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No. 348

THE DRAG OF AIRSHIPS

DRAG OF BARE HULLS - II

By Lieut. Clinton H. Havill, U.S.N.

Washington
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 248.

THE DRAG OF AIRSHIPS.

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Summary

The extension of wind tunnel tests of models of airship hulls to full scale requires an extension from a VL of the order of less than 500 sq.ft./sec., to the order of 80000 sq.ft./sec., where V = air speed, feet per second, L = length in feet of the particular form of hull. The reason for this research was to furnish the airship designer with a method for finding the VL curve of any conventional type of hull, using data obtained from actual performance of airships flown prior to 1926.

This digest as given here in Part II, was begun in preliminary details, in June, 1922, and completed in April, 1926, as it was necessary to complete Part I before Part II could be completed; the period between September, 1923, and December, 1925, was devoted to work on Part I.

The outstanding results are as follows:

1. An empirical method for finding the drag coefficient of any bare airship hull with its VL curve from 100,000 cu.ft. volume to 6,400,000 cu.ft. volume. (See diagrams Figs. 7 and 8

and example to illustrate its use.)

2. The derivation of an empirical shape coefficient that can be calculated from the hull contour that defines the VL curve of any conventional airship shape within the limits placed on Figs. 7 and 8.

3. (a) That the slope of each VL curve differs with each type of hull and that its slope is not quite constant.

(b) That C_H = function of $(VL)^n$ and n is a variable at different values of VL. C_H = drag coefficient of bare airship hull. Drag = $C_H \frac{\rho}{2}$ $(\text{Volume})^{2/3}$ V^2.

(c) That the value of n varies slowly so that extrapolations beyond that given by diagrams Figs. 7 and 8 of the VL curve are not much in error, as requirement 3 of illustrative problem shows.

4. The region from model tests to a volume of 100,000 cu.ft. size indicates that in this region the most rapid change in the slope occurs with the conclusion that "The best model in the wind tunnel will probably be the best (lowest drag) airship hull but not necessarily" as their VL curves may cross and again may re-cross at higher values of VL. In view of this as found by extrapolating the VL curves calibrated on performance back to wind tunnel values and extrapolating wind tunnel results to higher values of VL together with the fact that airship designers are not interested in airship hulls of less than

100,000 cu.ft. of volume, this part of these researches was left out. The scale on diagrams at .3 cu.ft. volume calibrated on existing wind tunnel data is merely for general information.

Introduction

The principal components of the drag of bodies in a wind stream has been laid down by Reynolds, Stanton, Munk, Prandtl, Froude, Bairstow and others, so that it is not necessary to outline their work here. Reference to the summary of their work in the recent N.A.C.A. Technical Report No. 219, "Some Aspects of the Comparison of Model and Full Scale Tests" by D. W. Taylor, is invited, which expressed in words: Drag = pressure difference + skin friction + wave making + compressibility effect.

Symbols Drag = R = Drag = $F_1 (\rho L^2 V^2) F_2 \left(\frac{\rho V L}{\mu}\right) F_3 \left(\frac{L g}{V^2}\right) F_4 \left(\frac{V^2}{V_s^2}\right)$

L = Linear dimensions of length.

V = Air speed.

ρ = Mass density of air.

μ = Viscosity.

V_s = Velocity of sound in air.

G = Acceleration of gravity.

R = Drag.

It has been well established in theory and practice that as far as airships are concerned the compressibility effect expressed by $\left(\frac{V^2}{V_s^2}\right)$ is negligible or zero as the air speeds in flight are so far below the speed of sound at which compressibility exists. The wave making $\left(\frac{Lg}{V^2}\right)$ so important in surface ships is negligible in airships and if it does exist in a microscopic percentage, can be included in the constants and exponents in the remaining two. So that $R = F_1(\rho L^2 V^2) F_2 \left(\frac{\rho VL}{\mu}\right)^n$ where n is a variable depending on type of hull - fineness ratio, virtual volume, length, diameter, eccentricity of nose ellipse, cylindrical coefficient, and on the value of VL as found out in this research. Or, if reduced to a standard value of kinematic viscosity of $\frac{\rho}{\mu}$ then $R = \text{constant } (\rho L^2 V^2)\ F_2\ (VL)^n$.

Let $2K =$ the constant; $(\text{Volume})^{2/3} = L^2$,

then $R = K \frac{\rho}{2} (\text{Volume})^{2/3} V^2,\ F_2\ (VL)^n$.

Let $C_H = K + \dfrac{F_2\ (VL)^n}{\frac{\rho}{2}\ (\text{Volume})^{2/3}\ V^2}$,

then $R = C_H \frac{\rho}{2} (\text{Volume})^{2/3} V^2$ in which case it is seen that C_H is a variable depending on the value of $(VL)^n$.

It now remains to give a method of finding the value of C_H knowing the contour and size of the airship hull. In brief, this was done by taking the whole ship performance of a large number of ships (all Zeppelin types and Navy nonrigids) as given in Part I, and calculating their external drag and getting the hull drag. Then to find a quantity of linear dimensions that is calculated from the contour and size of each ship such that if the drag is plotted against this VL that the results show it to be a smooth curve. With this as a basis, it now was necessary to find a dimensionless quantity that would define each ship - such a quantity called here "whole hull shape coefficient" (Y + Z) such that it could be calibrated against the various values of C_H based on performance.

Body of Report

An exhaustive research was made to find a dimensionless quantity that sufficiently defines a given hull and to express the relation between C_H at various values of VL and this quantity. The effective velocity over the skin of different types of hulls at different speeds was found to be so different that it could not be expressed as a constant times air speed, so the surface area times KV^n was given up as n apparently was a very sensitive quantity. So shapes were geometrically expanded to the volume of known ships for comparison. From this comparison, relative drag coefficients were obtained by discovering that the drag of an airship hull follows very closely the VL principle over a short range and results are comparable if L is defined as L_g defined here as geometric length where

$$L_g = \sqrt[4]{(\text{Volume}) + \frac{\pi r^3}{3} \ (\text{length})} = \sqrt[4]{(\text{Virtual Vol.})\ (\text{length})};$$

this was discovered by trial and error in analyzing the wind tunnel results and plotting their drag in pounds versus VL_g as shown in Fig. 6.

The external drags of all the items (about 90 hulls - 26 separate types) of Part I can be separated by calculating the external drags of about six types of hulls and by simultaneous equations solving for the external drags of all the remaining types of hulls. However, the results are no better than the correctness of the external drag of the five or six types calculated. Yet these results when plotted against VL_g show a smooth curve. For this report it was better, therefore, to calculate the external drag for all the 26 types of hulls (given in Part I) and to plot them against VL_g (Fig. 1) is such a curve.

There is another way in which the external drag of various airships can be calculated, and that is to assume that the percentage of external drag remains the same part of the total as wind tunnel experiments indicate. In general, wind tunnel results show nonrigid types to have about 60% total drag = external drag; and rigid Zeppelin types to have 40% total drag = external drag. The exact percentage will of course vary with the type of cars, fins, struts, wires, etc., but various percentages can be assumed on each type based entirely on engineering judgment. The remaining hull drags, if plotted against VL_g, will give Fig. 2.

Now the mean between Fig. 1 and Fig. 2, is Fig. 3. In view of the fact that Fig. 1 and Fig. 2 give a curve that is practically identical, it gives in Fig. 3 a basis of comparison of hull drag coefficients when ships are expanded or contracted to the same volume and the same speed. In other words, the ratio of hull drag coefficients (C_H) at the same volume and speed is the ratio of the drags of the bare hulls as

$$\frac{\text{Drag of hull 1}}{\text{Drag of hull 2}} = \frac{C_{H1}\,\frac{\rho}{2}\,(\text{Vol})^{2/3}\,V^2}{C_{H2}\,\frac{\rho}{2}\,(\text{Vol})^{2/3}\,V^2} \; ;$$

if ρ, (Vol), and V are the same for both ships, then

$$\frac{\text{Drag of hull 1}}{\text{Drag of hull 2}} = \frac{C_{H1}}{C_{H2}} \; .$$

Now with curve [drags, vs. (VL_g)] as in Fig. 3, the comparison of ships at different volumes and $V = 100$ ft./sec., can be carried out. A comparison at 100,000; 200,000; 400,000; 800,000; 6,400,000 was carried out. It necessitated a small extrapolation of curve (Fig. 3) to get 6,400,000 yet as the curve is fairly definite and the value of $\left(\frac{\rho}{\mu}\ VL_g\right)^n$ shows n to change value so slowly that this extrapolation is justified.

From here on various methods were tried to find a dimensionless quantity which would show to be a function of these values of C_H that comparison indicated. If such a quantity was established it could be represented on a plot or diagram and calibrated on the comparative results.

Speed and density was kept constant so that for a given volume the relative values of C_H were the same as the relative values of their drags as $\frac{\rho}{2}\,(\mathrm{Vol})^{2/3}V^2$ = constant. The dimensionless quantity that proved to sufficiently define a hull and to have no conflicts with the comparative results was $(Y + Z)$. Y = (eccentricity of nose ellipse) (cylindrical coefficient) (fineness ratio); $Z = \left(\frac{\text{length}}{\text{geometric length}}\right)$ (fineness ratio). Hulls were now grouped according to their values of Y and the parametric equation of Y against C_H was plotted (Fig. 4) where C_H was the total hull drag coefficient of ships with the same value of Y. A mean curve was drawn through the points plotted - a curve for volumes 100,000; 800,000; 6,400,000 cu.ft. Likewise, for Z on Fig. 5. It is to be noted that $Y = (e)\left(\frac{4\ \mathrm{Vol}}{\pi\ D^2\ L}\right) \times \left(\frac{L}{D}\right) = (e)\left(\frac{4\ \mathrm{Vol}}{\pi D^3}\right)$, is independent of length except as length affects volume. An interesting research by simultaneous equations by the author reveals that this function Y, for the ten ships on which it was calculated, appears to be a true function of that part of the drag due to pressure difference, and that $KYL^2V^2 + F_3 Z \left(\frac{\rho VL}{\mu}\right)^n = R$ gives K a constant for all values of VL. The writer hopes to be able to analyze all existing ships, in the near future, in order to prove or disprove this relation. Rather letting Fig. 4 indicate $C_H = F_1\ Y + F_2\ Z$ and plot total C_H against Y and likewise Z in Fig. 5. This amounts to a calibration of Y and Z on C_H. $Z = \frac{L}{L_g D} \times \frac{L}{D} = \frac{L^2}{L_g D}$ gives length the predominate factor effect in Z. Now with the values of Y and Z for each model in the wind tunnel the values of C_H according to Y called C_{HY} and the values of C_H called C_{HZ} according to Z were picked off. To let each have its proper effect, the formula $\frac{Y\ C_{HY} + Z\ C_{HZ}}{Y + Z} = C_H$ for given $(Y + Z)$ was used to give the value of C_H at the various volumes. With these various values of C_H from model to full scale on the 17 models, the scales could be calibrated.

The interval from .3 cu.ft. volume to 100,000 cu.ft. volume was calibrated on the diagrams (Figs. 7 and 8) and the slope given. The remaining ships from Part I were now added to give a complete calibration at 100,000; 800,000; and 6,400,000 cu.ft. volume; (An exploration of the region just beyond the usual wind tunnel model size (100 cu.ft. volume) indicates that perhaps some very sharp changes in VL curve is probable) so that the slope lines from .3 cu.ft. to 100,000 cu.ft. are the mean over this part of the VL curve. However, beyond 100,000 cu.ft. volume the diagrams in Figs. 7 and 8 will give the VL curve very accurately if used in the manner as shown by the example (Fig. 9). Since the scales are not uniform sight interpolation of values of C_H at various volumes other than 100,000; 800,000; and 6,400,000 are very misleading. The illustrative problem shows how to get the value of C_H (from the VL curve obtained) for other volumes.

The limits from which this data is designed are placed on each diagram and there is no justification for using it other than within the limits given. However, these limits will cover practically all contours of airship hulls that exist or are proposed today.

Further ground for research is to separate bare hull drag into pressure difference and skin friction, a large part of which has been done during the trial and error methods used to discover the quantities Y and Z.

Assumptions

1. That external drag, cars, fins, wires, etc., vary as the square of the speed.

2. The coefficients used in calculating drag of cars, fins, etc., were assumed based on engineering judgment. The idea was to get the curve drag versus (VL_g) oriented at the proper order of magnitude as a further check on the results which would be obtained by the percentage of external drag method. However, it is believed that the coefficients used to calculate drag of cars, fins, wires, etc., are as nearly correct as the present science of aerodynamics can give.

Units used throughout this report are ft., lb., sec. Everything in this report is reduced to:

A standard density of ρ = .00237 slugs/cu.ft.

A standard viscosity of μ = .0000003779 slugs/ft.sec.

A standard kinematic viscosity of $\nu = \frac{\mu}{\rho}$ = .000159 sq.ft./sec.

Example to Illustrate Method for Use of Diagrams, Figs. 7 & 8.

Part II.

Problem:

An Airship hull is constructed with a contour like the U.S.S. Los Angeles if 100 ft. parallel section had been added at the point of maximum ordinate; and to make it such dimensions that the air volume of hull = 5,000,000 cu.ft.

Required:

1. Hull drag coefficient-V_s-VL, curve of this airship hull
2. Bare hull drag in lb. at 100 ft./sec., standard density, (ρ = .00237 slugs/cu.ft.)
3. Horsepower absorbed in overcoming bare hull drag at 120 ft./sec.

Data

Present dimensions of U.S.S. Los Angeles.

			Symbol
Air volume of hull	2,764,461.0	cu.ft.	(Vol)
Length	658.3	ft.	L
Maximum diameter	90.7	ft.	D
Cylindrical coefficient	.650		$\left(\frac{4(\text{Vol})}{\pi D^2 L}\right)$
Eccentricity of nose ellipse	.978		$\left(\frac{\sqrt{x^2-r^2}}{x}\right) = e$
Fineness ratio	7.25		L/D

Calculations of dimensions of hull in problem and dimensionless quantities of shape.

(Vol) added in parallel section cu.ft.

$$100\ \pi\ r^2 = 100\ \pi\ \overline{45.35}^2 = 646,108$$

Former (Vol) 2,764,461

New (Vol) 3,410,569

New length = L + 100 = 658.3 + 100 = 758.3 ft.

Max. diameter, as formerly 90.7 ft.

e " " .978

New fineness ratio $\frac{L}{D} = \frac{758.3}{90.7} = 8.36$

$$\text{Cylindrical coef.} = \frac{(\text{Vol})}{\text{Vol of circumscribing cylinder}} = \frac{4(\text{Vol})}{\pi D^2 L} =$$

$$= \frac{4 \times 3,410,569}{\pi (90.7)^2 \times 758.3} = \frac{13,642,276}{19,597,764} = .6961$$

$$\text{Virtual (Vol)} = V_M\ (\text{Vol}) + \frac{\pi r^3}{3} = 3,410,569 + \frac{\pi (45.35)^3}{3} =$$

$$= 3,410,569 + 97,670 = 3,508,239 \text{ cu.ft.}$$

$$\begin{aligned}\mathrm{Log}_{10}\, V_M &= 6.54509\\ \mathrm{Log}_{10}\, L &= 2.87984\\ \text{"}\ (V_M L) &= 9.42493\end{aligned}$$

$$L_g = \text{Geometric length} = \sqrt[4]{\left(\text{Vol} + \frac{\pi r^3}{3}\right)(\text{length})} = \sqrt[4]{V_M L} = 227.1 \text{ ft.}$$

$$\text{"}\ \sqrt[4]{V_M L} = \frac{9.42493}{4} = 2.35623 = \log_{10} L_g;\ L_g = 227.1 \text{ ft. at Vol} = 3,410,569 \text{ cu.ft.}$$

$$Y = (e)\ (\text{cylindrical coef.})\ (\text{fineness ratio})$$

$$Y = .978 \times .6961 \times 8.36 = 5.691$$

$$Z = \frac{L\ (\text{fineness ratio})}{L_g} = \frac{L^2}{L_g\, D} = \frac{(758.3)^2}{227.1 \times 90.7} = \frac{575,020}{20,598} = 27.916$$

$$(Y + Z) = 5.691 + 27.916 = 33.607$$

$$\mathrm{Log}_{10}(Y + Z) = 1.53643$$

Note:

[e, $\frac{L}{D}$, $\frac{4\ \text{Vol}}{\pi D^2 L}$, $\frac{L}{L_g}$, are dimensionless quantities and can be calculated from any set of dimensions that pertain to the same volume. $(Y + Z)$ – independent of volume.]

When $L = 758.3$ ft. Vol. = 3,410,569 cu.ft.

$$\left(\frac{L \text{ at } 100000}{758.3}\right)^3 = \frac{100000}{3,410,569} = .02932$$

$$L \text{ at } 100000 = \sqrt[3]{(758.3)^3 \times .02932} = \sqrt[3]{12,785,000} = 233.83 \text{ ft.}$$

By logs_{10}

$$\begin{aligned}&\log \overline{758.3}^3 = 3 \times 2.87984 = 8.63952\\ &\text{"}\ .02932 \qquad\qquad\qquad\qquad\ \ \underline{8.46716-10}\\ &\qquad\qquad\qquad\qquad\qquad\qquad 3\,\big|\,\underline{7.10668}\\ &\log L \text{ at } 100000 \qquad\qquad\quad\ 2.36889 \quad L \text{ at } 100000 = 233.83 \text{ ft.}\end{aligned}$$

$$\frac{\text{Desired Vol}}{100000} = \frac{5,000,000}{100000} = 50.$$

log (L at 100,000)^3 as before 7.10668
" 50 1.69897

$3 \overline{)8.80565}$

log $L_{5,000,000}$ 2.93522 = 861.41 ft. = length of desired hull.

Requirement 1:

L at 100,000 ft.^{3} = 233.83 ft.

L at 800,000 ft.^{3} = 467.66 ft.

L at 6,400,000 ft.^{3} = 935.32 ft.

L at 5,000,000 ft.^{3} = 861.41 ft.

VL at 100,000 & 100 ft./sec. = 100 × 233.83 = 23383 ft.^{2}/sec. Log_{10} VL = 4.36889

VL at 800,000 & 100 ft./sec. = 100 × 467.66 = 46766 ft.^{2}/sec. Log_{10} VL = 4.66992

VL at 6,400,000 & 100 ft./sec. = 100 × 935.32 = 93532 ft.^{2}/sec. Log_{10} VL = 4.97095

VL at 5,000,000 & 100 ft./sec. = 100 × 861.41 = 86141 ft.^{2}/sec. Log_{10} VL = 4.93522

Enter left-hand scale of Fig. 8 with $\log_{10}(Y + Z) = 1.52643$ and follow across to scale .3 cu.ft. Vol. (see dotted line, Fig. 8).

From .3 cu.ft. Vol., interpolate for slope and follow across to 100,000 cu.ft. scale (see dotted line).

From 100,000 cu.ft. scale, follow across, interpolating for slope, to 800,000 and 6,400,000 cu.ft. scales.

From 800,000 to 6,400,000 scale is a straight line (see dotted line solution of this problem in Fig. 8).

Pick off the following values of C_H, and take logs:

Volume	C_H	Log_{10} C_H
100,000	.02180	8.33846-10
800,000	.01654	8.21854-10
6,400,000	.01380	8.13988-10

Note: Figs. 7 and 8 are for a speed of 100 ft./sec., ρ = .00237 slugs/ft.^{3}, and standard ρ/μ. Enter Fig. 9 with $\log_{10}$ VL = 4.93522 and from curve pick off $\log_{10}$ C_H = 8.147-10. Whence C_H = .01403 at 5,000,000 cu.ft. and 100 ft./sec. Use this value in Requirement 2.

Requirement 2:

Bare hull drag at 100 ft./sec. ρ = .00237 slugs/cu.ft.

$$\text{Drag} = C_H \frac{\rho}{2} (\text{Vol})^{2/3} V^2$$

L = 861.4, V = 100, VL = 86141 ft.^{2}/sec.;
$\log_{10}$ VL = 4.93522.

From Fig. 9 with $\log_{10}$ VL = 4.93522 pick off $\log_{10} C_H$=8.147-10;
C_H = .01403 as explained above.

$$\text{Drag} = .01403 \times \frac{.00237}{2} \times (5,000,000)^{2/3} \times 100^2 = 4860.5 \text{ lb.}$$

Requirement 3:

HP. absorbed in overcoming bare hull drag at 120 ft./sec.

L = 861.41 ft.; V = 120 ft./sec.; VL = 103369 ft.^{2}/sec.,
$\log_{10}$ VL = 5.01439

From Fig. 9 with $\log_{10}$ VL = 5.01439 pick off
$\log_{10} C_H$ = 8.132-10; C_H = .01355

$$\text{Drag} = C_H \frac{\rho}{2} (\text{Vol})^{2/3} V^2 = .01355 \times \frac{.00237}{2} \times (5,000,000)^{2/3} \times 120^2 = 6761.8 \text{ lb.}$$

$$\text{HP. absorbed} = \frac{\text{Drag } V}{550} = \frac{6761.8 \times 120}{550} = 1475.3 \text{ HP.}$$

$$\text{Note: HP. to equip ship with} = \frac{(\text{Hull Drag + External Drag})\ V_{max}}{550 \times \text{Propeller Efficiency}}.$$

Symbols and Formulas

Length	L ft.
Maximum diameter	D ft.
Distance nose to max. dia.	x ft.
Maximum radius	r ft.
(Vol) - air volume	(Vol) cu.ft.
Eccentricity, nose ellipse	e no dimensions $e = \frac{\sqrt{x^2 - r^2}}{x}$ no dimensions
Geometric length	$L_g = \sqrt[4]{[(Vol) + \frac{\pi r^3}{3}] L}$ ft.
Cylindrical coef. (Cyl. Coef.)	$= \frac{(Vol)}{\frac{\pi D^2 L}{4}} = \frac{4 (Vol)}{\pi D^2 L}$ no dimensions
Fineness ratio	L/D no dimensions
Pressure difference shape coef.	$Y = e$ (Cyl. Coef.) (L/D) no dimensions. $Y = e \left(\frac{4 (Vol)}{\pi D^3} \right)$
Skin friction shape coef.	$Z = \frac{L}{L_g} \times \frac{L}{D} = \frac{L^2}{L_g D}$ no dimensions
Whole hull shape coef.	$(Y + Z)$
Virtual volume	$V_M = (Vol) + \frac{\pi r^3}{3}$ cu.ft.
Density	ρ slugs/cu.ft.
Air speed	V - ft./sec.
VL	Air speed × length ft.^{2}/sec.
Drag	R $C_H \frac{\rho}{2} (Vol)^{2/3} V^2$ lb.

Symbols ans Formulas (Cont.)

