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THE DRAG OF AIRSHIPS

DRAG OF BARE HULLS - II

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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

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

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

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

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

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 $KYL^2V^2 + F_2 Z\left(\frac{\rho VL}{\mu}\right)^n = R$ 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

$$\frac{Y\ C_{HY} + Z\ C_{HZ}}{Y + Z} = C_H \text{ for given } (Y + Z)$$

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

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

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

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

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

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

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

$$''\ \sqrt[4]{V_M L} = \frac{9.42493}{4} = 2.35623 = \log_{10} L_g;\ L_g = 227.1 \text{ ft. at}$$

$$\text{Vol} = 3,410,569 \text{ cu.ft.}$$

$Y = (e)$ (cylindrical coef.) (fineness ratio)

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

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

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

$$\text{Log}_{10}(Y + Z) = 1.52643$$

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}

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

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

$\log (L \text{ at } 100{,}000)^3$ as before 7.10668
" 50 $\underline{1.69897}$
$3\,\underline{|8.80565}$
$\log L_{5{,}000{,}000}$ 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., $\rho = .00237$ 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. $\rho = .00237$ 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
$\log_{10} C_H = 8.132-10$; $C_H = .01355$

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

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

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

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	$L_g = \sqrt[4]{\left[(Vol) + \frac{\pi r^3}{3}\right] L}$ 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	$R \quad C_H \frac{\rho}{2} (Vol)^{2/3} V^2$ lb.

Symbols ans Formulas (Cont.)

Drag coef. of bare hull C_H no dimensions

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

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

PART II

	Item	Builder's Numbers.	Remarks.
Continuous Curvature	1	U.S.N. "B"	Non Rigid, One Car, One Engine, Navy N9 Fuselage Type Of Car, Bumpers Separate And Below The 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 Outriggers, Pusher Propellers, " " " " " " ".
	3	U.S.N. "D"	" " , " " , " " , " " " , " " " " , " " , " " " " " " ".
	4	U.S.N. "E"	" " , " " , One Engine , " " " , " Below Car, Engine On Stern Of Car, —— " " , " " " " " " ".
	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, Control Car Adjacent To Hull ———— , " " " " " " ".
	7	LZ-126 U.S.S. Los Angeles (No Water Recovery)	" , Five " " " , Control Car Adjacent To Hull, Small Amount Of External Bracing, Well Streamlined 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 Surfaces, Large 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 Including 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 35	" , " " " " " , " " " " " " " , " " " " " " " , " " " " " " " , One " " Each Car.
	15	LZ-36	" , " " " " " , " " " " " " " " , No External Keel, Large Flat Plate 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 " " " , " " " Smaller " " " " " " " , Smaller " " " " , " " " " " .
	18	LZ-72 To 90 (Except 73, 77 & 81)	" , Two " " Two " , " " " " Two " " " , " " " " " " " " " " , Small " " " " , " " " " " .
	19	LZ-91 To 94	" , Three " " One " , " " " " " " " , " " " Normal Size " " " " " " " , " " " " " , " " " " " .
	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 ———— , " " " " " Better Stream Lined " " " , " " " " " , " " " " Power Car.
	26	ZR-1 U.S.S. Shenandoah.	" , " " " " " , " " " ———— , " " " " " " " " " " " , " " " " " , " " " " " "

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Lieut., U. S. Navy.

PRELIMINARY PLOT No 5

DRAG COEF OF BARE HULL–VS–$\frac{L^2}{L_g D}$ @ 100 FT/SEC.

CHANGES OF DRAG COEF, AS AFFECTED PRIMARILY BY LENGTH; SPEED CONSTANT @ 100 FT/SEC.

←Z→

$$\frac{(\text{LENGTH})^2}{\left[\sqrt[4]{\left(\text{VOLUME} \div \frac{\pi L^3}{3}\right)(\text{LENGTH})}\right](\text{DIAMETER})} = \frac{L^2}{L_g D}$$

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

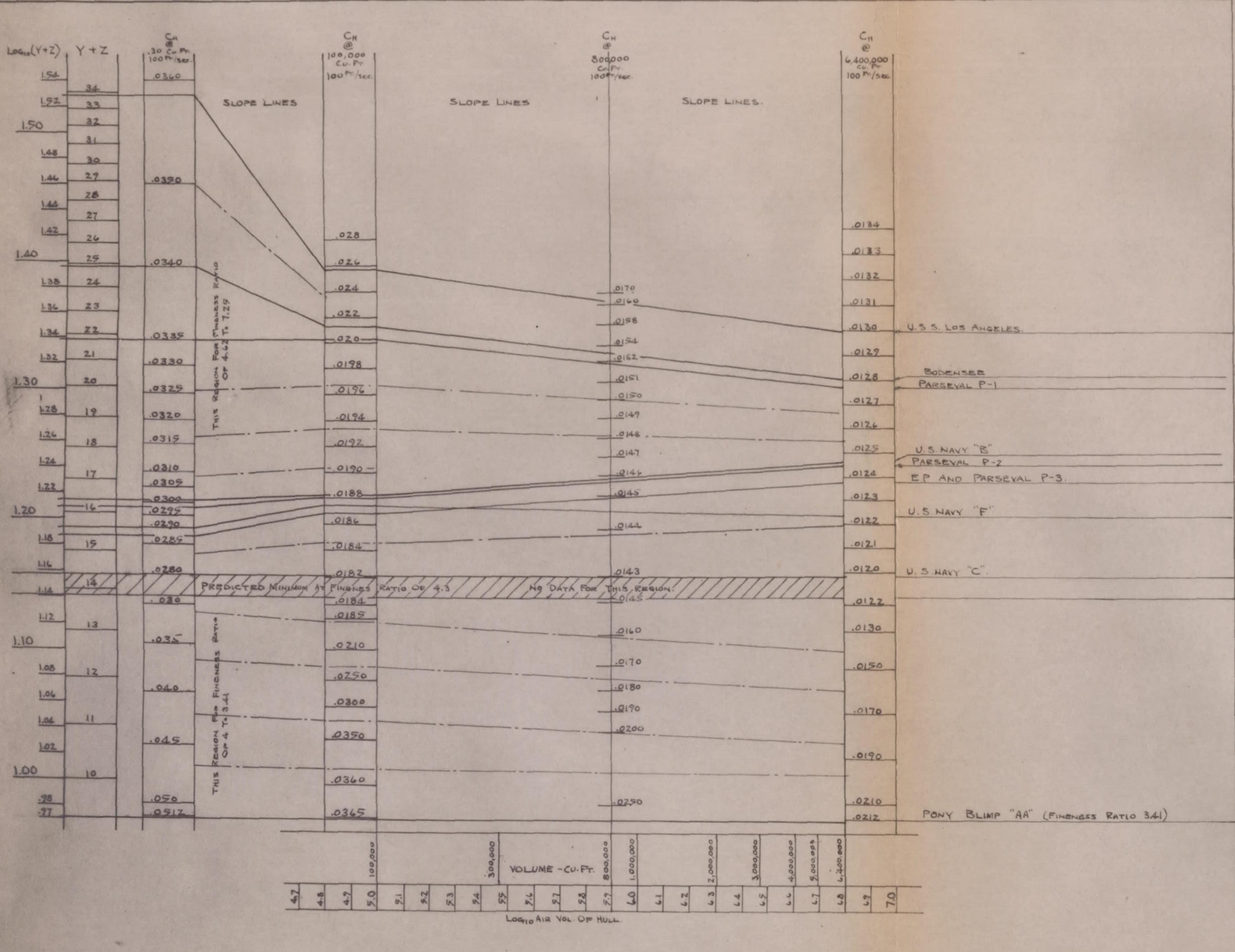
——NOTE THIS QUANTITY APPEARS TO AFFECT THAT PART OF THE DRAG COEF DUE TO SKIN FRICTION——

FIGURE 5

DIAGRAM SHOWING THE CHANGE OF DRAG COEFFICIENT OF BARE AIRSHIP HULLS WITH VOLUME. SPEED CONSTANT @ 100 FT./SEC.

FROM MODEL TO FULL SIZE – FOR AIRSHIP HULLS WITH CONTINUOUS CURVATURE. CONTOUR.

FOR HULLS WITH CONTINUOUS CURVATURE CONTOUR, FINENESS RATIOS 3.41 TO 7.25, CYLINDRICAL COEF. .589 TO .656, ECCENTRICITY OF NOSE ELLIPSE .932 TO .978, AND DISTANCE FROM NOSE TO MAXIMUM ORDINATE 30% T. 47.33% LENGTH.



DEFINITIONS & SYMBOLS FOR THIS DIAGRAM.

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

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

R_H = DRAG OF BARE HULL. (LBS.)

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

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

ρ = DENSITY OF AIR (γ 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".

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

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

WHERE $V_M = \left(\text{VOL. OF SHIP} + \frac{\pi r^3}{3}\right)$ (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_H @ .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 $C_{H\text{-}100{,}000}$ – $C_{H\text{-}800{,}000}$ & $C_{H\text{-}6{,}400{,}000}$, 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 $\left[\frac{\text{ACTUAL LENGTH OF PARTICULAR SHIP}}{\text{LENGTH AT VOLUME "X"}}\right]^3 = \left[\frac{\text{VOLUME OF PARTICULAR SHIP}}{\text{VOLUME "X"}}\right]$. 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.

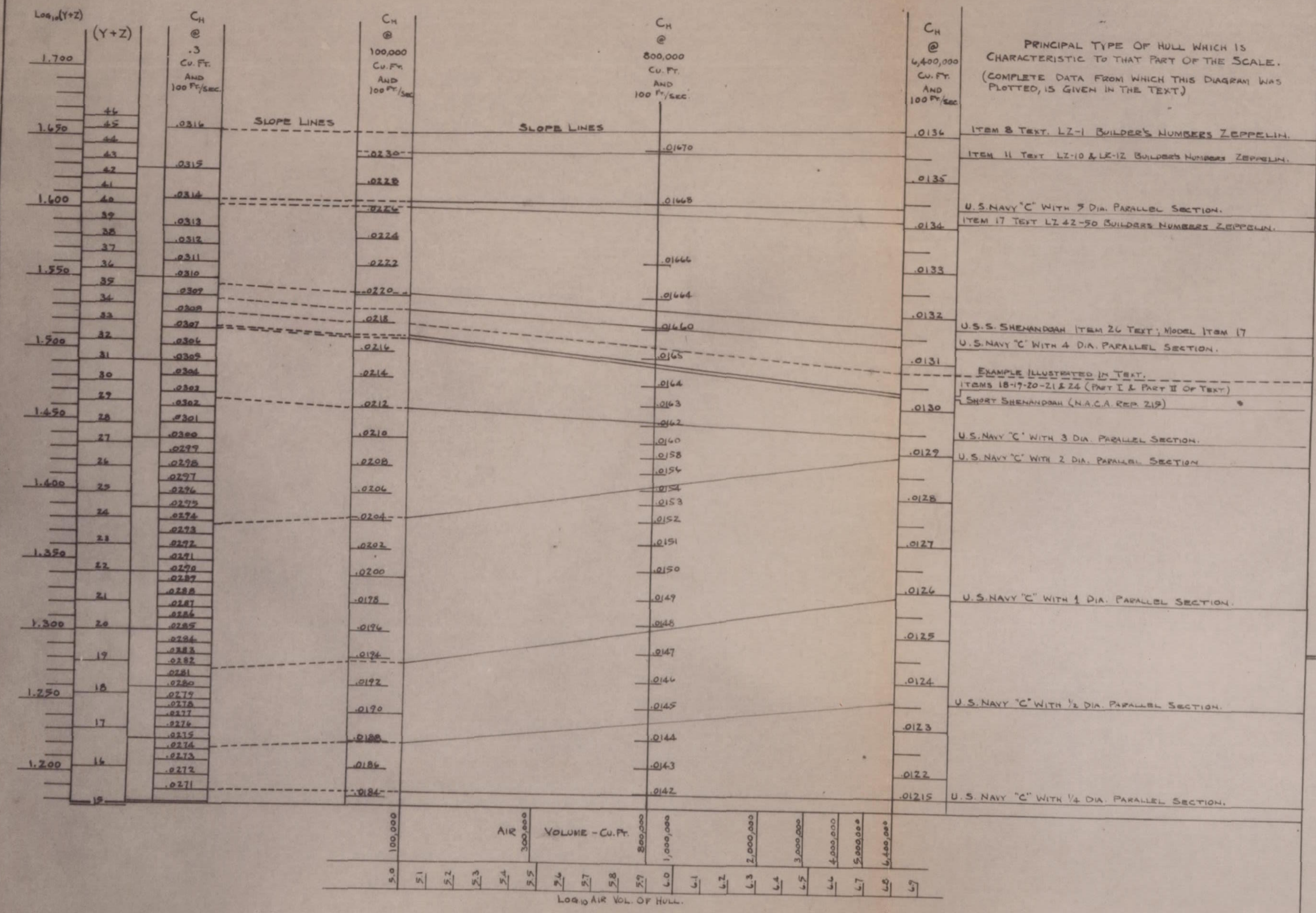
CALCULATIONS BY Clinton H. Havill
LIEUT. U. S. NAVY.

