.6393522	11.2933784	8.2181656	5.6847672	21.3774393
-4.9929367	-5.4918893	-3.9628538	-1.7890584	4.8907150
-2.2783773	-22.1802971	5.0908844	7.1318989	16.8954766

-5.3170545	31.9314883	-2.6228630	2.2978479	-6.7321571
11.8046221	16.8483317	-1.3616961	-8.0307753	-12.9745721
-8.0623987	3.7068108	17.5423138	16.8846807	15.0283954
33.0343471	4.3873239	-13.0649903	-24.7953579	-11.6603972
5.3567724	31.9054513	25.5359321	30.3489339	18.1544290
16.9426033	-21.3634393	-14.9297326	-30.0821266	2.7397027
18.8139179	14.2128931	10.4517306	9.0564336	18.7859466
-6.9630762	-8.2956539	-5.7272328	-.1419604	10.5126357
2.3896891	-13.4521494	6.2375143	7.1761674	9.1655771
-5.5363443	21.1195140	-.6466088	5.3161080	-2.7937962
7.6491293	13.9565181	.3390148	-5.9243636	-9.7889333
-5.9891410	2.1740156	12.9872986	12.2557778	13.8835579
26.4788816	4.7188652	-10.3004735	-20.0587032	-8.1084230
3.9316863	24.9271210	19.5834780	23.1302602	15.4776404
12.8033336	-15.1794297	-12.9500010	-21.2708123	1.9024716
16.5526330	11.9899117	11.2554277	7.8358411	13.8824370
-6.9536052	-7.4361722	-5.8352085	.9578657	10.4258676
4.4426124	-8.2991840	5.9466958	5.5967175	4.0256317
-4.5155461	13.0371617	.4170871	6.2461205	-.4626160
4.9686791	8.6509578	.2686214	-3.3365207	-5.9321306
-2.8857442	1.1369262	7.5211015	7.1035506	7.4280680
17.1709690	3.2091572	-6.2114894	-11.8777188	-4.8145428
2.0169939	15.3641480	11.9175990	15.3347312	9.5342816
7.4719890	-8.9593991	-8.3577209	-12.3337072	1.3293714
10.6678203	8.1875609	7.5991908	5.2796269	8.1964577
-4.8612539	-4.9861941	-3.8979355	.8635454	7.7172657
3.4956292	-3.7062310	3.8165946	3.4439623	1.0522689
-2.7007209	6.6725984	.7108781	4.5104439	.3161128

1.8698787	4.1853800	.1487274	-1.4806088	-2.4141309
-1.3599608	.3849398	3.2194672	3.2861004	3.5065768
8.0321795	1.1042810	-2.7129406	-5.4433204	-1.5610843
.9066764	7.0042307	5.4522433	7.2624248	4.5968636
3.2530742	-4.0148737	-3.9639859	-5.8328272	.4449681
5.1658454	3.8165532	4.6500745	2.2620510	3.7979926
-2.7570346	-2.3180079	-2.2647659	.6140505	3.8909949
2.1204210	-1.9672355	2.0035094	1.5157595	.0777516
-1.2868009	3.2611810	.5318359	2.6815342	.3713358

.6317063	1.2919876	-.0614546	-.3943637	-.7158684
-.2238261	.1009914	.9291503	1.0207273	.6062516
2.7640227	.1930576	-.8110600	-1.5137119	-.4134494
.2020339	2.2247532	1.7596720	2.7374516	1.3432676
.9466791	-1.3162949	-1.2800668	-1.9916549	.1605352
1.6722767	1.3877910	1.6617658	.7139192	1.2068615
-1.0138914	-.8003770	-.7665300	.2162399	1.4866735
.7438036	-.5834124	.6620204	.4691336	-.1558392
-.3716514	1.0945180	.2508349	.9909297	.1530140
.0595172	.2578350	.0155676	-.0807562	-.0264893
-.1076959	.0035852	.0877803	.2221843	.1107132
.4579571	-.0435932	-.0877597	-.2452759	.1088370
.0257313	.3892129	.2623063	.5089674	.2720818
.1193083	-.2068912	-.2309001	-.4405312	-.0214911
.2874346	.1844823	.4975139	.0289373	.2555876
-.2742635	-.0980271	-.2669222	.0689909	.2763594
.2169974	-.3020333	.1725841	.0330133	-.0344202
-.0965055	.3777790	.0780696	.3087687	.0584769
.2541038	.4232967	.0767439	.1033556	-.5678897
.7987619	1.0533708	.3139602	.5438935	-.0938585
.9878004	.5471122	.1808243	-.2561980	.7543287
1.9480702	.9869102	1.2266403	.5290113	.4983636
-.3784830	.9161593	.0801562	1.5257091	1.1486063
1.1457925	.6738259	.7930704	.5889751	.6864411
.2257404	.2943734	-.1804690	.7857257	1.2769962
.6674957	.5787748	.7219169	1.3900262	-.3900655
-.0823217	-1.1923424	.5723766	.7177579	.6897469
-1.0719834	.9188903	-.2299209	-.0254478	-.5325940
1.1443952	1.9209181	.5186395	1.3433188	.0203828
1.4899997	1.1614208	.6623049	-1.4928314	1.9979573
3.1552848	1.4906462	1.5940904	1.0182827	.7293936
-.6929912	1.4401117	.7414124	2.3014983	1.7849107
2.0873592	.9807466	1.2909711	1.1519414	.6958462
.4851619	.4529909	-.0444665	1.4314161	2.2627113
1.5785205	1.3146395	.9956002	2.9576373	-.7126732
-.1463156	-2.5368023	.8150229	1.3667119	.8183961
-.6352645	.3808873	-.0352766	.1244402	-1.0131074
1.2090834	1.0037405	.0483412	.4136766	-.0070176
.7654355	.3941625	.0799502	-.3910394	.8957470
1.6873821	.7706689	1.0262161	.7978415	.1869531

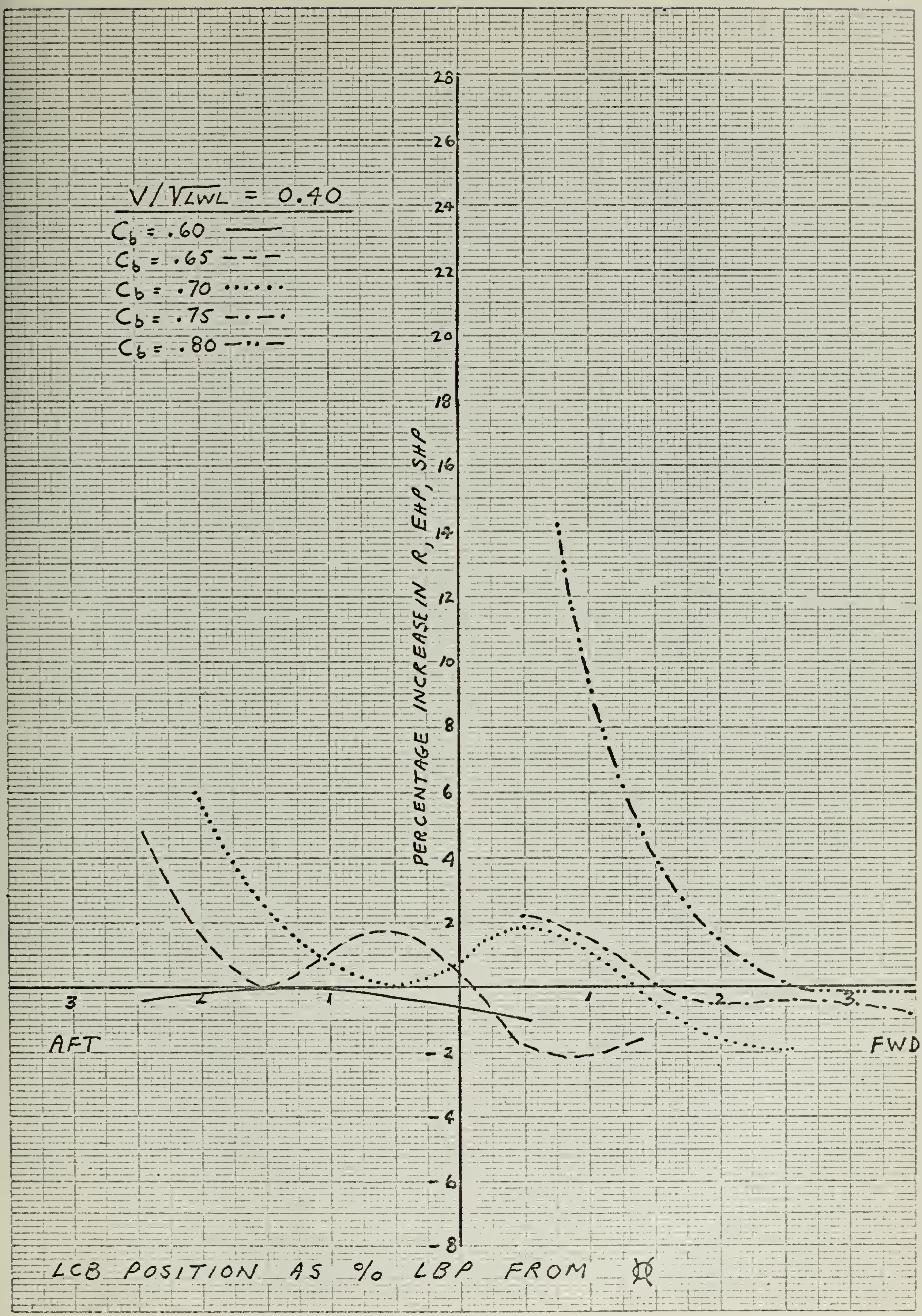
-1.0174062	1.2272588	.0277420	2.2248897	.6622314
1.2343022	.3191111	1.2313373	.2914792	.6947060
.2556209	.5969617	-.5552304	.4701235	1.7656431
.6015071	.9678315	.5887362	1.9449540	-.5314181
.0696292	-2.0758149	.5709173	1.0927017	.9293203
-.5433651	.0979775	-.4586072	-.1679318	-.3841697
.5995327	.2387508	-.3154302	.2309270	.1913938
-.3164427	.1301091	.1871417	-1.0789750	.9485394
-.1030191	-.2956169	-.3943946	.5244963	-.4128682
-1.0915548	.5134319	.3548732	1.0662324	-.6020940
.4450613	-.4476712	.7233817	-.2412496	-.2129788
.1716482	.4584015	-.3765060	-.2220825	1.0245646
.3836390	.9218967	-.2218696	1.5729171	-.3337805
.2509693	-1.8923499	-.0188731	.7975764	.1627162