Drag coef. of bare hull C_H no dimensions

Horsepower absorbed by drag R[illegible]; $HP. = \frac{R\ V}{550}$

$$\left(\frac{\text{Length at Volume 1}}{\text{Length at Volume 2}}\right)^3 = \frac{\text{Volume 1}}{\text{Volume 2}}$$

PART II

	ITEM	BUILDER'S NUMBERS.	REMARKS.
CONTINUOUS CURVATURE	1	U.S.N. "B"	Non Rigid, One Car, One Engine, Navy No 9 Fuselage Type Of Car, Bumpers Outside And Below Car, Tractor Propeller, Surfaces Flat Plate Type On Stern Only.
	2	U.S.N. "C"	" " , " " Two Engines, Well Designed Car, Bumpers Included In Car, Engines On Arms, Pusher Propellers, " " " " " " ".
	3	U.S.N. "D"	" " , " " , " " , " " " , " " " " " " , " " , " " " " " " ".
	4	U.S.N. "E"	" " , " " , One Engine , " " " , " Below Car, Engine On Stern (?) — " " " , " " " " " " ".
	5	U.S.N. "F"	" " , " " , " " , " " " , ———— " " " , ———— , " " " " " " ".
	6	LZ-120 & 121 BODENSEE (AFTER LENGTHENING). NORDSTERN.	Rigid, Two Small Power Cars, One Large Power Car With Two Engines On One Propeller, Central Car Att. To Hull ————, " " " " " " ".
	7	LZ-126 U.S.S. LOS ANGELES (NO WATER RECOVERY)	" , Five " " " , Central Car Adjacent To Hull, Small Amount Of External Bracing, Well Mounted Surfaces On Stern Only.
PARALLEL SECTION.	8	LZ-1	Rigid, Two Power Cars One Engine Each, One Of Which Is Control Car, External Keel, Bow & Stern Sur arge Amount Of External Bracing, Box Type Surfaces On Stern, Flat Plate Type Surfaces On Bow.
	9	LZ-4 & 5	" , " " " " " " , " " " " " " , " " " " " " " " " , " " " " " " , " " " " " " ".
	10	LZ-7 & 8	" , " " " , One Combined Power & Control Car, Total Of Three Engines, Large External Keel Inc Passenger Space, Quadruple Surfaces On Bow, Large Amount Of External Bracing, Four Propellers On Outriggers.
	11	LZ-10 & 12	" , " " " , " " " " " " , " " " " , " " " " " " , Large Box Type Surfaces On Stern, " " " " " , " " " " ".
	12	LZ-15 & 16	" , One " " Single Engine, One Combined Control & Two Engine Power Car, " " " " " " " , " " " " " " " , " " " " " , " " " " ".
	13	LZ-22 & 23	" , " " " " " , " " " " " " " , " " " " " " " , " " " " " , " " " " ".
	14	LZ-24 To 37	" , " " " " " , " " " " " " " , " " " " " " " , " " " " " , One " " Each Car.
	15	LZ-36	" , " " , " " " , " " " " " " " " , No External Keel, Larg ate Type Surfaces On Stern, Smaller Amount Of External Bracing & Struts, " " " " ".
	16	LZ-42 To 50	" , " " " Two " , " " " " " " " " , " " " " " " " " " , Large " " " " , " " " " ".
	17	LZ-59 To 61, & 64 To 71 (EXCEPT 60 & 70	" , Three " " One " , " " " One " " " , " " " Small " " " " " , Smaller " " " " , " " " " ".
	18	LZ-72 To 90 (EXCEPT 73, 77 & 81)	" , Two " " Two " , " " " Two " " " , " " " " " " " " " , Small " " " " , " " " " ".
	19	LZ-91 To 94	" , Three " " One " , " " " " " " " , " " " Hexagonal S " " " " " , " " " " " , " " " " ".
	20	LZ-95 To 99	" , " " " " " , " " " " " " " , " " " " " " " " , " " " " " , " " " " ".
	21	LZ-100 & 101	" , " " " " " , " " " " " " " , " " " " " " " " , " " " " " , " " " " ".
	22	LZ-102	" , " " " " " , " " " " " " " , " " " " " " " " , " " " " " , " " " " ".
	23	LZ-104	" , " " " " " , " " " " " " " , " " " " " " " " , " " " " " , " " " " ".
	24	LZ-106 To 111	" , " " " " " , " " " " " " " , " " " " " " " " , " " " " " , " " " " ".
	25	LZ-112 To 114	" , Five " " " " , " Control Car ————, " " " " Streamlined " " " , " " " " " , " " " " Power Car.
	26	ZR-1 U.S.S. SHENANDOAH.	" , " " " " " , " " " ————, " " " " " " " " " , " " " " " , " " " " " ".

CALCULATIONS BY CLINTON H. HAVILL.
LIEUT., U.S. NAVY.

PART II

	POWER CARS - SMALL					TWO ENGINE POWER CARS.			CONTROL CARS ADJ. TO HULL			*SEPARATE C	
ITEM	MAX. CROSS SECT. AREA ONE CAR Sq.Ft.	CAR COEF.	AREA OF DRAG FOR POWER CAR. POWER ON Sq.Ft.	NO OF CARS	TOTAL AREA OF DRAG FOR ALL CARS. Sq.Ft.	CROSS SECT. AREA (MAX.) Sq.Ft.	CAR COEF	AREA OF DRAG. POWER ON Sq.Ft.	CROSS SECT. AREA (MAX.) Sq.Ft	COEF.	AREA OF DRAG Sq.Ft.	CROSS SECT. AREA (MAX) Sq.Ft.	COE
1												23.11	.45
2												49.72	.40
3												49.72	.40
4												33.00	.41
5												33.00	.41
6	31	.32	9.92	2	19.84	42	.44	18.48	121.00	.11	13.31		
7	40 △	.30	12.00	5	60.00				176.84	.09	15.91		
8	36	.45	16.20	2	32.40								
9	38	.45	17.10	2	34.20								
10	40	.43	17.20	1	17.20							46.	.35
11	42	.43	18.06	1	18.06							48	.35
12	43	.43	18.49	1	18.49							49	.35
13	43	.43	18.49	1	18.49							49	.35
14	45	.42	18.90	1	18.90							51	.36
15	45	.41	18.45	1	18.45							51	.36
16	42	.40	16.80	1	16.80	47	.45	21.15				48	.35
17	37	.40	14.80	3	44.40							43	.3
18	37	.40	14.80	2	29.60	47	.45	21.15				43	.34
19	35	.40	14.00	3	42.00							41	.39
20	35	.40	14.00	3	42.00							41	.31
21	35	.40	14.00	3	42.00							41	.31
22	35	.40	14.00	3	42.00							41	.31
23	35	.40	14.00	3	42.00							41	.31
24	35	.35	12.25	3	36.75							41	.31
25	33.1	.33	10.92	5	54.60							36	.30
26	34.3△	.33	11.32	5	56.60							36.16	.30

* SOME HAVE ENGINES.

⊕ EXTERNAL BUMPERS INCLUDED.

△ MEASURED FROM PLANS.

† INCLUDES EXTERNAL BRACINGS, OUTRIGGERS

NOTE:- IT IS TO BE NOTED THAT THIS HU DRAG CAN SO FAR ONLY BE COMPUTED FOR U_{MAX} AS IT IS NOT KNOWN IF THE HULL DRAG VARIES AS U^2 O T. THE U_{MAX} AND AREA OF DRAG FOR THE WHOLE SHIP AS GIVEN IN PART I, WERE ONLY AT THE POINT WHERE AGREE, SUCH AS HP_{MAX}, U_{MAX}, E & K AT U_{MAX}. REYNOLDS LAW IS THAT "SIMILAR SHIPS HAVE THE SAME DRAG AND SAME UL". THE DATA THUS FAR WAS PLOTTED AGAINST A NUMBER OF FUNCTIONS AND AS SHIPS WERE DISSIMILAR A TE EQUIVALENT TO UL WAS FINALLY OBTAINED. $L_q = \sqrt[4]{(\text{AIR VOL} + \frac{\pi r^3}{3})(\text{LENGTH})}$, U = VELOCITY IN FEET PER SECOND. TH FOR SIMILAR SHIPS THIS DEFINITION OF UL_q APPLIES AND FOR DISSIMILAR SHIPS GIVES THE RESULTS OF PLOT I THE RESEARCH FOR THIS UL_q TERM EXTENDED OVER A PERIOD OF ABOUT FIVE MONTHS.

NTROL CAR	CONTROL SURFACES.																PRELIM. PLOT No 1.	
AREA OF DRAG Sq. Ft.	ACTUAL AREA OF BOTH SIDES OF ALL CONT. SURFACES. Sq. Ft.	COEF.	AREA OF DRAG. Sq. Ft.	DRAG AREA ★ ALLOWED FOR Sq. Ft.	SUM OF FOREGOING DRAG AREA (POWER ON) Sq. Ft.	TOTAL DRAG AREA FOR WHOLE SHIP. (FROM PART I) Sq. Ft.	AREA OF DRAG OF HULL. Sq. Ft.	U_{MAX} (FROM PART I) Ft/Sec.	BARE HU DRAG AT U_{MAX}. ($A_H \frac{\rho}{2} U_M^2$) Lbs.	VIRTUAL VOL FROM PART I AIR VOL + $\frac{\pi r^3}{3}$ Cu. Ft.	$Log_{10} V_M$	LENGTH (FROM PART I) Ft.	Log_{10} LENGTH Log (Ft.)	$Log_{10} [V_M L]$ Ft^4	L = (GEOM. LENGTH) $Log_{10} L = Log \sqrt[4]{V_M L(ft)}$ Log (GEOM. LENGTH) Log (Ft.)	LOG U_{MAX}.	LOG UL AT U_{MAX}.	BARE HULL DRAG AT U_{MAX}. Lbs.
10.40	1370	.0072	9.87	29	49.27	87.40	38.13	69.00	215.1	90380	4.95607	163	2.21219	7.16826	1.79207	1.83885	3.63092	215.11
19.89	1969	.0072	14.17	34	67.80	127.37	59.57	88.00	546.9	189710	5.27809	196	2.29226	7.57035	1.89259	1.94448	3.83907	546.92
19.89	1969	.0072	14.17	34	67.80	131.46	63.66	83.11	521.0	199710	5.30040	198	2.29667	7.59707	1.89927	1.91965	3.81892	521.04
13.53.	1125	.0072	8.10	15	36.63	78.00	41.37	82.20	331.2	99820	4.99922	162	2.20952	7.20874	1.80219	1.91487	3.71705	331.24
13.53	1125	.0072	8.10	17	38.09	79.01	40.96	77.30	290.0	99820	4.99922	162	2.20952	7.20874	1.80219	1.88818	3.69036	290.01
	9180	.0062	56.91	17	125.54	170.01	44.47	119.99	204.5	827920	5.91799	427	2.63043	8.54842	2.13711	2.07914	4.21625	204.50
	8460	.0052	43.92	8	127.83	356.99	229.16	115.00	3591.2	2862061	6.45667	658.3	2.81842	9.27509	2.31877	2.06070	4.37947	3591.24
	1731	.0281	48.63	42	123.03	251.00	127.97	26.40	105.6	407310	5.60992	428	2.63124	8.24136	2.06034	1.42160	3.48194	105.66
	5357	.0281	150.55	42	226.75	383.01	156.26	41.00	311.2	582200	5.76507	446	2.64933	8.41440	2.10360	1.61278	3.71638	311.24
16.10	4651	.0273	126.98	40	200.28	374.00	173.72	51.98	555.8	746680	5.87312	486	2.68664	8.55976	2.13994	1.71584	3.85578	555.81
16.80	13530	.0242	327.41	35	397.27	563.00	165.73	62.40	764.8	643680	5.80867	460	2.66276	8.47153	2.11788	1.79518	3.91304	764.69
17.15	7197	.0240	171.77	35	242.41	412.00	169.59	67.50	915.5	759210	5.88036	466	2.66839	8.54875	2.13719	1.82930	3.96649	915.57
17.19	9793	.0238	233.08	32	300.44	482.00	181.56	66.69	955.2	802210	5.90428	512	2.70927	8.61355	2.15339	1.82406	3.97745	955.21
18.36	10720	.0238	255.08	30	322.44	409.00	86.56	70.89	512.	873210	5.94111	519	2.71517	8.65628	2.16407	1.85058	4.01465	512.46
18.36	14950	.0065	97.23	19	153.04	333.98	145.99	77.09	1273.	903040	5.95569	530	2.72428	8.67997	2.16999	1.88700	4.05699	1273.62
16.80	15920	.0068	108.29	25	187.99	393.00	205.01	81.61	1617.	1250900	6.09722	536	2.72916	8.82638	2.20659	1.91174	4.11833	1617.67
14.62	13680	.0065	88.93	19	166.95	369.49	202.54	86.00	1775.	1393900	6.14422	586	2.76790	8.91212	2.22803	1.93450	4.16253	1775.09
14.62	21110	.0071	149.91	19	234.28	474.00	239.72	92.40	2425.	2211820	6.34473	645	2.80956	9.15429	2.28897	1.96567	4.25424	2425.07
15.99	15390	.0071	109.28	18	185.27	423.00	237.73	92.41	2405.	2202820	6.34297	645	2.80956	9.15253	2.28813	1.96572	4.25385	2405.02
12.71	10510	.0063	66.27	15	135.98	372.00	236.02	96.19	2586.	2202820	6.34297	645	2.80956	9.15253	2.28813	1.98313	4.27126	2586.77
12.71	10260	.0063	64.62	15	134.33	371.00	236.67	97.40	2660.	2203820	6.34297	645	2.80956	9.15253	2.28813	1.98856	4.27669	2660.63
12.71	11280	.0063	71.05	17	142.76	419.00	276.24	94.29	2909.	2702820	6.43182	745	2.87216	9.30398	2.32599	1.97447	4.30046	2909.85
12.71	12060	.0063	75.99	18	148.70	424.00	275.30	94.19	2893.	2702820	6.43182	745	2.87216	9.30398	2.32599	1.97400	4.29999	2893.69
12.71	11180	.0063	70.49	17	134.95	372.00	235.05	104.81	3068.	2203820	6.34297	645	2.80956	9.15253	2.28813	2.02040	4.30853	3068.87
10.84	10600	.0062	65.77	16	147.21	404.00	256.79	113.12	3892.	2462820	6.39142	745	2.87216	9.26358	2.31589	2.05357	4.36943	3892.34
10.84	11304	.0062	70.08	17	152.92	402.51	249.99	91.00	2453.	2352681	6.37156	680.2	2.83264	9.20420	2.30105	1.95904	4.26009	2453.15
					A_X	A_{TOTAL}	$A_H = A_{TOTAL} - A_X$		SEE NOTE AT TOP OF PAGE.	V_M		L						

KEEL ETC.

CALCULATIONS BY CLINTON H. HAVILL.
LIEUT, U. S. NAVY.

PART II

					Prelin. Plot # 2												
ITEM	U_{MAX} From Part I Ft/Sec	Total Area of Drag Whole Ship Power On Sq. Ft	Total Drag of Whole Ship @ U_{MAX}. Lbs.	% of Total Drag for Hull (Estimated) #	Bare Hull Drag at U_{MAX} Lbs	$Log_{10} UL$ at U_{MAX}.	Virtual Volume V_M From Part I Cu. Ft.	$Log_{10} V_M$	Actual Length L_A From Part I. Ft.	Log_{10} Length	$Log_{10} V_M L_A$	$Log_{10} \sqrt[4]{V_M L_A^3}$ = Log_{10} Geom Length = $Log_{10} L_g$	U_{MAX} From Part I Ft./Sec	$Log_{10} U_{MAX}$	$Log_{10} UL_g$ @ U_{MAX}. Same as Used in Plots 1 & 2	Bare Hull Drag at U_{MAX}. From Plot #3 Lbs	Dra Coe of B Hul U_M 2 Cum
1	69.00	87.40	493.08	44	216.95	3.63092	90380	4.9560	163	2.21219	7.16826	1.79207	69.00	1.83885	3.63092	215	.01
2	88.00	127.40	1167.09	47*	549.47	3.83707	189710	5.2780	196	2.29226	7.57035	1.89259	88.00	1.94448	3.83707	547	.01
3	83 11	131.49	1076.06	48*	516.50	3.81892	199710	5.3004	198	2.29667	7.59707	1.89927	83.11	1.91965	3 81892	521	.01
4	82.20	78.00	624.53	53	331.00	3.71705	99820	4.9992	162	2.20952	7.20874	1.80218	82.20	1.91487	3.71705	331	.01
5	77.30	79.01	559.42	57	318.86	3.69036	99820	4.9992	162	2.20952	7.20874	1.80218	77.30	1.88818	3.69036	270	.02
6	119.99	170.01	2898.50	60	1739.10	4.21625	827920	5.9179	427	2.63043	8 54842	2.13711	119.99	2.07914	4.21625	2110	.01
7	115.00	356.99	5594.97	64*	3580.52	4.37947	2862061	6.4566	658.3	2.81842	9.27509	2.31877	115.00	2.06070	4.37947	3910	.01
8	26.40	251.00	207.26	51	105.70	3.48194	407310	5.6099	428	2.63144	8.24136	2.06034	26.40	1.42160	3.48194	106	.02
9	41.00	383.01	762.92	41	312.79	3.71638	582200	5.7650	446	2.64933	8.41440	2.10360	41.00	1.61278	3.71638	311	.02
10	51.98	374.00	1196.61	46	550.44	3.85578	746680	5.8731	486	2.68664	8.55976	2.13994	51.98	1.71584	3.85578	556	.02
11	62.40	563.00	2597.85	43	1117.07	3.91304	643680	5.8086	460	2.66276	8.47153	2.11788	62.40	1.79518	3.91304	765	.02
12	67.50	412.00	2224.31	41	911.76	3.96649	759210	5.8803	466	2.66839	8.54875	2.13719	67.50	1.82930	3.96649	916	.02
13	66.69	482.00	2535.94	38	963.65	3.97745	802210	5.9042	512	2.70927	8.61355	2.15339	66.69	1.82406	3.97745	955	.02
14	70.89	409.00	2421.52	46	1113.89	4.01465	873210	5.9411	519	2.71517	8.65628	2.16407	70.89	1.85058	4 01465	1090	.02
15	77.09	333.98	2350.85	54	1269.46	4.05699	703040	5.9956	530	2.72428	8.67997	2.16999	77.09	1.88700	4.05699	1274	.01
16	81.61	393.00	3101.08	52	1612.56	4.11833	1250900	6.0972	536	2.72916	8.82638	2.20659	81.61	1.91174	4.11833	1520	.01
17	86.00	369.49	3238.28	55	1781.05	4.16253	1393900	6.1442	586	2.76790	8.91212	2.22803	86.00	1.93450	4.16253	1779	.01
18	92.40	474.00	4795.13	51	2445.51	4.25424	2211820	6.3447	645	2.80956	9.15429	2.28857	92.40	1.96567	4.25424	2425	.01
19	92.41	423.00	4279.49	56	2396.51	4.25385	2202820	6.3429	645	2.80956	9.15253	2.28813	92.41	1.96572	4.25385	2405	.01
20	96.19	372.00	4077.12	63	2568.58	4.27126	2202820	6.3429	645	2.80956	9.15253	2.28813	96.19	1.98313	4.27126	2587	.01
21	97.40	371.00	4170.78	64	2669.29	4.27669	2203820	6.3429	645	2.80956	9.15253	2.28813	97.40	1.98856	4.27669	2661	.01
22	94.29	419.00	4413.75	66	2913.07	4.30046	2702820	6.4318	745	2.87216	9.30398	2.32599	94.29	1.97447	4.30046	2910	.01
23	94.19	424.00	4456.66	65	2896.83	4.29999	2702820	6.4318	745	2.87216	9.30398	2.32599	94.19	1.97400	4.29999	2874	.01
24	104.81	372.00	4851.25	63	3056.28	4.30853	2203820	6.3429	645	2.80956	9.15253	2.28813	104.81	2.02040	4.30853	3069	.01
25	113.12	404.00	6123.83	63	3858.01	4.36943	2462820	6.3914	745	2.87216	9.26358	2.31589	113.12	2.05354	4.36943	3893	.01
26	91.00	402.51	3949.43	62*	2448.64	4.26009	2352681	6.3715	680.2	2.83264	9.20420	2.30105	91.00	1.95904	4.26007	2480	.01
					D_H		V_M		L_A							D_H	

Comparison Of Bare Hull Drag At 100 Ft/Sec.			
Log$_{10}$ UL$_g$ @ 100 Ft/Sec = Log$_{10}$ L$_g$+2	Bare Hull Drag At 100 Ft/Sec From Plot #3 Lbs	Drag. Coef Of Bare Hull @ 100 Ft/Sec C_H	Explanation
3.79207	420	.0185	Comparison Of Ships If Reduced Or
3.89259	640	.0170	Expanded To The Same Air Volume Of
3.89927	660	.0169	Hull. Relation Between Two Similar
3.80218	432	.0175	Solids Of Linear Dimensions In The Ratio
3.80218	432	.0175	Of $\frac{L1}{L2}$ Are As Follows:- $\frac{Vol\,1}{Vol\,2} = \left(\frac{L1}{L2}\right)^3$.
4.13711	1650	.0163	For The Same Or Geometrically Similar
4.31877	3120	.0125	Airship Hulls But Of Different Sizes. $\frac{\text{Air Vol. Of Hull 1}}{\text{Air Vol. Of Hull 2}} = \left(\frac{\text{Similar Linear Dimension 1}}{\text{Similar Linear Dimension 2}}\right)^3 = \left(\frac{\text{Geometric Lgth 1}}{\text{Geometric Lgth 2}}\right)^3 = \left(\frac{Lg1}{Lg2}\right)^3$.
			$\frac{\text{Actual Air Vol Of Hull}}{\text{New Air Vol Of Hull}} = \left(\frac{\text{Actual Lg}}{\text{New Lg}}\right)^3$
4.06034	1275	.0199	
4.10360	1460	.0179	To Reduce All Items To 100,000 Cu.Ft. Air Vol.
4.13994	1640	.0171	Of Hull. $\frac{\text{Actual Air Vol. Of Hull}}{100000} = \left(\frac{\text{Actual Lg}}{\text{New Lg}}\right)^3$.
4.11788	1530	.0164	By Logs$_{10}$.
4.13719	1630	.0168	$\text{Log}_{10}(\text{New Lg}) = \frac{1}{3}\text{Log}_{10}100000 - \frac{1}{3}\text{Log}_{10}(\text{Actual Air Vol}) +$
4.15339	1700	.0169	$\text{Log}_{10}(\text{Actual Lg})$.
4.16407	1750	.0164	$\text{Log}_{10}(\text{New Lg}) = \frac{5}{3} - \frac{1}{3}\text{Log}_{10}(\text{Air Vol.}) + (\text{Log}_{10}\text{Lg As Tabulated Before})$
4.16999	1775	.0163	
4.20659	1970	.0146	
4.22803	2110	.0145	
4.28857	2615	.0133	
4.28813	2615	.0133	
4.28813	2615	.0133	
4.28813	2615	.0133	
4.32599	3050	.0135	
4.32599	3050	.0135	
4.28813	2615	.0133	
4.31589	2905	.0137	
4.30105	2740	.0134	
	D_H	C_H	

Calculations By Clinton H. Havill
Lieut., U. S. Navy.