FIGURE 7.

DIAGRAM SHOWING THE CHANGE OF DRAG COEFFICIENT OF BARE AIRSHIP HULLS WITH VOLUME. SPEED CONSTANT @ 100 FT./SEC.

FROM MODEL TO FULL SIZE – <u>FOR AIRSHIP HULLS WITH PARALLEL SECTIONS.</u>

LIMITS OF THE DATA FROM WHICH THIS WAS DERIVED:– FOR HULLS WITH PARALLEL SECTION EQUAL TO NOT LESS THAN ¼ OF THE DIAMETER, FINENESS RATIO FROM 4.85 TO 10.61, CYLINDRICAL COEFFICIENT FROM .674 TO .914, ECCENTRICITY OF NOSE ELLIPSE FROM .932 TO .984, AND DISTANCE FROM NOSE TO FIRST MAXIMUM ORDINATE FROM 14.37 % TO 30.80 % OF THE LENGTH.



DEFINITIONS & SYMBOLS FOR THIS DIAGRAM.

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

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

R_H = DRAG OF BARE HULL. (LBS.)

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

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

ρ = DENSITY OF AIR ($\frac{\text{LBS}}{g}$/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).

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

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

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 = $\frac{\text{DIAM.}}{2}$

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

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)

$Z = \left(\frac{\text{LENGTH}}{\text{GEOMETRIC LENGTH}}\right)$(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".

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

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

WHERE $V_H = \left(\text{Vol. of Ship} + \frac{\pi r^3}{3}\right)$ – (CU. FT.)

L = LENGTH (FT.)

$L_g = \sqrt[4]{\left(\text{Vol.} + \frac{\pi r^3}{3}\right)(L)}$ [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_H @ .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 $C_{H\text{-}100000}$ – $C_{H\text{-}800000}$ & $C_{H\text{-}6,400,000}$, 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 $\left[\frac{\text{ACTUAL LENGTH OF PARTICULAR SHIP}}{\text{LENGTH AT VOLUME "X"}}\right]^3 = \left[\frac{\text{VOLUME OF PARTICULAR SHIP}}{\text{VOLUME "X"}}\right]$. 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.

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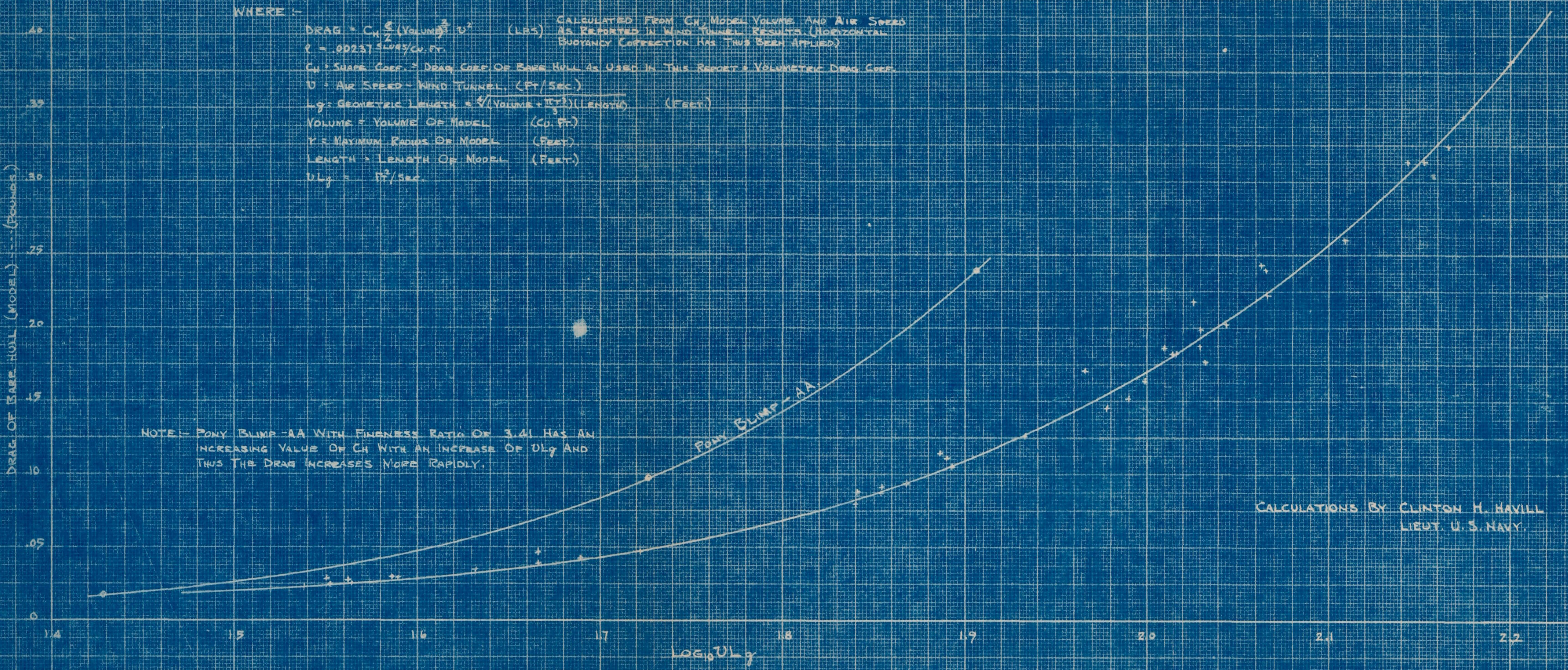
FIGURE 8.

PLOT OF WIND TUNNEL RESULTS ON THE SEVENTEEN MODELS TABULATED IN THE TEXT.

DRAG OF BARE HULL (MODEL) VS LOG$_{10}$ UL$_g$.



WHERE :-

DRAG = $C_H \frac{\rho}{2} (\text{VOLUME})^{\frac{2}{3}} U^2$ (LBS) CALCULATED FROM C_H, MODEL VOLUME AND AIR SPEED AS REPORTED IN WIND TUNNEL RESULTS (HORIZONTAL BUOYANCY CORRECTION HAS THUS BEEN APPLIED.)

ρ = .00237 SLUGS/CU. FT.

C_H = SHAPE COEF. = DRAG COEF. OF BARE HULL AS USED IN THIS REPORT = VOLUMETRIC DRAG COEF.

U = AIR SPEED - WIND TUNNEL. (FT/SEC.)

L_g = GEOMETRIC LENGTH = $\sqrt[4]{(\text{VOLUME} + \frac{\pi r^2}{3})(\text{LENGTH})}$ (FEET.)

VOLUME = VOLUME OF MODEL (CU. FT.)

r = MAXIMUM RADIUS OF MODEL (FEET.)

LENGTH = LENGTH OF MODEL (FEET.)

UL_g = FT^2/SEC.

NOTE:- PONY BLIMP-AA WITH FINENESS RATIO OF 3.41 HAS AN INCREASING VALUE OF C_H WITH AN INCREASE OF UL_g AND THUS THE DRAG INCREASES MORE RAPIDLY.

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FIGURE 6.

PART II

SOLUTION OF EXAMPLE

SHIP 5,000,000 CU. FT. AIR VOLUME OF HULL. CONTOUR SAME AS LOS ANGELES
WITH 100 FT, PARALLEL SECTION ADDED AND THE WHOLE EXPANDED TO 5,000,000 CU. FT.

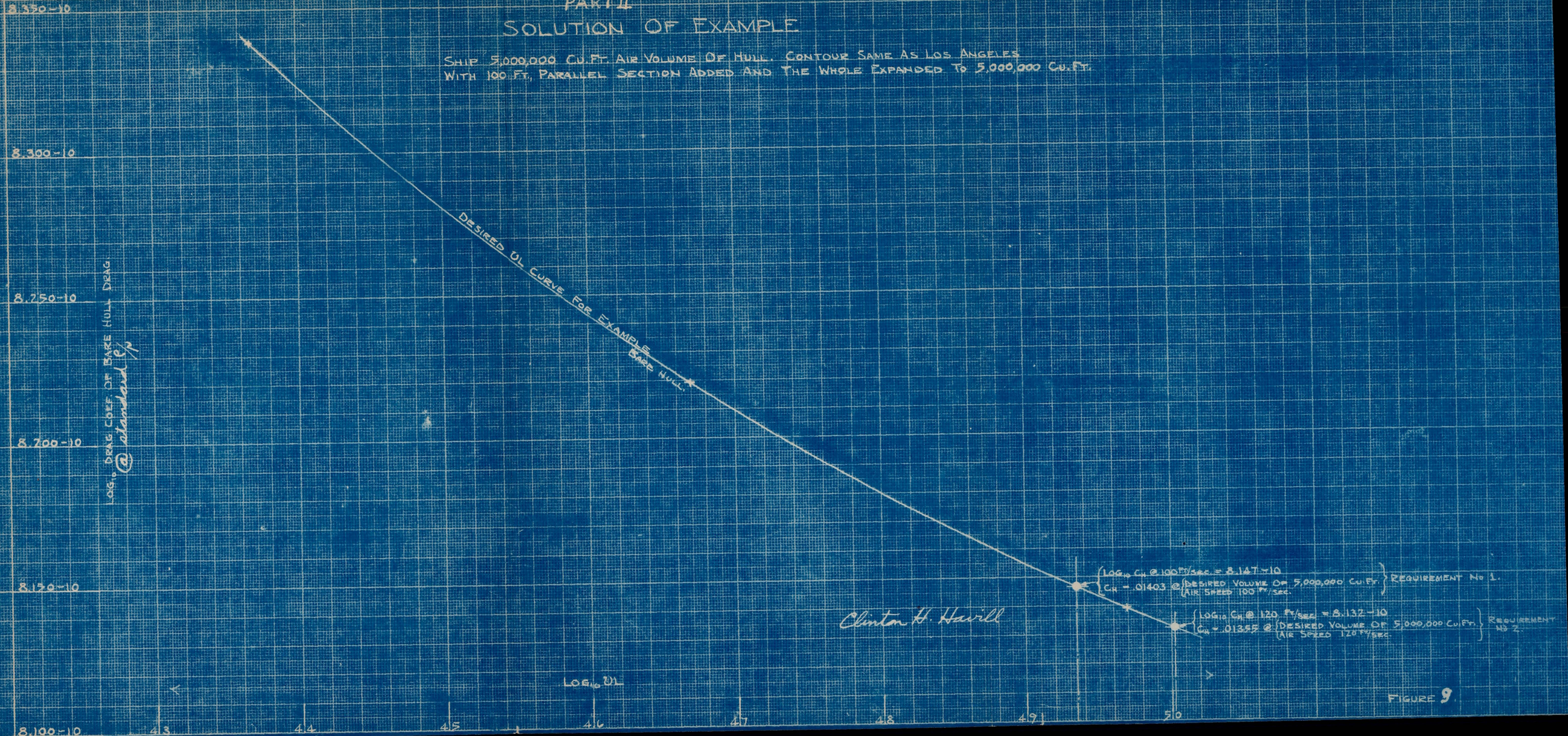

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FIGURE 9.