-.2318116	-.2726382	-.2250979	-.0597742	-.6425973
.5356344	-.4447516	-.6417488	-.4441709	.0796384
-.7687533	-.3785159	-.2327542	-.1812488	.0687391
-1.1483278	-.8185137	-.7978703	.2427631	-.7178155
-1.0971849	.2720826	-.1814688	.8221986	-1.3255902
-.2798935	-.8826237	.5132478	-.8240440	-.2302237
-.0121929	.4837445	-.6689419	-.8747298	.4838448
-.3730438	.5433489	-.5471104	.5888725	-.1386250
.4040951	-1.3120895	-.2039831	.4822506	.1838319
-.1914066	-.2330157	-.3476290	-.1605618	-.1694998
.1840011	-.5599873	-.6129426	-.3196826	.1466315
-.9493364	-.2697778	-.0688175	-.4867885	.1795903
-1.4804842	-1.0588940	-1.1611848	.0495641	-.7078288
-.8066642	-.0784238	.0271390	.1701530	-1.4417000
-.4933256	-.9517099	.1416311	-.8027830	-.5760616
-.0270473	.3197329	-.3942372	-.8647953	.1014275
-.2766065	.4118123	-.7883457	.3610556	-.0280498
.3881132	-.9727482	-.3786107	.2734010	-.2005255
-.0486688	-.2215381	-.1073853	-.0491817	-.2416412
.1666388	-.4835957	-.4904987	-.3828980	.0474045
-.6489097	-.2746769	-.1604075	-.0117688	-.1063150
-1.1093966	-.7749705	-.7614009	-.0470969	-.4841899
-.5111476	-.0602084	-.1597147	.1598024	-1.0513411

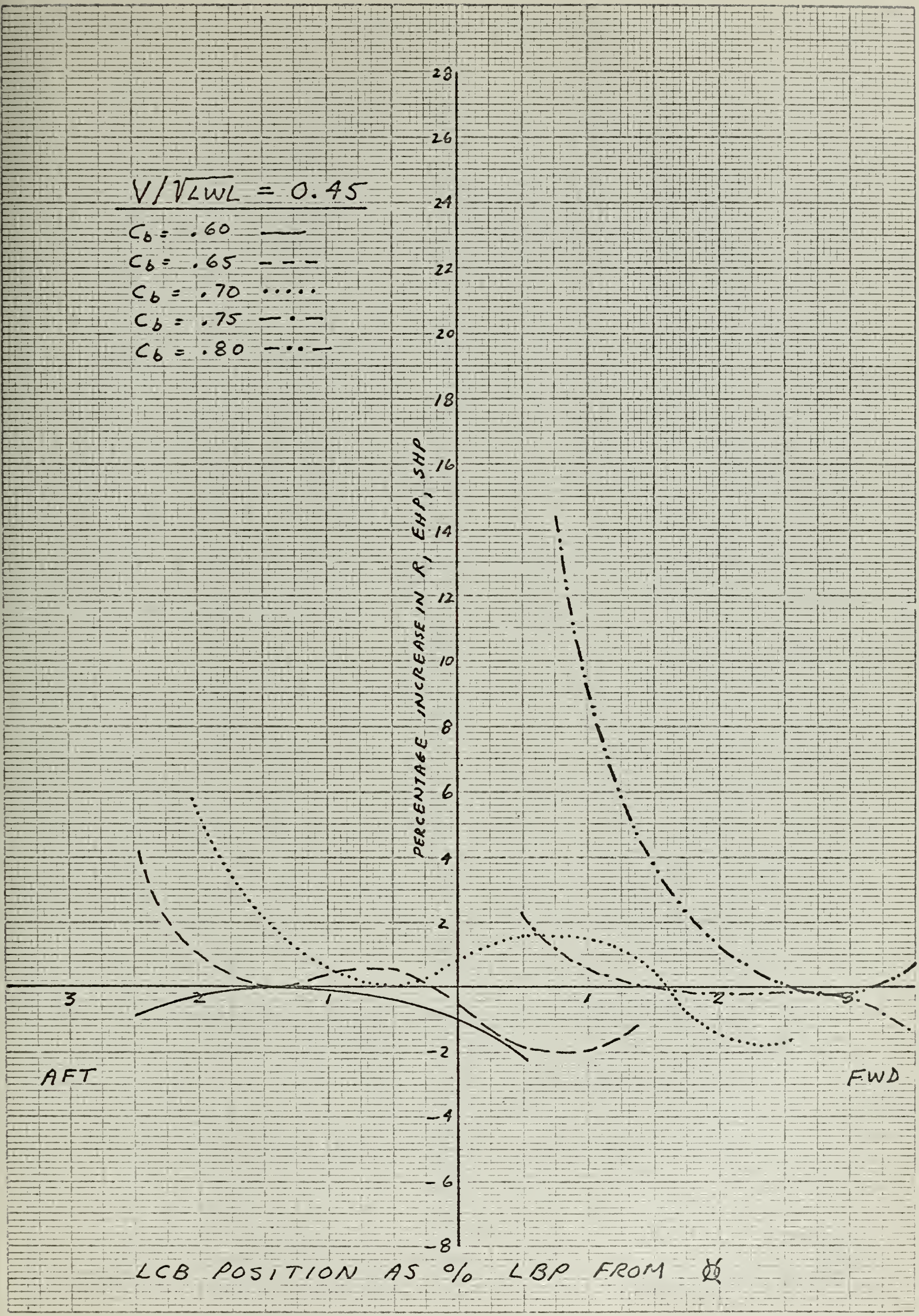
-.4893074	-.6992539	.0503937	-.6744570	-.3157174
-.0603174	.2381461	-.3582849	-.7025383	-.0198854
-.3919283	.1651889	-.5856972	-.0308532	.0264681
.3309325	-.5212609	-.2487222	.1319267	-.0511100
-.0509913	-.0689196	-.1021630	-.0482668	-.0185932
.0554376	-.2413784	-.2571989	-.1376140	.0573766
-.3685415	-.0669547	-.0234118	-.1049349	.0323723
-.6209035	-.4851913	-.4903417	-.0628357	-.2327750
-.2192922	-.0785230	-.0264358	.0064128	-.5756791
-.2806189	-.3999087	-.0542858	-.3525030	-.2659979
-.0285604	.1278625	-.1355842	-.3443935	-.0478000
-.1393590	.0934717	-.3946693	-.0007085	.0291116
.1817481	-.2881986	-.1653813	.0641398	-.1124139
-.0061540	-.0249686	-.0048420	.0013265	-.0401150
.0428432	-.0936094	-.1152594	-.0764807	.0105730
-.1125915	-.0292852	-.0272779	.0296546	-.0177826
-.2252641	-.1831350	-.1635496	-.0392735	-.0693002
-.0702668	-.0184580	-.0406982	.0341093	-.2122658
-.1295756	-.1557337	-.0287787	-.1532894	-.0781477
-.0150641	.0492547	-.0655933	-.1406032	-.0190101
-.0881553	.0136718	-.1586125	-.0490134	.0105931
.0932999	-.1000036	-.0483666	.0249204	-.0093009
-.0079566	.0067028	-.0119163	-.0007928	.0075951
.0136688	-.0126482	-.0189720	-.0022155	.0095868
-.0284385	.0120257	.0055343	-.0025614	.0089682
-.0494890	-.0555365	-.0458509	-.0137878	-.0046506
-.0087769	-.0044427	-.0042037	.0086206	-.0475444
-.0242116	-.0408702	-.0166316	-.0328551	-.0331722
-.0072865	.0205311	-.0094810	-.0207007	-.0044426
-.0004944	.0054106	-.0484847	-.0031020	.0037651
.0152624	-.0331273	-.0169808	.0093473	-.0149762