PART II

								Co
								1
ITEM	AIR VOLUME OF HULL FROM PART I CU.FT.	Log_{10} (AIR VOL OF HULL)	$\text{Log}_{10}\sqrt[3]{\text{Vol}}$	Log_{10} (Lg) AS TABULATED BEFORE FOR ACTUAL SIZE	$\text{Log}_{10}\sqrt[3]{100,000} = \frac{5}{3} = 1.66667$	Log_{10} Lg + 1.66667	Log_{10} Lg WHEN AIR VOL = 100 000 CU.FT. LOG Lg @ 100,000 = (LOG Lg + 1.6666 − LOG $\sqrt[3]{\text{Vol}}$)	Log_{10} @ 100 F AND 100,000 C VOLUME Log_{10} L @ 100,000 +
1	84000	4.92428	1.64143	1.79207	1.66667	3.45874	1.81731	3.817
2	180000	5.25527	1.75176	1.89259	″	3.55926	1.80750	3.807
3	190000	5.27875	1.75958	1.89927	″	3.56594	1.80636	3.806
4	95000	4.97772	1.65924	1.80218	″	3.46885	1.80961	3.809
5	95000	4.97772	1.65924	1.80218	″	3.46885	1.80961	3.809
6	797000	5.90146	1.96715	2.13711	″	3.80378	1.83663	3.836
7	2764461	6.44161	2.14720	2.31877	″	3.98544	1.83824	3.838
8	400000	5.60206	1.86735	2.06034	1.66667	3.72701	1.85966	3.85
9	572000	5.75740	1.91913	2.10360	″	3.77027	1.85114	3.851
10	734000	5.86574	1.95525	2.13994	″	3.80661	1.85136	3.851
11	631000	5.80003	1.93334	2.11788	″	3.78455	1.85121	3.851
12	741000	5.87157	1.95719	2.13719	″	3.80386	1.84667	3.846
13	787000	5.89597	1.96532	2.15339	″	3.82006	1.85474	3.854
14	858000	5.93349	1.97783	2.16407	″	3.83074	1.85291	3.852
15	884000	5.94645	1.98215	2.16999	″	3.83666	1.85451	3.854
16	1220000	6.08636	2.02879	2.20659	″	3.87326	1.84417	3.844
17	1363000	6.13450	2.04483	2.22803	″	3.89470	1.84987	3.849
18	2149000	6.33224	2.11075	2.28857	″	3.95524	1.84417	3.844
19	2140000	6.33041	2.11014	2.28813	″	3.95480	1.84466	3.844
20	2140000	6.33041	2.11014	2.28813	″	3.95480	1.84466	3.844
21	2141000	6.33062	2.1102.	2.28813	″	3.95480	1.84459	3.844
22	2640000	6.42160	2.14053	2.32599	″	3.99266	1.85213	3.852
23	2640000	6.42160	2.14053	2.32599	″	3.99266	1.85213	3.852
24	2141000	6.33062	2.11021	2.28813	″	3.95480	1.84459	3.844
25	2400000	6.38021	2.12674	2.31589	″	3.98256	1.85582	3.85
26	2289861	6.35980	2.11993	2.30105	″	3.96772	1.84779	3.84

PARISON OF BARE HULLS AT VARYING AIR VOLUMES AND A VE

00 CU. FT.		200,000 CU. FT.			400,000 CU. FT.			800,000	
D_H From Plot 3 Bare Hull Drag @ 100 Ft/sec And 100000 Cu.Ft. Air Vol. (LBS)	C_H Drag Coef Of Bare Hull Drag $C_H=\frac{2D_H}{\rho U^2 (Vol)^{\frac{2}{3}}}$ $\rho=.00237$ $U=100$ $Vol=100000$ $C_H=.00003917D_H$	$Log_{10} ULq$ @ 100 Ft/sec And 200,000 Cu Ft. Volume $Log\ Lq @ 100000 + \frac{1}{3} Log\ 2 = Log\ L_{q\,100000} + .10034$	D_H From Plot 3 Bare Hull Drag @ 100 Ft/sec And 200000 Cu Ft Air Volume (LBS)	C_H Drag Coef Of Bare Hull Drag $C_H=\frac{2D_H}{\rho U^2 (Vol)^{\frac{2}{3}}}$ $\rho=.00237$ $U=100$ $Vol=200000$ $C_H=.00002465D_H$	$Log_{10} ULq$ @ 100 Ft/sec. And 400,000 Cu. Ft. Volume $Log\ Lq @ 200000 + \frac{1}{3} Log\ 2 = Log\ L_{q\,200000} + .10034$	D_H @ 400,000 Cu. Ft. Air Volume And 100 Ft/sec (LBS)	C_H $\rho=.00237$ $U=100$ $Vol=400,000$ $C_H=.0001555D_H$	$Log_{10} ULq$ @ 100 Ft sec And 800000 Cu Ft. Air Vol. $L_{q\,800000} = 2^{\frac{2}{3}} q_{100000}$ $Log\ DL_{q\,100000} + Log\ 2 = Log\ UL_{q\,800000}$ ($Log\ 2 = .30103$)	D_H From Plot 3 Bare Hull Drag @ 100 Ft/sec And 800000 Cu.Ft. Air Vol. LBS.
490	.01919	3.91765	730	.01801	4.01799	1090	.01695	4.11834	1540
475	.01861	3.90784	710	.01752	4.00818	1060	.01648	4.10853	1480
470	.01841	3.90670	705	.01739	4.00704	1056	.01642	4.10737	1478
480	.01880	3.90995	715	.01764	4.01029	1080	.01679	4.11064	1500
480	.01880	3.90995	715	.01764	4.01029	1080	.01679	4.11064	1500
540	.02115	3.93697	805	.01984	4.03731	1188	.01847	4.13766	1630
540	.02115	3.93858	806	.01987	4.03892	1190	.01850	4.13927	1640
595	.02331	3.96000	896	.02211	4.06034	1265	.01967	4.16069	1758
594	.02311	3.95148	880	.02171	4.05182	1230	.01913	4.15217	1710
591	.02315	3.95170	882	.02176	4.05204	1240	.01928	4.15239	1710
590	.02311	3.95154	880	.02171	4.05183	1238	.01925	4.15224	1710
570	.02233	3.94701	830	.02046	4.04735	1228	.01894	4.14770	1680
593	.02323	3.95508	885	.02182	4.05542	1245	.01936	4.15577	1718
592	.02319	3.95325	883	.02179	4.05359	1241	.01929	4.15394	1714
593	.02323	3.95485	885	.02184	4.05519	1245	.01936	4.15554	1718
568	.02225	3.94481	848	.02092	4.04515	1210	.01882	4.14550	1675
572	.02241	3.95021	852	.02102	4.05055	1212	.01885	4.15090	1700
560	.02194	3.94483	835	.02060	4.04517	1211	.01883	4.14552	1676
560	.02194	3.94500	835	.02060	4.04534	1213	.01886	4.14567	1630
560	.02194	3.94500	835	.02060	4.04534	1213	.01886	4.14569	1680
560	.02194	3.94493	835	.02060	4.04527	1213	.01886	4.14562	1678
582	.02279	3.95247	866	.02137	4.05281	1260	.01959	4.15316	1712
582	.02279	3.95247	866	.02137	4.05281	1260	.01959	4.15316	1712
560	.02194	3.94493	835	.02060	4.04527	1210	.01881	4.14562	1678
580	.02272	3.95616	865	.02134	4.05650	1260	.01959	4.15686	1720
570	.02233	3.94813	840	.02073	4.04847	1220	.01897	4.14882	1695
D_H	C_H								

OCITY OF 100 FEET PER SECOND.									
U. FT.	1,600,000 CU. FT.			6,400,000 CU. FT.					
C_H DRAG COEF OF BARE HULL DRAG $C_H=\frac{2D_H}{\rho v^2 (Vol)^{2/3}}$ $\rho=.00237$ $v=100$ Vol=800000 $C_H=.0000097925\,D_H$	LOG UL_γ @ 100 FT/SEC AND 1,600,000 CU. FT. AIR VOL. LOG L_γ @ 800000 + .10034	D_H @ 1,600,000 CU. FT. AIR VOLUME AND 100 FT/SEC (LBS)	C_H DRAG COEF OF BARE HULL DRAG $C_H=\frac{2D_H}{\rho v^2 (Vol)^{2/3}}$ $\rho=.00237$ $v=100$ Vol=1,600,000 $C_H=.0000061689\,D_H$	$Log_{10}\,UL_\gamma$ @ 100 FT/SEC. AND 6,400,000 CU. FT. AIR VOL. $L_{\gamma 6,400,000}=2L_{\gamma 800000}$ LOG $UL_{\gamma 800000}$ + LOG 2 = LOG UL_γ 6,400,000.	D_H @ 6,400,000 CU. FT. AIR VOLUME AND 100 FT. SEC. (LBS)	C_H DRAG COEF OF BARE HULL DRAG $C_H=\frac{2D_H}{\rho v^2 (Vol)^{2/3}}$ $\rho=.00237$ $v=100$ Vol=6,400,000 $C_H=$ .00000244[illegible] D_H	LOG UL_γ OF ACTUAL SHIP AT 100 FT/SEC (AS BEFORE)	D_H FROM PLOT 3 BARE HULL DRAG @ 100 FT/SEC (AS BEFORE) (LBS)	C_H DRAG COEF OF BARE HULL @ 100 FT/SEC
.01518	4.21868	2120	.01308	4.41937	5229	.01280	3.79207	420	.0185
.01449	4.20887	2060	.01271	4.40956	4902	.01200	3.89259	640	.0176
.01429	4.20773	2058	.01270	4.40842	4861	.01190	3.89927	660	.0175
.01469	4.21098	2080	.01283	4.41167	5021	.01229	3.80218	432	.0176
.01469	4.21098	2080	.01283	4.41167	5024	.01229	3.80218	432	.0176
.01576	4.23800	2290	.01413	4.43869	5555	.01359	4.13711	1650	.0163
.01605	4.23961	2285	.01409	4.44030	4943	.01210	4.31877	3120	.0125
.01718	4.26103	2495	.01539	4.46172	5392	.01320	4.06034	1275	.0199
.0167	4.25251	2422	.01594	4.45320	6209	.01520	4.10360	1460	.0179
.0167	4.25273	2422	.01594	4.45342	6291	.01540	4.13994	1640	.0171
.0167	4.25258	2422	.01594	4.45327	6250	.01530	4.11786	1530	.016[illegible]
.0164	4.24804	2381	.01571	4.44273	6209	.01520	4.13719	1630	.0168
.0168	4.25611	2428	.01498	4.45680	6[illegible]	.01460	4.15339	1700	.0169
.0167	4.25428	2425	.01496	4.45497	6617	.01617	4.16407	1750	.0164
.0168	4.25588	2425	.01498	4.45657	6295	.01589	4.16999	1775	.0163
.0164	4.24584	2340	.01444	4.44653	6250	.01530	4.20659	1970	.01[illegible]
.0166	4.23580	[illegible]	.01487	4.45193	6168	.01509	4.22803	2110	.0145
.0164	4.25124	2340	.01444	4.44655	5310	.01300	4.28857	2615	.0133
.0165	4.24603	2380	.01468	4.44672	5310	.01300	4.28813	2615	.0133
.0165	4.24603	2380	.01468	4.44672	5310	.01300	4.28813	2615	.0133
.0165	4.24603	2378	.01467	4.44665	5310	.01300	4.28813	2615	.0133
.0167	4.25350	2420	.01493	4.45419	5351	.01310	4.32599	3050	.0135
.0167	4.25350	2420	.01493	4.45419	5351	.01310	4.32599	3050	.0135
.0165	4.24596	2360	.01456	4.44665	5024	.01229	4.28813	2615	.0133
.0168	4.25720	2425	.01496	4.45789	5310	.01300	4.31587	2905	.0137
.0166	4.24916	2390	.01454	4.44985	5141	.01259	4.30105	2740	.0134

CALCULATIONS BY CLINTON H. HAVILL
LIEUT., U.S. NAVY.

A Shape Comparison Of Hull Drag Coef @ 100 Ft Sec

TEM	Ecc × Cyl × $\frac{L}{D}$ ☆	When The Ships Connected By Arrows Are Reduced Or Expanded To The Same Volume They Are Near Enough To The Same Identity That The Mean Of Their Drag Coefs Can Be Taken For Any Of Them	Mean Ecc × Cyl × $\frac{L}{D}$ Of Items Connected "Y"	Mean Value Of Drag Coef Of Hull @ 100,000 Cu Ft Vol	Mean Value Of Drag Coef Of Hull @ 800 000 Cu Ft Vol	Mean Value Of Drag Coef Of Hull @ 6,400,000 Cu Ft Vol	Log L_φ Log $\sqrt[3]{\text{Volume}}$	Log Length	Log $\left(\frac{\text{Length}}{\sqrt[3]{\text{Vol}}}\right)$ Log $\frac{L}{L_\varphi}$	$\frac{L}{L_\varphi}$	Fineness Ratio $\frac{L}{D}$	$\frac{L^2}{L_\varphi D}$	From Previous Comparison Ships Grouped According To 'Z'	Preliminary Plot No 5. Mean Value Of Drag Coef. Of Hull @ 100,000 Cu. Ft. Vol	Preliminary Plot No 5. Mean Value Of Drag Coef. Of Hull @ 800 000 Cu Ft Vol.	Preliminary Plot No 5. Mean Value Of Drag Coef. Of Hull @ 6,400,000 Cu. Ft. Vol	Mean Value Of $\frac{L^2}{L_\varphi D}$ Of Ships Connected
1	4.21		4.21	.01823	.01422	.01322	1.79207	2.21219	.42012	2.631	5.06	13.31		.01919	.01518	.01280	13.31
2	3.86		3.63	.01709	.01293	.01210	1.89259	2.29226	.39967	2.510	4.62	11.99					
3	3.40						1.89927	2.29667	.39740	2.509	4.72	11.84		.01851	.01439	.01195	11.71
4	3.10		3.10	.01740	.01329	.01240	1.80218	2.20952	.40734	2.555	4.84	12.37		.01880	.01469	.01229	12.37
5	3.10						1.80218	2.20952	.40734	2.955	4.84	12.37					
6	4.04		4.32	.01992	.01378	.01297	2.13711	2.63043	.49332	3.113	6.70	20.86					
7	4.61						2.31877	2.81842	.49969	3.160	7.25	22.91		.02115	.01600	.01284	21.89
8	7.20		7.27	.02232	.01639	.01424	2.06034	2.631[illegible]	.57[illegible]10	3.7[illegible]	10.21	[illegible]					
9	9.21		9.39	.02341	.01641	.01962	2.10360	2.[illegible]933	.54573	3.513	10.90	36.87		.02317	.01676	.01501	37.56
10	9.76						2.13994	2.68[illegible]	.54670	3.522	10.60	37.33					
11	8.14						2.11786	2.66276	.54490	3.507	10.00	35.07		.02317	.01670	.01959	39.57
12	8.12		8 2[illegible]	.02314	.01623	.01971	2.13719	2.66839	.53120	3.398	9.55	32.45					
13	8.45						2.15339	2.70927	.55588	3.596	10.48	37.69					
14	9.21						2.16407	2.71517	.55108	3.557	10.61	37.74					
15	7.55						2.16999	2.72428	.55429	3.583	10.08	36.12					
16	6.36						2.20659	2.72916	.52257	3.331	8.68	28.91		.02233	.01660	.01526	30.72
17	7.05						2.22803	2.76790	.53787	3.466	9.50	32.93					
18	5.55						2.28897	2.80996	.52099	3.319	8.24	27.35					
19	5.52		5.53	.01964	.01631	.01314	2.28813	2.80956	.52143	3.322	8.24	27.37		.02194	.01650	.01300	27.37
20	5.52						2.28813	2.80956	.52143	3.322	8.24	27.37					
21	5.53						2.28813	2.80956	.52143	3.322	8.24	27.37					
22	5.89		5.89	.02019	.01654	.01316	2.32599	2.87216	.54617	3.517	[illegible]	[illegible]		.02279	.01670	[illegible]	33.48
23	5.89						2.32599	2.87216	[illegible]	[illegible]							
24	5.53						2.28813	[illegible]	[illegible]		[illegible]	27.37					
25	6.38		6.37	.020[illegible]2	.01[illegible]62	.01324	2.31988	[illegible]	.59627	3.[illegible]	[illegible]	34.27		.02272	[illegible]	.01300	34.27
26	5.84						2.30107	2.83264	.53[illegible]	3.[illegible]	8.[illegible]	27.38		.02233	.01660	.01259	29.38
	"Y"											"Z"					

☆ Ecc × Cyl × $\frac{L}{D}$ = (Eccentricity Of Nose Ellipse) × (Cylindrical Coefficient) × (Fineness Ratio).

Calculations By Clinton H. Havill
Lieut. U. S. Navy.

PRISMATIC COEF. $\frac{V}{L(\frac{\pi D^2}{4})}$	VOLUMETRIC DRAG COEF'S (MODEL TESTS) C_H			MODEL DRAG @ STANDARD DENSITY-.00237 (LBS)			MODEL RADIUS r = MAX. DIA / 2 (FT.)	MODEL r^3 (FT.³)	ADDITIONAL VOLUME $\frac{\pi r^3}{3}$ (CU.FT.)	MODEL VOLUME V CU-FT.
	@ 20 MI/HR 29.334 FT/SEC	@ 40 MI/HR 58.667 FT/SEC	@ 60 MI/HR 88 FT/SEC	@ 20 MI/HR 29.334 FT/SEC	@ 40 MI/HR 58.667 FT/SEC	@ 60 MI/HR 88 FT/SEC				
7	8	9	10	11	12	13	14	15	16	17
.6175	.0336	.0308	.0296	.0303	.1111	.2404	.34835	.042273	.044268	.8304
.6562	.0318	.0288	.0272	.0237	.0859	.1828	.32085	.033029	.034588	.6259
.6621	.0336	.0292	.0284	.0262	.0911	.1996	.32085	.033029	.034588	.6690
.5891	.0332	.0294	.0276	.0238	.0842	.1779	.32085	.033029	.034588	.5890
.5679	.0370	.0348	.0330	.0305	.1145	.2440	.32085	.033029	.034588	.7240
.5677	.0362	.0340	.0328	.0260	.0975	.2117	.32085	.033029	.034588	.5891
.6095	.0358	.0338	.0322	.0269	.1017	.2180	.32085	.033029	.034588	.6331
.6003	.0410	.0510	.0554	.0196	.0973	.2380	.29165	.024809	.025980	.3196
.6749	.0308	.0280	.0264	.0243	.0881	.1869	.32085	.033029	.034588	.6777
.6909	.0306	.0282	.0270	.0253	.0936	.2013	.32085	.033029	.034588	.7297
.7184	.0328	.0292	.0272	.0296	.1055	.2210	.32085	.033029	.034588	.8330
.7611	.0350	.0300	.0272	.0366	.1253	.2572	.32085	.033029	.034588	1.0404
.7925	.0346	.0312	.0296	.0406	.1465	.3147	.32085	.033029	.034588	1.2471
.8167	.0350	.0314	.0292	.0458	.1641	.3446	.32085	.033029	.034588	1.4548
.8358	.0328	.0308	.0296	.0470	.1765	.3814	.32085	.033029	.034588	1.6625
.6856	.03355	.03122	.03004	.0393	.1454	.3140	.32810	.035321	.036988	1.2335
.7009	.03442	.03077	.02917	.0423	.1514	.3229	.32810	.035321	.036988	1.3250

DRAG @ 58.667 FT/SEC (LBS)	$LOG_{10}\ DL_g$ @ 88 FT/SEC.	DRAG @ 88 FT/SEC (LBS)	TO REDUCE OR EXPAND ALL MODELS TO THE SAME VOLUME.	$\frac{1}{3}LOG_{10}\ .3$	$LOG_{10}\ L_g$	$\frac{1}{3}LOG_{10}$(VOL. MOD.)	$LOG_{10}\ L_g$ @ .3 CU.FT. VOL.
33	34	35		36	37	38	39
.1111	2.06679	.2404	$\frac{\text{VOL. X}}{\text{VOL. MODEL}} = \left(\frac{L_g \text{ AT VOL. X}}{L_g \text{ OF MODEL}}\right)^3$ $(\text{VOL. X})(L_g \text{ OF MODEL})^3 = (\text{VOL. OF MODEL})(L_g \text{ AT VOL. X})^3$ $(L_g \text{ AT VOL. X})^3 = \frac{(\text{VOL. X})(L_g \text{ OF MODEL})^3}{\text{VOL. OF MODEL}}$, NOW LET X = .3 CU. FT. $3 \text{ LOG } L_g \text{ AT VOL. X} = \text{LOG } .3 + 3 \text{ LOG } L_g \text{ MODEL} - \text{LOG VOL. MODEL}$. $\text{LOG } L_g \text{ AT VOL. X} = \frac{1}{3} \text{ LOG } .3 + \text{LOG } L_g \text{ MODEL} - \frac{1}{3} \text{ LOG VOL. MODEL}$	9.82571-10	.12231	9.97309-10	9.79493-10
.0859	2.01686	.1828		"	.07238	9.93217-10	9.96592-10
.0911	2.03002	.1996		"	.08554	9.94181-10	9.96944-10
.0842	2.01576	.1779		"	.07128	9.92337-10	9.97362-10
.1145	2.06341	.2440		"	.11893	9.95325-10	9.99139-10
.0975	2.01978	.2117		"	.07530	9.92337-10	9.97764-10
.1017	2.02709	.2180		"	.08260	9.93382-10	9.97449-10
.0973	1.90394	.2380		"	9.95946-10	9.93487-10	9.95030-10
.0881	2.03084	.1869		"	.08632	9.94368-10	9.96835-10
.0936	2.04393	.2013		"	.09945	9.95438-10	9.97078-10
.1055	2.06783	.2210		"	.12335	9.97355-10	9.97551-10
.1253	2.10897	.2572		"	.16449	.00573	9.98447-10
.1465	2.14328	.3147		"	.19888	.03197	9.99262-10
.1641	2.17312	.3446		"	.22864	.05424	.00011
.1765	2.19927	.3814		"	.25479	.07359	.00691
.1454	1.97693	.3140		"	.20853	.03038	.00386
.1514	1.98988	.3229		"	.22148	.04074	.00645

Model Virtual Vol. $V_M = V + \frac{\pi r^3}{3}$ Cu.Ft.	Model Length (Ft.)	Model Log₁₀ Virt. Vol. (Log₁₀ V_M)	Model Log₁₀ Length (Log₁₀ L)	Model Log₁₀ ($V_M \bar{L}$)	Model $\log_{10} \sqrt[4]{V_M L}$ = Log₁₀ L_γ	Model (U = 29.334 Ft/sec) Log₁₀ U
18	19	20	21	22	23	24
.87467	3.527	9.94184−10	.54741	.48925	.12231	1.46737
.66049	2.949	9.81986−10	.46967	.28953	.07238	"
.70359	3.125	9.84732−10	.49485	.34217	.08554	"
.62359	3.092	9.79490−10	.49024	.28514	.07128	"
.75859	3.942	9.88000−10	.59572	.47572	.11893	"
.62369	3.208	9.79497−10	.50623	.30120	.07530	"
.66769	3.205	9.82457−10	.50583	.33040	.08260	"
.34558	1.992	9.53855−10	.29929	9.83784−10	9.95946−10	"
.71224	3.109	9.85265−10	.49262	.34527	.08632	"
.76429	3.270	9.88325−10	.514 5	.39780	.09945	"
.86759	3.590	9.93832−10	.55509	.49341	.12335	"
1.07499	4.232	.03141	.62655	.65796	.16449	"
1.28169	4.872	.10779	.68771	.79550	.19888	"
1.48939	5.515	.17301	.74155	.91456	.22864	"
1.69709	6.158	.22972	.78944	1.01916	.25479	"
1.27049	5.372	.10398	.73014	.83412	.20853	"
1.36199	5.646	.13418	.75174	.88592	.22148	"

*From Points Of Each Plotted On Figure 6. Not From Smooth Mean Curve.