PART II

PRELIMINARY PLOT Nº 4.

DRAG COEF. OF BARE HULL-VS-(ECCENTRICITY OF NOSE ELLIPSE)(PRISMATIC COEF)(FINENESS RATIO)

THIS PLOT TO INDICATE RELATION BETWEEN DRAG COEF., DIAMETER EFFECT, WITH VOLUME, WITH VELOCITY CONSTANT @ 100 FT/SEC.

(ECCENTRICITY OF NOSE ELLIPSE)(PRISMATIC COEF)(FINENESS RATIO) $= (\lambda)\left(\frac{Vol}{\frac{\pi D^2}{4} L}\right)\left(\frac{L}{D}\right) = (\lambda)\left(\frac{4\,Vol}{\pi D^3}\right)$

NOTE THIS QUANTITY IS INDEPENDENT OF LENGTH EXCEPT AS IT AFFECTS VOLUME.

NOTE THIS QUANTITY HAS THE MAXIMUM EFFECT OF DIAMETER, AS DIAMETER ENTERS AS THE THIRD POWER.

NOTE THIS QUANTITY APPEARS TO AFFECT THAT PART OF THE DRAG COEF DUE TO PRESSURE DIFFERENCE.

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FIGURE 4.

PRELIMINARY PLOT NO 3.

DRAG OF BARE AIRSHIP HULL
- VS -
LOG$_{10}$ VL

WHERE:–

L = GEOMETRIC LENGTH = $\sqrt[4]{(\text{VIRTUAL VOLUME})(\text{LENGTH})}$ = FT. = $\sqrt[4]{(\text{AIR VOL OF HULL} + \frac{\pi r^3}{5})(\text{LENGTH})}$

V = AIR SPEED (FT/SEC), r = MAX RADIUS (FT), VOLUMES (CU. FT.), LENGTH (FT.).

MEAN CURVE OF PRELIMINARY PLOTS 1 & 2.

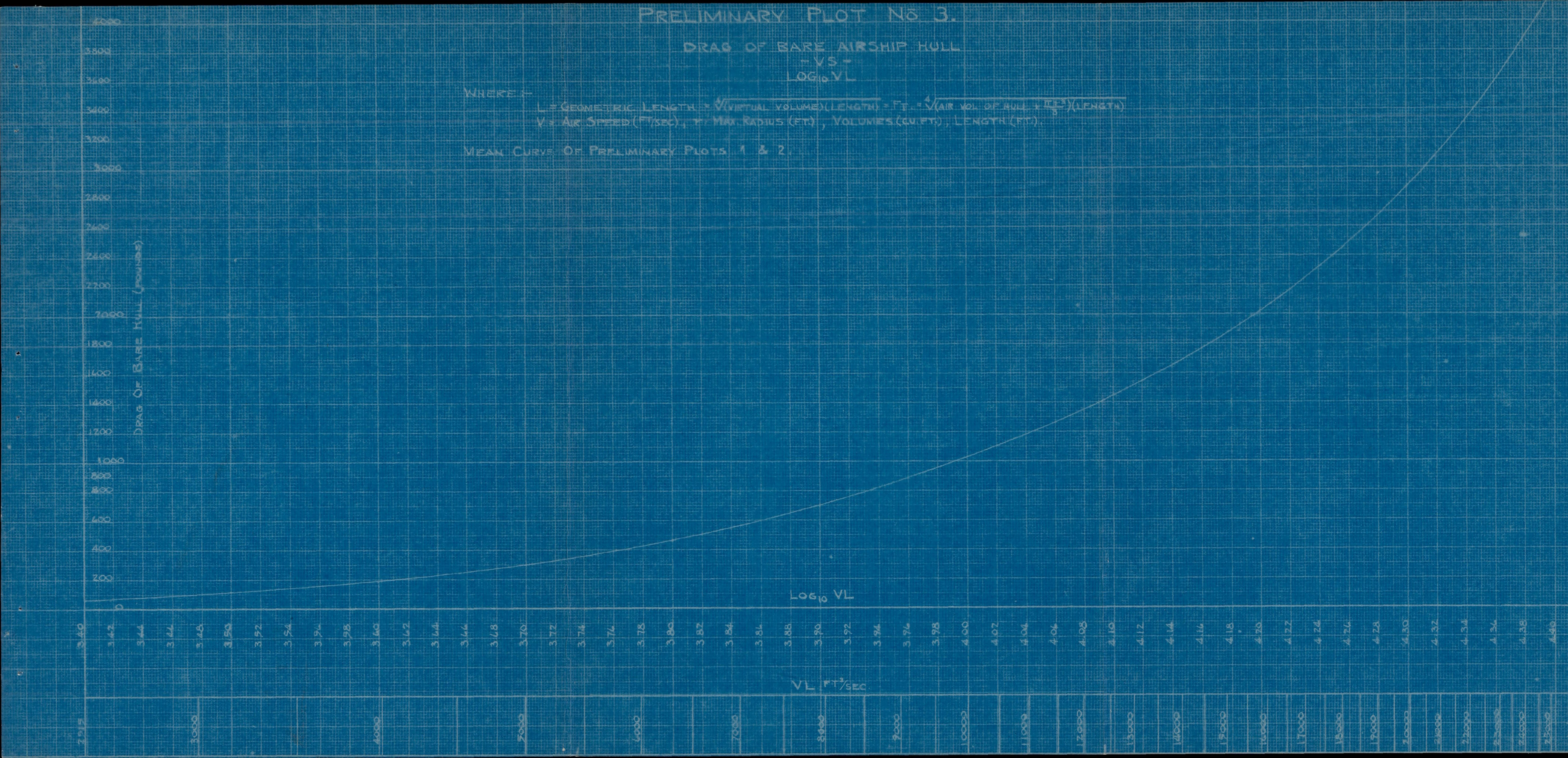

Fig. 3

PRELIMINARY PLOT No 2

DRAG OF BARE AIRSHIP HULL
VS
LOG_{10} VL

WHERE :-

L = GEOMETRIC LENGTH = $\sqrt[4]{(\text{VIRTUAL VOLUME})(\text{LENGTH}}$ = FT. = $\sqrt[4]{(\text{AIR VOL. OF HULL} + \frac{\pi r^3}{3})(\text{LENGTH})}$

V = AIR SPEED (FT/SEC), r = MAX. RADIUS (FT.), VOLUMES (CU.FT.), LENGTH (FT).

BARE HULL DRAG CALCULATED BY PERCENTAGE METHOD.
ESTIMATE OF % BASED ON EXISTING WIND TUNNEL DATA.

