AD ____________

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION ALEXANDRIA, VIRGINIA

4197

86476

Resistance Experiments on a Systematic Series of Streamlined Bodies of Revolution - For Application to the Design of High-Speed Submarines - and Appendixes 1 - 7	86 478 (None)
Gertler, Morton Taylor, David W. Model Basin, Wash., D. C. (Same)	C-297

Apr '50	Confd'l	U.S.	English	144	photo, tables, diagrs, graphs	(Same)

Resistance tests were made on various shapes of mathematically related, streamlined bodies-of-revolution in order to provide basic data for the hull design of high-submerged-speed submarines. The primary purpose of the resistance tests was to determine the effect, upon submerged resistance, of the variation of five selected geometrical parameters, which can be used to define the shape of streamlined bodies-of-revolution. The characteristics and derivation of the series forms are given; the methods of testing are described in detail; the techniques for the reduction of model data and methods for predicting prototype performance are explained; and suggested considerations for the selection of the minimum resistance form for application to submarine design are given. The results of tests of four models at near-surface or snorkelling conditions are also given to show their effect upon the final selection of the optimum form.

Route requests for copies to CADO thru Originating Agency.

Water-Borne Aircraft (21)
Hydrodynamic Theory (1)
Navy Materiel (28)
Marine Engineering (6)

Hydrodynamics
Hulls, Ship
Hulls - Design
Submarines

Bodies of revolution -

NAVY DEPARTMENT

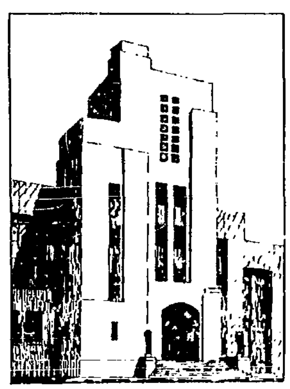
THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

RESISTANCE EXPERIMENTS ON A SYSTEMATIC SERIES OF STREAMLINED BODIES OF REVOLUTION—FOR APPLICATION TO THE DESIGN OF HIGH-SPEED SUBMARINES

by

Morton Gertler



April 1950

Report C-297

NS 715-080

CONFIDENTIAL

INITIAL DISTRIBUTION

Serials	
1 - 20	Chief, BuShips, Project Records (Code 362), for distribution:
	1 - 5 Project Records
	6 Deputy and Asst. Chief (Code 101)
	7 Technical Asst. to Chief (Code 106)
	8 Research (Code 330)
	9 Applied Science (Code 370)
	10 Ship Design (Code 410)
	11 - 12 Preliminary Design (Code 420)
	13 Submarines (Code 515)
	14 Landing Craft (Code 519)
	15 Minesweeping (Code 620)
	16 Torpedo Countermeasures (Code 620c)
	17 Auxiliary Machinery (Code 647)
	18 Propellers and Shafting (Code 654)
	19 Internal Communication and Fire Control (Code 665)
	20 Sonar (Code 940)
21	Commander, Submarine Force, U.S. Atlantic Fleet
22	Commander, Submarine Force, U.S. Pacific Fleet
23	Chief, BuAer, Aero and Hydrodynamics (DE-3)
24 - 25	Chief, Bureau of Ordnance, Research (Re6)
26	Chief of Naval Research, Fluid Mechanics Branch
27	Executive Secretary, Research and Development Board, Pentagon, Washington 25, D.C.
28 - 29	Commander, Naval Ordnance Laboratory, Silver Spring, Md.
30	Director, Naval Research Laboratory, Washington 25, D.C.
31	Commander, Naval Ordnance Test Station, Underwater Ordnance Division, Pasadena, Calif.
32	Commanding Officer and Director, U.S. Navy Underwater Sound Laboratory, Fort Trumbull, New London, Conn.
33	Commanding Officer and Director, U.S. Navy Electronics Laboratory, San Diego 52, Calif.
34	Commanding Officer, U.S. Naval Torpedo Station, Newport, R.I.
35	Commander, Portsmouth Naval Shipyard, Portsmouth, New Hampshire

Serials

36 Commander, Mare Island Naval Shipyard, Vallejo, Calif.

37 - 38 Supervisor of Shipbuilding, USN and Naval Inspector of Ordnance, Electric Boat Co., Groton, Conn.; one copy for Rear Admiral A.I. McKee, USN (Ret.), Member, Panel on the Hydrodynamics of Submerged Bodies and Assistant General Manager, Electric Boat Co.