CALCULATION OF ECCENTRICITY OF NOSE ELLIPSE. (e)

Model Log₁₀ ULγ @ .3 Cu.Ft Vol. and 100 Ft/sec. (Log₁₀ Lγ + 2)	* Hull Drag @ 100 Ft/sec .3 Cu.Ft.Vol. D_H (Lbs)	C_H @ 100 Ft/sec .3 Cu.Ft.Vol. C_H = .1883 D_H	Dist. From Nose To Max. Ordinate X (Ft)	X^2	Max 2d ÷ 2 = Max. Rad. = r (Ft)	r^2	$X^2 - r^2$	$\sqrt{X^2 - r^2}$	$\left[\frac{\sqrt{X^2-r^2}}{X}\right]$ = e
40	41	42	43	44	45	46	47	48	49
1.79493	.1598	.0301	1.333	1.7729	.3483	.12131	1.65159	1.2853	.964
1.96592	.1492	.0281	.885	.7832	.3208	.10291	.68029	.8248	.932
1.96944	.1540	.0290	1.133	1.2837	.3208	.10291	1.18079	1.0867	.959
1.97362	.1508	.0285	1.283	1.6461	.3208	.10291	1.54319	1.2422	.968
1.99139	.1779	.0335	1.527	2.3317	.3208	.10291	2.22879	1.4909	.976
1.97764	.1583	.0298	1.161	1.3479	.3208	.10291	1.24499	1.1155	.960
1.97449	.1540	.0290	1.147	1.3156	.3208	.10291	1.21269	1.1101	.967
1.95030	.2719	.0512	.847	.7174	.2916	.08503	.63237	.7953	.938
1.96835	.1439	.0271	.885	.7832	.3208	.10291	.68029	.8248	.932
1.97078	.1450	.0273	.885	.7832	.3208	.10291	.68029	.8248	.932
1.97551	.1556	.02741	.885	.7832	.3208	.10291	.68029	.8248	.932
1.98447	.1597	.02819	.885	.7832	.3208	.10291	.68029	.8248	.932
1.99262	.1607	.03026	.885	.7832	.3208	.10291	.68029	.8248	.932
2.00011	.1640	.03088	.885	.7832	.3208	.10291	.68029	.8248	.732
2.00691	.1667	.0314	.885	.7832	.3208	.10291	.68029	.8248	.932
2.00386	.1629	.03068	2.015	4.0602	.3281	.10765	3.95255	.9831	.986
2.00645	.1644	.03096	2.015	4.0602	.3281	.10765	3.95255	.9831	.986

CALCULATIONS BY CLINTON H. HAVILL

C_{HY} @ 800,000 Cu.Ft. From Fig 4	C_{HY} @ 6,400,000 Cu.Ft. From Fig 4	YC_{HY} @ 100,000 Cu.Ft.	YC_{HY} @ 800,000 Cu.Ft.	YC_{HY} @ 6,400,000 Cu.Ft.	"Z" ([illegible])	C_{HZ} @ 100 000 Cu.Ft. From Fig 5	C_{HZ} @ 800000 Cu.Ft. From Fig 5	C_{HZ} @ 6,400,000 Cu.Ft. From Fig 5	ZC_{HZ} @ 100,000 Cu.Ft
59	60	61	62	63	64	65	66	67	68
.0134	.0125	.052711	.040362	.037652	13.465	.0191	.0149	.0125	.25701
.0135	.0125	.049728	.038144	.035319	11.531	.0184	.0145	.0118	.21217
.0133	.0124	.053804	.041126	.038343	12.496	.0188	.0147	.0122	.23492
.0136	.0127	.048650	.037381	.034907	12.647	.0189	.0148	.0123	.23907
.0130	.0121	.058195	.044242	.041179	18.408	.0206	.0156	.0129	.37920
.0137	.0128	.048679	.037257	.034809	13.458	.0192	.0149	.0124	.25839
.0135	.0128	.050880	.039704	.037645	13.224	.0191	.0148	.0123	.25258
.0171	.0154	.040322	.032834	.029569	7.457	.0331	.0280	.0227	.24683
.0133	.0124	.053082	.040574	.037829	12.362	.0187	.0147	.0121	.23117
.0131	.0122	.056485	.043020	.040065	13.262	.0192	.0148	.0124	.25468
.0130	.0121	.064146	.048482	.045126	15.050	.0197	.0152	.0127	.29648
.0150	.0131	.088484	.070226	.061330	19.127	.0208	.0157	.0129	.39784
.0163	.0129	.109878	.091379	.072318	23.392	.0214	.0162	.01295	.50059
.0166	.0134	.136685	.108564	.087636	27.986	.0220	.0165	.0130	.61569
.0162	.0145	.167509	.121145	.108432	32.880	.0227	.0168	.0132	.74638
.0164	.0129	.108461	.090753	.071385	27.210	.0218	.0164	.0130	.59318
.0166	.013[illegible]	.118922	.098706	.077894	29.176	.0221	.0166	.01305	.64479

REMARKS		Data From Original List Of Ships For Points Between 100,000 And 6,400,000 Cu.Ft. Volume Where Wind Tunnel Data Are Not Available.	"Y"	Log$_{10}$L (Of Act. Ship)
Continuous Curvature		Bodensee	4.04	2.13711
		Los Angeles	4.61	2.31877
Parallel Section	↑ Builders' Numbers ↓	LZ-1.	7.20	2.06034
		LZ-4 & 5.	9.21	2.10360
		LZ-7 & 8.	9.76	2.13994
		LZ-10 & 12.	8.14	2.11786
		LZ-15 & 16.	8.12	2.13719
		LZ-22 & 23.	8.45	2.1533
		LZ-24 To 35.	9.21	2.16407
		LZ-36.	7.55	2.1699
		LZ-42 To 50.	6.36	2.2065
		LZ-59 To 61, 64 To 71 Except 60 & 70.	7.05	2.2280
		LZ-72 To 90 Except 73-77 & 81.	5.55	2.2885
		LZ-91 To 94.	5.52	2.2881
		LZ-95 To 99.	5.52	2.2881
		LZ-100 & 101.	5.53	2.28813
		LZ-102.	5.89	2.3259
		LZ-104	5.89	2.3259
		LZ-106 To 111.	5.53	2.2881
		LZ-112 To 114.	6.38	2.3158

ZC_{HZ} @ 800,000 Cu. Ft.	ZC_{HZ} @ 6,400,000 Cu. Ft.	$YC_{HY}+ZC_{HZ}$ @ 100,000 Cu. Ft.	$YC_{HY}+ZC_{HZ}$ @ 800,000 Cu. Ft.	$YC_{HY}+ZC_{HZ}$ @ 6,400,000 Cu. Ft.	"Y"+"Z" (As Before)	$\frac{YC_{HY}+ZC_{HZ}}{Y+Z}$ @ 100,000 Cu. Ft.	$\frac{YC_{HY}+ZC_{HZ}}{Y+Z}$ @ 800,000 Cu. Ft.	$\frac{YC_{HY}+ZC_{HZ}}{Y+Z}$ @ 6,400,000 Cu. Ft.
69	70	71	72	73	74	75	76	77
.20049	.16820	.30972	.24085	.20585	16.468	.01881	.01459	.01247
.16720	.13607	.26189	.20534	.17139	14.356	.01824	.01430	.01193
.18369	.15245	.28872	.22482	.19079	15.588	.01878	.01442	.01223
.18720	.15558	.28772	.22458	.19049	15.396	.01868	.01448	.01238
.28716	.23746	.43739	.33140	.27864	21.811	.02019	.01519	.01278
.20052	.16688	.30707	.23778	.20169	16.177	.01880	.01458	.01245
.19572	.16265	.30346	.23542	.20029	16.165	.01874	.01458	.01236
.20879	.16927	.28715	.24162	.19884	9.377	.03620	.02600	.02120
.18172	.14958	.28425	.22229	.18741	15.413	.01842	.01442	.01215
.19632	.16449	.31116	.23934	.20456	16.548	.01880	.01446	.01236
.22876	.19135	.36063	.27724	.23648	18.779	.01939	.01478	.01259
.30029	.24674	.48632	.37052	.30807	23.809	.02042	.01542	.01288
.37895	.30293	.61047	.47033	.37525	28.998	.02120	.01622	.01274
.46177	.36382	.75238	.57033	.45146	34.346	.02190	.01661	.01340
.55238	.43402	.91389	.67353	.54245	40.358	.02263	.01668	.01344
.44624	.35373	.70164	.53699	.42512	32.744	.02164	.01647	.01303
.48432	.38074	.76371	.58303	.45863	35.122	.02201	.01666	.01317

$Log_{10}L$ (Of Act. Ship)	$Log_{10}\left(\frac{L}{L_g}\right)$	$\frac{L}{L_g}$	$\frac{L}{D}$	"Z"	"Y"+"Z"	$\frac{YC_{HY}+ZC_{HZ}}{Y+Z}$ @ 100,000 Cu. Ft.	$\frac{YC_{HY}+ZC_{HZ}}{Y+Z}$ @ 800,000 Cu. Ft.	$\frac{YC_{HY}+ZC_{HZ}}{Y+Z}$ @ 6,400,000 Cu. Ft.
2.63043	.49332	3.1140	6.70	20.864	24.904	.02070	.01522	.01280
2.81842	.49965	3.1598	7.25	29.086	33.696	.02480	.01610	.01300
2.63144	.57110	3.7247	10.21	38.029	45.229	.02320	.01673	.01362
2.64935	.54570	3.5132	10.50	36.888	46.398	.02420	.01699	.01392
2.68664	.54670	3.5212	10.60	37.325	47.085	.02490	.01720	.01400
2.66276	.54490	3.5065	10.00	35.065	43.205	.02310	.01670	.01356
2.66839	.53120	3.3979	9.55	32.450	40.570	.02290	.01700	.01380
2.70927	.55588	3.5967	10.48	37.693	46.143	.02410	.01690	.01380
2.71517	.55110	3.5571	10.61	37.741	46.951	.02430	.01720	.01405
2.72428	.55429	3.5835	10.08	36.122	43.672	.02320	.01680	.01360
2.72916	.52257	3.3310	8.68	28.913	35.273			
2.76790	.53987	3.4665	9.50	32.932	39.982	.02262	.01667	.01342
2.80956	.52099	3.3189	8.24	27.348	32.898	.02164	.01648	.01304
2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
2.87216	.54617	3.5170	9.52	33.482	39.372	.02268	.01668	.01349
2.87216	.54617	3.5170	9.52	33.482	39.372	.02268	.01668	.01349
2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
2.87216	.55627	3.5998	9.52	34.270	40.650	.02270	.01670	.01350

CALCULATIONS BY CLINTON H. HAVILL

NOTES.

The Scales On Figures 7 & 8 Were Plotted With $\text{Log}_{10}(Y+Z)$ A Uniform Scale Of Logarithms. The Model Scale Was Constructed Nearly Uniform And The Scale @100,000 Was Calibrated On This Data. The Scale @ 6,400,000 Was Constructed Nearly Uniform And The Slope Lines Drawn In From Scale @100,000. The Scale @ 800,000 Was Allowed To Calibrate Itself On The Data Given Here. Curves Of The Scales Were Drawn And The Graduations Marked Were Thus Transferred Back To The Scale.

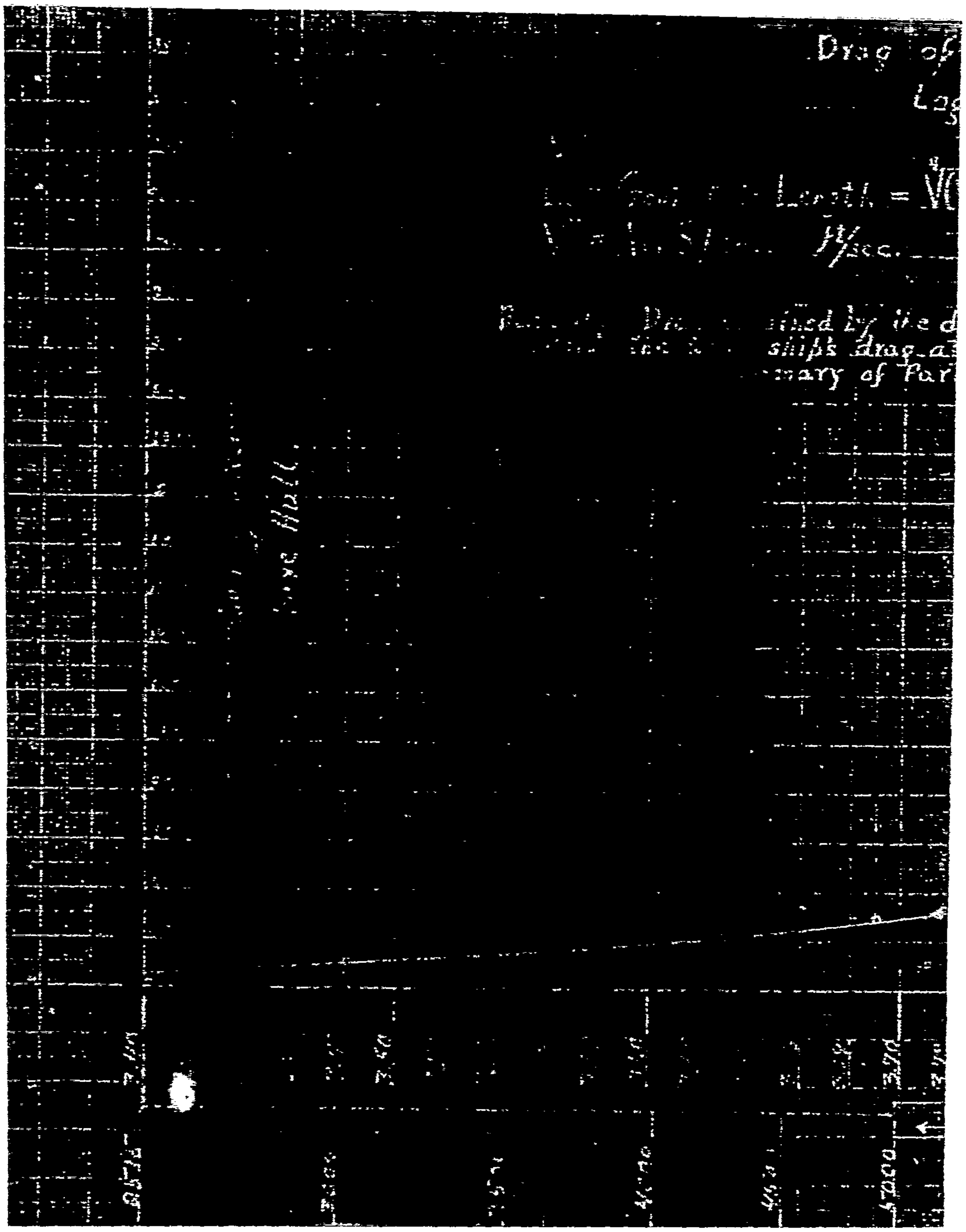
It Is Thus Seen That The Scales Are Empirically Calibrated On The Data Here, Making The Slope Lines Straight Lines And Graduating The Scales Accordingly.

Calculations By Clinton H. Havill
Lieut., U.S. Navy.

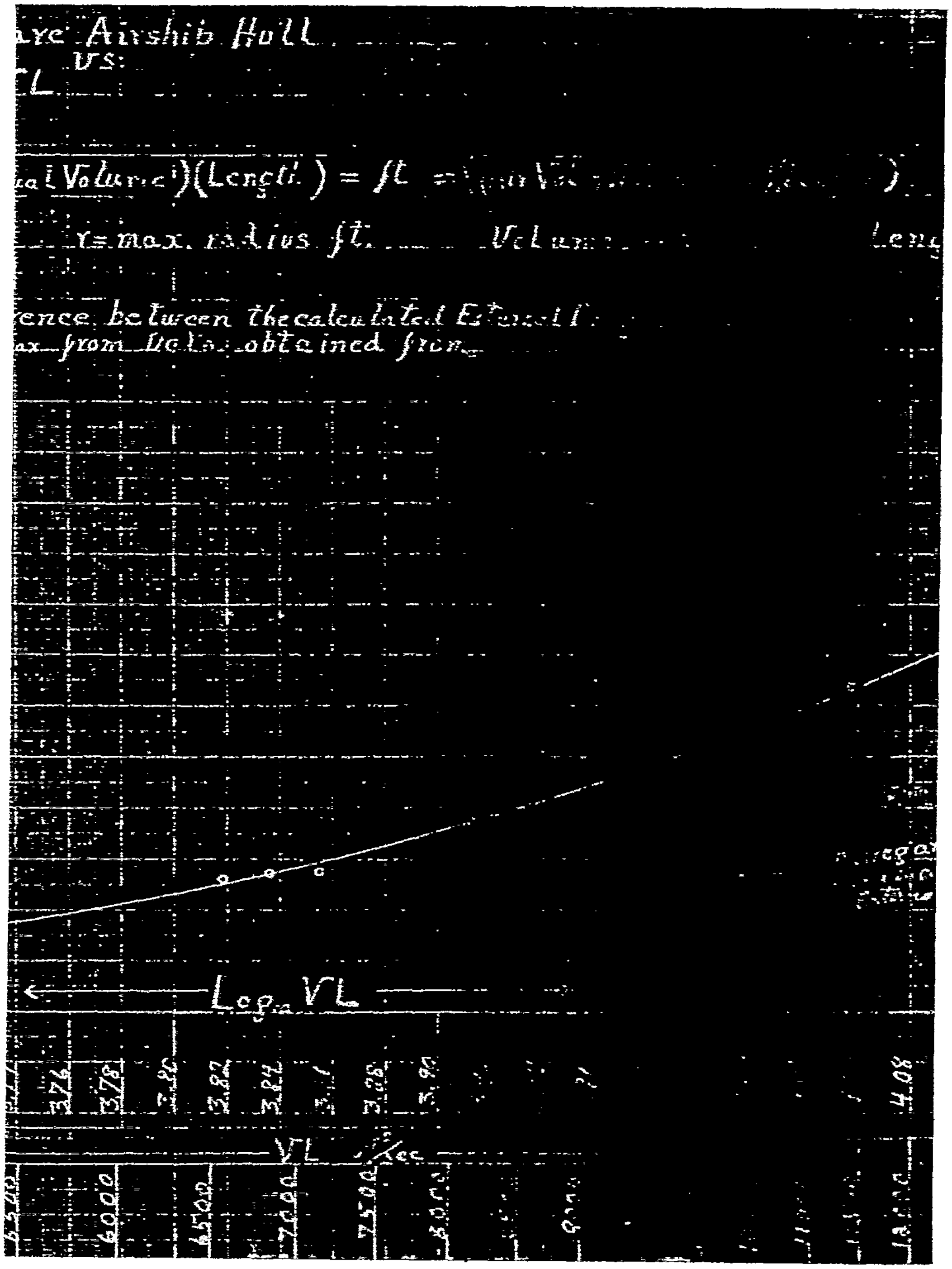
FINAL SUMMARY OF PART II

Arrangement Of Previous Data In Ascending Values Of "Y+Z"

	SHIPS	"Y"+"Z"	DRAG COEFFICIENT – C_H			
			@ .3 Cu. Ft.	@ 100,000 Cu. Ft.	@ 800,000 Cu. Ft.	@ 6,400,000 Cu. Ft.
CONTINUOUS CURVATURE	"AA"	9.377	.0512	.03620	.02600	.02120
	"C"	14.356	.0280	.01824	.01430	.01193
	"EP"	15.396	.0285	.01868	.01442	.01228
	"F"	15.588	.0290	.01878	.01445	.01233
	"P-3"	16.165	.0295	.01880	.01458	.01236
	"P-2"	16.177	.0298	.01881	.01458	.01245
	"B"	16.468	.0301	.01882	.01459	.01247
	"P-1"	21.811	.0335	.02019	.01519	.01278
	BODENSEE	24.904		.02070	.01522	.01280
	LOS ANGELES	33.696		.02480	.01610	.01300
PARALLEL SECTION	"C" + 1/4 DIA.	15.413	.0271	.01842	.01442	.01215
	"C" + 1/2 DIA.	16.548	.02741	.01880	.01446	.01236
	"C" + 1 DIA.	18.779	.02819	.01939	.01478	.01259
	"C" + 2 DIA.	23.809	.02938	.02042	.01542	.01288
	"C" + 3 DIA.	28.998	.03026	.02120	.01622	.01274
	SHORT SHENANDOAH	32.744	.03068	.02164	.01647	.01303
	LZ-72 TO 90 EXCEPT 73, 77 & 81.	32.898		.02164	.01648	.01304
	LZ-91 TO 94, 95 TO 99, 100, 101 & 106 TO 111	32.907		.02165	.01649	.01305
	"C" + 4 DIA.	34.346	.03088	.02190	.01661	.01340
	SHENANDOAH.	35.122	.03090	.02201	.01666	.01347
	LZ-42 TO 50.	35.273		.02238	.01666	.01348
	LZ-102 & 104.	39.372		.02258	.01667	.01349
	LZ-59 TO 61, 64 TO 71 EXCEPT 60 & 70.	39.982		.02262	.01668	.01342
	"C" + 5 DIA.	40.358	.0314	.02263	.01668	.01344
	LZ-112 TO 114.	40.650		.02270	.01670	.01350
	LZ-10 & 12.	43.205		.02310	.01680	.01356
	LZ-1.	45.229		.02320	.01683	.01362
	LZ-4 & 5.	46.398		.02420	.01699	.01392
	LZ-7 & 8.	47.085		.02490	.01720	.01400



Drag of
Log
L = ... Length = $\sqrt[4]{(}$
V = ... ft/sec.
... Dra... ...tied by the d
... ships drag a
...mary of Par
Bare Hull
3.40
3.60
3.70
4700


are Airship Hull
VS:
L
al Volume)(Length) = ft
r = max. radius ft.
Volume
Leng
ence between the calculated E
ax from Data obtained from
Log VL
3.76
3.78
3.80
3.82
3.84
3.88
3.90
4.08
VL
6000
6500
7000
7500
8000
9000
12000