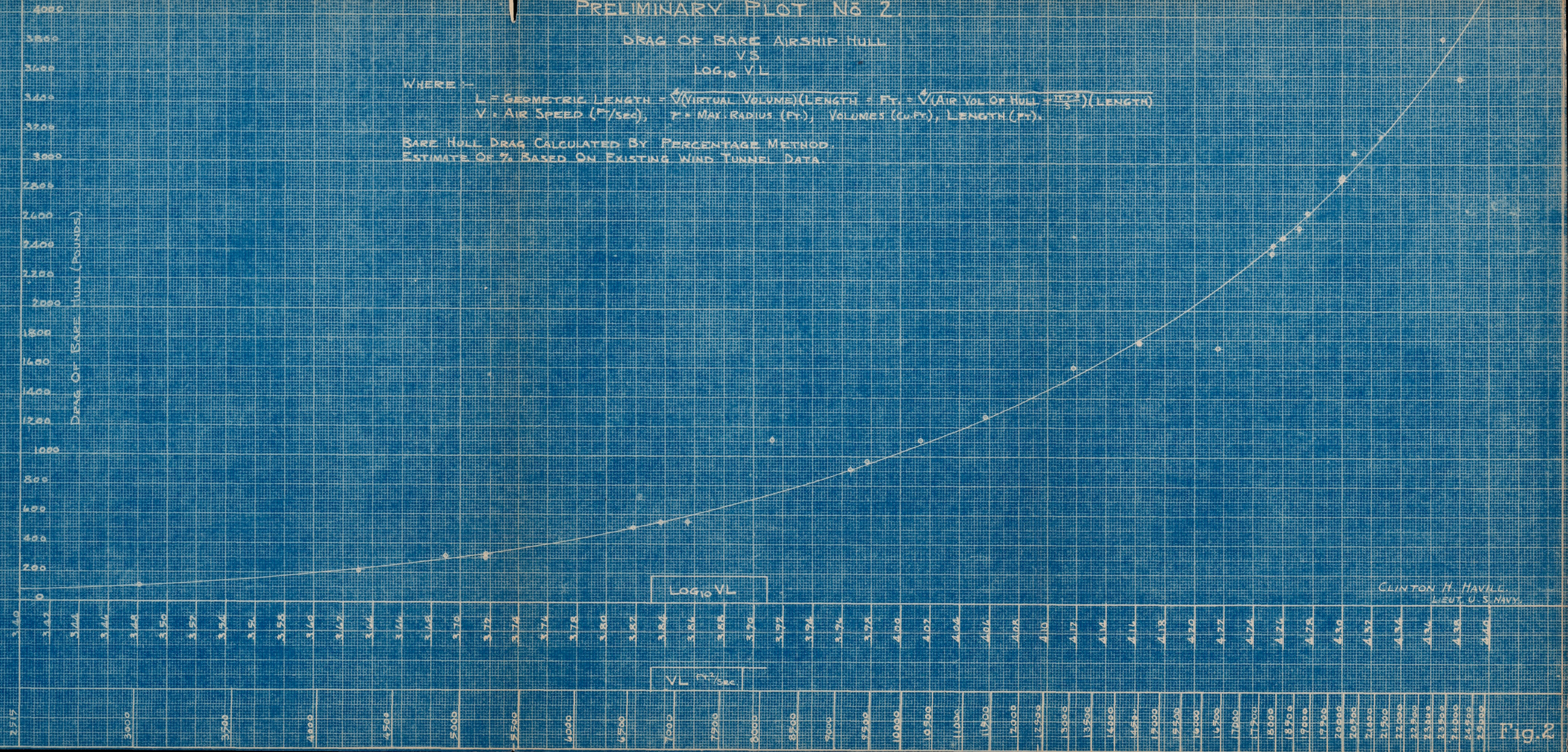

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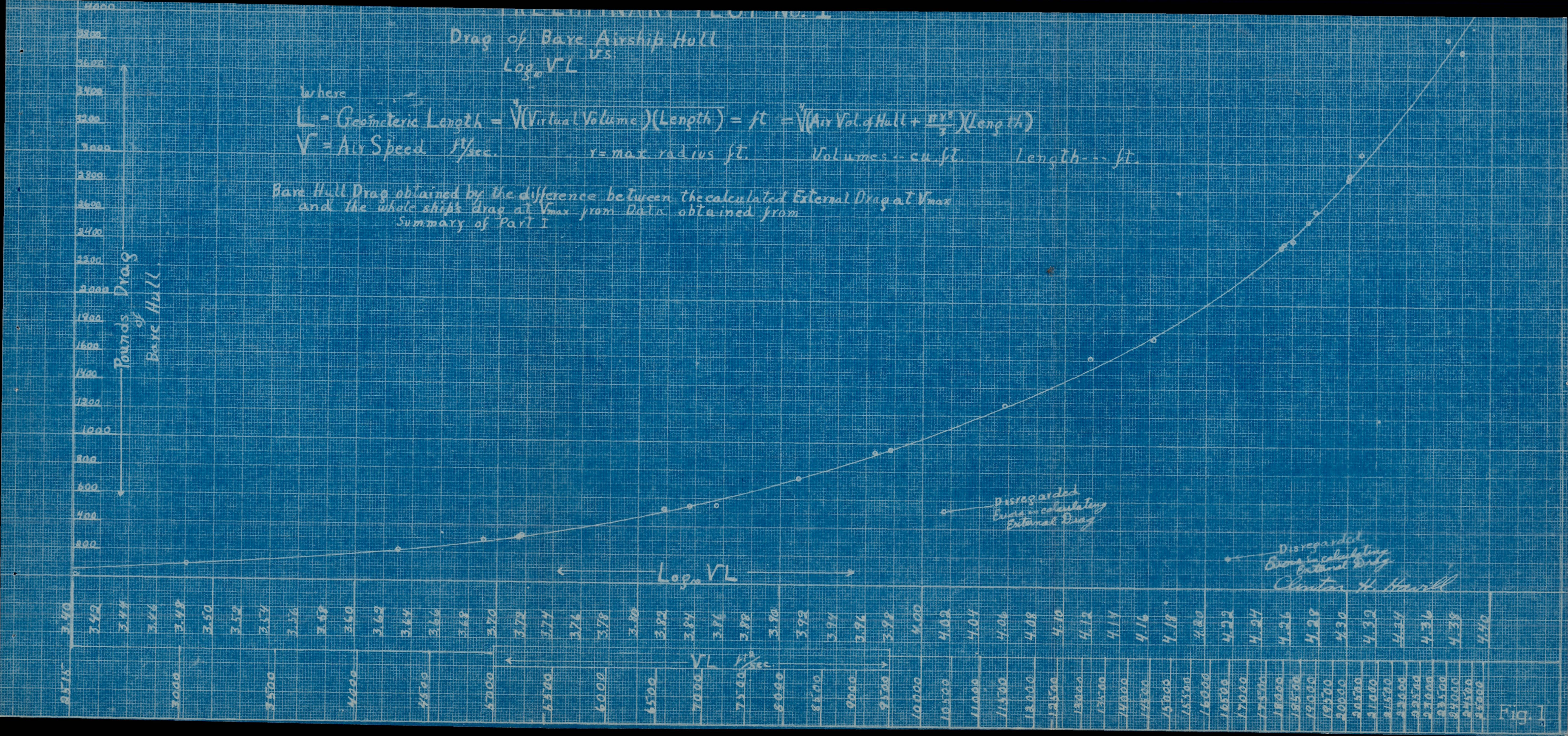
Fig. 2



Drag of Bare Airship Hull
vs.
$Log_{10} VL$

where

L = Geometeric Length = $\sqrt[4]{(\text{Virtual Volume})(\text{Length})}$ = ft = $\sqrt[4]{(\text{Air Vol. of Hull} + \frac{\pi r^3}{3})(\text{Length})}$

V = Air Speed ft/sec. r = max radius ft. Volumes -- cu. ft. Length -- ft.

Bare Hull Drag obtained by the difference between the calculated External Drag at V_{max} and the whole ship's drag at V_{max} from Data obtained from Summary of Part I

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Fig. 1

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	FIGURE 7.
	"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	FIGURE 8.
	"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	.01294	
	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	

NOTES.

THE SCALES ON FIGURES 7 & 8 WERE PLOTTED WITH $\log_{10}(Y+Z)$ 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.

MODEL ITEM	PRISMATIC COEFF. (CYL. COEF)	FINENESS RATIO	(R)(CYL COEF)(FIN. RATIO) $(R)\left(\frac{4\,VOL}{\pi D^2 L}\right)\left(\frac{L}{D}\right) =$ "Y"	LENGTH / GEOM. LGTH. $\frac{L}{L_g}$	$\left(\frac{L}{L_g}\right)\times\left(\frac{L}{D}\right) = \frac{L^2}{L_g D} =$ "Z"	C_H @ 100 Ft/sec .3 Cu. Ft. Vol.	"Y" + "Z"	"Y" (As Before)	C_{HY} @ 100,000 Cu. Ft. From Fig 4.	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" (As Before)	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.	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.
COL. NO.	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77
1	.6175	5.060	3.01206	2.661	13.465	.0301	16.468	3.01206	.0175	.0134	.0125	.052711	.040362	.037652	13.465	.0191	.0149	.0125	.25701	.20049	.16820	.30972	.24085	.20585	16.468	.01881	.01459	.01247
2	.6562	4.620	2.82549	2.496	11.531	.0281	14.356	2.82549	.0176	.0135	.0125	.049728	.038144	.035319	11.531	.0184	.0145	.0118	.21217	.16720	.13607	.26189	.20534	.17139	14.356	.01824	.01430	.01193
3	.6621	4.870	3.09220	2.566	12.496	.0290	15.588	3.09220	.0174	.0133	.0124	.053804	.041126	.038343	12.496	.0188	.0147	.0122	.23492	.18369	.15245	.28872	.22482	.19079	15.588	.01878	.01442	.01223
4	.5891	4.820	2.74860	2.624	12.647	.0284	15.396	2.74860	.0177	.0136	.0127	.048650	.037381	.034907	12.647	.0189	.0148	.0123	.23907	.18720	.15558	.28772	.22458	.19049	15.396	.01868	.01448	.01238
5	.5679	6.140	3.40321	2.998	18.408	.0335	21.811	3.40321	.0171	.0130	.0121	.058195	.044242	.041179	18.408	.0206	.0156	.0129	.37920	.28716	.23746	.43739	.33140	.27864	21.811	.02019	.01519	.01278
6	.5677	4.990	2.71950	2.697	13.458	.0298	16.177	2.71950	.0179	.0137	.0128	.048679	.037257	.034809	13.458	.0192	.0149	.0124	.25839	.20052	.16688	.30707	.23778	.20169	16.177	.01880	.01458	.01245
7	.6097	4.990	2.94106	2.650	13.224	.0290	16.165	2.94106	.0173	.0135	.0128	.050880	.039704	.037645	13.224	.0191	.0148	.0123	.25258	.19572	.16265	.30346	.23542	.20029	16.165	.01874	.01458	.01236
8	.6003	3.410	1.92010	2.187	7.457	.0512	9.377	1.92010	.0210	.0171	.0154	.040322	.032834	.029569	7.457	.0331	.0280	.0227	.24683	.20879	.16927	.28715	.24162	.19884	9.377	.03620	.02600	.02120
9	.6749	4.850	3.05070	2.549	12.362	.0271	15.413	3.05070	.0174	.0133	.0124	.053082	.040574	.037829	12.362	.0187	.0147	.0121	.23117	.18172	.14958	.28425	.22229	.18741	15.413	.01842	.01442	.01215
10	.6909	5.100	3.28399	2.601	13.262	.0273	16.548	3.28399	.0172	.0131	.0122	.056485	.043020	.040065	13.262	.0192	.0148	.0124	.25468	.19632	.16449	.31116	.23934	.20456	16.548	.01880	.01446	.01236
11	.7184	5.570	3.72939	2.702	15.050	.02741	18.779	3.72939	.0172	.0130	.0121	.064146	.048482	.045126	15.050	.0197	.0152	.0127	.29648	.22876	.19135	.36063	.27724	.23648	18.779	.01939	.01478	.01259
12	.7611	6.600	4.68171	2.898	19.127	.02819	23.809	4.68171	.0189	.0150	.0131	.088484	.070226	.061330	19.127	.0208	.0157	.0129	.39784	.30029	.24674	.48632	.37052	.30807	23.809	.02042	.01542	.01288
13	.7925	7.590	5.60605	3.082	23.392	.03026	28.998	5.60605	.0196	.0163	.0129	.109878	.091379	.072318	23.392	.0214	.0162	.01295	.50059	.37895	.30293	.61047	.47033	.37525	28.998	.02120	.01622	.01294
14	.8167	8.590	6.53999	3.258	27.986	.03018	34.346	6.53999	.0209	.0166	.0134	.136685	.108564	.087636	27.986	.0220	.0165	.0130	.61569	.46177	.36382	.75238	.57033	.45146	34.346	.02190	.01661	.01340
15	.8358	9.600	7.47811	3.425	32,880	.0314	40.358	7.47811	.0224	.0162	.0145	.167509	.121145	.108432	32.880	.0227	.0168	.0132	.74638	.55238	.43402	.91389	.67353	.54245	40.358	.02263	.01668	.01344
16	.6896	8.186	5.53374	3.324	27.210	.03068	32.744	5.53374	.0196	.0164	.0129	.108461	.090753	.071385	27.210	.0218	.0164	.0130	.59318	.44624	.35373	.70164	.53699	.42512	32.744	.02164	.01647	.01303
17	.7009	8.604	5.94614	3.391	29.176	.03096	35.122	5.94614	.0200	.0166	.0131	.118922	.098706	.077894	29.176	.0221	.0166	.01305	.64479	.48432	.38074	.76371	.58303	.45863	35.122	.02201	.01666	.01317

MODEL ITEM	(MODEL) C_H @ 100 Ft/sec & .3 Cu. Ft. Vol	$\text{Log}_{10}(Y+Z)$	REMARKS
COL. NO.	78	79	
1	.0301	1.21667	ITEMS 1 TO 8 INCLUSIVE ARE MODELS OF HULLS WITH CONTINUOUS CURVATURE CONTOURS. DATA HEREUNDER ARE USED FOR CALIBRATION OF SCALES FROM MODEL TO FULL SIZE IN FIGURE 7.
2	.0281	1.15703	
3	.0290	1.19279	
4	.0285	1.18735	
5	.0335	1.33868	
6	.0298	1.20890	
7	.0295	1.20857	
8	.0512	.97206	
9	.0271	1.18780	ITEMS 9 TO 17 INCLUSIVE ARE MODELS OF HULLS WITH PARALLEL SECTION CONTOURS. DATA HEREUNDER ARE USED FOR CALIBRATION OF SCALES FROM MODEL TO FULL SIZE IN FIGURE 8.
10	.0274	1,21880	
11	.0282	1.27370	
12	.0294	1.37676	
13	.0303	1.46225	
14	.0309	1.53590	
15	.0314	1.60595	
16	.0307	1.51508	
17	.0309	1.54555	