39 U.S. Navy Inspector of Machinery, General Electric Co., Schenectady 1, N.Y., for Mr. W. Vermeulen, General Electric Co.

40 - 41 Inspector of Naval Material, 1060 Broad St., Newark, N.J., for Dr. K.S.M. Davidson, Chairman, Panel on the Hydrodynamics of Submerged Bodies, Stevens Institute and for the Experimental Towing Tank, Stevens Institute of Technology, 711 Hudson St., Hoboken, N.J.

42 Inspector of Naval Material, 1206 South Santee St., Los Angeles 15, Calif., for Dr. R.T. Knapp, Director, Hydrodynamic Laboratories, California Institute of Technology, Pasadena, Calif.

43 - 44 Inspector of Naval Material, 495 Summer St., Boston 10, Mass., for Vice Admiral E.L. Cochrane USN (Ret.), Member, Panel on the Hydrodynamics of Submerged Bodies and Head, Dept. of Naval Architecture, Massachusetts Institute of Technology, Cambridge, Mass., and for Director, Woods Hole Oceanographic Institution, Woods Hole, Mass.

45 Inspector of Naval Material, 401 Water St., Baltimore 2, Md., for Dr. G.F. Wislicenus, Member, Panel on the Hydrodynamics of Submerged Bodies and Chairman, Dept. of Mechanical Engineering, Johns Hopkins University, Baltimore, Md.

46 Inspector of Naval Material, 17 Brief Ave., Upper Darby, Pa., for Director, Ordnance Research Laboratory, Pennsylvania State College, State College, Pa.

47 Supervisor of Shipbuilding, USN and Naval Inspector of Ordnance, 11 Broadway, New York 4, N.Y., for Rear Admiral P.F. Lee, USN (Ret.), Member, Panel on the Hydrodynamics of Submerged Bodies and Vice President, Gibbs and Cox, Inc., New York.

48 Director of Aeronautical Research, National Advisory Committee for Aeronautics, 1724 F St., N.W., Washington 25, D.C.

Serials

49 Mr. F.L. Thompson, Member, Panel on the Hydrodynamics of Submerged Bodies and Director of Research, Langley Memorial Aeronautical Laboratory, National Advisory Committee for Aeronautics, Langley Field, Va.

50 Captain W.S. Diehl, USN, Associate Member, Panel on the Hydrodynamics of Submerged Bodies, Bureau of Aeronautics, Navy Dept., Washington, D.C.

51 Commanding Officer, Naval Training Schools, Massachusetts Institute of Technology, Cambridge 39, Mass.

52 Commanding Officer, Branch Office, U.S. Navy, Office of Naval Research, 495 Summer Street, Boston 10, Mass.

53 Commanding Officer, Branch Office, U.S. Navy, Office of Naval Research, 50 Church Street, New York 7, N.Y.

54 Commanding Officer, Branch Office, U.S. Navy, Office of Naval Research, 844 North Rush Street, Chicago 11, Illinois

55 Commanding Officer, Branch Office, U.S. Navy, Office of Naval Research, 801 Donahue Street, San Francisco 24, Calif.

56 Commanding Officer, Branch Office, U.S. Navy, Office of Naval Research, 1080 East Green Street, Pasadena 1, Calif.

57 - 58 Assistant Naval Attache for Research, U.S. Navy, Office of Naval Research, American Embassy, London, England, Navy 100, FPO, New York, N.Y.