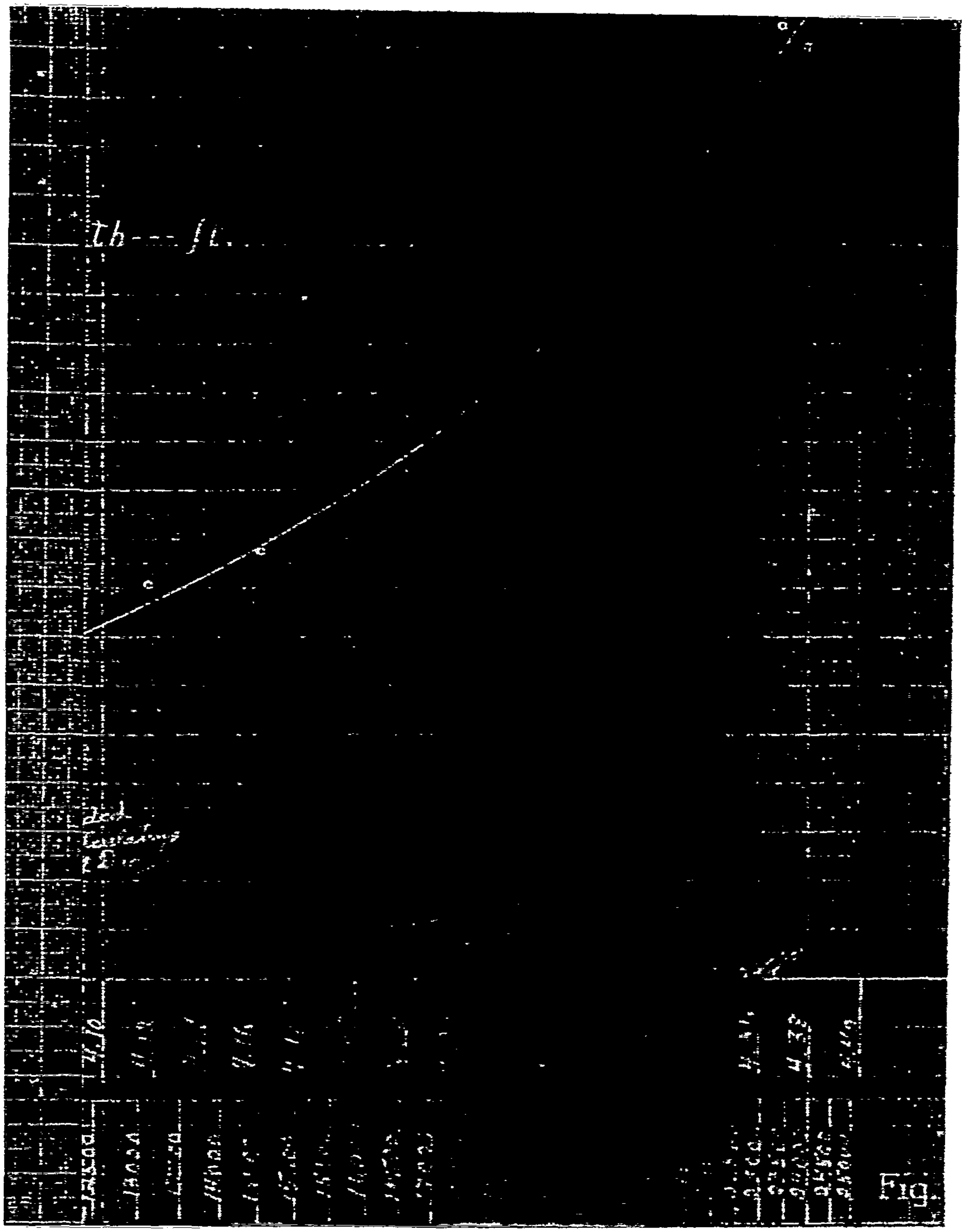
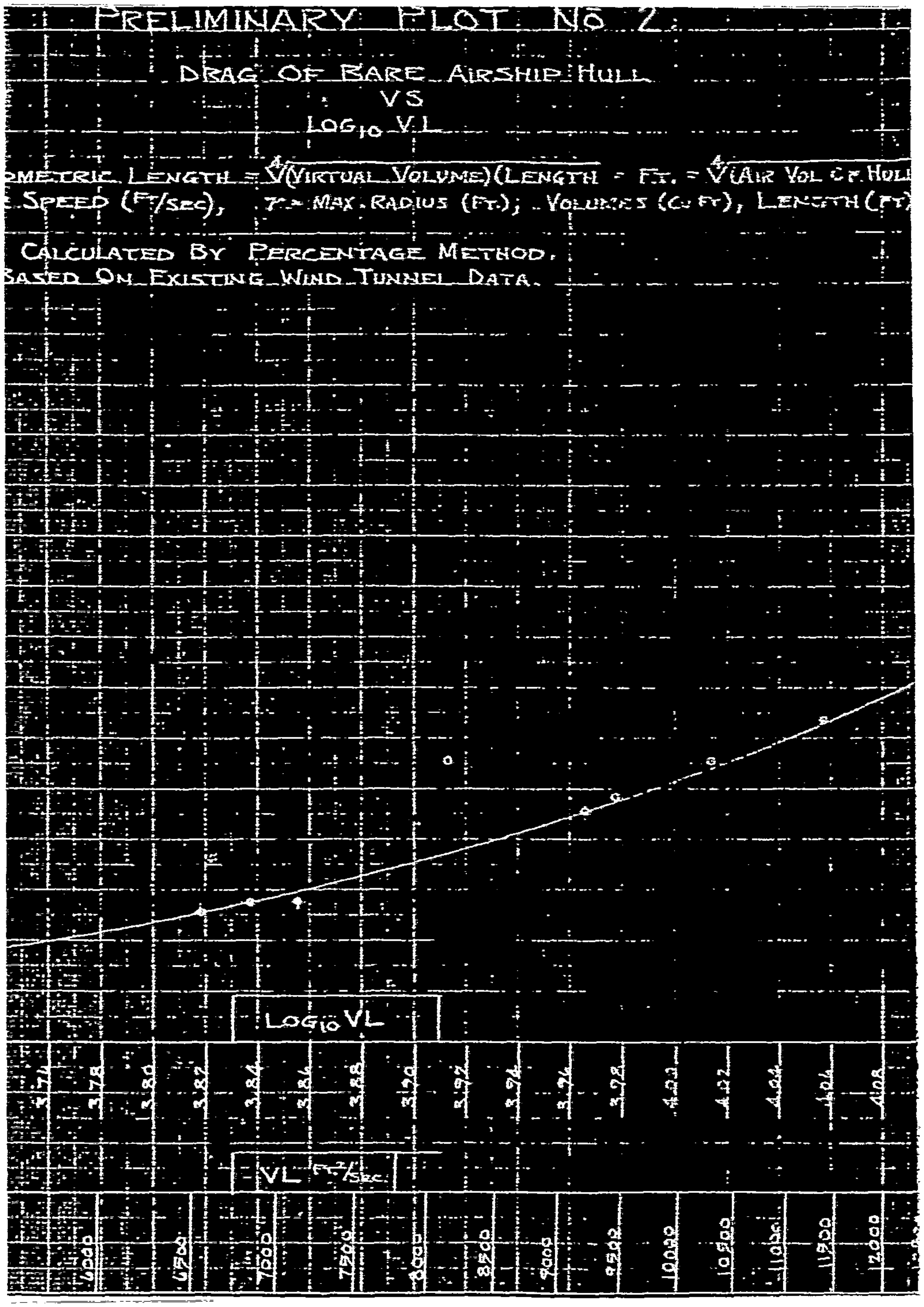
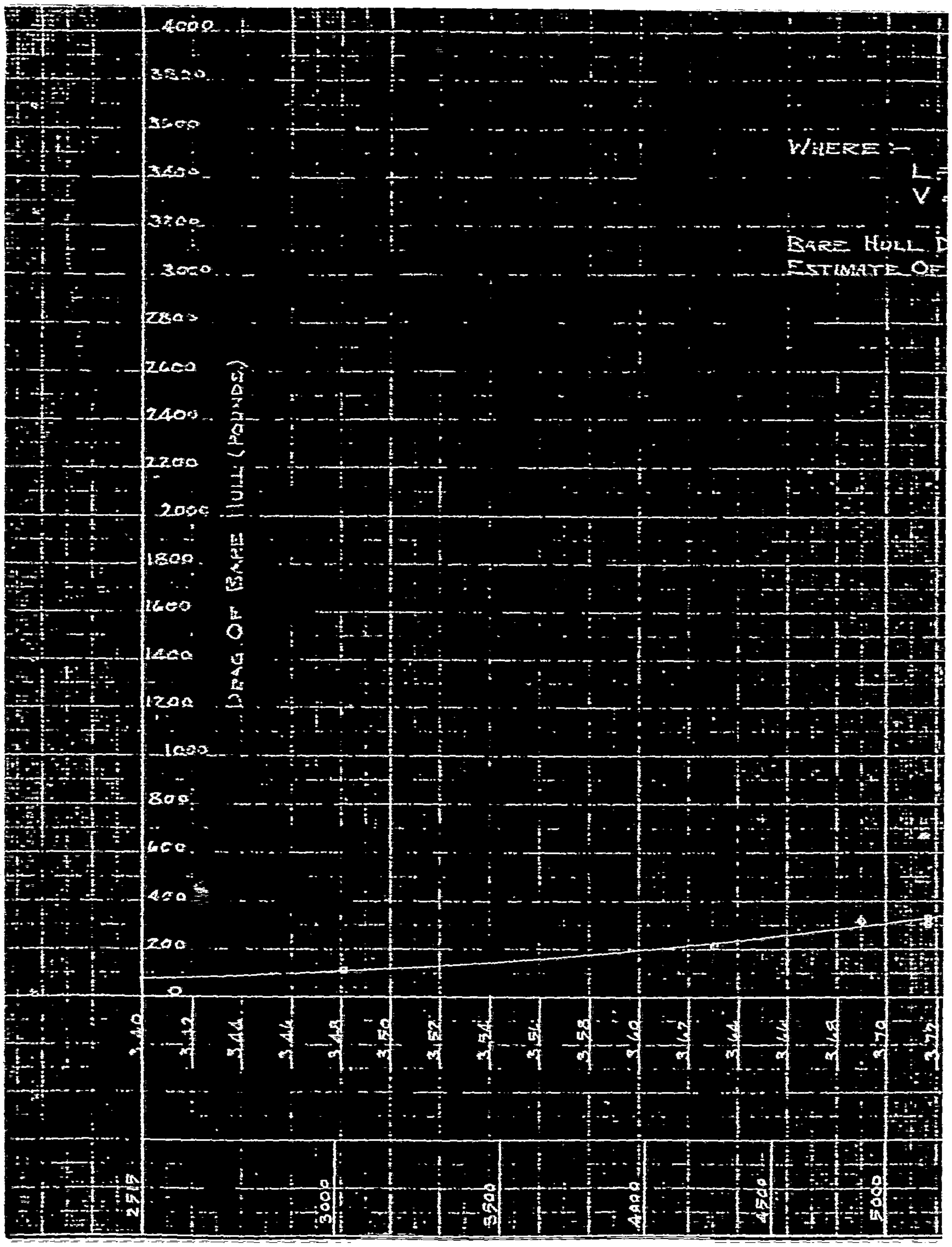
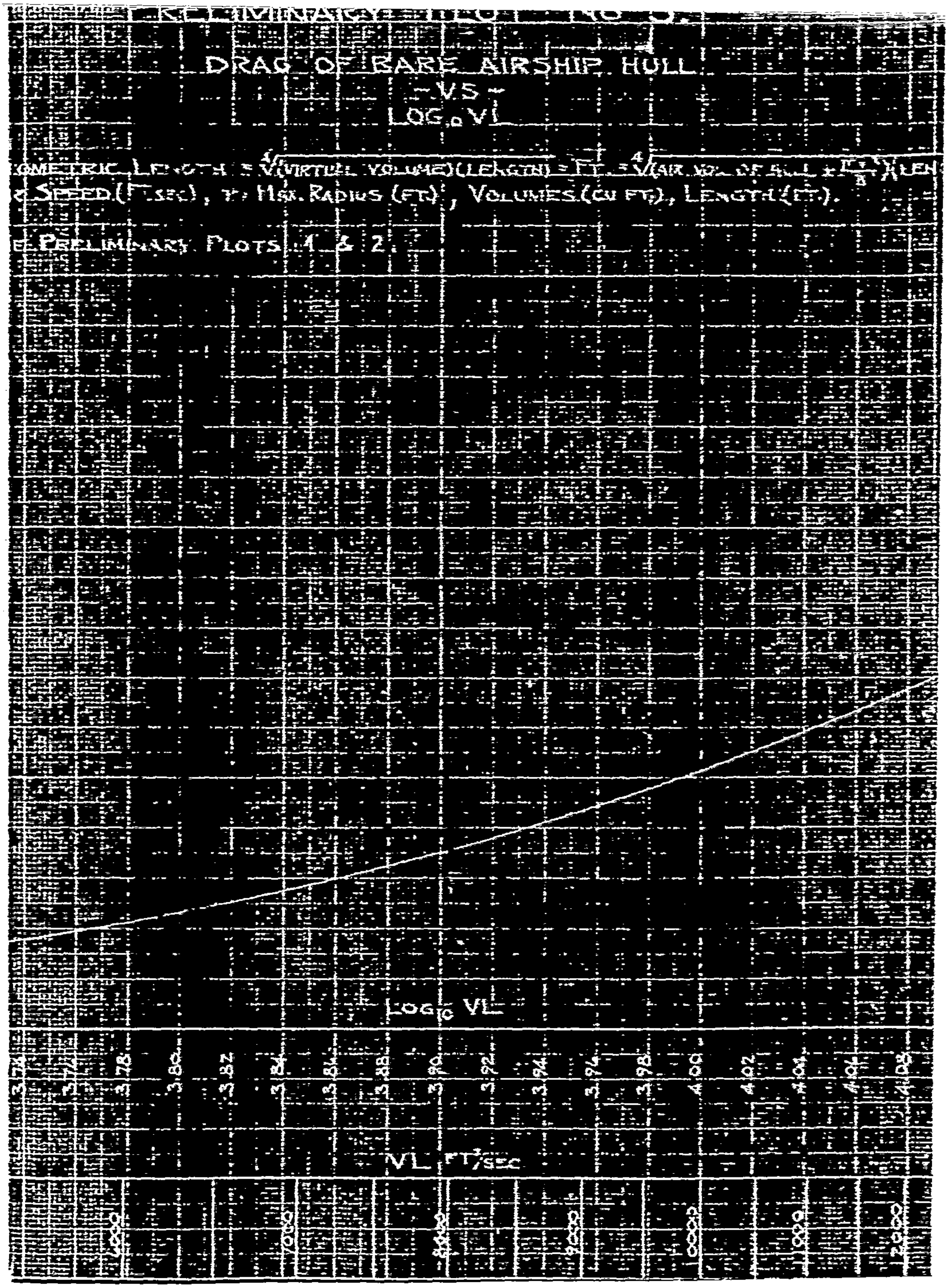


Fig.


PRELIMINARY PLOT NO 2.
DRAG OF BARE AIRSHIP HULL
VS
LOG₁₀ V.L.
METRIC LENGTH = $\sqrt[4]{(\text{VIRTUAL VOLUME})(\text{LENGTH}}$ - FT. = $\sqrt[4]{(\text{AIR VOL OF HULL}}$
SPEED (FT/SEC), r = MAX. RADIUS (FT.); VOLUMES (CU FT), LENGTH (FT)
CALCULATED BY PERCENTAGE METHOD.
BASED ON EXISTING WIND TUNNEL DATA.
LOG10 VL
3.76
3.78
3.80
3.82
3.84
3.86
3.88
3.90
3.92
3.94
3.96
3.98
4.00
4.02
4.04
4.06
4.08
VL FT²/SEC.
6000
6500
7000
7500
8000
8500
9000
9500
10000
10500
11000
11500
12000


4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
DRAG OF BARE HULL (POUNDS)
3.40
3.42
3.44
3.46
3.48
3.50
3.52
3.54
3.56
3.58
3.60
3.62
3.64
3.66
3.68
3.70
3.72
2519
3000
3500
4000
4500
5000
WHERE :-
L =
V
BARE HULL D
ESTIMATE OF


PRELIMINARY PLOT NO 3.
DRAG OF BARE AIRSHIP HULL
-VS-
LOG₁₀ VL
OMETRIC LENGTH = ∜(VIRTUAL VOLUME)(LENGTH) = FT. = ∜(AIR VOL OF HULL + πr²/8)(LEN
SPEED (FT/SEC), r: MAX. RADIUS (FT), VOLUMES (CU FT), LENGTH (FT).
E PRELIMINARY PLOTS 1 & 2.
LOG₁₀ VL
3.74
3.76
3.78
3.80
3.82
3.84
3.86
3.88
3.90
3.92
3.94
3.94
3.98
4.00
4.02
4.04
4.06
4.08
VL FT²/SEC
6000
7000
8000
9000
10000
11000
12000

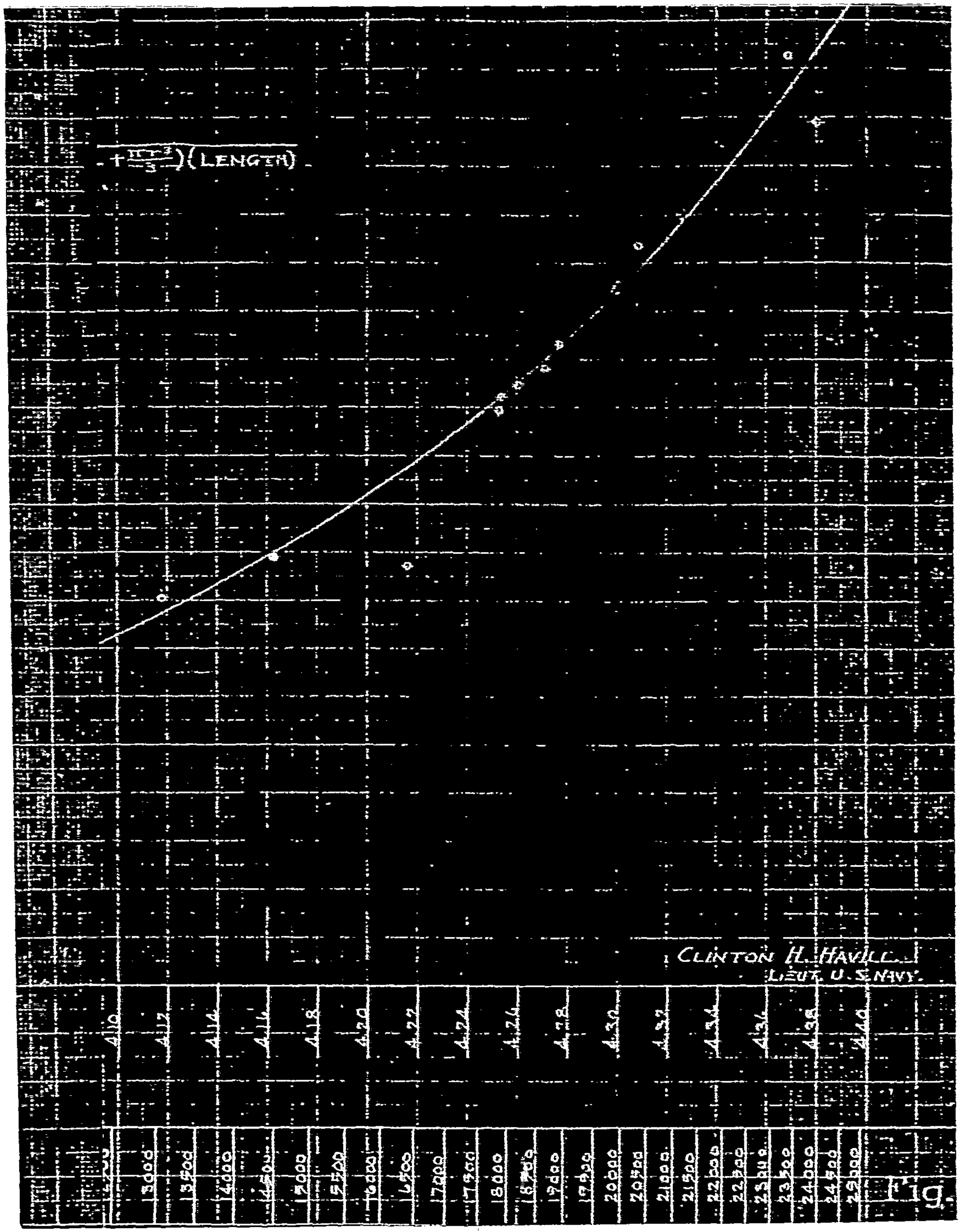
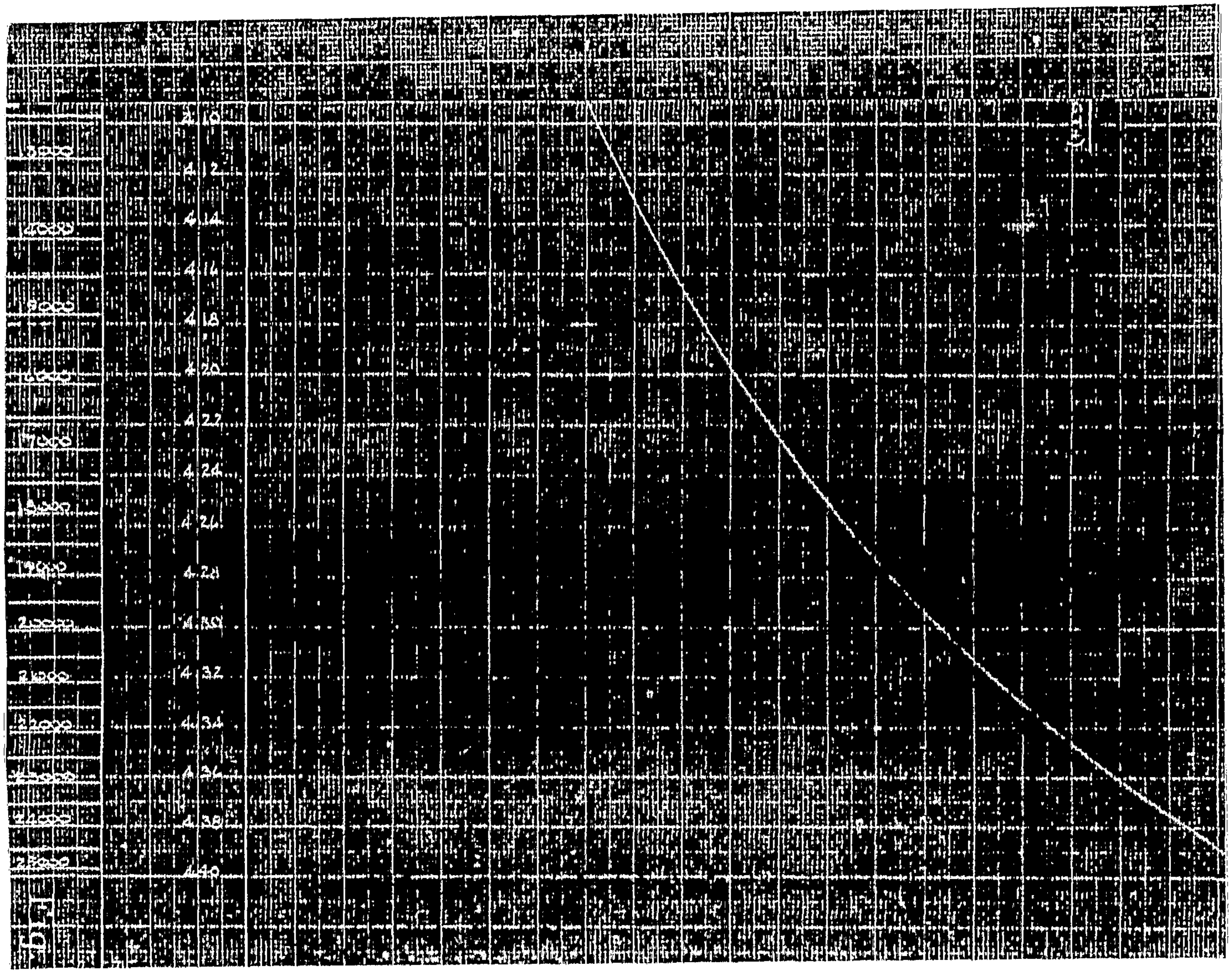

+ πr³/3)(LENGTH)
CLINTON H. HAVILL
LIEUT. U.S. NAVY.
4.10
4.12
4.14
4.16
4.18
4.20
4.22
4.24
4.26
4.28
4.30
4.32
4.34
4.36
4.38
4.40
12500
13000
13500
14000
14500
15000
15500
16000
16500
17000
17500
18000
18500
19000
19500
20000
20500
21000
21500
22000
22500
23000
23500
24000
24500
25000

Fig.


4.10
4.12
4.14
4.16
4.18
4.20
4.22
4.24
4.26
4.28
4.30
4.32
4.34
4.36
4.38
4.40
14000
16000
17000
18000
19000
20000
21000
22000
23000
24000
25000
Fig