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"	$\text{Log}_{10} L_g$ (OF ACT. SHIP)	$\text{Log}_{10} L$ (OF ACT. SHIP)	$\text{Log}_{10}\left(\frac{L}{L_g}\right)$	$\frac{L}{L_g}$	$\frac{L}{D}$	"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.
CONTINUOUS CURVATURE	BODENSEE	4.04	2.13711	2.63043	.49332	3.1140	6.70	20.864	24.904	.02070	.01522	.01280
	LOS ANGELES	4.61	2.31877	2.81842	.49965	3.1598	7.25	29.086	33.696	.02480	.01610	.01300
PARALLEL SECTION BUILDER'S NUMBERS.	LZ-1.	7.20	2.06034	2.63144	.57110	3.7247	10.21	38.029	45.229	.02320	.01673	.01362
	LZ-4 & 5.	9.21	2.10360	2.64933	.54570	3.5132	10.50	36.888	46.398	.02420	.01699	.01392
	LZ-7 & 8.	9.76	2.13994	2.68664	.54670	3.5212	10.60	37.325	47.085	.02490	.01720	.01400
	LZ-10 & 12.	8.14	2.11786	2.66276	.54490	3.5065	10.00	35.065	43.205	.02310	.01670	.01356
	LZ-15 & 16.	8.12	2.13719	2.66839	.53120	3.3979	9.55	32.450	40.570	.02290	.01700	.01380
	LZ-22 & 23.	8.45	2.15339	2.70927	.55588	3.5967	10.48	37.693	46.143	.02410	.01690	.01380
	LZ-24 To 35.	9.21	2.16407	2.71517	.55110	3.5571	10.61	37.741	46.951	.02430	.01720	.01405
	LZ-36.	7.55	2.16999	2.72428	.55429	3.5835	10.08	36.122	43.672	.02320	.01680	.01360
	LZ-42 To 50.	6.36	2.20659	2.72916	.52257	3.3310	8.68	28.913	35.273			
	LZ-59 To 61, 64 To 71 EXCEPT 60 & 70.	7.05	2.22803	2.76790	.53987	3.4665	9.50	32.932	39.982	.02262	.01667	.01342
	LZ-72 To 90 EXCEPT 73 - 77 & 81.	5.55	2.28857	2.80956	.52099	3.3189	8.24	27.348	32.898	.02164	.01648	.01304
	LZ-91 To 94.	5.52	2.28813	2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
	LZ-95 To 99.	5.52	2.28813	2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
	LZ-100 & 101.	5.53	2.28813	2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
	LZ-102.	5.89	2.32599	2.87216	.54617	3.5170	9.52	33.482	39.372	.02268	.01668	.01349
	LZ-104	5.89	2.32599	2.87216	.54617	3.5170	9.52	33.482	39.372	.02268	.01668	.01349
	LZ-106 To 111.	5.53	2.28813	2.80956	.52144	3.3225	8.24	27.377	32.907	.02165	.01648	.01304
	LZ-112 To 114.	6.38	2.31589	2.87216	.55627	3.5998	9.52	34.270	40.650	.02270	.01670	.01350

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

Model Item	Name of Ship – Model –	Model Length L (Ft)	Model Max. Diam. D (Ft)	Model Volume V (Cu. Ft)	Fineness Ratio $\frac{L}{D}$	Distance Max. Ord From Nose (Ft.)	Distance Max. Ord From Nose % Lgth.	Prismatic Coef. $\frac{V}{L(\frac{\pi D^2}{4})}$	Volumetric Drag Coef's (Model Tests) C_H			Model Drag @ Standard Density-.00237 Slugs/Cu.Ft. (Lbs.)		
									@ 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
Col. No.		1	2	3	4	5	6	7	8	9	10	11	12	13
1	U. S. Navy "B"	3.527	.6967	.8304	5.060	1.333	37.80	.6175	.0336	.0308	.0296	.0303	.1111	.2404
2	" " " "C"	2.949	.6417	.6259	4.620	.885	30.00	.6562	.0318	.0288	.0272	.0237	.0859	.1828
3	" " " "F"	3.125	.6417	.6690	4.870	1.133	36.25	.6621	.0336	.0292	.0284	.0262	.0911	.1996
4	E. P.	3.092	.6417	.5890	4.820	1.283	41.50	.5891	.0332	.0294	.0276	.0238	.0842	.1779
5	Parseval "P-1"	3.942	.6417	.7240	6.140	1.527	38.75	.5679	.0370	.0348	.0330	.0305	.1145	.2440
6	" "P-2"	3.208	.6417	.5891	4.990	1.161	38.90	.5677	.0362	.0340	.0328	.0260	.0975	.2117
7	" "P-3"	3.205	.6417	.6331	4.990	1.147	47.33	.6095	.0358	.0338	.0322	.0269	.1017	.2180
8	'AA'	1.992	.5833	.3196	3.410	.847	42.50	.6003	.0410	.0510	.0554	.0196	.0973	.2380
9	"C" Ship With 1/4 Dia. Parallel Sect.	3.109	.6417	.6777	4.850	.885	28.46	.6749	.0308	.0280	.0264	.0243	.0881	.1869
10	" " " 1/2 " " "	3.270	.6417	.7297	5.100	.885	27.06	.6909	.0306	.0282	.0270	.0253	.0936	.2013
11	" " " 1 " " "	3.590	.6417	.8330	5.570	.885	24.50	.7184	.0328	.0292	.0272	.0296	.1055	.2210
12	" " " 2 " " "	4.232	.6417	1.0404	6.600	.885	20.91	.7611	.0350	.0300	.0272	.0366	.1253	.2572
13	" " " 3 " " "	4.872	.6417	1.2471	7.590	.885	18.16	.7925	.0346	.0312	.0296	.0406	.1465	.3147
14	" " " 4 " " "	5.515	.6417	1.4548	8.590	.885	16.04	.8167	.0350	.0314	.0292	.0458	.1641	.3446
15	" " " 5 " " "	6.158	.6417	1.6625	9.600	.885	14.37	.8358	.0328	.0308	.0296	.0470	.1765	.3814
16	Short Shenandoah (Ref. N.A.C.A. # 215)	5.372	.6562	1.2335	8.186	2.015	37.50	.6856	.03355	.03122	.03004	.0393	.1454	.3140
17	Long " (" " ")	5.646	.6562	1.3250	8.604	2.015	35.71	.7009	.03442	.03077	.02917	.0423	.1514	.3229

Model Item	Model Radius $r = \frac{\text{Max. Dia}}{2}$ (Ft)	Model r^3 (Ft³)	Model Additional Volume $\frac{\pi r^3}{3}$ (Cu. Ft.)	Model Volume V Cu. Ft.	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 L)	Model Log₁₀ $\sqrt[4]{V_M L}$ = Log₁₀ Lg.	Model (U = 29.334 Ft/sec) Log₁₀ U
Col. No.	14	15	16	17	18	19	20	21	22	23	24
1	.34835	.042273	.044268	.8304	.87467	3.527	9.94184-10	.54741	.48925	.12231	1.46737
2	.32085	.033029	.034588	.6259	.66049	2.949	9.81986-10	.46967	.28953	.07238	"
3	.32085	.033029	.034588	.6690	.70359	3.125	9.84732-10	.49485	.34217	.08554	"
4	.32085	.033029	.034588	.5890	.62359	3.092	9.79490-10	.49024	.28514	.07128	"
5	.32085	.033029	.034588	.7240	.75859	3.942	9.88000-10	.59572	.47572	.11893	"
6	.32085	.033029	.034588	.5891	.62369	3.208	9.79497-10	.50623	.30120	.07530	"
7	.32085	.033029	.034588	.6331	.66769	3.205	9.82457-10	.50583	.33040	.08260	"
8	.29165	.024809	.025980	.3196	.34558	1.992	9.53855-10	.29929	9.83784-10	9.95946-10	"
9	.32085	.033029	.034588	.6777	.71224	3.109	9.85265-10	.49262	.34527	.08632	"
10	.32085	.033029	.034588	.7297	.76429	3.270	9.88325-10	.51455	.39780	.09945	"
11	.32085	.033029	.034588	.8330	.86759	3.590	9.93832-10	.55509	.49341	.12335	"
12	.32085	.033029	.034588	1.0404	1.07499	4.232	.03141	.62655	.65796	.16449	"
13	.32085	.033029	.034588	1.2471	1.28169	4.872	.10779	.68771	.79550	.19888	"
14	.32085	.033029	.034588	1.4548	1.48939	5.515	.17301	.74155	.91456	.22864	"
15	.32085	.033029	.034588	1.6625	1.69709	6.158	.22972	.78944	1.01916	.25479	"
16	.32810	.035321	.036988	1.2335	1.27049	5.372	.10398	.73014	.83412	.20853	"
17	.32810	.035321	.036988	1.3250	1.36199	5.646	.13418	.75174	.88592	.22148	"

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

Model Item	Model Log₁₀ ULg @ 29.334 Ft/Sec.	Model (U = 58.667 Ft/sec) Log₁₀ U	Model Log₁₀ ULg @ 58.667 Ft/sec	Model (U = 88 Ft/sec) Log₁₀ U	Model Log₁₀ ULg @ 88 Ft/Sec.	Figure 6					
						Log₁₀ ULg @ 29.334 Ft/sec	Drag @ 29.334 Ft/sec (Lbs)	Log₁₀ ULg @ 58.667 Ft/sec	Drag @ 58.667 Ft./Sec. (Lbs)	Log₁₀ ULg @ 88 Ft/Sec.	Drag @ 88 Ft/sec (Lbs)
Col. No.	25	26	27	28	29	30	31	32	33	34	35
1	1.58968	1.76840	1.89071	1.94448	2.06679	1.58968	.0303	1.89071	.1111	2.06679	.2404
2	1.53975	"	1.84078	"	2.01686	1.53975	.0237	1.84078	.0859	2.01686	.1828
3	1.55291	"	1.85394	"	2.03002	1.55291	.0262	1.85394	.0911	2.03002	.1996
4	1.53865	"	1.83968	"	2.01576	1.53865	.0238	1.83968	.0842	2.01576	.1779
5	1.58630	"	1.88733	"	2.06341	1.58630	.0305	1.88733	.1145	2.06341	.2440
6	1.54267	"	1.84370	"	2.01978	1.54267	.0260	1.84370	.0975	2.01978	.2117
7	1.54997	"	1.85100	"	2.02709	1.54997	.0269	1.85100	.1017	2.02709	.2180
8	1.42683	"	1.72786	"	1.90394	1.42683	.0196	1.72786	.0973	1.90394	.2380
9	1.55369	"	1.85472	"	2.03084	1.55369	.0243	1.85472	.0881	2.03084	.1869
10	1.56682	"	1.86785	"	2.04393	1.56682	.0253	1.86785	.0936	2.04393	.2013
11	1.59072	"	1.89175	"	2.06783	1.59072	.0296	1.89175	.1055	2.06783	.2210
12	1.63186	"	1.93289	"	2.10897	1.63186	.0366	1.93289	.1253	2.10897	.2572
13	1.66625	"	1.96728	"	2.14328	1.66625	.0406	1.96728	.1465	2.14328	.3147
14	1.69601	"	1.99704	"	2.17312	1.69601	.0458	1.99704	.1641	2.17312	.3446
15	1.72216	"	2.03319	"	2.19927	1.72216	.0470	2.03319	.1765	2.19927	.3814
16	1.67590	"	1.97693	"	2.15301	1.67590	.0393	1.97693	.1454	1.97693	.3140
17	1.68885	"	1.98988	"	2.16596	1.68885	.0423	1.98988	.1514	1.98988	.3229