APPENDIX B

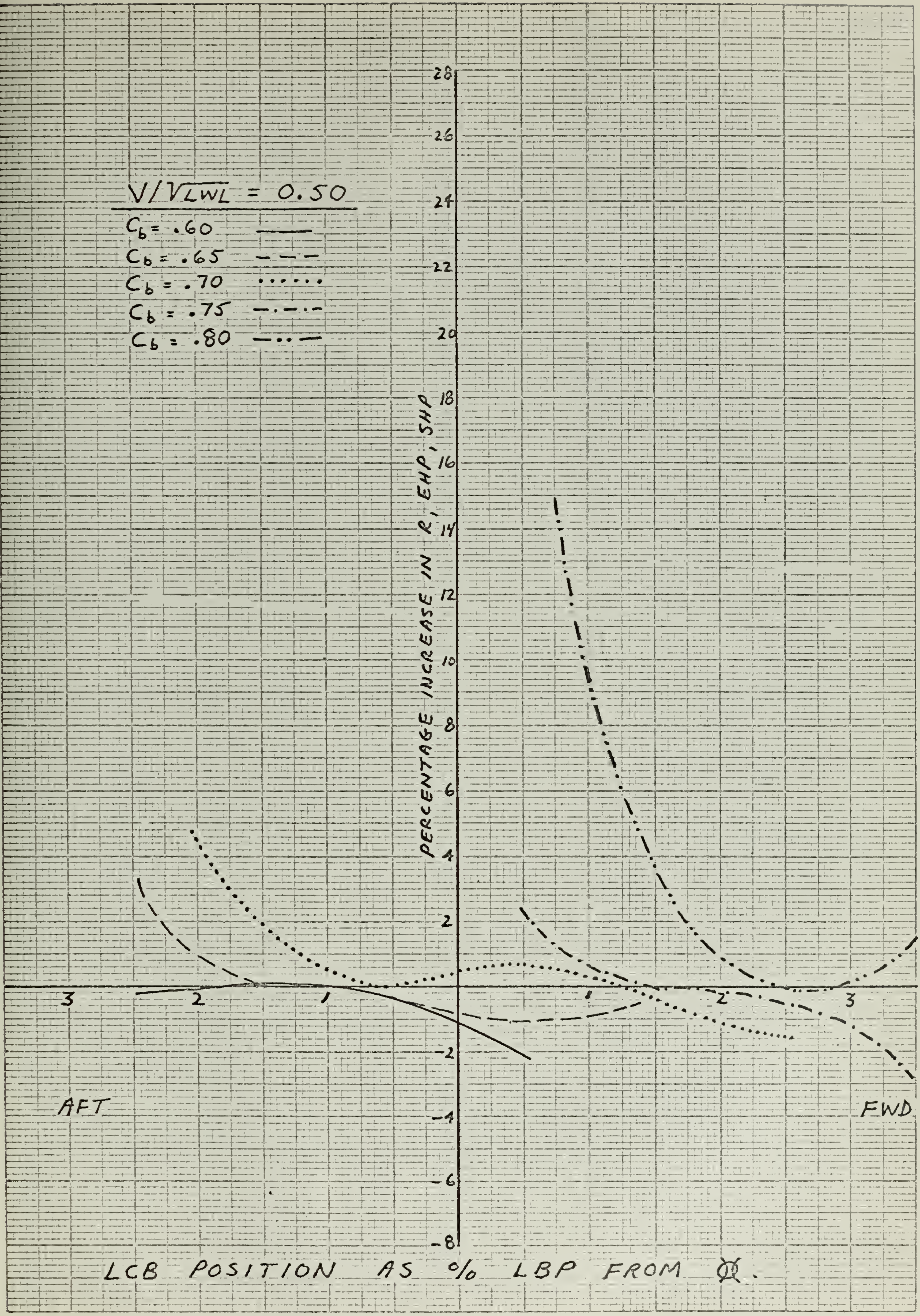
GRAPHS FOR USE IN CORRECTION OF EHP AND SHP FOR VARIATION IN LCB POSITION



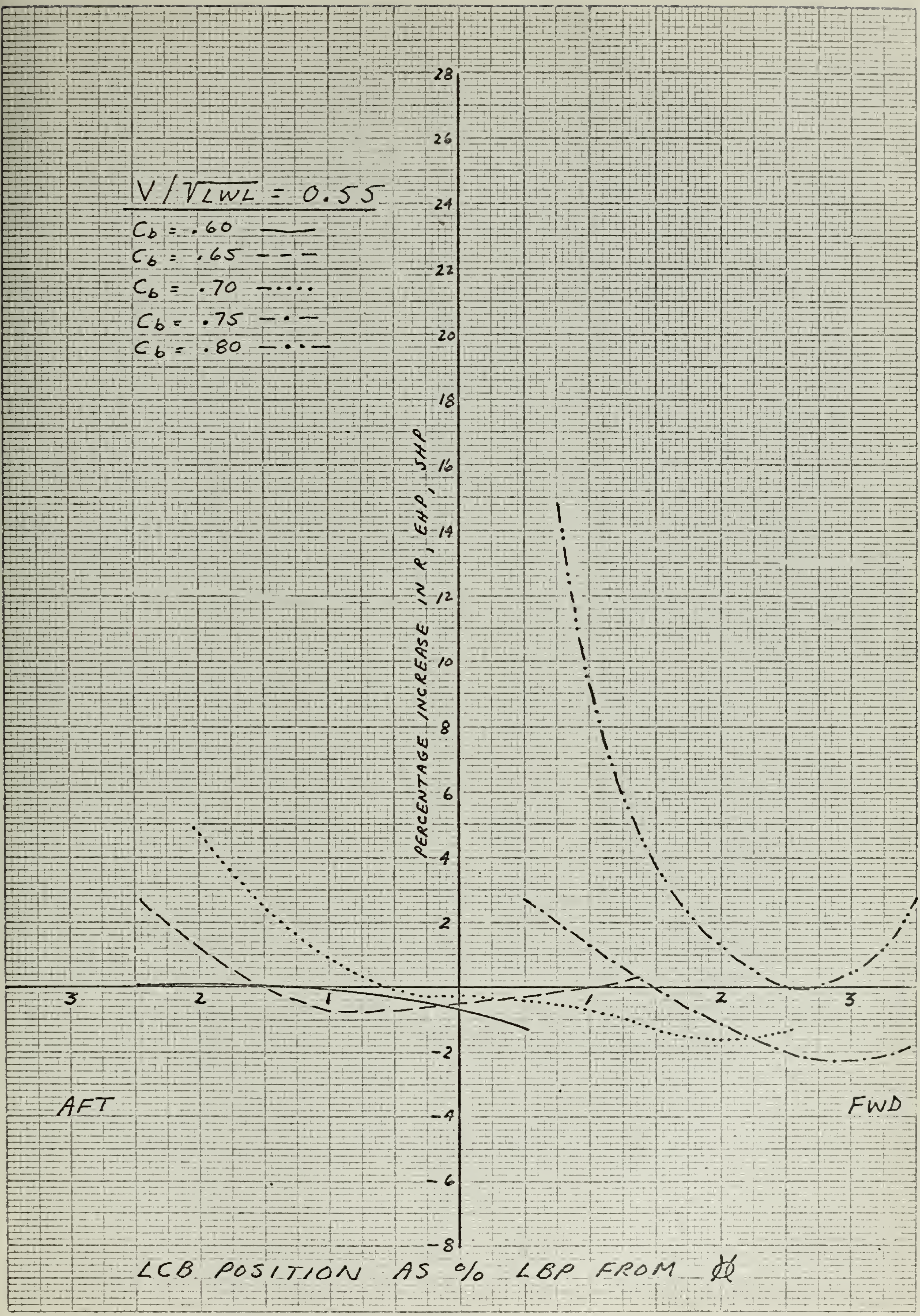
V/√LWL = 0.40
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗



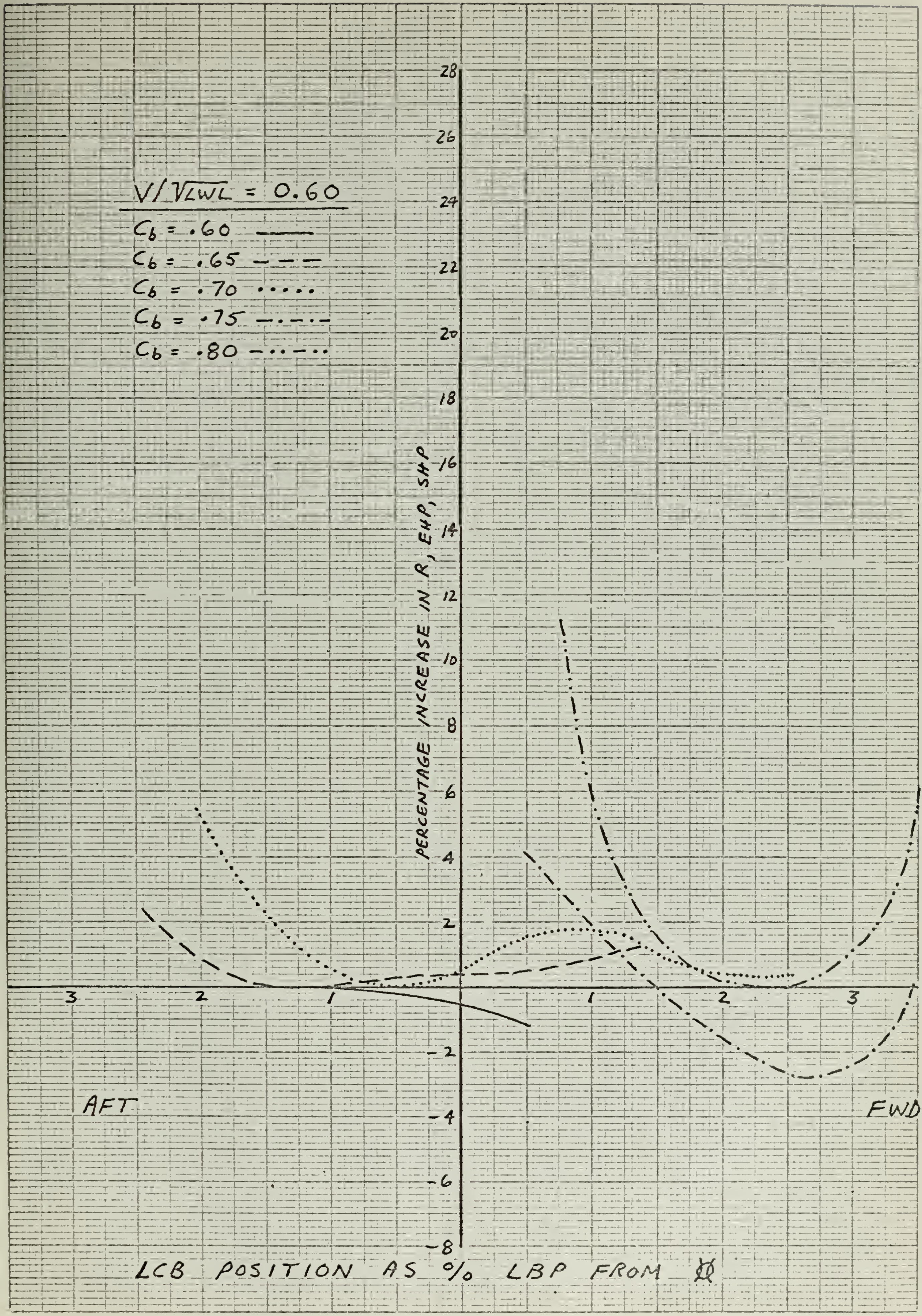
V/√LWL = 0.45
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗

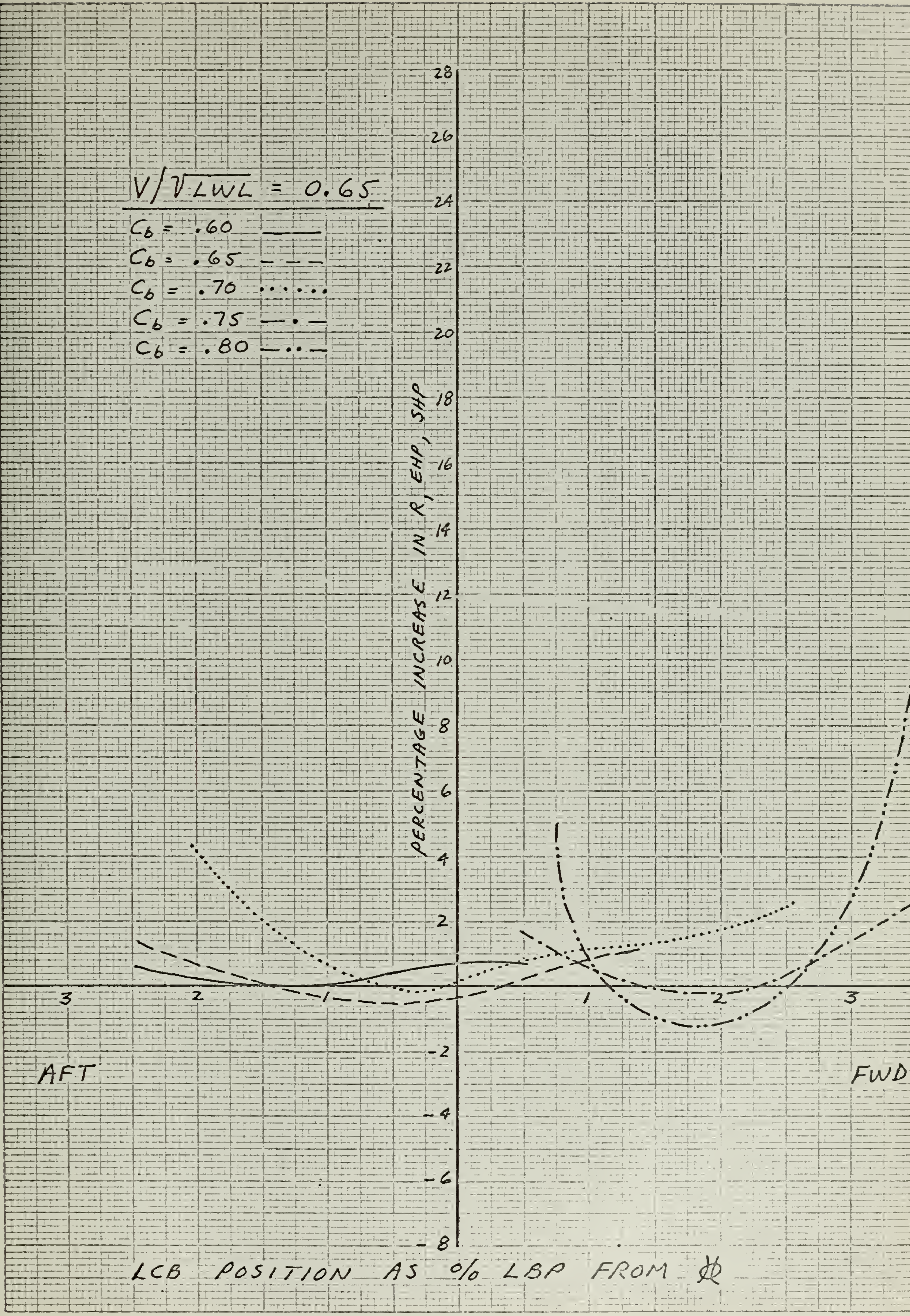


V/√LWL = 0.50
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ℄.