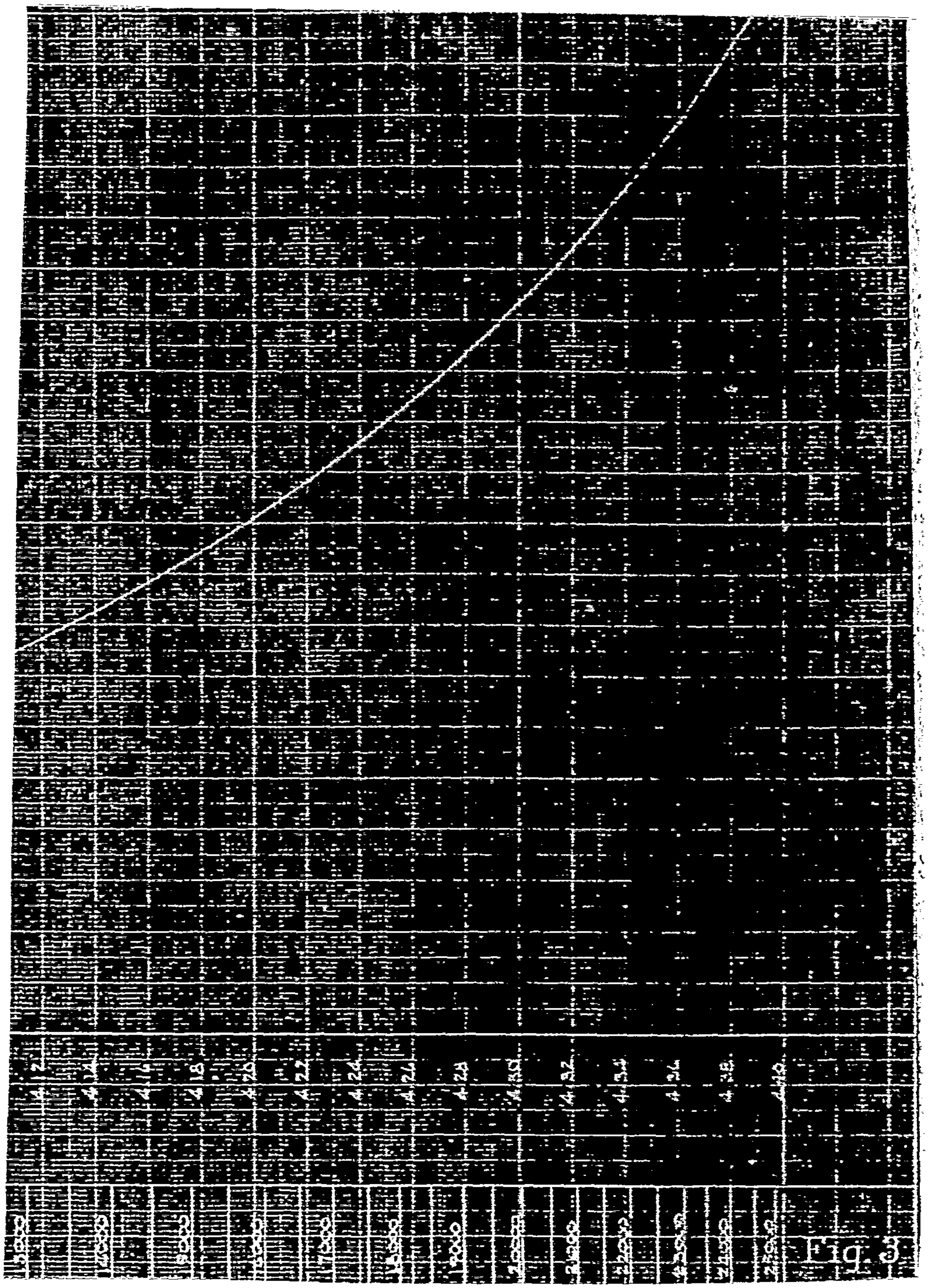
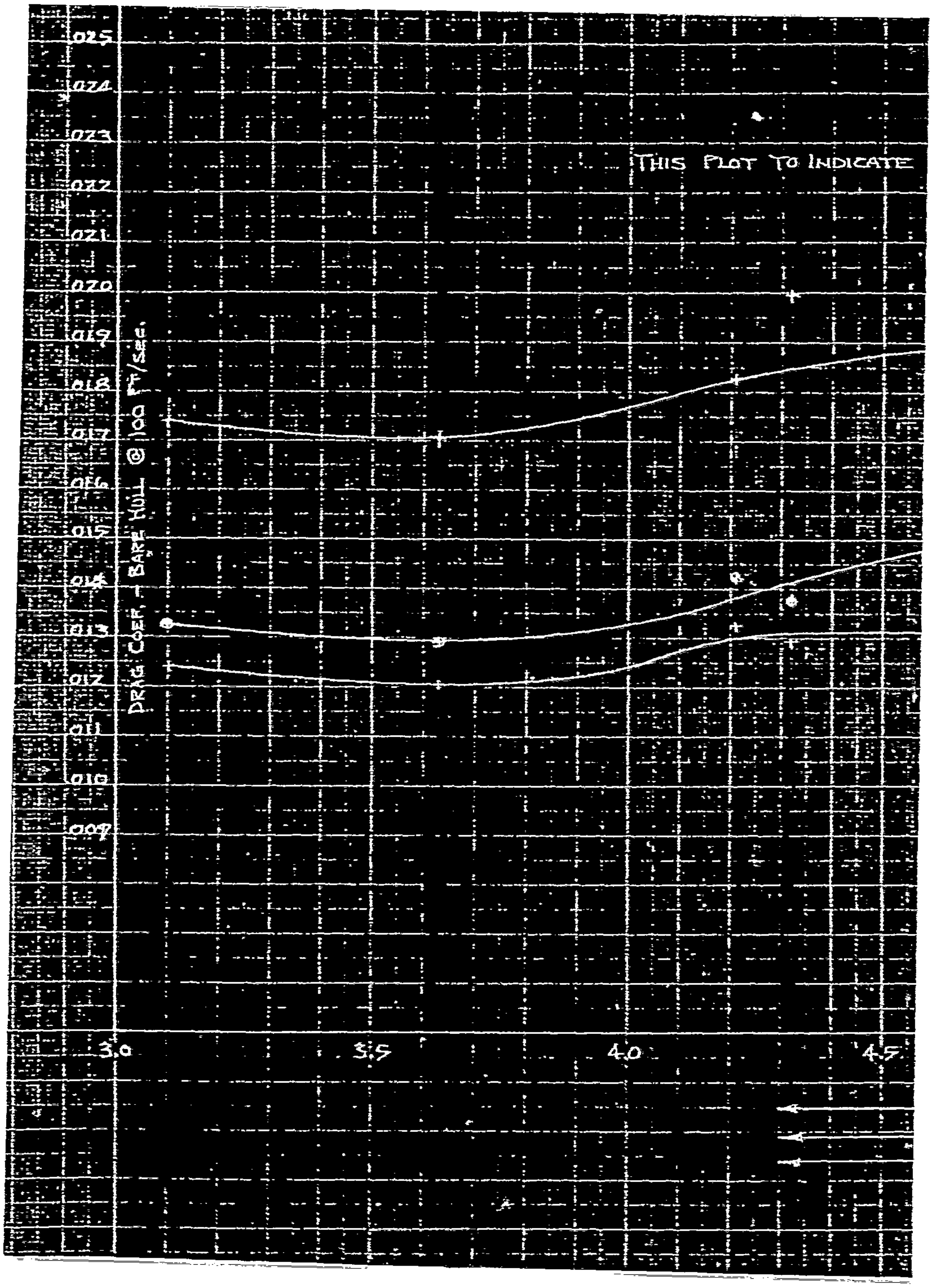
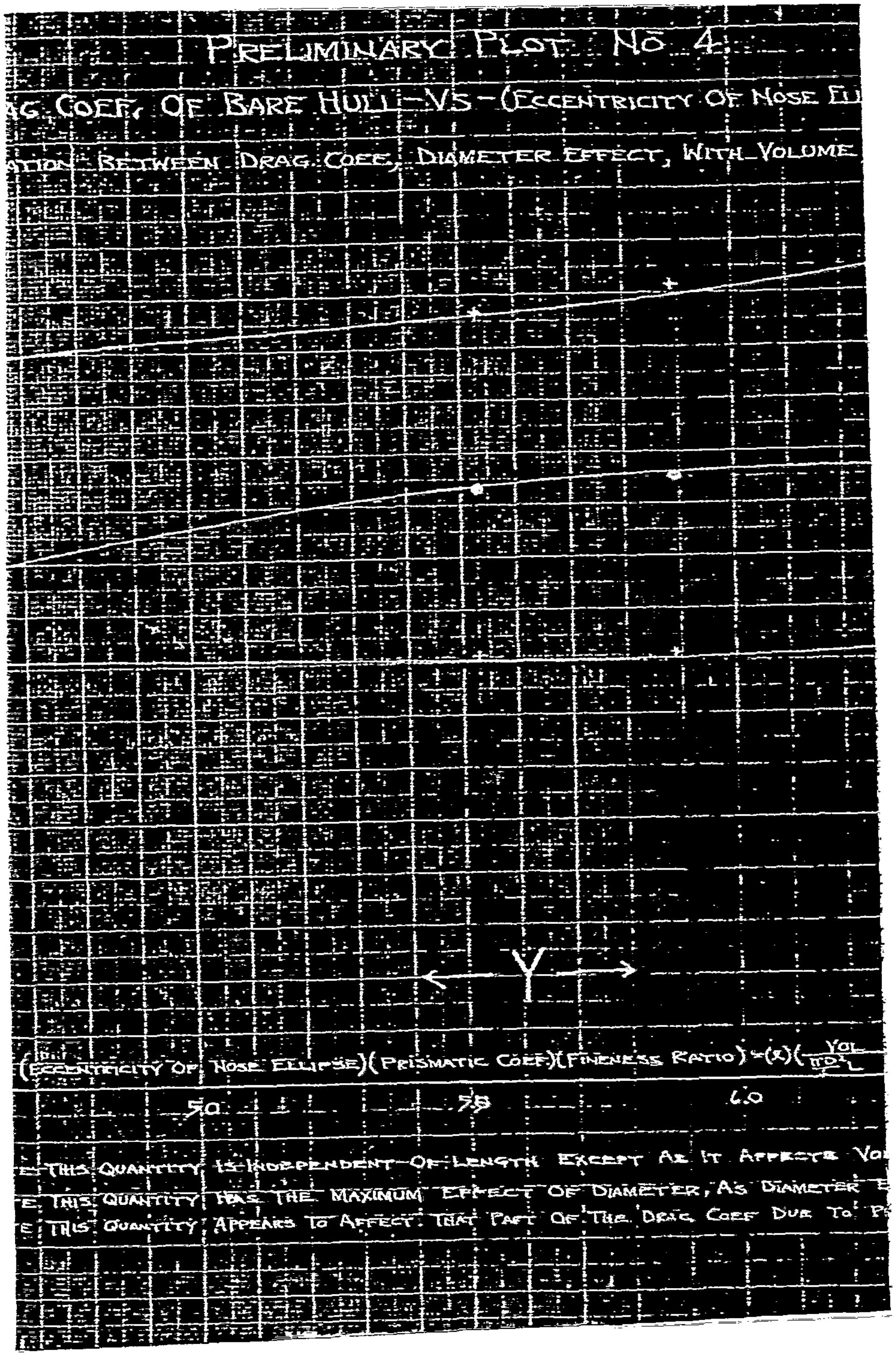


Fig. 3


.025
.024
.023
.022
.021
.020
.019
.018
.017
.016
.015
.014
.013
.012
.011
.010
.009
DRAG COEF. – BARE HULL @ 100 FT/SEC.
THIS PLOT TO INDICATE
3.0
3.5
4.0
4.5



PRELIMINARY PLOT NO 4

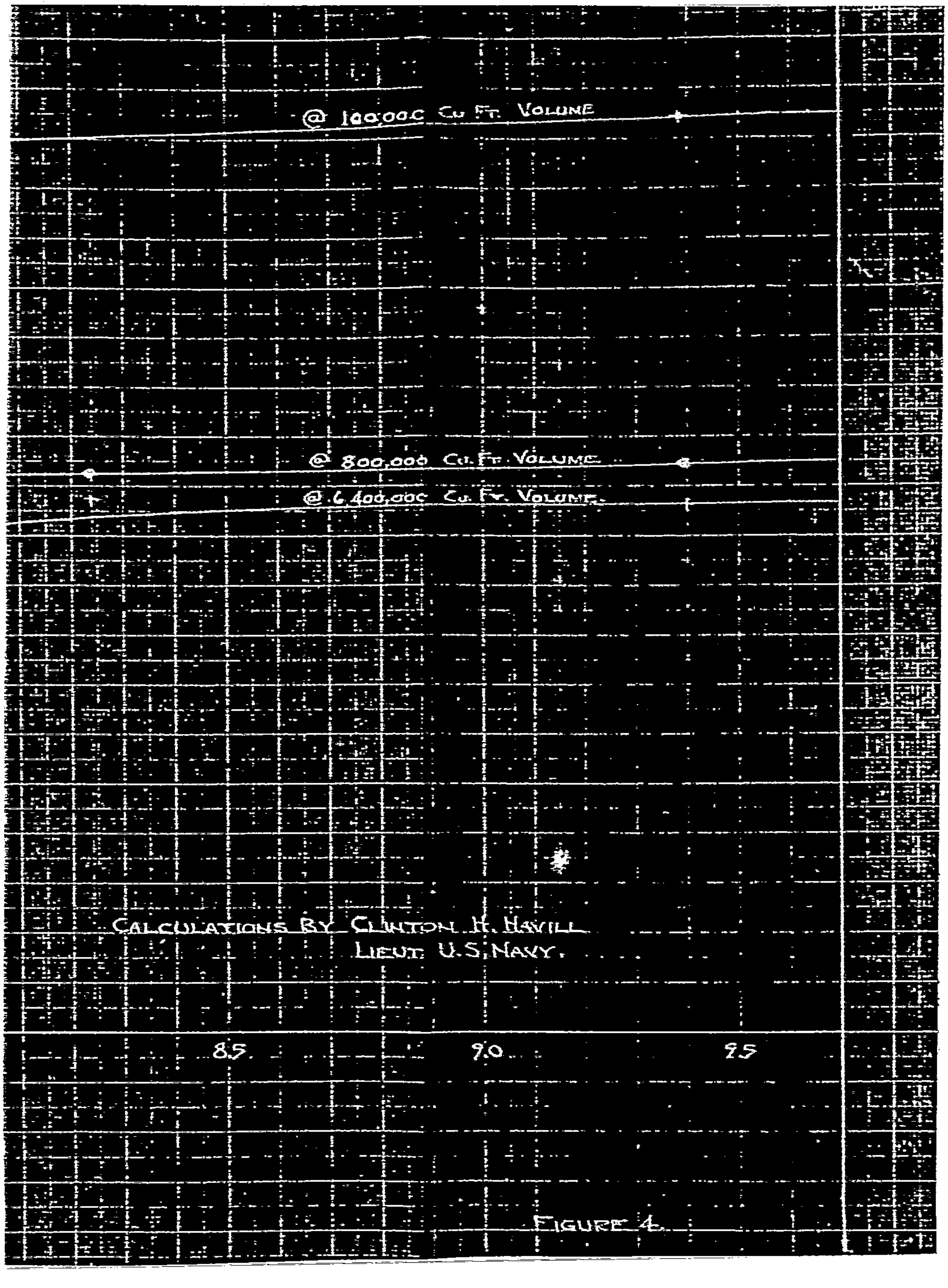
AG COEF, OF BARE HULL - VS - (ECCENTRICITY OF NOSE EL

ATION BETWEEN DRAG COEF, DIAMETER EFFECT, WITH VOLUME

E THIS QUANTITY IS INDEPENDENT OF LENGTH EXCEPT AS IT AFFECTS VO

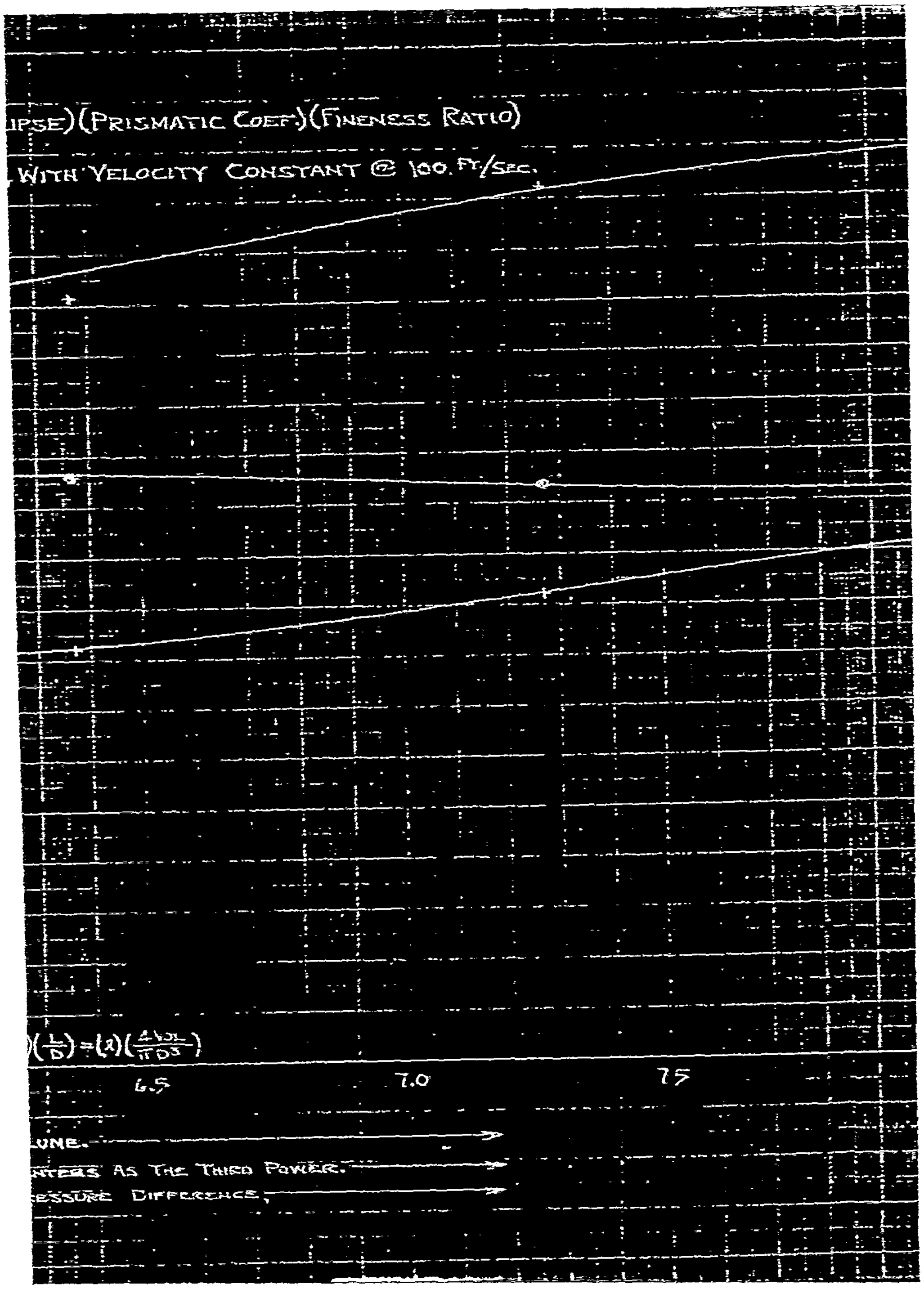
E. THIS QUANTITY HAS THE MAXIMUM EFFECT OF DIAMETER, AS DIAMETER E

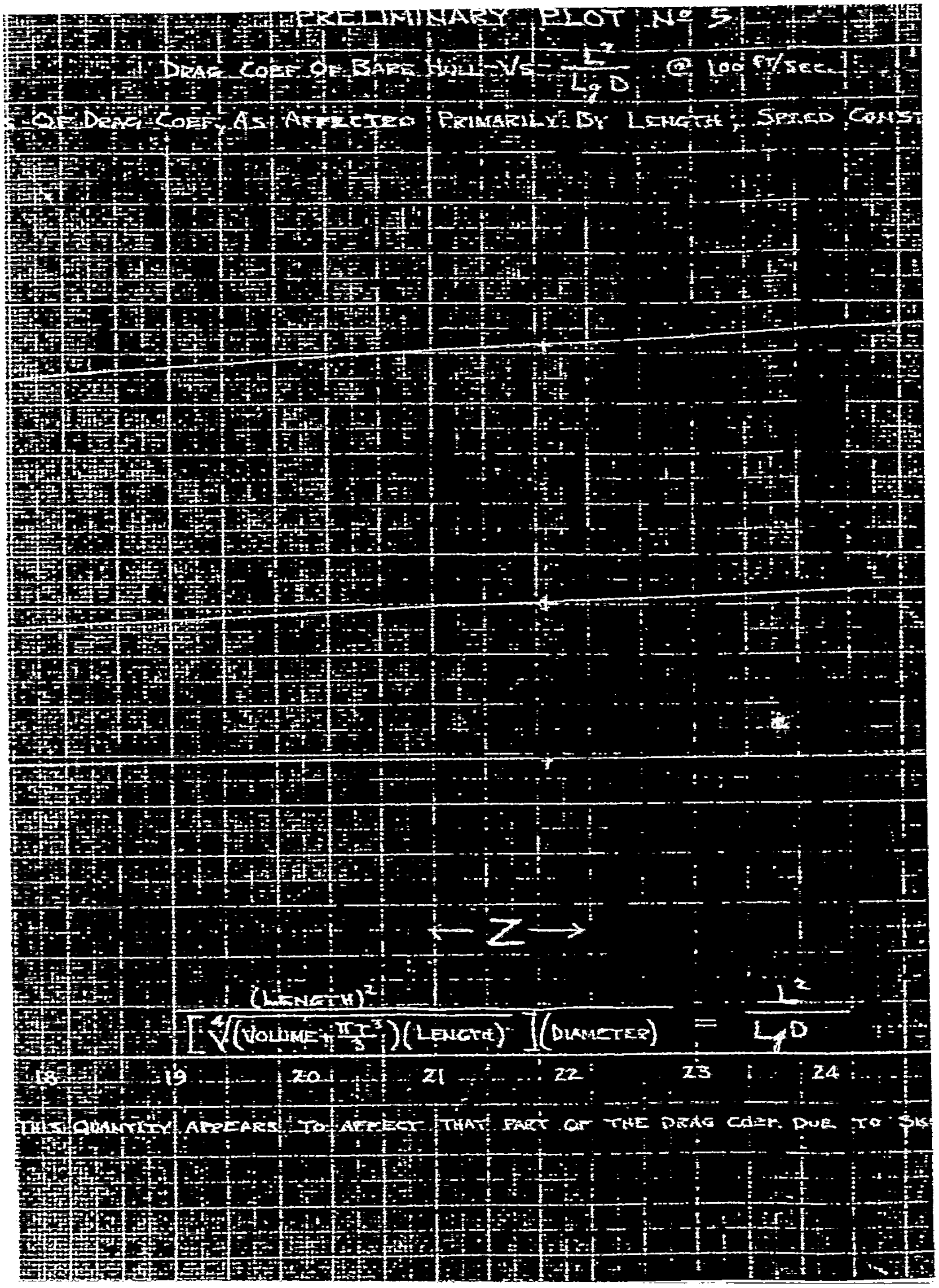
E THIS QUANTITY APPEARS TO AFFECT THAT PART OF THE DRAG COEF DUE TO P

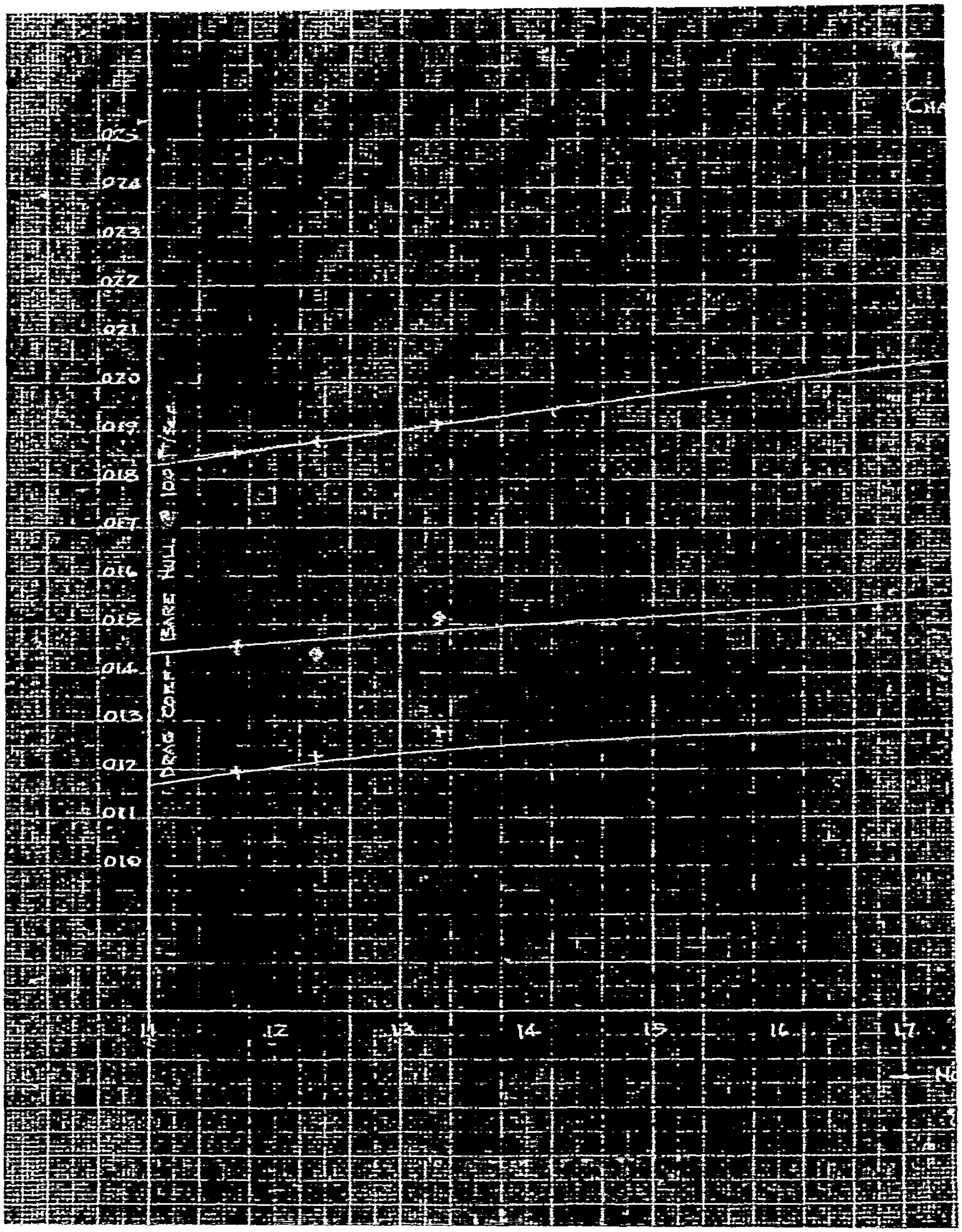


Calculations By Clinton H. Havill
Lieut. U.S. Navy.