Model Item	To Reduce Or Expand All Models To The Same Volume.	$\frac{1}{3}$ Log₁₀ .3	Log₁₀ Lg	$\frac{1}{3}$ Log₁₀ (Vol. Mod.)	Log₁₀ Lg @ .3 Cu. Ft. Vol	Model Log₁₀ ULg @ .3 Cu. Ft. Vol. and 100 Ft/sec. (Log₁₀ Lg + 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
Col. No.		36	37	38	39	40	41	42
1	$\frac{\text{Vol. X}}{\text{Vol. Model}} = \left(\frac{\text{Lg At Vol X}}{\text{Lg Of Model}}\right)^3$ $(\text{Vol. X})(\text{Lg Of Model})^3 = (\text{Vol. Of Model})(\text{Lg At Vol X})^3$ $(\text{Lg At Vol X})^3 = \frac{(\text{Vol X})(\text{Lg Of Model})^3}{\text{Vol. Of Model}}$, Now Let X = .3 Cu. Ft. 3 Log Lg At Vol X = Log .3 + 3 Log Lg Model − Log Vol. Model. Log Lg At Vol. X = $\frac{1}{3}$ Log .3 + Log Lg Model − $\frac{1}{3}$ Log Vol. Model	9.82571-10	.12231	9.97309-10	9.79493-10	1.79493	.1598	.0301
2		"	.07238	9.93217-10	9.96592-10	1.96592	.1492	.0281
3		"	.08554	9.94181-10	9.96944-10	1.96944	.1540	.0290
4		"	.07128	9.92337-10	9.97362-10	1.97362	.1508	.0285
5		"	.11893	9.95325-10	9.99139-10	1.99139	.1779	.0335
6		"	.07530	9.92337-10	9.97764-10	1.97764	.1583	.0298
7		"	.08260	9.93382-10	9.97449-10	1.97449	.1540	.0290
8		"	9.95946-10	9.93487-10	9.95030-10	1.95030	.2719	.0512
9		"	.08632	9.94368-10	9.96835-10	1.96835	.1439	.0271
10		"	.09945	9.95438-10	9.97078-10	1.97078	.1450	.0273
11		"	.12335	9.97355-10	9.97551-10	1.97551	.1556	.02741
12		"	.16449	.00573	9.98447-10	1.98447	.1597	.02819
13		"	.19888	.03197	9.99262-10	1.99262	.1607	.03026
14		"	.22864	.05424	.00011	2.00011	.1640	.03088
15		"	.25479	.07359	.00691	2.00691	.1667	.0314
16		"	.20853	.03038	.00386	2.00386	.1629	.03068
17		"	.22148	.04074	.00645	2.00645	.1644	.03096

Model Item	Calculation Of Eccentricity Of Nose Ellipse. (α)						
	Dist. From Nose To Max. Ordinate X (Ft)	X^2	$\frac{\text{Max. Dia}}{2}$ = Max. Rad. = r (Ft.)	r^2	$X^2 - r^2$	$\sqrt[2]{X^2 - r^2}$	$\alpha = \frac{\sqrt[2]{x^2 - r^2}}{x}$
Col. No.	43	44	45	46	47	48	49
1	1.333	1.7729	.3483	.12131	1.65159	1.2853	.964
2	.885	.7832	.3208	.10291	.68029	.8248	.932
3	1.133	1.2837	.3208	.10291	1.18079	1.0867	.959
4	1.283	1.6461	.3208	.10291	1.54319	1.2422	.968
5	1.527	2.3317	.3208	.10291	2.22879	1.4909	.976
6	1.161	1.3479	.3208	.10291	1.24499	1.1155	.960
7	1.147	1.3156	.3208	.10291	1.21269	1.1101	.967
8	.847	.7174	.2916	.08503	.63237	.7953	.938
9	.885	.7832	.3208	.10291	.68029	.8248	.932
10	.885	.7832	.3208	.10291	.68029	.8248	.932
11	.885	.7832	.3208	.10291	.68029	.8248	.932
12	.885	.7832	.3208	.10291	.68029	.8248	.932
13	.885	.7832	.3208	.10291	.68029	.8248	.932
14	.885	.7832	.3208	.10291	.68029	.8248	.732
15	.885	.7832	.3208	.10291	.68029	.8248	.932
16	2.015	4.0602	.3281	.10765	3.95255	.9831	.986
17	2.015	4.0602	.3281	.10765	3.95255	.9831	.986

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

PART II

A SHAPE COMPARISON OF HULL DRAG COEF @ 100 FT/SEC

PRELIMINARY PLOT NO. 5.

ITEM	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×$\frac{L}{D}$ for 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 Lg Log $\sqrt[4]{V_M}$ Lgth	Log. Length	Log $\left(\frac{\text{Length}}{\sqrt[4]{V_M}\text{ Lgth}}\right)$ Log $\frac{L}{Lg}$	$\frac{L}{Lg}$	Fineness Ratio $\frac{L}{D}$	$\frac{L^2}{LgD}$	From previous comparison ships grouped according to "Z"	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.	Mean value of $\frac{L^2}{LgD}$ 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	386		3.63	.01705	.01293	.01210	1.89259	2.29226	.39967	2.510	4.62	11.59					
3	3.40						1.89927	2.29667	.39740	2.509	4.72	11.84		.01851	.01439	.01195	11.71
4	3.10						1.80218	2.20952	.40734	2.555	4.84	12.37					
5	3.10		3.10	.01740	.01329	.01240	1.80218	2.20952	.40734	2.555	4.84	12.37		.01880	.01469	.01229	12.37
6	4.04						2.13711	2.63043	.49332	3.113	6.70	20.86					
7	4.61		4.32	.01992	.01378	.01297	2.31877	2.81842	.49965	3.160	7.25	22.91		.02115	.01600	.01284	21.89
8	7.20		7.27	.02232	.01635	.01424	2.06034	2.63144	.57110	3.724	10.21	38.02					
9	9.21						2.10360	2.64933	.54573	3.513	10.50	36.89		.02319	.01676	.01501	37.56
10	9.76		9.39	.02341	.01641	.01562	2.13994	2.68664	.54670	3.522	10.60	37.33					
11	8.14						2.11786	2.66276	.54490	3.507	10.00	35.07		.02317	.01670	.01559	35.59
12	8.12		8.24	.02314	.01623	.01571	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					
17	7.05						2.22803	2.76790	.53987	3.466	9.50	32.93		.02233	.01660	.01526	30.92
18	5.55						2.28857	2.80956	.52099	3.319	8.24	27.35					
19	5.52						2.28813	2.80956	.52143	3.322	8.24	27.37					
20	5.52		5.53	.01964	.01631	.01314	2.28813	2.80956	.52143	3.322	8.24	27.37		.02194	.01650	.01300	27.37
21	5.53						2.28813	2.80956	.52143	3.322	8.24	27.37					
22	5.89						2.32599	2.87216	.54617	3.517	9.52	33.48					
23	5.89		5.89	.02019	.01654	.01316	2.32599	2.87216	.54617	3.517	9.52	33.48		.02279	.01670	.01310	33.48
24	5.53						2.28813	2.80956	.52143	3.322	8.24	27.37					
25	6.38		6.37	.02012	.01662	.01324	2.31589	2.87216	.55627	3.600	9.52	34.27		.02272	.01680	.01300	34.27
26	5.84						2.30105	2.83264	.53199	3.401	8.64	29.38		.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.