CONFIDENTIAL

RESISTANCE EXPERIMENTS ON A SYSTEMATIC SERIES OF STREAMLINED BODIES OF REVOLUTION—FOR APPLICATION TO THE DESIGN OF HIGH-SPEED SUBMARINES

by

Morton Gertler

April 1950 Report C-297

CONFIDENTIAL

TABLE OF CONTENTS

NOTATION

Symbol	Description	Dimensions in Mass-Length-Time System
L	Overall length	L
D	Diameter at the maximum section	L
S	Wetted-surface area	L^2
$\forall$	Volume	L^3
R	Dimensional radius	L
R_o	Dimensional nose radius	L
R_1	Dimensional tail radius	L
X	Dimensional abscissa	L
Y	Dimensional ordinate	L
x	Nondimensional abscissa, $\frac{X}{L}$	
y	Nondimensional ordinate, $\frac{Y}{D}$	
L/D	Fineness ratio	
C_p	Prismatic coefficient	
C_{PF}	Forebody prismatic coefficient	
C_{PA}	Afterbody prismatic coefficient	
LCB	Position of the longitudinal center of buoyancy measured from the nose expressed as a ratio to the length.	
m	Distance of maximum section from the nose expressed as a ratio to the length	
r	Nondimensional radius	
r_o	Nondimensional nose radius	
r_1	Nondimensional tail radius	
C_s	Wetted surface coefficient	
V	Speed	LT^{-1}
ρ	Mass density	ML^{-3}
ν	Kinematic viscosity	L^2T^{-1}
R_t	Total resistance	MLT^{-2}
R_f	Frictional resistance	MLT^{-2}
R_r	Residual resistance	MLT^{-2}
ΔR_1	Resistance added due to sand roughness	MLT^{-2}
ΔR_2	Resistance added due to strut interference effect	MLT^{-2}
EHP	Effective horsepower	
R_l	Reynolds number based on length of body	
C_t	Total-resistance coefficient	
C_f	Frictional-resistance coefficient	
C_r	Residual-resistance coefficient	

ABSTRACT

The results of experiments with a systematic series of 24 mathematically related streamlined bodies of revolution, showing how the resistance of these bodies at deep submergence varies with changes in five selected geometrical parameters, are presented. These geometrical parameters are the fineness ratio, the prismatic coefficient, the nose radius, the tail radius, and the position of the maximum section.

The characteristics of the series forms, the techniques used in testing, the procedures used in analyzing the data, the methods of predicting prototype performance, and the means used to show relative performance are explained. The results of tests of four models at near-surface or snorkelling conditions are also included.

The series forms are compared on an equal volume basis including the estimated added resistance due to control surfaces necessary for prescribed directional stability characteristics. These comparisons indicate that there is a large variation in submerged resistance among these forms and that there is a definite minimum resistance on each parameter variation except for the nose radius.

INTRODUCTION

The Bureau of Ships requested[1] the David Taylor Model Basin to conduct a broad investigative program on the resistance of various shapes of underwater bodies, in order to provide basic data for the hull design of high-submerged-speed submarines. The investigation was intended not only to cover bare-hull performance but also to consider the effect on resistance of those control surfaces that are necessary to meet certain directional-stability requirements.

The David Taylor Model Basin had previously made a survey of the literature and existing aeronautical data and incorporated its findings in a memorandum which, because of its original limited circulation, is reproduced in Appendix 1. The conclusion that was reached from this survey was that systematic data on the resistance of streamlined forms deeply submerged in a fluid, was practically nonexistent. Consequently the Taylor Model Basin formulated a mathematically derived series of bodies of revolution which was designated Series 58. Twenty-four 9-foot models were constructed for the series. These were tested to determine their resistance at a submergence which was deep enough to substantially eliminate free-surface effects.

---

*All references are listed on page 34 of this report.

The primary purpose of the resistance tests was to determine the effect, upon submerged resistance, of the variation of five selected geometrical parameters which can be used to define the shape of streamlined bodies of revolution.