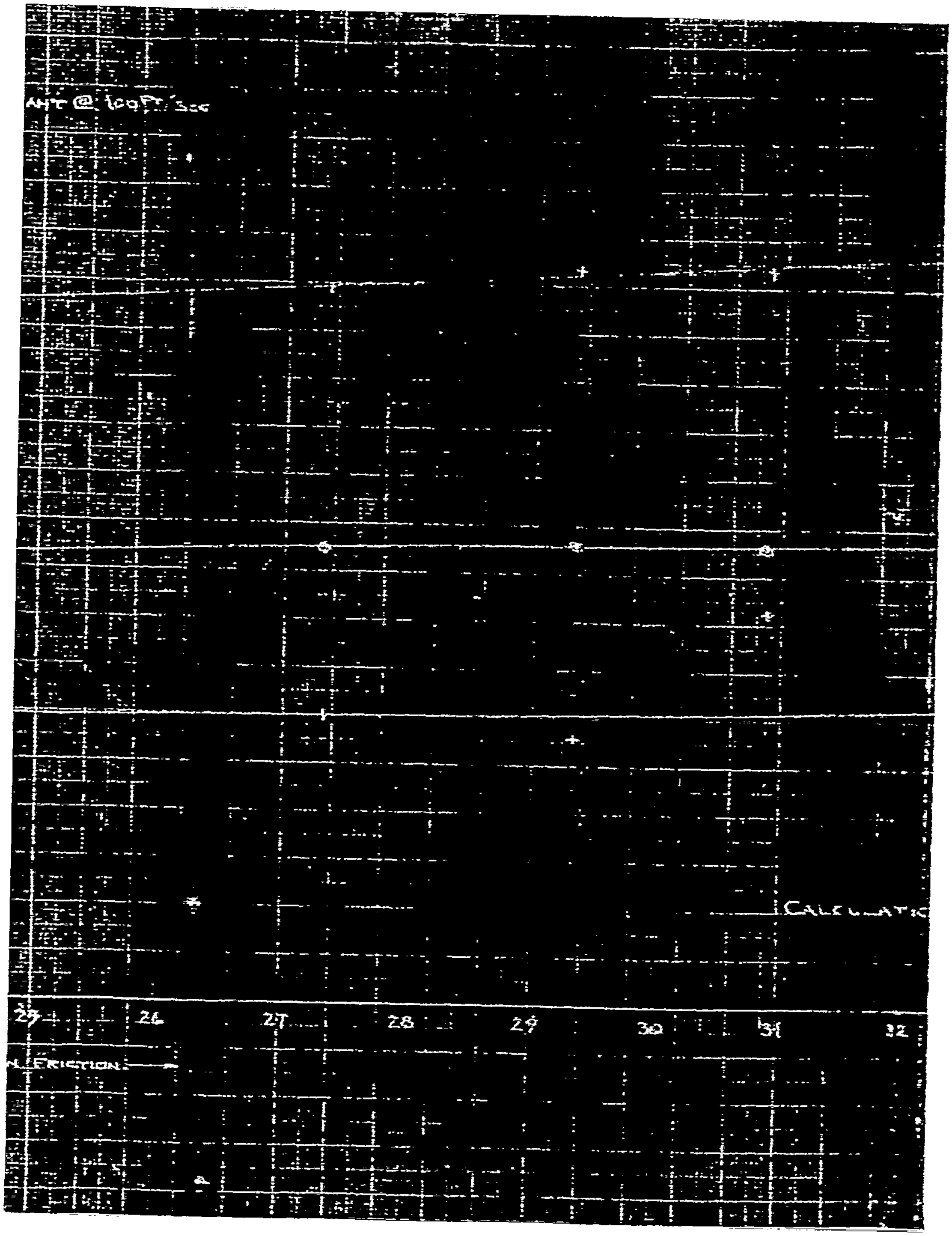
Figure 4.


IPSE)(PRISMATIC COEF.)(FINENESS RATIO)
WITH VELOCITY CONSTANT @ 100. FT/SEC.
)$(\frac{L}{D}) = (\lambda)(\frac{4 Vol}{\pi D^3})$
6.5
7.0
7.5
UME.
NTERS AS THE THIRD POWER.
ESSURE DIFFERENCE,


PRELIMINARY PLOT No 5
DRAG COEF OF BARE HULL VS $\frac{L^2}{L_q D}$ @ 100 FT/SEC.
S OF DRAG COEF. AS AFFECTED PRIMARILY BY LENGTH; SPEED CONST
← Z →
$\frac{(\text{LENGTH})^2}{\left[\sqrt[4]{(\text{VOLUME} \div \frac{\pi L^3}{3})(\text{LENGTH})}\right](\text{DIAMETER})} = \frac{L^2}{L_q D}$
18
19
20
21
22
23
24
THIS QUANTITY APPEARS TO AFFECT THAT PART OF THE DRAG COEF. DUE TO SK



CHA
.025
.024
.023
.022
.021
.020
.019
.018
.017
.016
.015
.014
.013
.012
.011
.010
DRAG COEFF - BARE HULL @ 100 FT/SEC
11
12
13
14
15
16
17
No


ANT @ 100FT/SEC
CALCULATIC
25
26
27
28
29
30
31
32
N FRICTION →

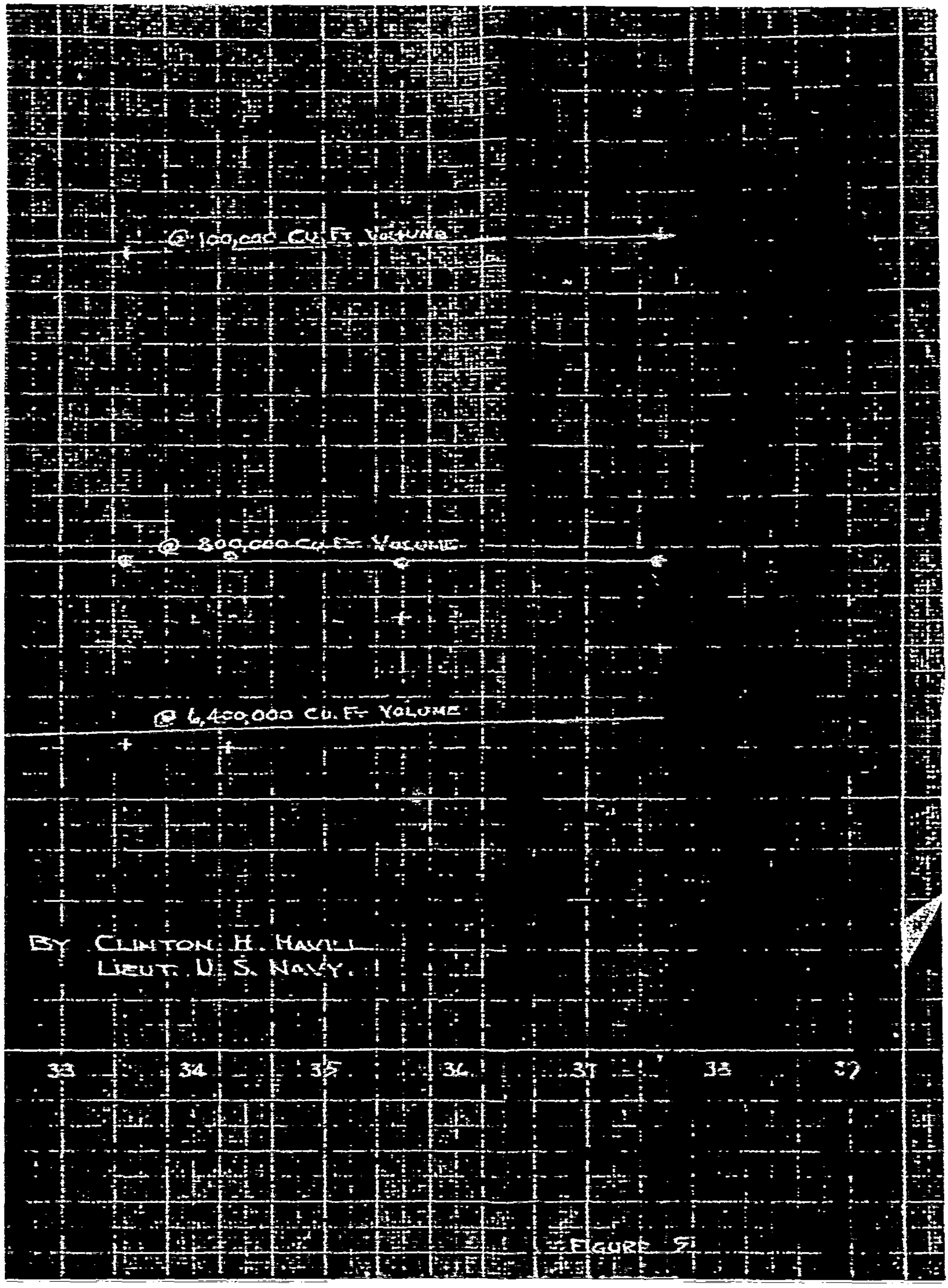
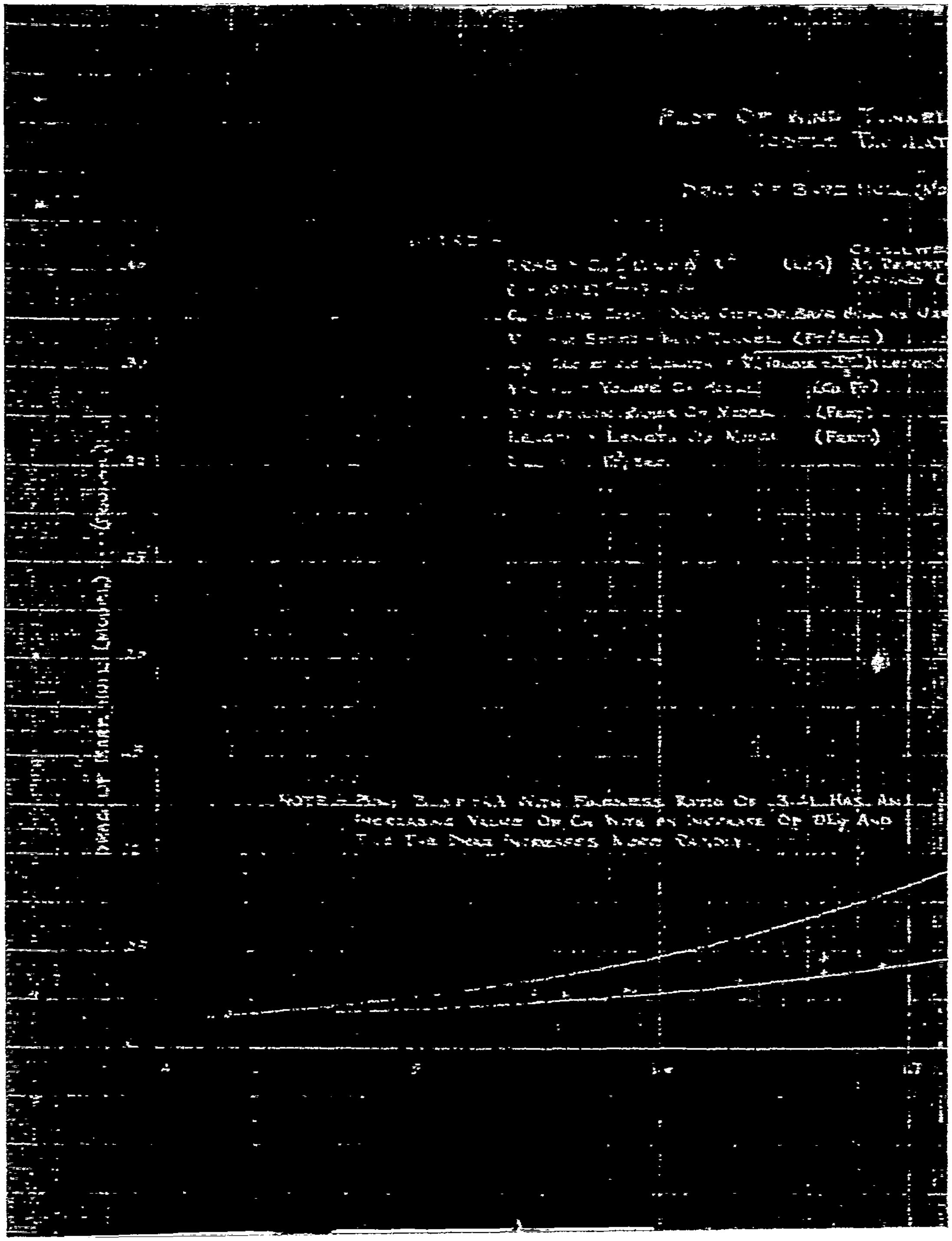

@ 100,000 CU. FT. VOLUME
@ 800,000 CU. FT. VOLUME
@ 6,400,000 CU. FT. VOLUME
BY CLINTON H. HAVILL
LIEUT. U. S. NAVY.
33
34
35
36
37
38
39

FIGURE 5


Plot Of Wind Tunnel
Drag Of Bare Hull (Mo
(Lbs)
(Ft/Sec)
(Cu Ft)
(Feet)
Length - Length Of Model (Feet)
Drag Of Bare Hull (Model)
NOTE - With Fineness Ratio Of 3-4L Has An
Increasing Value Of Cd With An Increase Of DLy And
The Drag Increases More Rapidly.

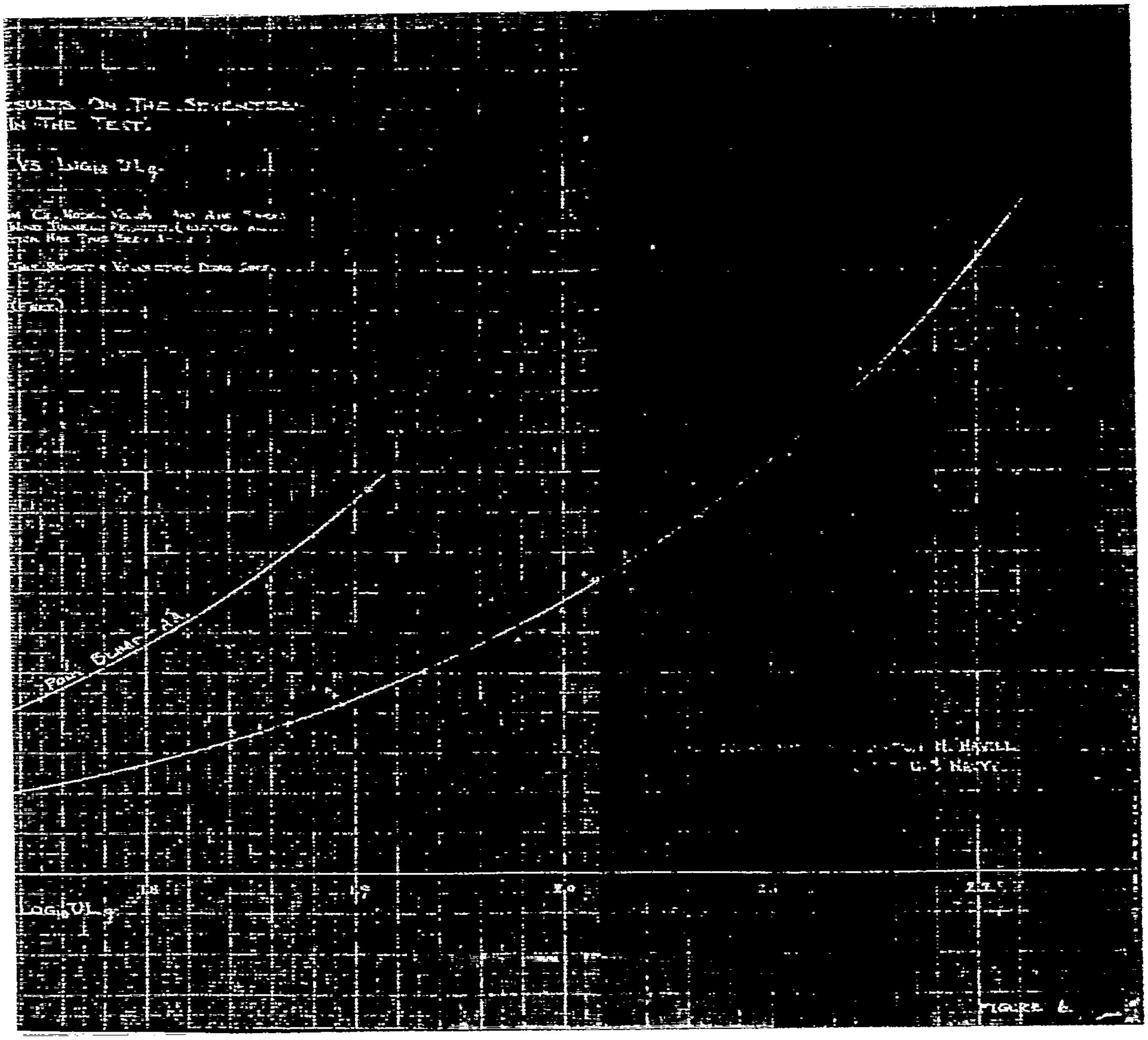
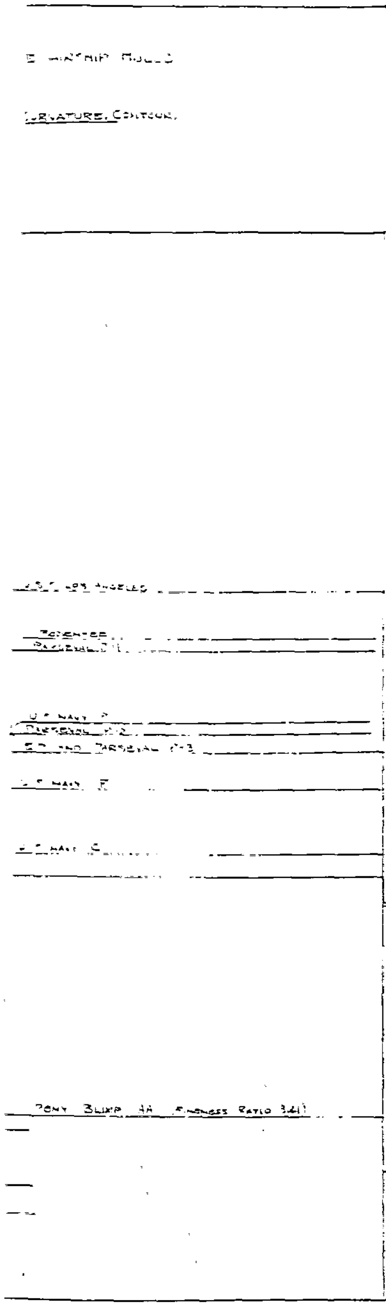

…SULTS ON THE SEVENTEEN…
IN THE TEXT.
…VS LOG₁₀ UL_g.
(F EXP.)
FOR BUMP
1.8
1.9
2.0
2.2
LOG₁₀ UL_g.
H. HAVELL
U.S. NAVY

FIGURE 6.



DEFINITIONS & SYMBOLS FOR THIS DIAGRAM.

C_D = DRAG COEF OF BARE HULL (NO DIMENSIONS).

$C_D = \frac{D}{\frac{\rho}{2}(Vol)^{2/3}V^2}$

D = DRAG OF BARE HULL (LBS)

Vol = VOLUME OF HULL (CU. FT)

V = AIR SPEED: FT SEC.

ρ = DENSITY OF AIR ($T^{.0023}$) (STANDARD CONDITIONS)

Y = AN EMPIRICAL TERM WHICH PRIMARILY DETERMINES A FUNCTION — THAT PART OF THE DRAG COEF DUE TO PRESSURE DIFFERENCE.

Y = (NO DIMENSIONS)

Y = (ECCENTRICITY OF NOSE ELLIPSE)(CYLINDRICAL COEF)(FINENESS RATIO).

$Y = e\left(\frac{Vol}{\frac{\pi D^2 L}{4}}\right)\left(\frac{L}{D}\right)$

$Y = e\left(\frac{4Vol}{\pi D^3}\right)$

WHERE

D = MAX DIAM (FEET)

Vol = VOLUME (CU FT)

e = ECCENTRICITY OF NOSE ELLIPSE.

$e = \frac{\sqrt{x^2 - r^2}}{x}$

WHERE

x = DISTANCE ALONG AXIS OF SHIP, FROM NOSE TO FIRST POINT OF MAX DIAM.

r = MAX RADIUS = $\frac{DIAM}{2}$

CYLINDRICAL COEF = $\frac{VOLUME}{\frac{\pi D^2 L}{4}}$

FINENESS RATIO = $\frac{L}{D}$.

Z = AN EMPIRICAL TERM WHICH PRIMARILY DETERMINES A FUNCTION — THAT PART OF THE DRAG COEF DUE TO SKIN FRICTION.

Z = (NO DIMENSIONS)

$Z = \left(\frac{LENGTH}{GEOMETRIC\ LENGTH}\right)$(FINENESS RATIO)

$Z = \left(\frac{L}{L_g}\right)\left(\frac{L}{D}\right) = \frac{L^2}{L_g D}$

WHERE

L = LENGTH OF HULL (FT)

L_g = A TERM OF LINEAR DIMENSIONS USED TO COMPARE SHIPS AT THE SAME VOL — DEFINED IN TEXT AS "GEOMETRIC LENGTH".

$L_g = \sqrt[4]{(VIRTUAL\ VOLUME)(LENGTH)}$

$L_g = \sqrt[4]{V_v L}$

WHERE V_v = (VOL OF SHIP + $\frac{\pi r^3}{3}$) (CU FT)

L = LENGTH (FT)

$L_g = \sqrt[4]{\left(Vol + \frac{\pi r^3}{3}\right)(L)}$ [r = FT (SEE ABOVE)]

L_g = (FEET)

THIS DIAGRAM FOR STANDARD VALUE OF $\frac{\rho}{\mu}$

DIRECTIONS FOR USE:—

CALCULATE "Y" & "Z" AND ADD THEM. ENTER THE LEFT HAND SCALE WITH THE VALUE OF $LOG_{10}(Y+Z)$ AND FOLLOW THROUGH HORIZONTALLY TO SCALE OF C_D @ .30 CU FT THEN FOLLOW ACROSS THE DIAGRAM, INTERPOLATING THE SLOPE BETWEEN THE ADJACENT SLOPE LINES. PICK OFF THE DRAG COEF'S AT VOLUMES OF 100,000 — 800,000 & 6,400,000 CU. FT. THESE DRAG COEF'S ARE FOR THE VOLUMES GIVEN AT 100 FT SEC. AIR SPEED. FOR INTERPOLATION FOR VOLUMES OTHER THAN THOSE GIVEN, PROCEED AS FOLLOWS. WITH THE THREE VALUES OF DRAG COEF. AS PICKED OFF FROM THE DIAGRAM, CALLED $C_{D100000}$ — $C_{D800000}$ & $C_{D6400000}$, PLOT THE LOG_{10} OF THESE THREE VALUES AGAINST THE LOG_{10} OF (LENGTH × 100) WHERE LENGTH IS THE LENGTH AT VOLUMES OF 100,000 — 800,000 & 6,400,000 CU FT. FOR REDUCTION OR EXPANSION $\left[\frac{ACTUAL\ LENGTH\ OF\ PARTICULAR\ SHIP}{LENGTH\ AT\ VOLUME\ X}\right]^3 = \left[\frac{VOLUME\ OF\ PARTICULAR\ SHIP}{VOLUME\ X}\right]$. THE CURVE OF LOG_{10} DRAG COEF VS LOG_{10} VL DIFFERS WITH EACH TYPE OF SHIP. PASS A SMOOTH CURVE THROUGH THE THREE POINTS ESTABLISHED (USE REASONABLY SMALL VL SCALE) AND PICK OFF THE VALUE OF DRAG COEF. THAT CORRESPONDS TO A VL OF 100 TIMES LENGTH OF THE PARTICULAR SHIP. FOR FURTHER INFORMATION SEE PART II OF TEXT. SEE EXAMPLE FOR ILLUSTRATING USE OF THIS DIAGRAM IN PART II OF TEXT.

CALCULATIONS BY Clinton H. Havill
LIEUT U.S. NAVY.

FIGURE 7.