PART II

								COMPARISON OF BARE HULLS AT VARYING AIR VOLUMES AND A VELOCITY OF 100 FEET PER SECOND.																				
								100,000 CU. FT.			200,000 CU. FT.			400,000 CU. FT.			800,000 CU. FT.			1,600,000 CU. FT.			6,400,000 CU. FT.					
ITEM	AIR VOLUME OF HULL FROM PART I CU. FT.	LOG$_{10}$ (AIR VOL OF HULL)	LOG$_{10}\sqrt[3]{VOL}$	LOG$_{10}$(Lg) AS TABULATED BEFORE FOR ACTUAL SIZE	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 + 1.66667 − LOG $\sqrt[3]{VOL}$)	LOG$_{10}$ ULg @ 100 FT/SEC AND 100,000 CU. FT. VOLUME. LOG$_{10}$ Lg @ 100,000 + 2	D_H FROM PLOT 3 BARE HULL DRAG @ 100 FT/SEC AND 100,000 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 $C_H = .00003917 D_H$	LOG$_{10}$ ULg @ 100 FT/SEC AND 200,000 CU. FT. VOLUME. LOG Lg @ 100,000 + $\frac{1}{3}$ LOG 2 = LOG Lg_{100000} + .10034	D_H FROM PLOT 3 BARE HULL DRAG @ 100 FT/SEC AND 200,000 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 $C_H = .000024675 D_H$	LOG$_{10}$ ULg @ 100 FT/SEC AND 400,000 CU. FT. VOLUME LOG Lg @ 200,000 + $\frac{1}{3}$ LOG 2 = LOG Lg_{200000} + .10334	D_H @ 400,000 CU. FT. AIR VOLUME AND 100 FT/SEC. (LBS)	C_H $\rho = .00237$ $U = 100$ VOL = 400,000 $C_H = .0001555 D_H$	LOG$_{10}$ ULg @ 100 FT/SEC AND 800,000 CU. FT. AIR VOL. $Lg_{800000} = 2 Lg_{100000}$ LOG ULg_{100000} + LOG 2 = LOG ULg_{800000} (LOG 2 = .30103)	D_H FROM PLOT 3 BARE HULL DRAG @ 100 FT/SEC AND 800000 CU. FT. AIR VOL LBS.	C_H DRAG COEF OF BARE HULL DRAG $C_H = \frac{2D_H}{\rho U^2 (Vol)^{2/3}}$ $\rho = .00237$ $U = 100$ VOL = 800000 $C_H = .0000097925 D_H$	LOG ULg @ 100 FT/SEC AND 1,600,000 CU. FT. AIR VOL LOG Lg @ 800,000 + .10034	D_H @ 1,600,000 CU. FT. AIR VOLUME AND 100 FT/SEC (LBS)	C_H DRAG COEF OF BARE HULL DRAG $C_H = \frac{2D_H}{\rho U^2 (Vol)^{\frac{2}{3}}}$ $\rho = .00237$ $U = 100$ VOL = 1,600,000 $C_H = .0000061689 D_H$	LOG$_{10}$ ULg @ 100 FT/SEC. AND 6,400,000 CU. FT. AIR VOL. $Lg_{6,400,000} = 2 Lg_{800,000}$ LOG ULg_{800000} + LOG 2 = LOG ULg 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 $C_H = \frac{2D_H}{\rho U^2 (Vol)^{2/3}}$ $\rho = .00237$ $U = 100$ VOL = 6,400,000. $C_H = .000002448 D_H$	LOG ULg 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
1	84000	4.92428	1.64143	1.79207	1.66667	3.45874	1.81731	3.81731	490	.01919	3.91765	730	.01801	4.01799	1090	.01695	4.11834	1540	.01518	4.21868	2120	.01308	4.41937	5229	.01280	3.79207	420	.0185
2	180000	5.25527	1.75176	1.89259	"	3.55926	1.80750	3.80750	475	.01861	3.90784	710	.01752	4.00818	1060	.01648	4.10853	1480	.01449	4.20887	2060	.01271	4.40956	4902	.01200	3.89259	640	.0176
3	190000	5.27875	1.75958	1.89927	"	3.56594	1.80636	3.80636	470	.01841	3.90670	705	.01739	4.00704	1056	.01642	4.10739	1478	.01429	4.20773	2058	.01270	4.40842	4861	.01190	3.89927	660	.0175
4	95000	4.97772	1.65924	1.80218	"	3.46885	1.80961	3.80961	480	.01880	3.90995	715	.01764	4.01029	1080	.01679	4.11064	1500	.01469	4.21098	2080	.01283	4.41167	5024	.01229	3.80218	432	.0176
5	95000	4.97772	1.65924	1.80218	"	3.46885	1.80961	3.80961	480	.01880	3.90995	715	.01764	4.01029	1080	.01679	4.11064	1500	.01469	4.21098	2080	.01283	4.41167	5024	.01229	3.80218	432	.0176
6	797000	5.90146	1.96715	2.13711	"	3.80378	1.83663	3.83663	540	.02115	3.93697	805	.01986	4.03731	1188	.01847	4.13766	1630	.01596	4.23800	2290	.01413	4.43869	5955	.01359	4.13711	1650	.0163
7	2764461	6.44161	2.14720	2.31877	"	3.98544	1.83824	3.83824	540	.02115	3.93858	806	.01989	4.03892	1190	.01850	4.13927	1640	.01605	4.23961	2285	.01409	4.44030	4943	.01210	4.31877	3120	.0125
8	400000	5.60206	1.86735	2.06034	1.66667	3.72701	1.85966	3.85966	595	.02331	3.96000	896	.02211	4.06034	1265	.01967	4.16069	1758	.01718	4.26103	2495	.01539	4.46172	5392	.01320	4.06034	1275	.0199
9	572000	5.75740	1.91913	2.10360	"	3.77027	1.89114	3.85114	590	.02311	3.95148	880	.02171	4.05182	1230	.01913	4.15217	1710	.0167	4.25251	2422	.01594	4.45320	6209	.01520	4.10360	1460	.0179
10	734000	5.86574	1.95525	2.13994	"	3.80661	1.85136	3.85136	591	.02315	3.95170	882	.02176	4.05204	1240	.01928	4.15239	1710	.0167	4.25273	2422	.01594	4.45342	6291	.01540	4.13994	1640	.0171
11	631000	5.80003	1.93334	2.11788	"	3.78455	1.85121	3.85121	590	.02311	3.95154	880	.02171	4.05188	1238	.01925	4.15224	1710	.0167	4.25258	2422	.01594	4.45327	6250	.01530	4.11786	1530	.0164
12	744000	5.87157	1.95719	2.13719	"	3.80386	1.84667	3.84667	570	.02233	3.94701	830	.02048	4.04735	1228	.01894	4.14770	1680	.0164	4.24804	2384	.01571	4.44873	6209	.01520	4.13719	1630	.0168
13	787000	5.89597	1.96532	2.15339	"	3.82006	1.85474	3.85474	593	.02323	3.95508	885	.02184	4.05542	1245	.01936	4.15577	1718	.0168	4.25611	2428	.01498	4.45680	6454	.01460	4.15339	1700	.0169
14	858000	5.93349	1.97783	2.16407	"	3.83074	1.85291	3.85291	592	.02319	3.95325	883	.02179	4.05359	1241	.01929	4.15394	1714	.0167	4.25428	2425	.01496	4.45497	6617	.01619	4.16407	1750	.0164
15	884000	5.94645	1.98215	2.16999	"	3.83666	1.85451	3.85451	593	.02323	3.95485	885	.02184	4.05519	1245	.01936	4.15554	1718	.0168	4.25588	2425	.01498	4.45657	6495	.01589	4.16999	1775	.0163
16	1220000	6.08636	2.02879	2.20659	"	3.87326	1.84447	3.84447	568	.02225	3.94481	848	.02092	4.04515	1210	.01882	4.14550	1675	.0164	4.24584	2340	.01444	4.44653	6250	.01530	4.20659	1970	.0146
17	1363000	6.13450	2.04483	2.22803	"	3.89470	1.84987	3.84987	572	.02241	3.95021	852	.02102	4.05055	1212	.01885	4.15090	1700	.0166	4.23580	2410	.01487	4.45193	6168	.01509	4.22803	2110	.0145
18	2149000	6.33224	2.11075	2.28857	"	3.95524	1.84449	3.84449	560	.02194	3.94483	835	.02060	4.04517	1211	.01883	4.14552	1676	.0164	4.25124	2340	.01444	4.44655	5310	.01300	4.28857	2615	.0133
19	2140000	6.33041	2.11014	2.28813	"	3.95480	1.84466	3.84466	560	.02194	3.94500	835	.02060	4.04534	1213	.01886	4.14569	1680	.0165	4.24603	2380	.01468	4.44672	5310	.01300	4.28813	2615	.0133
20	2140000	6.33041	2.11014	2.28813	"	3.95480	1.84466	3.84466	560	.02194	3.94500	835	.02060	4.04534	1213	.01886	4.14569	1680	.0165	4.24603	2380	.01468	4.44672	5310	.01300	4.28813	2615	.0133
21	2141000	6.33062	2.11021	2.28813	"	3.95480	1.84459	3.84459	560	.02194	3.94493	835	.02060	4.04527	1213	.01886	4.14562	1678	.0165	4.24603	2378	.01467	4.44665	5310	.01300	4.28813	2615	.0133
22	2640000	6.42160	2.14053	2.32599	"	3.99266	1.85213	3.85213	582	.02279	3.95247	866	.02137	4.05281	1260	.01959	4.15316	1712	.0167	4.25350	2420	.01493	4.45419	5351	.01310	4.32599	3050	.0135
23	2640000	6.42160	2.14053	2.32599	"	3.99266	1.85213	3.85213	582	.02279	3.95247	866	.02137	4.05281	1260	.01959	4.15316	1712	.0167	4.25350	2420	.01493	4.45419	5351	.01310	4.32599	3050	.0135
24	2141000	6.33062	2.11021	2.28813	"	3.95480	1.84459	3.84459	560	.02194	3.94493	835	.02060	4.04527	1210	.01881	4.14562	1678	.0165	4.24596	2360	.01456	4.44665	5024	.01229	4.28813	2615	.0133
25	2400000	6.38021	2.12674	2.31589	"	3.98256	1.85582	3.85582	580	.02272	3.95616	865	.02134	4.05650	1260	.01959	4.15686	1720	.0168	4.25720	2425	.01496	4.45789	5310	.01360	4.31589	2905	.0137
26	2289861	6.35980	2.11993	2.30105	"	3.96772	1.84779	3.84779	570	.02233	3.94813	840	.02073	4.04847	1220	.01897	4.14882	1695	.0166	4.24916	2390	.01454	4.44985	5147	.01259	4.30105	2740	.0134
									D_H	C_H																		

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

PART II

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) *	Prelim. Plot # 2		Virtual Volume V_M From Part I Cu. Ft.	$Log_{10} V_M$.	Actual Length L_A From Part I Ft.	Log_{10} Length	$Log_{10} V_M L_A$	$Log_{10} \sqrt[4]{V_M L_A}$ = Log_{10} Geom. Length = $Log_{10} L_g$	U_{max} From Part I Ft. /Sec	$Log_{10} U_{max}$.	$Log_{10} U L_g$ @ U_{max}. Same As Used In Plots 1 & 2	Bare Hull Drag At U_{max}. From Plot # 3 Lbs	Drag Coef. Of Bare Hull At U_{max}. = $\frac{2 D_H}{\rho (Vol)^{\frac{2}{3}} U_{max}^2}$	Comparison Of Bare Hull Drag At 100 Ft/Sec.			Explanation
					Bare Hull Drag At U_{max} Lbs.	$Log_{10} UL$ At U_{max}.												$Log_{10} UL_g$ @ 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	
1	69.00	87.40	493.08	44	216.95	3.63092	90380	4.95607	163	2.21219	7.16826	1.79207	69.00	1.83885	3.63092	215	.0199	3.79207	420	.0185	Comparison Of Ships If Reduced Or Expanded To The Same Air Volume Of Hull. Relation Between Two Similar
2	88.00	127.40	1169.09	47*	549.47	3.83707	189710	5.27809	196	2.29226	7.57035	1.89259	88.00	1.94448	3.83707	547	.0186	3.89259	640	.0170	
3	83.11	131.49	1076.06	48*	516.50	3.81892	199710	5.30040	198	2.29667	7.59707	1.89927	83.11	1.91965	3.81892	521	.0193	3.89927	660	.0169	
4	82.20	78.00	624.53	53	331.00	3.71705	99820	4.99922	162	2.20952	7.20874	1.80218	82.20	1.91487	3.71705	331	.0198	3.80218	432	.0175	Solids Of Linear Dimensions In The Ratio Of $\frac{L_1}{L_2}$ Are As Follows:- $\frac{Vol_1}{Vol_2} = \left(\frac{L_1}{L_2}\right)^3$. For The Same Or Geometrically Similar
5	77.30	79.01	559.42	57	318.86	3.69036	99820	4.99922	162	2.20952	7.20874	1.80218	77.30	1.88818	3.69036	290	.0217	3.80218	432	.0175	
6	119.99	170.01	2898.50	60	1739.10	4.21625	827920	5.91799	427	2.63043	8.54842	2.13711	119.99	2.07914	4.21625	2110	.0160	4.13711	1650	.0163	
7	115.00	356.99	5594.57	64*	3580.52	4.37947	2862061	6.45667	658.3	2.81842	9.27509	2.31877	115.00	2.06070	4.37947	3910	.0118	4.31877	3120	.0125	Airship Hulls But Of Different Sizes. $\frac{\text{Air Vol. Of Hull}_1}{\text{Air Vol. Of Hull}_2} = \left(\frac{\text{Similar Linear Dimension}_1}{\text{Similar Linear Dimension}_2}\right)^3 = \left(\frac{\text{Geometric Lgth}_1}{\text{Geometric Lgth}_2}\right)^3 = \left(\frac{L_{g1}}{L_{g2}}\right)^3$.
8	26.40	251.00	207.26	51	105.70	3.48194	407310	5.60992	428	2.63144	8.24136	2.06034	26.40	1.42160	3.48194	106	.0236	4.06034	1275	.0199	$\frac{\text{Actual Air Vol Of Hull}}{\text{New Air Vol Of Hull}} = \left(\frac{\text{Actual } L_g}{\text{New } L_g}\right)^3$
9	41.00	383.01	762.92	41	312.79	3.71638	582200	5.76507	446	2.64933	8.41440	2.10360	41.00	1.61278	3.71638	311	.0224	4.10360	1460	.0179	To Reduce All Items To 100,000 Cu. Ft. Air Vol. Of Hull. $\frac{\text{Actual Air Vol. Of Hull}}{100000} = \left(\frac{\text{Actual } L_g}{\text{New } L_g}\right)^3$. By $Logs_{10}$.
10	51.98	374.00	1196.61	46	550.44	3.85578	746680	5.87312	486	2.68664	8.55976	2.13994	51.98	1.71584	3.85578	556	.0212	4.13994	1640	.0171	
11	62.40	563.00	2597.85	43	1117.07	3.91304	643680	5.80867	460	2.66276	8.47153	2.11788	62.40	1.79518	3.91304	765	.0209	4.11788	1530	.0164	
12	67.50	412.00	2224.31	41	911.96	3.96649	759210	5.88036	466	2.66839	8.54875	2.13719	67.50	1.82930	3.96649	916	.0206	4.13719	1630	.0168	$Log_{10}(\text{New } L_g) = \frac{1}{3} Log_{10} 100000 - \frac{1}{3} Log_{10}(\text{Actual Air Vol}) + Log_{10}(\text{Actual } L_g)$. $Log_{10}(\text{New } L_g) = \frac{5}{3} - \frac{1}{3} Log_{10}(\text{Air Vol.}) + (Log_{10} L_g \text{ As Tabulated Before})$
13	66.69	482.00	2535.94	38	963.65	3.97745	802210	5.90428	512	2.70927	8.61355	2.15339	66.69	1.82406	3.97745	955	.0212	4.15339	1700	.0169	
14	70.89	409.00	2421.52	46	1113.89	4.01465	873210	5.94111	519	2.71517	8.65628	2.16407	70.89	1.85058	4.01465	1090	.0204	4.16407	1750	.0164	
15	77.09	333.98	2350.85	54	1269.46	4.05699	903040	5.95569	530	2.72428	8.67997	2.16999	77.09	1.88700	4.05699	1274	.0195	4.16999	1775	.0163	
16	81.61	393.00	3101.08	52	1612.56	4.11833	1250900	6.09722	536	2.72916	8.82638	2.20659	81.61	1.91174	4.11833	1520	.0179	4.20659	1970	.0146	
17	86.00	369.49	3238.28	55	1781.05	4.16253	1393900	6.14422	586	2.76790	8.91212	2.22803	86.00	1.93450	4.16253	1775	.0165	4.22803	2110	.0145	
18	92.40	474.00	4795.13	51	2445.51	4.25424	2211820	6.34473	645	2.80956	9.15429	2.28857	92.40	1.96567	4.25424	2425	.0144	4.28857	2615	.0133	
19	92.41	423.00	4279.49	56	2396.51	4.25385	2202820	6.34297	645	2.80956	9.15253	2.28813	92.41	1.96572	4.25385	2405	.0144	4.28813	2615	.0133	
20	96.19	372.00	4077.12	63	2568.58	4.27126	2202820	6.34297	645	2.80956	9.15253	2.28813	96.19	1.98313	4.27126	2587	.0142	4.28813	2615	.0133	
21	97.40	371.00	4170.78	64	2669.29	4.27669	2203820	6.34297	645	2.80956	9.15253	2.28813	97.40	1.98856	4.27669	2661	.0142	4.28813	2615	.0133	
22	94.29	419.00	4413.75	66	2913.07	4.30046	2702820	6.43182	745	2.87216	9.30398	2.32599	94.29	1.97447	4.30046	2910	.0144	4.32599	3050	.0135	
23	94.19	424.00	4456.66	65	2896.83	4.29999	2702820	6.43182	745	2.87216	9.30398	2.32599	94.19	1.97400	4.29999	2894	.0144	4.32599	3050	.0135	
24	104.81	372.00	4851.25	63	3056.28	4.30853	2203820	6.34297	645	2.80956	9.15253	2.28813	104.81	2.02040	4.30853	3069	.0142	4.28813	2615	.0133	
25	113.12	404.00	6123.83	63	3858.01	4.36943	2462820	6.39142	745	2.87216	9.26358	2.31589	113.12	2.05354	4.36943	3893	.0143	4.31589	2905	.0137	
26	91.00	402.51	3949.43	62*	2448.64	4.26009	2352681	6.37156	680.2	2.83264	9.20420	2.30105	91.00	1.95904	4.26009	2480	.0143	4.30105	2740	.0134	
					D_H		V_M		L_A							D_H	C_H		D_H	C_H	