The subject matter of this report concerns the establishment of general criteria for designing minimum resistance forms for given service requirements. The characteristics and derivation of the series forms are given; the methods of testing including the towing apparatus, the devices used to correct for strut-interference effects, and the method of stimulating turbulence are described in detail; the techniques for the reduction of model data and methods for predicting prototype performance are explained; and suggested considerations for the selection of the minimum resistance form for application to submarine design are given. The results of tests of four models at near-surface or snorkelling conditions are also given to show their influence upon the final selection of the optimum form.

CHARACTERISTICS OF SERIES 58

The offsets of the models composing Series 58 are derived, by the method described in Reference 2, from a sixth degree polynomial of the form $y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$, where x is the nondimensional abscissa and y is the nondimensional ordinate. The arbitrary constants a_1, a_2, etc., for each form are determined when the values for the geometrical parameters are assigned. The geometrical parameters which are varied are, nondimensionally, the overall prismatic coefficient C_P, the position of the maximum section m, the nose radius r_0, the tail radius r_1, and the fineness ratio L/D. The nondimensional offsets X/L vs. Y/D are the same for all fineness ratios, once the other four parameters have been fixed. The nose and tail radii are nondimensionalized by the following relationship:

$$r = \frac{RL}{D^2} = \frac{\frac{R}{D}}{\frac{D}{L}} \qquad [1]$$

where r is the nondimensional radius,

R is the dimensional radius,

L is the length, and

D is the diameter.

It should be noted that the nose-radius and tail-radius parameters as used here do not apply merely to the extremities of the given forms but actually affect the shape of the whole form.[2] This is shown in Figure 3 where