DIAGRAM SHOWING THE CHANGE OF DRAG COEFFICIENT
WITH VOLUME. SPEED CONSTANT @ 10

FROM MODEL TO FULL SIZE – FOR AIRSHIP HULLS WITH CONT

FOR HULLS WITH CONTINUOUS CURVATURE CONTOUR, FINENESS RATIOS 3.41 TO 7.29, CYLINDRICAL COEF. .587 TO .6
ECCENTRICITY OF NOSE ELLIPSE .932 TO .978, AND DISTANCE FROM NOSE TO MAXIMUM ORDINATE 30% TO 47.33% LENGTH

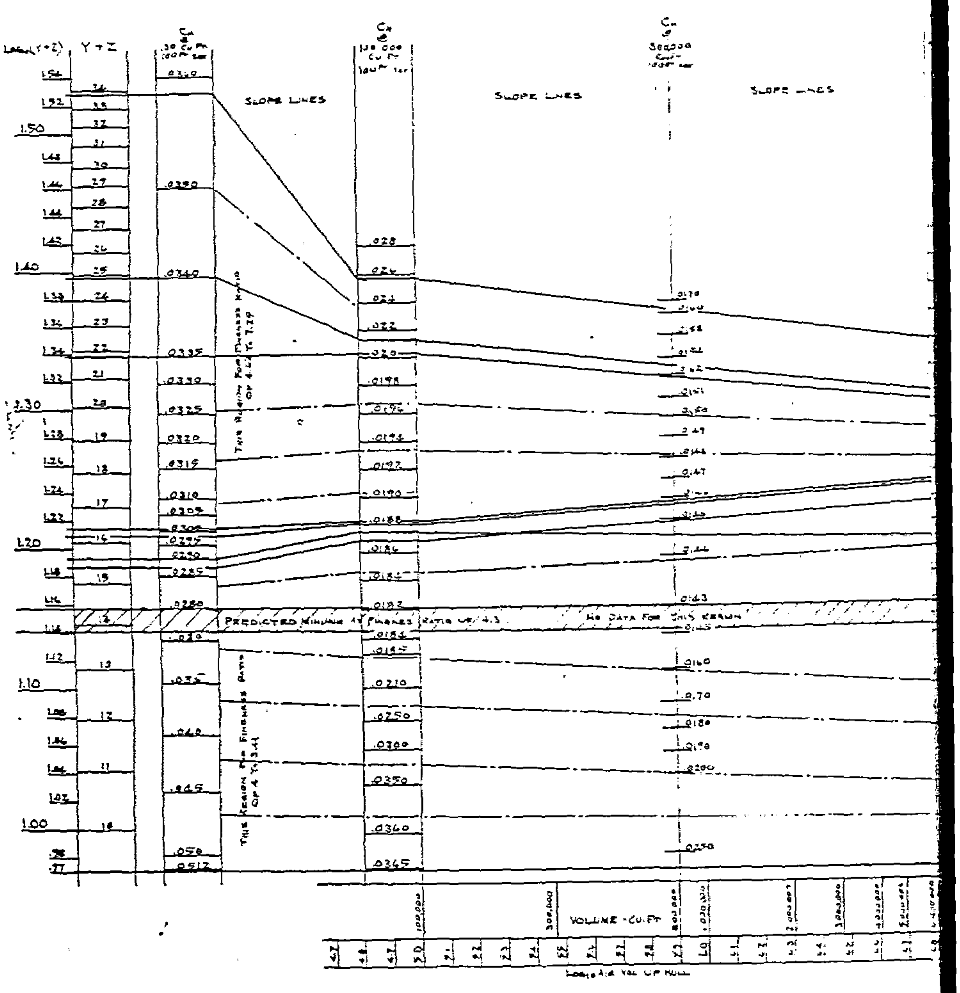
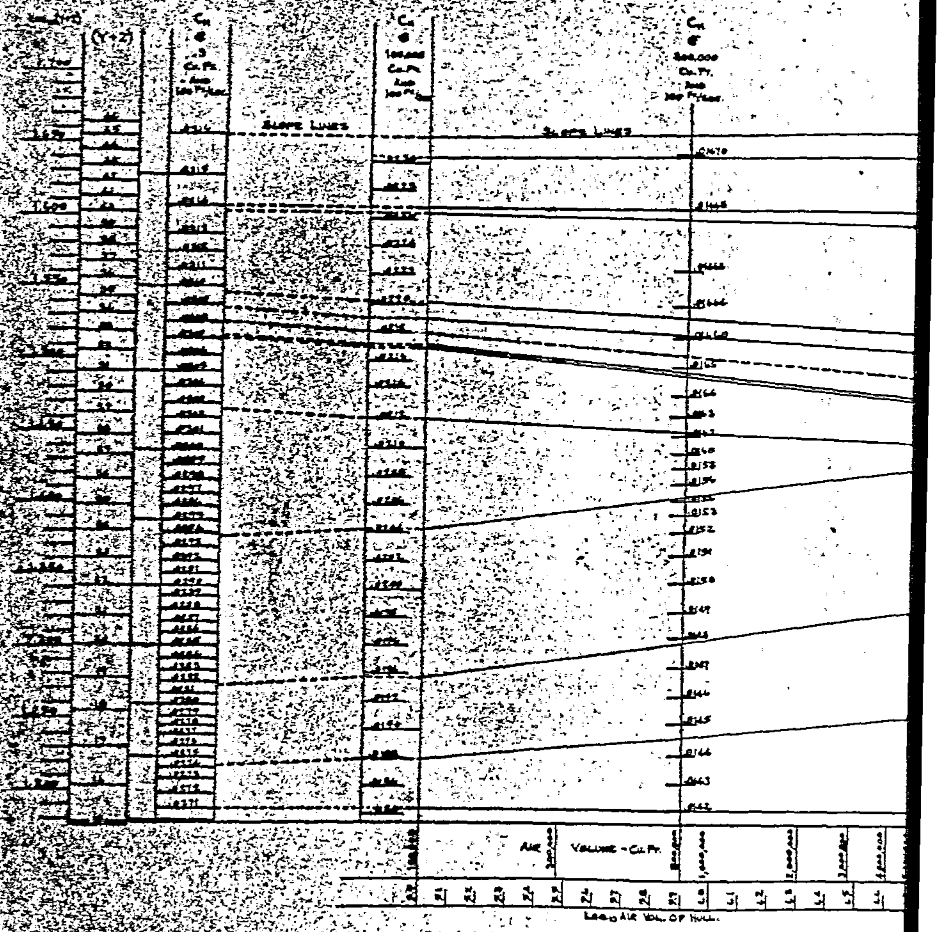


DIAGRAM SHOWING THE CHANGE OF DRAG COEFFIC

WITH VOLUME. SPEED CONSTANT

FROM MODEL TO FULL SIZE – FOR AIRSHIP HULLS WITH

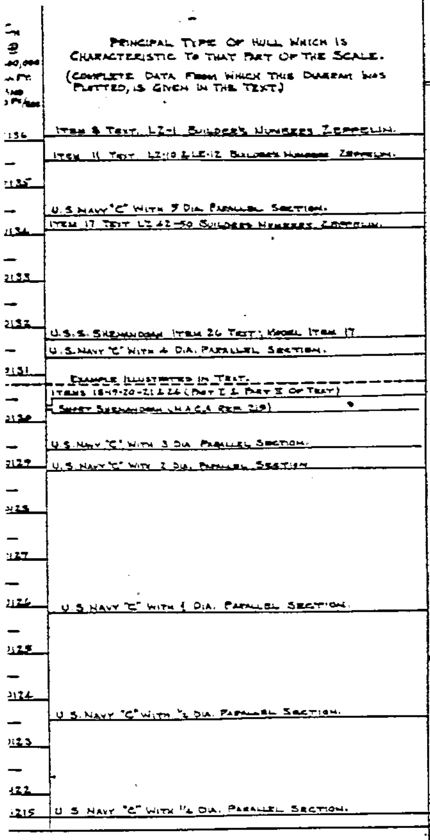
LIMITS OF THE DATA FROM WHICH THIS WAS DERIVED:– FOR HULLS WITH PARALLEL SECTION EQUAL TO NOT LESS THAN ⅓ OF THE DIAM
FINENESS RATIO FROM 4.37 TO 10.41, CYLINDRICAL COEFFICIENT FROM .576 TO .914, ECCENTRICITY OF NOSE ELLIPSE FROM .932 TO
AND DISTANCE FROM NOSE TO FIRST MAXIMUM ORDINATE FROM 14.37% TO 30.84 % OF THE LENGTH.



- BARE AIRSHIP HULLS

T/SEC.

L SECTIONS.



DEFINITIONS & SYMBOLS FOR THIS DIAGRAM.

C_H = DRAG COEF. OF BARE HULL (NO DIMENSIONS).

$C_H = \frac{2R_H}{\rho (Vol)^{2/3} U^2}$

R_H = DRAG OF BARE HULL. (LBS.)

Vol = AIR VOL. OF HULL. (CU.FT.)

U = AIR SPEED. (FT./SEC.)

ρ = DENSITY OF AIR (# LBS./CU.FT.) OR (SLUGS/CU.FT.)

Y = AN EMPIRICAL TERM WHICH PRIMARILY DETERMINES A FUNCTION — THAT PART OF THE DRAG COEF. DUE TO PRESSURE DIFFERENCE.

Y = (NO DIMENSIONS)

Y = (ECCENTRICITY OF NOSE ELLIPSE)(CYLINDRICAL COEF.)(FINENESS RATIO).

$Y = (\varepsilon)\left(\frac{Vol}{\frac{\pi D^2 L}{4}}\right)\left(\frac{L}{D}\right)$

$Y = (\varepsilon)\left(\frac{4\,Vol}{\pi D^3}\right)$

WHERE

D = MAX. DIAM. (FEET)

Vol = VOLUME (CU.FT.)

ε = ECCENTRICITY OF NOSE ELLIPSE.

$\varepsilon = \frac{\sqrt{x^2 - r^2}}{x}$

WHERE

x = DISTANCE, ALONG AXIS OF SHIP, FROM NOSE TO FIRST POINT OF MAX. DIAM.

r = MAX. RADIUS = $\frac{Diam.}{2}$

CYLINDRICAL COEF. = $\frac{Volume}{\frac{\pi D^2 L}{4}}$

FINENESS RATIO = $\frac{L}{D}$.

Z = AN EMPIRICAL TERM WHICH PRIMARILY DETERMINES A FUNCTION — THAT PART OF THE DRAG COEF. DUE TO SKIN FRICTION.

Z = (NO DIMENSIONS)

Z = $\left(\frac{LENGTH}{GEOMETRIC\ LENGTH}\right)$(FINENESS RATIO)

$Z = \left(\frac{L}{L_g}\right)\left(\frac{L}{D}\right) = \frac{L^2}{L_g D}$

WHERE L = LENGTH OF HULL (FT.)

L_g = A TERM OF LINEAR DIMENSIONS USED TO COMPARE SHIPS AT THE SAME UL_g. — DEFINED IN TEXT AS "GEOMETRIC LENGTH".

$L_g = \sqrt[4]{(VIRTUAL\ VOLUME)(LENGTH)}$

$L_g = \sqrt[4]{V_v L}$

WHERE $V_v = (Vol.\ Of\ Ship + \frac{\pi r^3}{2})$ — (CU.FT.)

L = LENGTH (FT.)

$L_g = \sqrt[4]{(Vol + \frac{\pi r^3}{2})(L)}$ [r = FT. (SEE ABOVE).]

L_g = (FEET.)

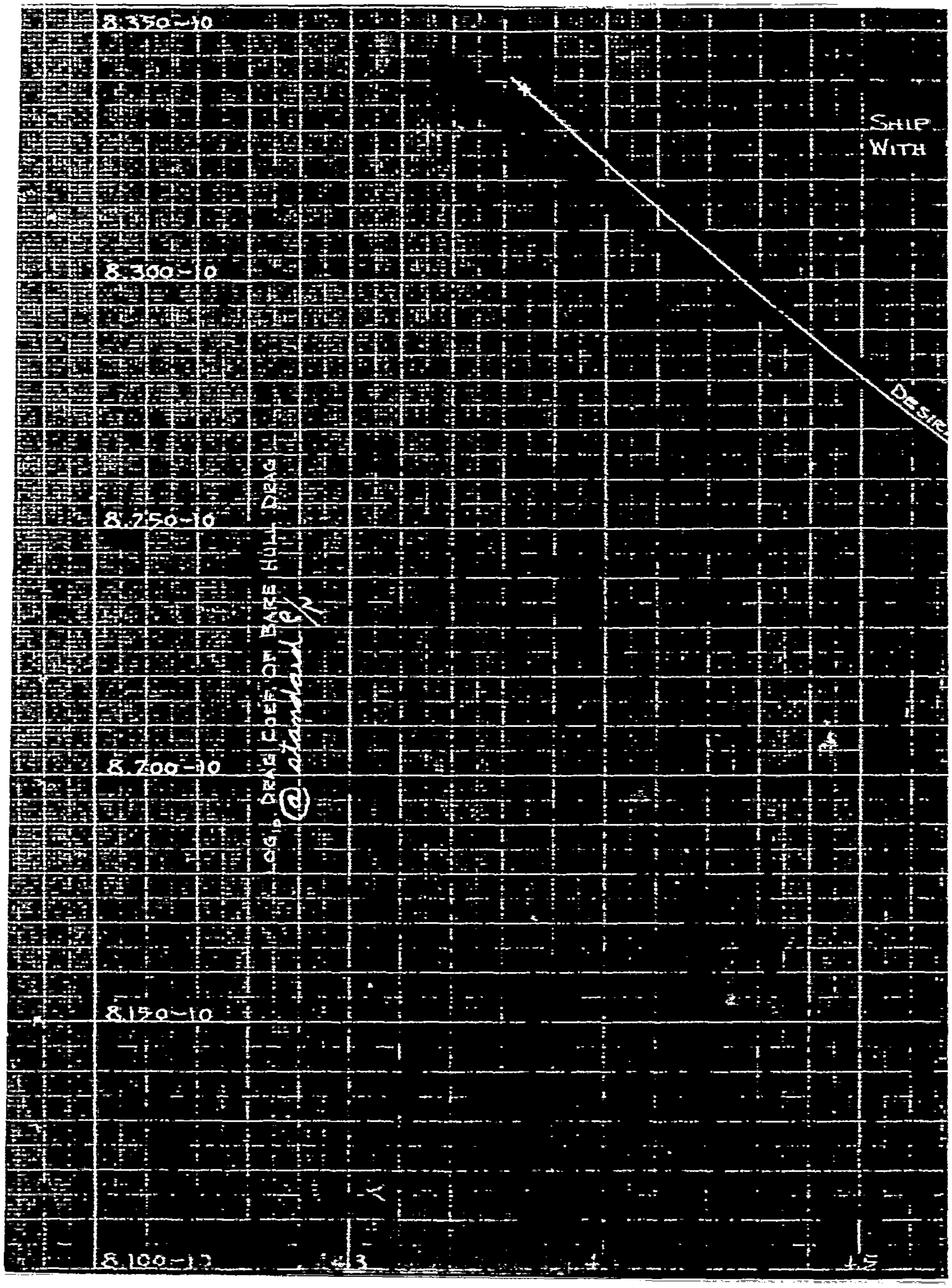
THIS DIAGRAM FOR STANDARD VALUE OF $\frac{\rho}{\mu}$.

DIRECTIONS FOR USE:—

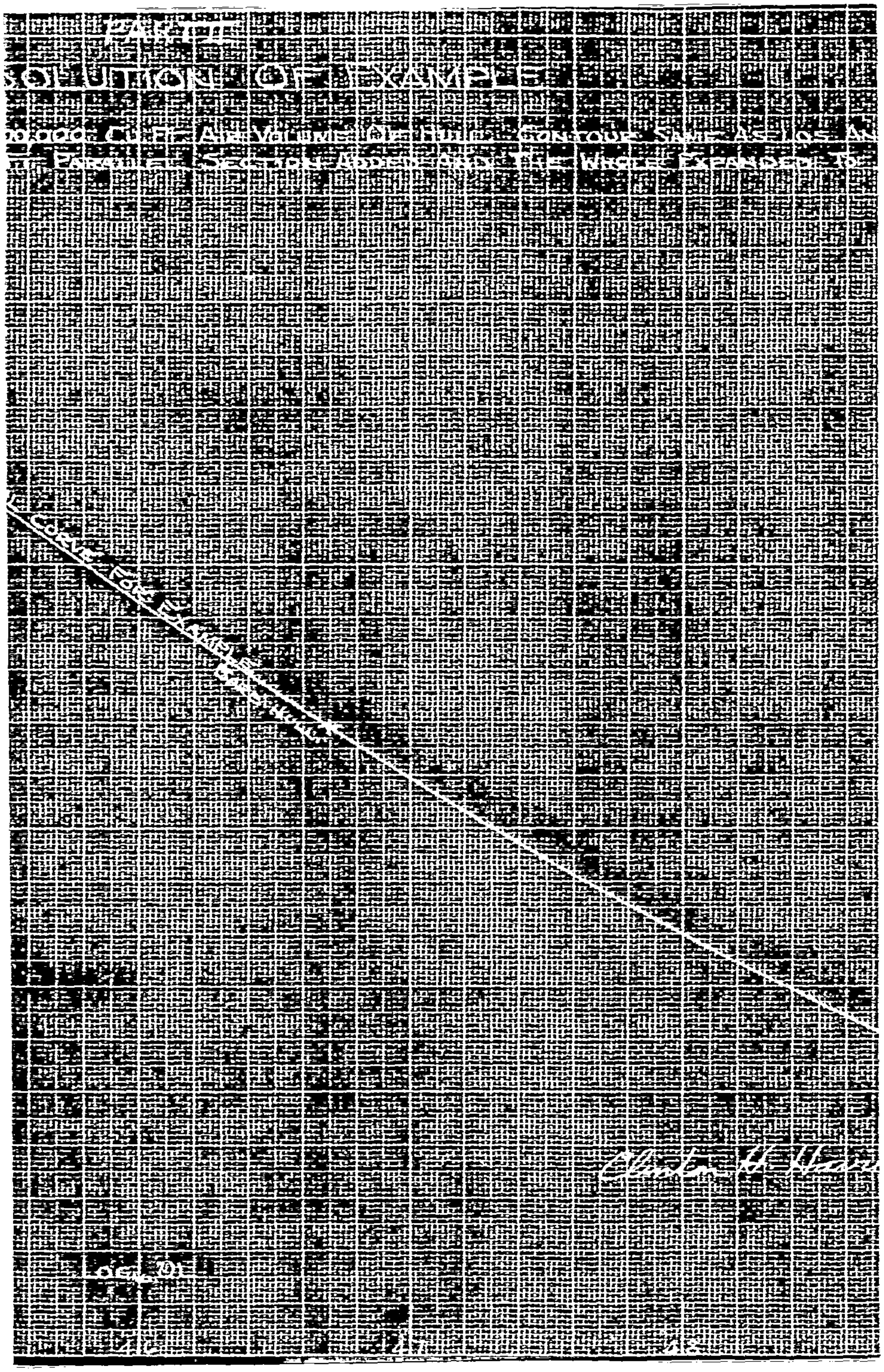
CALCULATE "Y" & "Z" AND ADD THEM. ENTER THE LEFT HAND SCALE WITH THE VALUE OF $LOG_{10}(Y+Z)$ AND FOLLOW THROUGH HORIZONTALLY TO SCALE OF C_H @ .50 CU.FT. THEN FOLLOW ACROSS THE DIAGRAM, INTERPOLATING THE SLOPE BETWEEN THE ADJACENT SLOPE LINES. PICK OFF THE DRAG COEF'S AT VOLUMES OF 100,000 – 800,000 & 6,400,000 CU.FT. THESE DRAG COEF'S, ARE FOR THE VOLUMES GIVEN AT 100 FT SEC. AIR SPEED. FOR INTERPOLATION FOR VOLUMES OTHER THAN THOSE GIVEN, PROCEED AS FOLLOWS. WITH THE THREE VALUES OF DRAG COEF. AS PICKED OFF FROM THE DIAGRAM, CALLED $C_{H100000}$ – $C_{H800000}$ & $C_{H6400000}$, PLOT THE LOG_{10} OF THESE THREE VALUES AGAINST THE LOG_{10} OF (LENGTH × 100) WHERE LENGTH IS THE LENGTH AT VOLUMES OF 100,000 – 800,000 & 6,400,000 CU.FT. FOR REDUCTION OR EXPANSION $\left[\frac{ACTUAL\ LENGTH\ OF\ PARTICULAR\ SHIP}{LENGTH\ AT\ VOLUME\ "X"}\right]^3 = \left[\frac{VOLUME\ OF\ PARTICULAR\ SHIP}{VOLUME\ X}\right]$. THE CURVE OF LOG_{10} DRAG COEF. VS LOG_{10} UL DIFFERS WITH EACH TYPE OF SHIP. PASS A SMOOTH CURVE THROUGH THE THREE POINTS ESTABLISHED (USE REASONABLY SMALL UL SCALE) AND PICK OFF THE VALUE OF DRAG COEF. THAT CORRESPONDS TO A UL OF 100 TIMES LENGTH OF THE PARTICULAR SHIP. FOR FURTHER INFORMATION SEE PART II OF TEXT. SEE EXAMPLE FOR ILLUSTRATING USE OF THIS DIAGRAM IN PART II OF TEXT.

CALCULATIONS BY Clinton H Havill
LIEUT. U.S. NAVY.

FIGURE 8.



8.350-10
8.300-10
8.250-10
8.200-10
8.150-10
8.100-10
LOG10 DRAG COEF OF BARE HULL DRAG
@ standard R/N
.3
.4
.5
SHIP
WITH
DESIR


PART II
SOLUTION OF EXAMPLE
CU. FT. AIR VOLUME OF HULL, CONTOUR SAME AS 105 AN
PARALLEL SECTION ADDED AND THE WHOLE EXPANDED TO
CURVE FOR EXAMPLE
LOG. 01

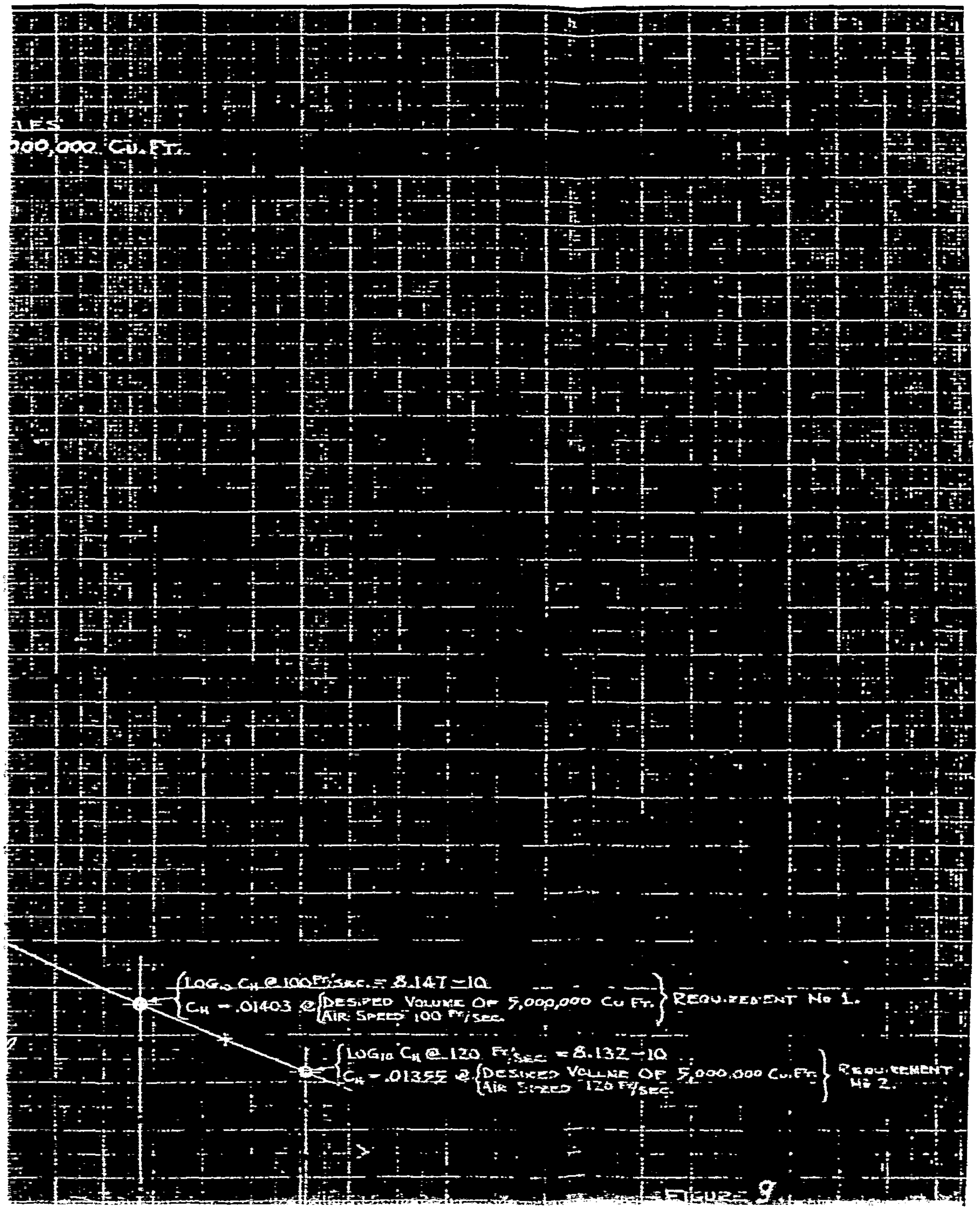

LES
00,000 CU. FT.
LOG₁₀ C_H @ 100 FT/SEC. = 8.147 − 10
C_H = .01403 @ DESIRED VOLUME OF 5,000,000 CU FT. / AIR SPEED 100 FT/SEC.
REQUIREMENT No 1.
LOG₁₀ C_H @ 120 FT/SEC = 8.132 − 10
C_H = .01355 @ DESIRED VOLUME OF 5,000,000 CU. FT. / AIR SPEED 120 FT/SEC.
REQUIREMENT No 2.

FIGURE 9