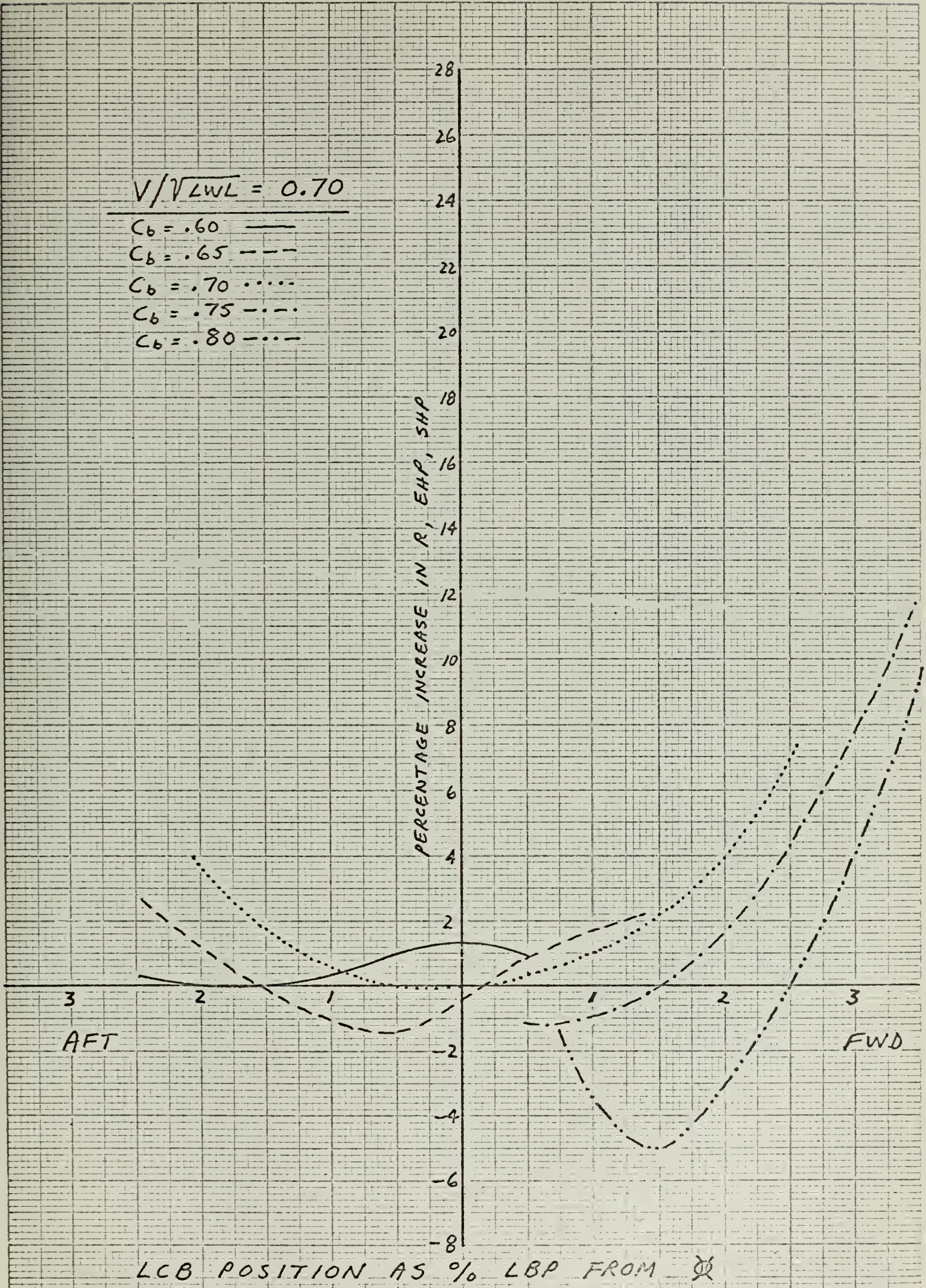


V/√LWL = 0.55
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊄

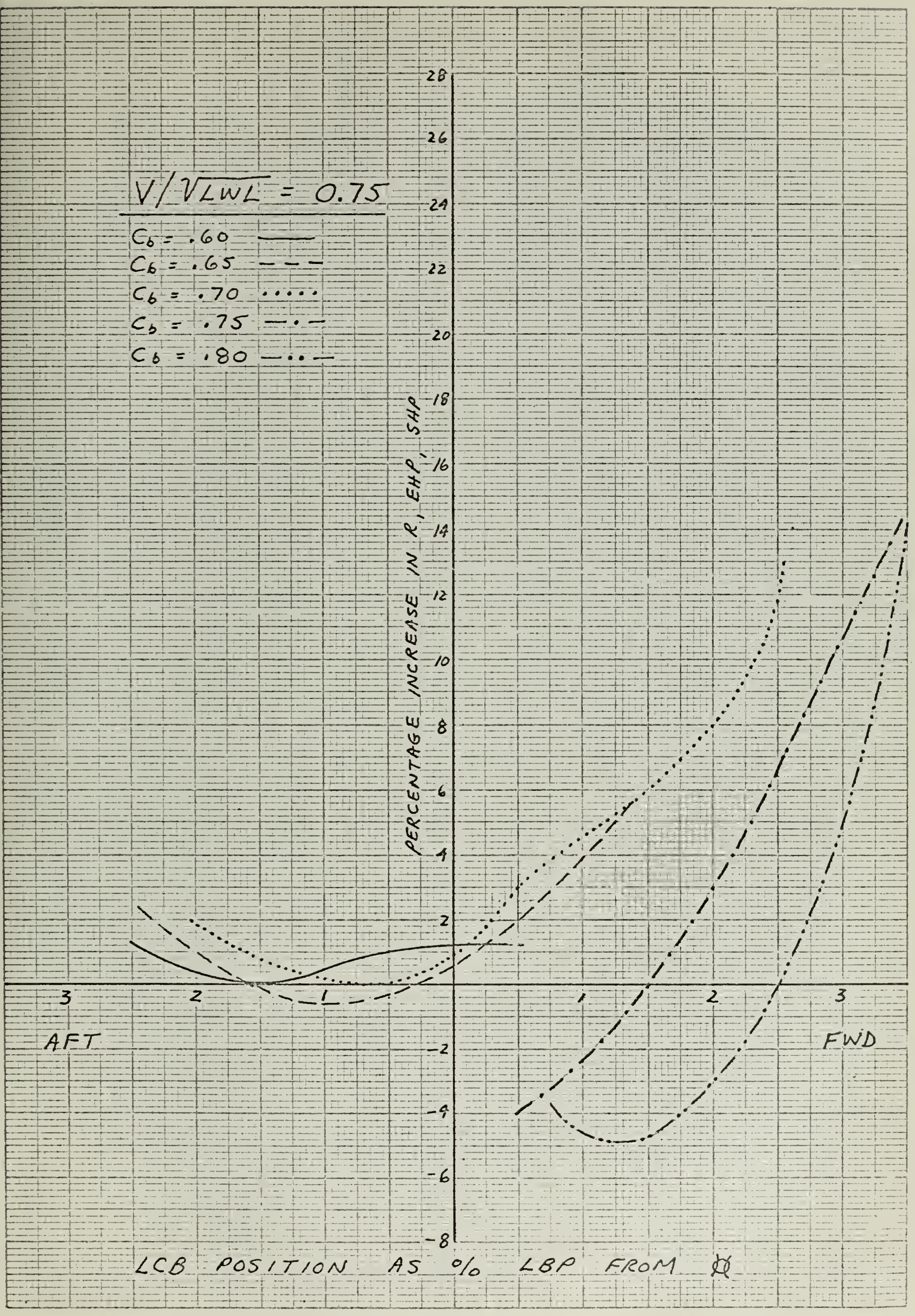

V/√LWL = 0.60
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80
PERCENTAGE INCREASE IN R, EHP, SHP
AFT
FWD
LCB POSITION AS % LBP FROM ⊄
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3



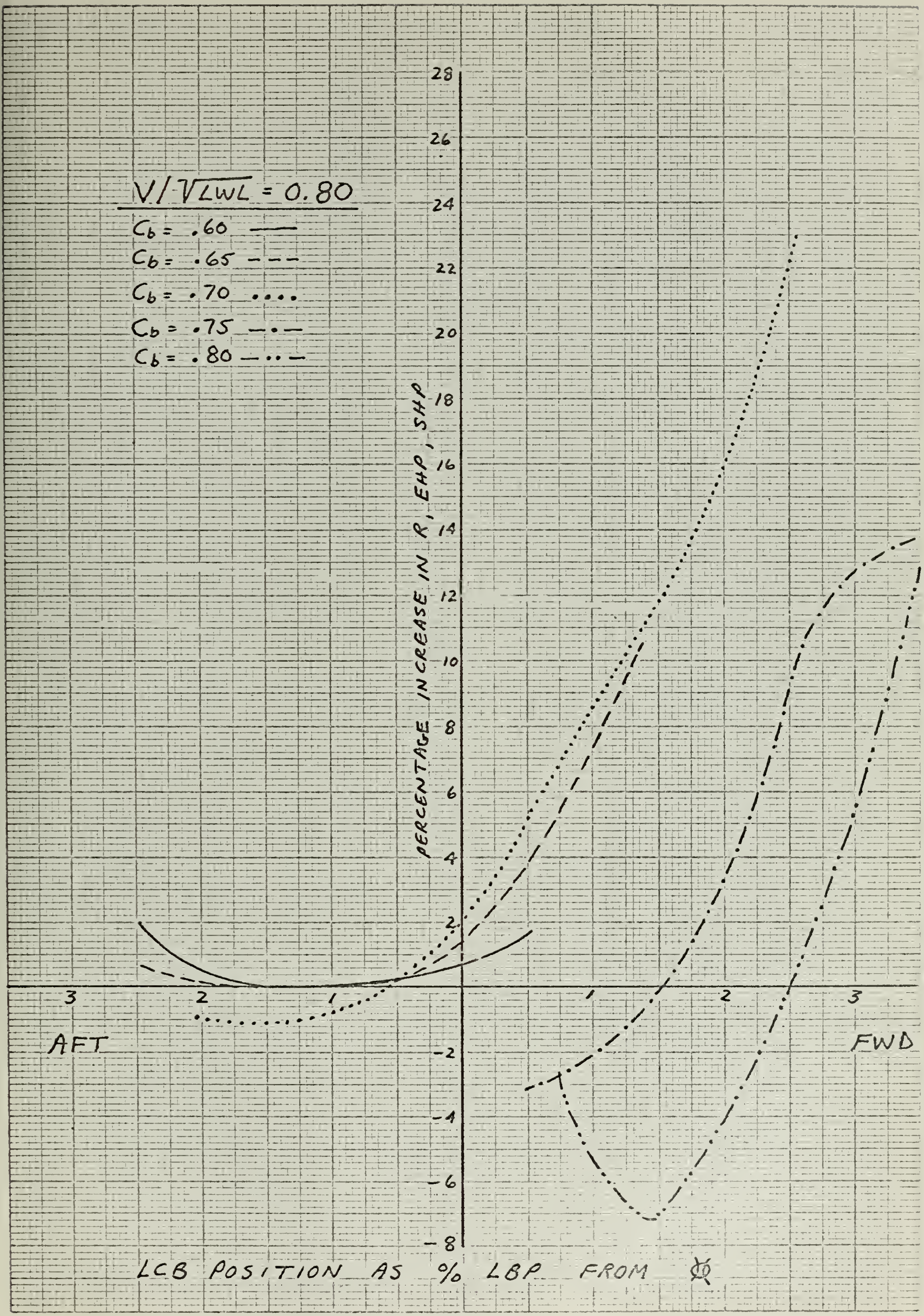
V/√LWL = 0.65
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ℄