Calculations By Clinton H. Havill
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PART II

NOTE:- It Is To Be Noted That This Hull Drag Can So Far Only Be Computed For U_{MAX} As It Is Not Known If The Hull Drag Varies As U^2 Or Not. The U_{MAX} And Area Of Drag For The Whole Ship As Given In Part I, Were Only At The Point Where All Agree, Such As HP_{MAX}, U_{MAX}, E & K At U_{MAX}. Reynolds Law Is That "Similar Ships Have The Same Drag At The Same UL". The Data Thus Far Was Plotted Against A Number Of Functions And As Ships Were Dissimilar A Term Equivalent To UL Was Finally Obtained. $L_g = \sqrt[4]{(\text{Air Vol} + \frac{\pi r^3}{3})(\text{Length})}$, U = Velocity In Feet Per Second. Thus For Similar Ships This Definition Of UL_g Applies And For Dissimilar Ships Gives The Results Of Plot I. The Research For This UL_g Term Extended Over A Period Of About Five Months.

	POWER CARS - SMALL					TWO ENGINE POWER CARS.			CONTROL CARS ADJ. TO HULL.			*SEPARATE CONTROL CARS			CONTROL SURFACES.																PRELIM. PLOT No 1.	
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.	COEF.	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 HULL DRAG AT U_{MAX}. $(A_H \frac{\rho}{2} U^2_{MAX})$ LBS.	VIRTUAL VOL. FROM PART I AIR VOL + $\frac{\pi r^3}{3}$ Cu. Ft.	$\text{Log}_{10} V_M$	LENGTH (FROM PART I) Ft.	Log_{10} LENGTH Log (Ft.)	$\text{Log}_{10}[V_M L]$ Ft^4	L = (GEOM. LENGTH) $\text{Log}_{10} L = \text{Log} \sqrt[4]{V_M \text{Lgth}}$ Log (GEOM. LENGTH) Log (Ft.)	LOG U_{MAX}.	LOG UL AT U_{MAX}.	BARE HULL DRAG AT U_{MAX}. LBS
1												23.11	.45⊕	10.40	1370	.0072	9.87	29	49.27	87.40	38.13	69.00	215.11	90380	4.95607	163	2.21219	7.16826	1.79207	1.83885	3.63092	215.11
2												49.72	.40	19.89	1969	.0072	14.17	34	67.80	127.37	59.57	88.00	546.92	189710	5.27809	196	2.29226	7.57035	1.89259	1.94448	3.83907	546.92
3												49.72	.40	19.89	1969	.0072	14.17	34	67.80	131.46	63.66	83.11	521.04	199710	5.30040	198	2.29667	7.59707	1.89927	1.91965	3.81892	521.04
4												33.00	.41	13.53	1125	.0072	8.10	15	36.63	78.00	41.37	82.20	331.24	99820	4.99922	162	2.20952	7.20874	1.80219	1.91487	3.71705	331.24
5												33.00	.41	13.53	1125	.0072	8.10	17	38.05	79.01	40.96	77.30	290.01	99820	4.99922	162	2.20952	7.20874	1.80219	1.88818	3.69036	290.01
6	31	.32	9.92	2	19.84	42	.44	18.48	121.00	.11	13.31				9180	.0062	56.91	17	125.54	170.01	44.47	119.99	204.50	827920	5.91799	427	2.63043	8.54842	2.13711	2.07914	4.21625	204.50
7	40△	.30	12.00	5	60.00				176.84	.09	15.91				8460	.0052	43.92	8	127.83	356.99	229.16	115.00	3591.24	2862061	6.45667	658.3	2.81842	9.27509	2.31877	2.06070	4.37947	3591.24
8	36	.45	16.20	2	32.40										1731	.0281	48.63	42	123.03	251.00	127.97	26.40	105.66	407310	5.60992	428	2.63124	8.24136	2.06034	1.42160	3.48194	105.66
9	38	.45	17.10	2	34.20										5357	.0281	150.55	42	226.75	383.01	156.26	41.00	311.24	582200	5.76507	446	2.64933	8.41440	2.10360	1.61278	3.71638	311.24
10	40	.43	17.20	1	17.20							46.	.35	16.10	4651	.0273	126.98	40	200.28	374.00	173.72	51.98	555.81	746680	5.87312	486	2.68664	8.55976	2.13994	1.71584	3.89578	555.81
11	42	.43	18.06	1	18.06							48	.35	16.80	13530	.0242	327.41	35	397.27	563.00	165.73	62.40	764.89	643680	5.80867	460	2.66276	8.47153	2.11788	1.79518	3.91304	764.69
12	43	.43	18.49	1	18.49							49	.35	17.15	7157	.0240	171.77	35	242.41	412.00	169.59	67.50	915.57	759210	5.88036	466	2.66839	8.54875	2.13719	1.82930	3.96649	915.57
13	43	.43	18.49	1	18.49							49	.35	17.15	9793	.0238	233.08	32	300.44	482.00	181.56	66.69	955.21	802210	5.90428	512	2.70927	8.61355	2.15339	1.82406	3.97745	955.21
14	45	.42	18.90	1	18.90							51	.36	18.36	10720	.0238	255.08	30	322.44	409.00	86.56	70.89	512.46	873210	5.94111	519	2.71517	8.65628	2.16407	1.85058	4.01465	512.46
15	45	.41	18.45	1	18.45							51	.36	18.36	14950	.0065	97.23	19	153.04	333.98	145.99	77.09	1273.62	903040	5.95569	530	2.72428	8.67997	2.16999	1.88700	4.05699	1273.62
16	42	.40	16.80	1	16.80	47	.45	21.15				48	.35	16.80	15920	.0068	108.29	25	187.99	393.00	205.01	81.61	1617.67	1250900	6.09722	536	2.72916	8.82638	2.20659	1.91174	4.11833	1617.67
17	37	.40	14.80	3	44.40							43	.34	14.62	13680	.0065	88.93	19	166.95	369.49	202.54	86.00	1775.09	1393900	6.14422	586	2.76790	8.91212	2.22803	1.93450	4.16253	1775.09
18	37	.40	14.80	2	29.60	47	.45	21.15				43	.34	14.62	21110	.0071	149.91	19	234.28	474.00	239.72	92.40	2425.07	2211820	6.34473	645	2.80956	9.15429	2.28857	1.96567	4.25424	2425.07
19	35	.40	14.00	3	42.00							41	.39	15.99	15390	.0071	109.28	18	185.27	423.00	237.73	92.41	2405.02	2202820	6.34297	645	2.80956	9.15253	2.28813	1.96572	4.25385	2405.02
20	35	.40	14.00	3	42.00							41	.31	12.71	10510	.0063	66.27	15	135.98	372.00	236.02	96.19	2586.77	2202820	6.34297	645	2.80956	9.15253	2.28813	1.98313	4.27126	2586.77
21	35	.40	14.00	3	42.00							41	.31	12.71	10260	.0063	64.62	15	134.33	371.00	236.67	97.40	2660.63	2203820	6.34297	645	2.80956	9.15253	2.28813	1.98856	4.27669	2660.63
22	35	.40	14.00	3	42.00							41	.31	12.71	11280	.0063	71.05	17	142.76	419.00	276.24	94.29	2909.85	2702820	6.43182	745	2.87216	9.30398	2.32599	1.97447	4.30046	2909.85
23	35	.40	14.00	3	42.00							41	.31	12.71	12060	.0063	75.99	18	148.70	424.00	275.30	94.19	2893.69	2702820	6.43182	745	2.87216	9.30398	2.32599	1.97400	4.29999	2893.69
24	35	.35	12.25	3	36.75							41	.31	12.71	11180	.0063	70.49	17	136.95	372.00	235.05	104.81	3068.87	2203820	6.34297	645	2.80956	9.15253	2.28813	2.02040	4.30853	3068.87
25	33.1	.33	10.92	5	54.60							36	.30	10.84	10600	.0062	65.77	16	147.21	404.00	256.79	113.12	3892.34	2462820	6.39142	745	2.87216	9.26358	2.31589	2.05357	4.36943	3892.34
26	34.3△	.33	11.32	5	56.60							36.16	.30	10.84	11304	.0062	70.08	17	152.52	402.51	249.99	91.00	2453.15	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						

* Some Have Engines.

⊕ External Bumpers Included.

△ Measured From Plans.

★ Includes External Bracings, Outriggers, Keel Etc.

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