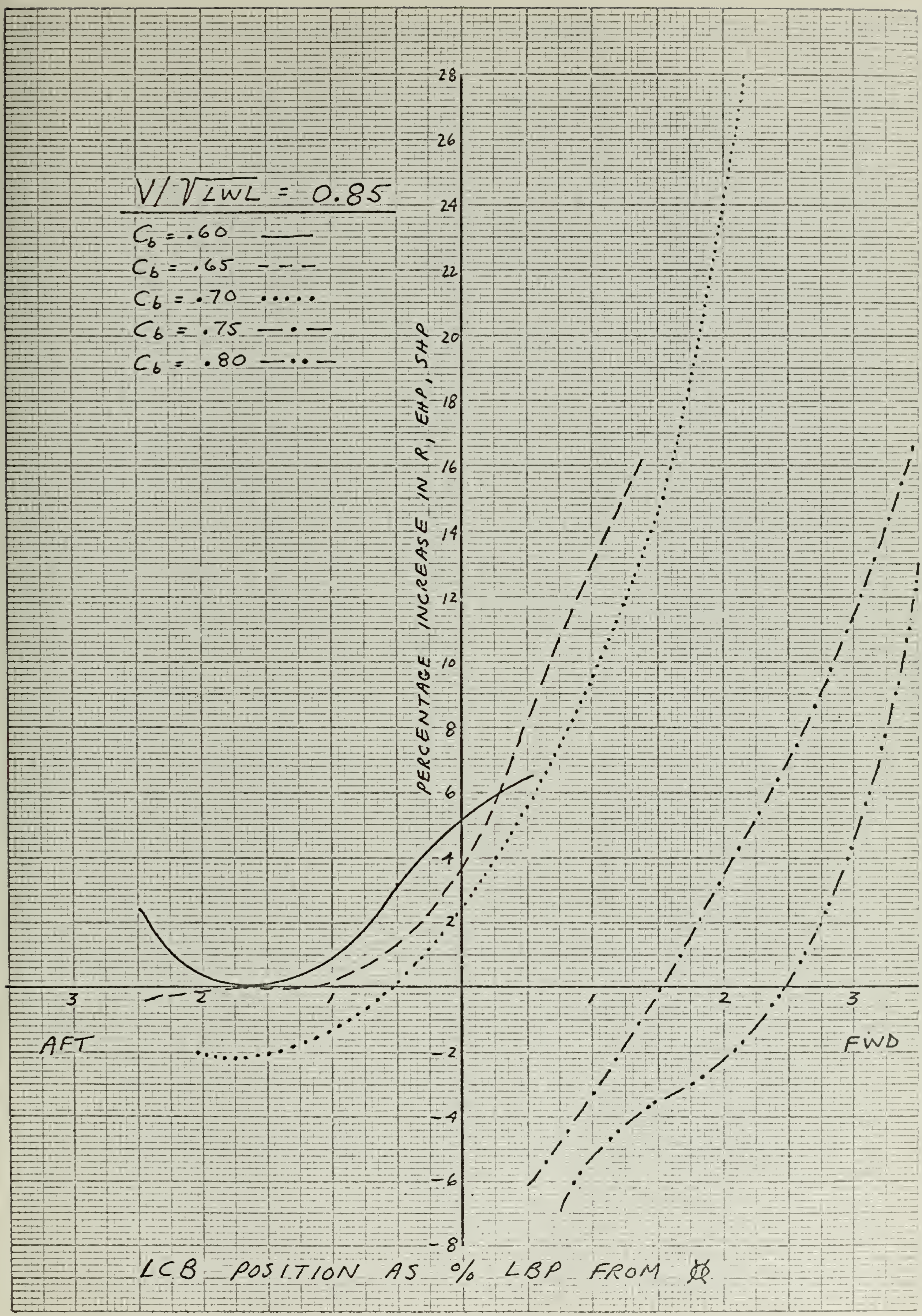


V/√LWL = 0.70
Cb = .60 ——
Cb = .65 - - -
Cb = .70 ·····
Cb = .75 -·-·
Cb = .80 -··-
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗

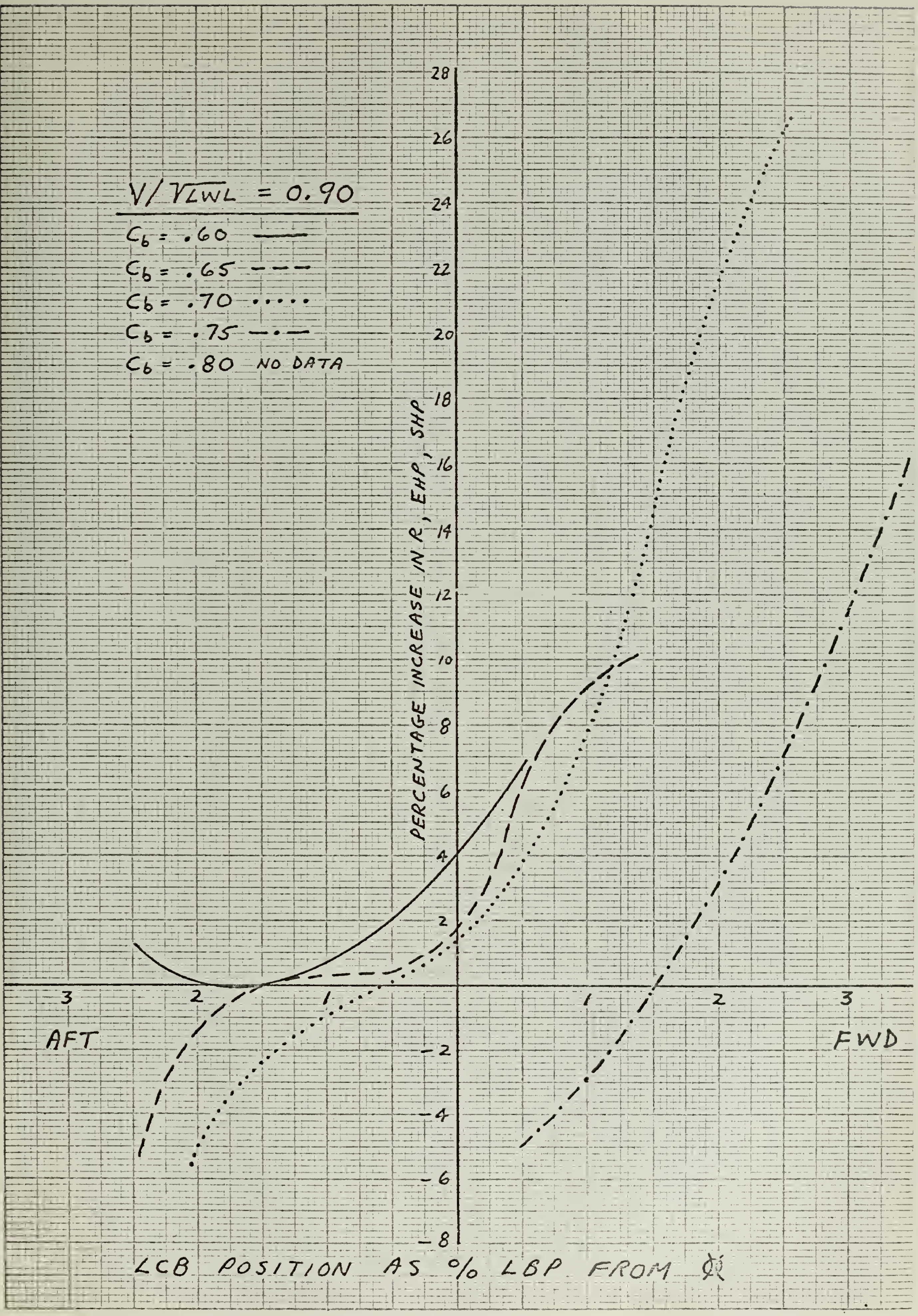


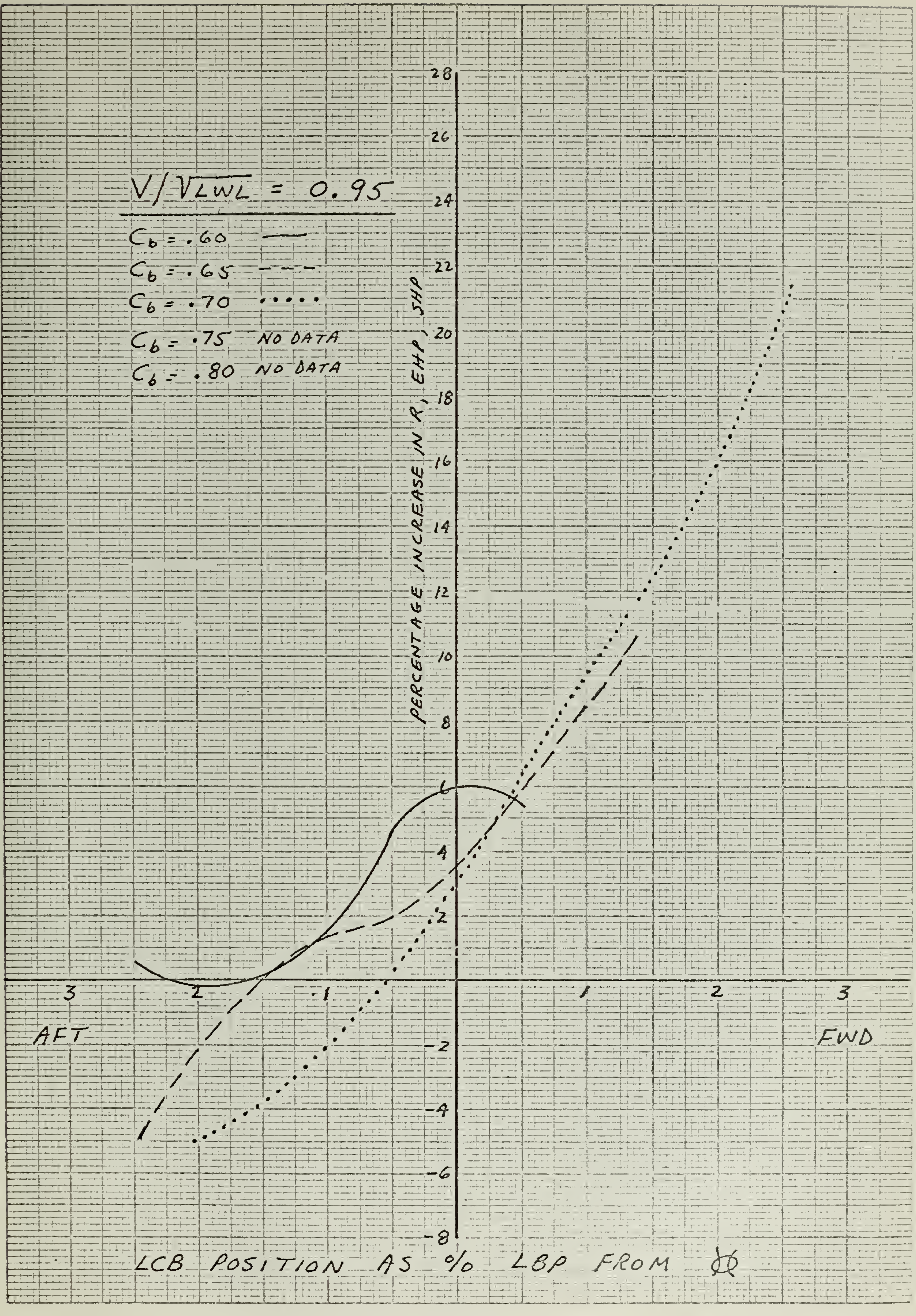
V/√LWL = 0.75
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊄

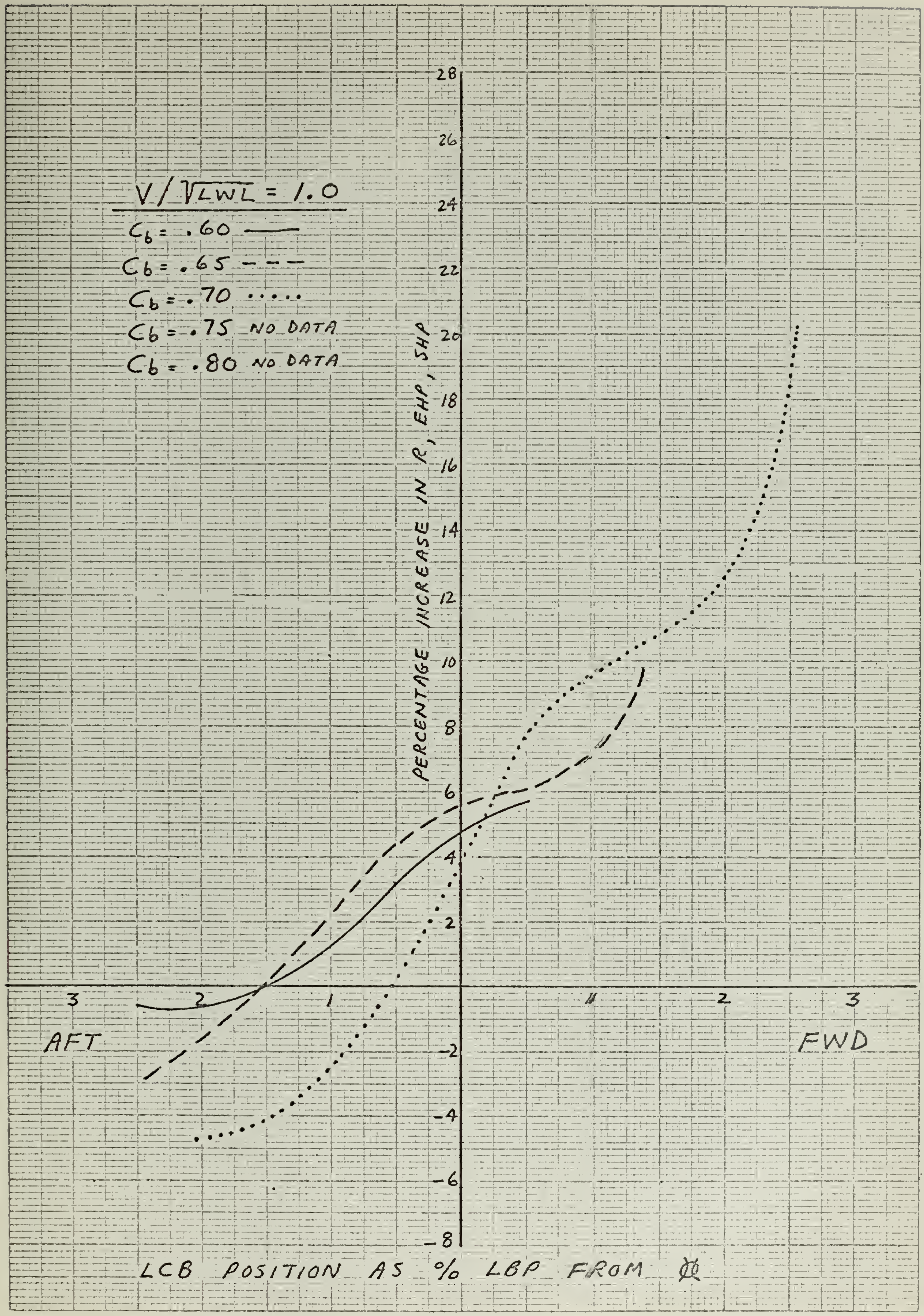

V/√LWL = 0.80
Cb = .60 ——
Cb = .65 - - -
Cb = .70 ....
Cb = .75 —.—
Cb = .80 —..—
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗



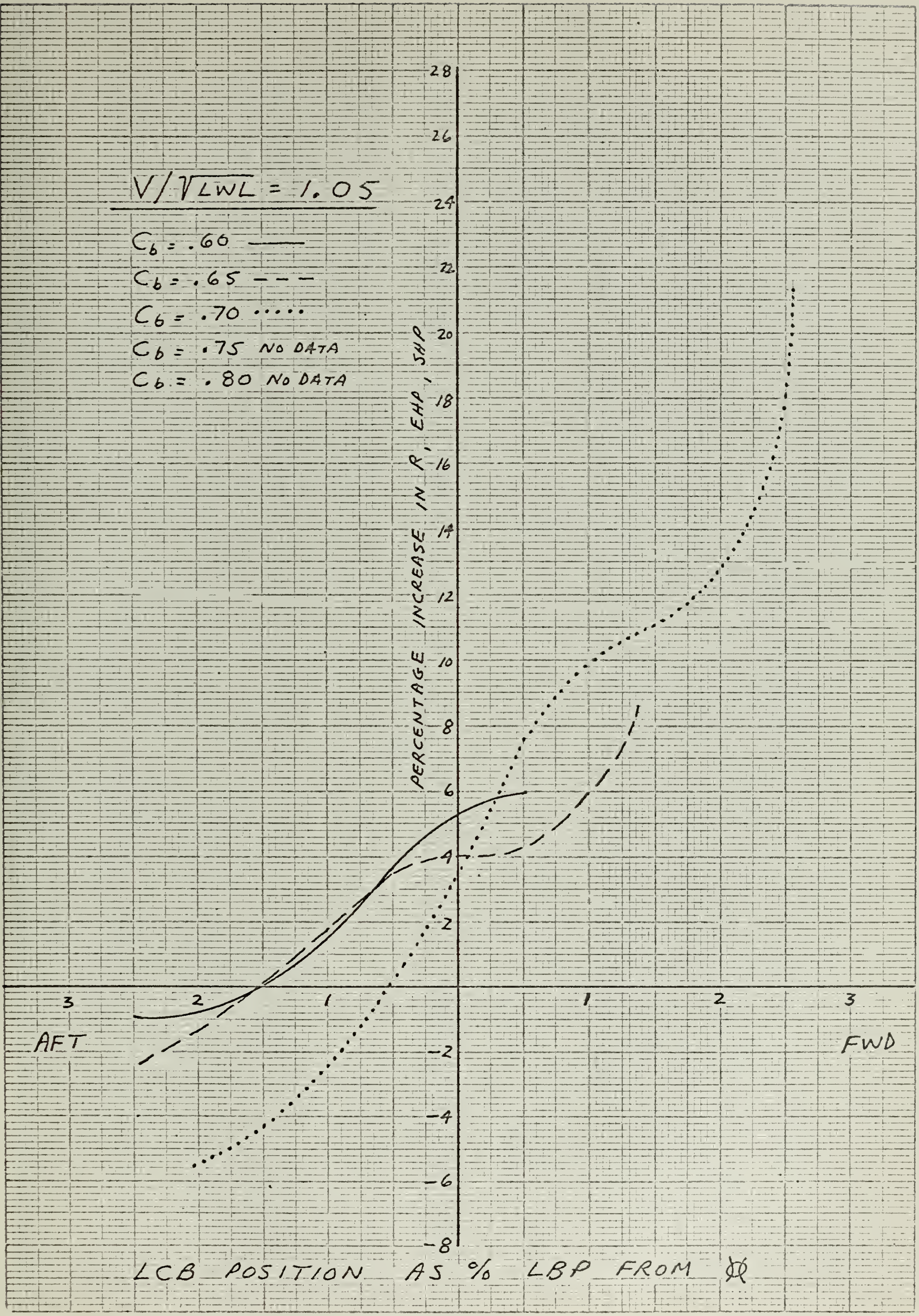
V/ √LWL = 0.85
Cb = .60 ———
Cb = .65 – – –
Cb = .70 .....
Cb = .75 —.—
Cb = .80 —..—
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗

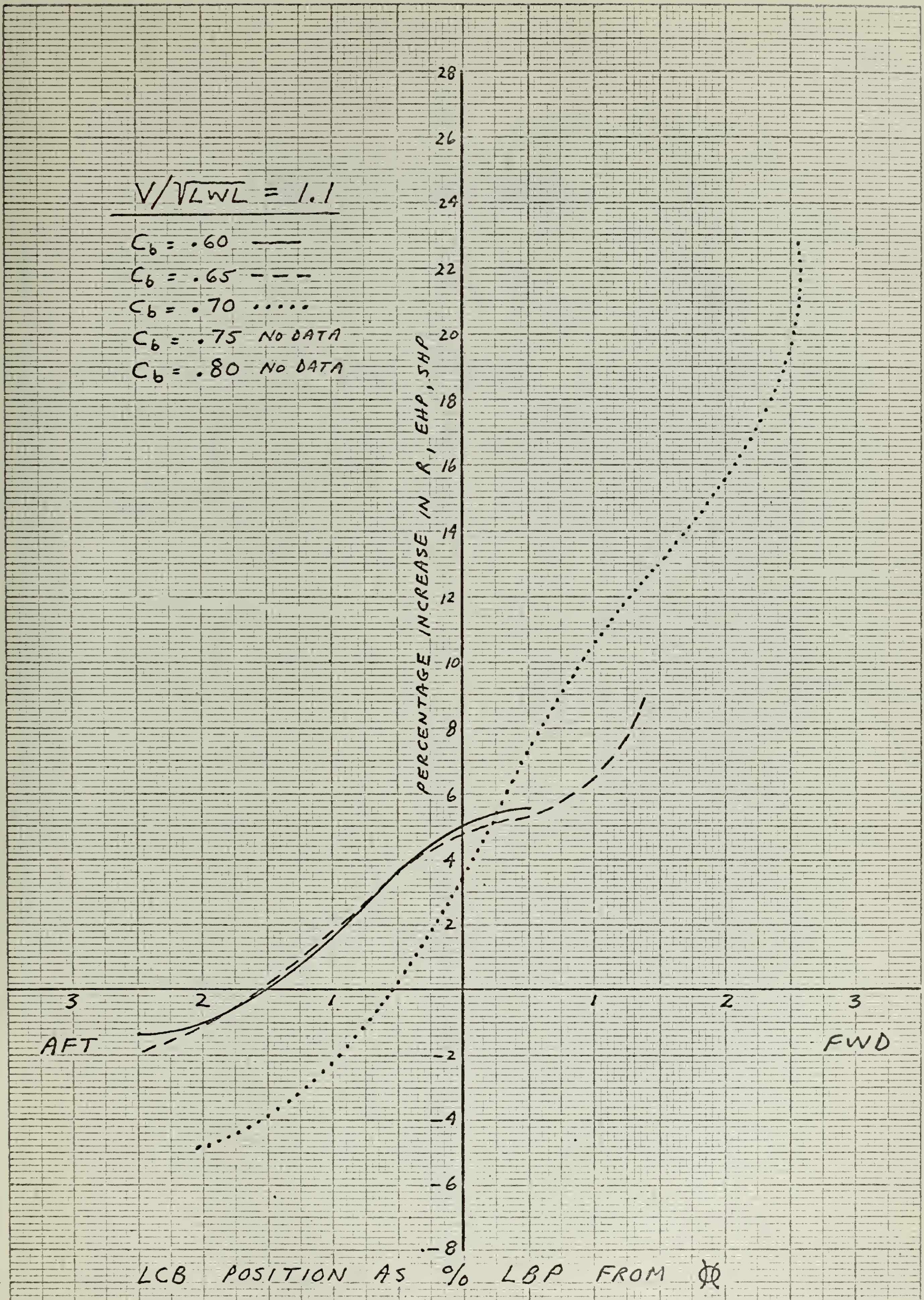

V/√LWL = 0.90
Cb = .60
Cb = .65
Cb = .70
Cb = .75
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ℄


V/√LWL = 0.95
Cb = .60 ——
Cb = .65 - - -
Cb = .70 .....
Cb = .75 NO DATA
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗



V / √LWL = 1.0
Cb = .60
Cb = .65
Cb = .70
Cb = .75 NO DATA
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊕


V/√LWL = 1.05
Cb = .60 ———
Cb = .65 - - -
Cb = .70 ·····
Cb = .75 NO DATA
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗


V/√LWL = 1.1
Cb = .60 ———
Cb = .65 – – –
Cb = .70 .....
Cb = .75 NO DATA
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊕

APPENDIX C

INSTRUCTIONS FOR USE OF THE EHP-SHP PROGRAM FOR SERIES 60

1. <u>Input deck for matrices $[A_{nl}]$ and $[B_{nl}]$</u>

The input of matrices $[A_{nl}]$ and $[B_{nl}]$, a total of 900 elements, is accomplished by reading them from a deck of 180 cards, with 5 elements on each card, arranged in Format 5F16.7. See Appendix A for their proper arrangement.

Total no. of cards = 180

2. <u>Identification card</u>

In columns 1 - 4, (NJOBS), Punch the integer number of ships to be calculated in this particular run, with the units digit of the integer in column 4. Format I4.

In columns 5 - 80, (QQ) Punch any identification information desired. Example: "SCHUYLER OTIS BLAND TEST RUN." Format 19A4.

Total no. of cards = 1

3. <u>Input for Ships</u>

a. If input Mode I is being used for a ship, punch the following <u>3 cards</u> for each ship:

<u>Card 1</u>

In columns 1 - 4, (INOPT), Punch a positive integer. Example: "+5". Format I4.

<u>Card 2</u>

In columns 1 - 10, (XLBP), Punch the length between perpendiculars in feet. Example: "400.0" Format F10.2.

In columns 11 - 20, (BM), Punch the maximum beam at the load water line in feet. Example: "66.0". Format F10.2.

In columns 21 - 30, (H), Punch the draft in feet. Example: "27.0". Format F10.2.

In columns 31 - 40, (CB), Punch the block coefficient. Example: "0.651". Format F10.2.

In columns 41 - 50, (VMIN), Punch the lowest speed in knots for which you desire information on EHP and SHP. Example: "8.557". Format F10.2

In columns 51 - 60, (VMAX), Punch the highest speed in knots for which you desire information on EHP and SHP. Example: "19.25". Format F10.2.

In columns 61 - 70, (VINC), Punch the increment of speed at which you wish information on EHP and SHP. Example: "1.07" Format F10.2.

<u>Card 3</u>

In columns 1 - 10, (DCF), Punch the frictional ship correlation factor you desire to use. Example: ".0004". Format F10.2.

In columns 11 - 20, (XLCB), Punch the position of LCB from ⊗ in feet, with a + sign if forward and a - sign if aft of ⊗ . Example: "- 4.0". Format F10.2.

In columns 21 - 30, (WSURF), Punch the wetted surface area in square feet. Example: "39994.0". Format F10.2. If wetted surface is not known, punch a "0.0" in this space and the program will calculate it.

In columns 31 - 40, (RHO), Punch the density of water in lb. $sec^2/ft.^4$ at the temperature desired. Example: "1.9905". Format F10.2.

In columns 41 - 50, (GNU), Punch the kinematic viscosity in $ft.^2/sec.$ Example: "1.2817E-05", for 1.2817×10^{-5}. Format E10.2.

<u>Note</u>: If information on EHP and SHP is desired for only one speed for the ship, e.g. service speed, on card 2 punch this speed in the spaces for VMIN <u>and</u> VMAX, and punch "0.0" in the space for VINC.

Total no. of cards = NJOBS x 3.

b. If input Mode II is being used for a ship, follow the instructions for Mode I above with the following exceptions:

<u>Card 1</u>

In columns 1 - 4, (INOPT), Punch a negative integer. Example: "-5". Format I4.

<u>Card 2</u>

In columns 11 - 20, (BH), Punch the beam to draft ratio. Example: "2.5". Format F10.2

In columns 21 - 30, (DEL), Punch the displacement in tons. Example: "10000.0". Format F10.2.

In columns 31 - 40, (CP), Punch the prismatic coefficient. Example ".612". Format F10.2.

Card 3

Identical to Mode I.

Mode I and Mode II input ships can be mixed at will as long as the cards are punched as above.

Graphs for making corrections to the computer output for variation in LCB position are contained in Appendix B.

4. Loading of cards

The cards are loaded in the following order:

1. Main EHP-SHP Program Deck
2. Subroutine CEF
3. Input deck for matrices $[A_{nl}]$ and $[B_{nl}]$
4. The identification card
5. Input cards for ships.