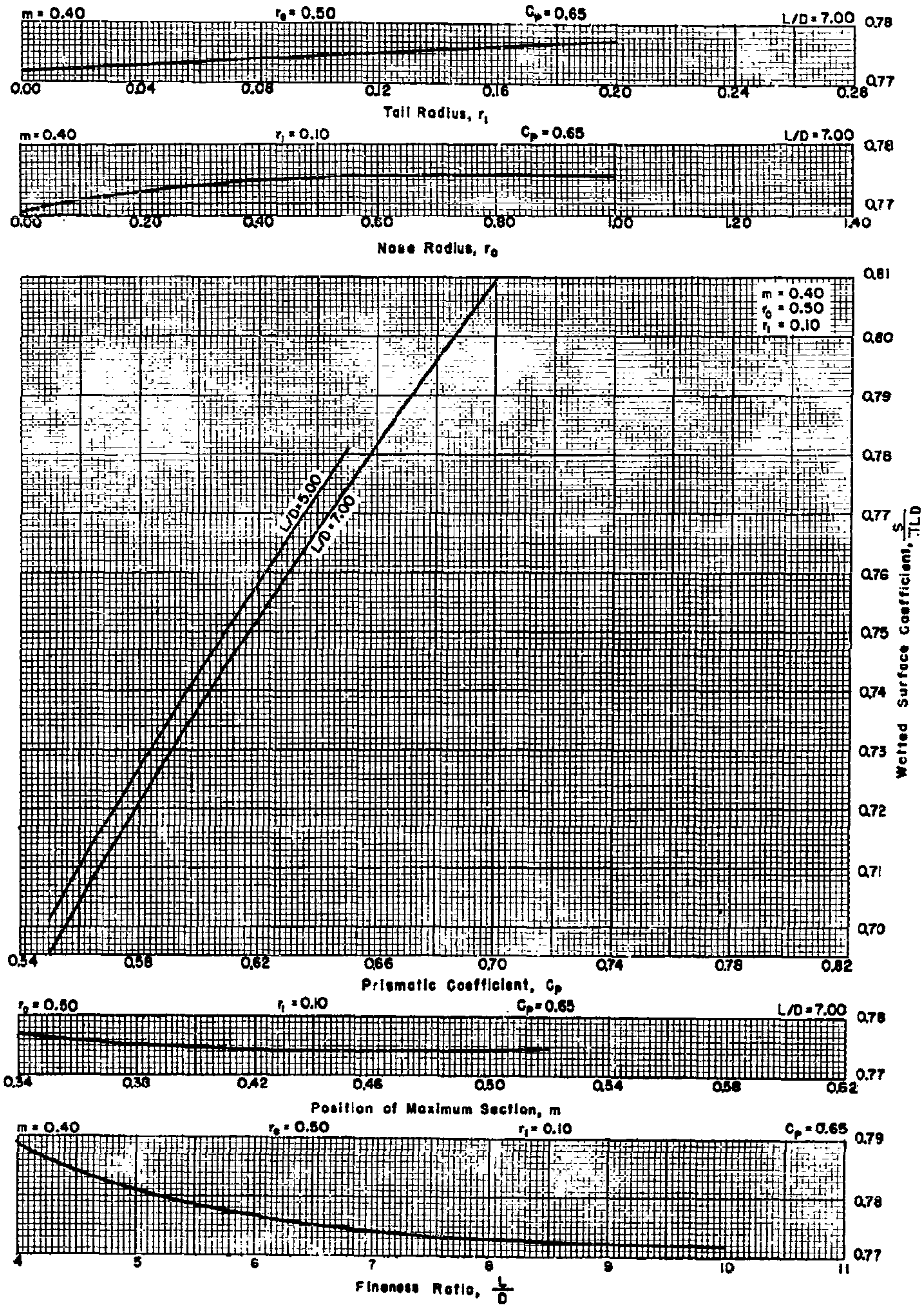


Figure 1 - Wetted Surface Coefficients for Series 58

The wetted-surface coefficient is defined as $S/\pi LD$ where S is the bare-hull wetted-surface area, L is the length, and D is the diameter.

it can be seen that substantial changes of prismatic of forebody and prismatic of afterbody occur with the changes in nose and tail radii.

A system of serial numbers which describes the nondimensional forms of the series has been used. The serial number for a given form generally consists of ten integers which are read from left to right in groups of two to denote the parameters in the following order: Position of maximum section, nose radius, tail radius, prismatic coefficient, and fineness ratio. Thus, to illustrate the parameters and position of the decimal points, for a serial of 40050165-70,

$$m = 0.40$$
$$r_0 = 0.50$$
$$r_1 = 0.10$$
$$C_p = 0.65$$
$$L/D = 7.00$$

When more than two integers are required to describe the parameter they are placed in parentheses. Thus for a tail radius of 0.05, the serial is given as (005).

The forms of Series 58 are defined by five parameters and, assuming that four variations on each parameter would be required to establish a curve accurately, it would require 4^5 or 1024 models to give complete coverage. Consequently, Series 58 was abbreviated by first selecting a parent form which would serve as an approximate central point for the variation of each parameter. The parent selected was one having a serial of 40050165-70. Twenty-two models based upon this parent were then constructed. The parameters for these models are shown in Table 1. One of these models, having an L/D = 5.0, was selected as a second parent and two additional models were constructed. The characteristics of these are also shown in Table 1.

A complete table of offsets for each series model is given in Appendix 2. Each table includes the nondimensional abscissas and ordinates and dimensional abscissas and ordinates for the construction of a 9-foot model. Other pertinent data—such as the maximum diameter, volume, wetted surface, position of the maximum section, position of the longitudinal center of buoyancy, etc., including the mathematical equation for the forms—are also given. Curves showing the variation of wetted-surface coefficient with the five prescribed geometrical parameters are given in Figure 1. Curves showing how the wetted surface varies on a fixed volume basis are shown in Figure 2.

It is interesting to note that when the comparisons are made on an equal-volume basis, there is only a small change in wetted surface with prismatic coefficient over the range of values covered. This is true even though there is a substantial change in the wetted-surface coefficients of these

TABLE 1

The Geometrical Parameters for Models of Series 58

Model	m	r_o	r_1	C_p	L/D
4154	0.40	0.50	0.10	0.65	4.0
4155	0.40	0.50	0.10	0.65	5.0
4156	0.40	0.50	0.10	0.65	6.0
4157	0.40	0.50	0.10	0.65	7.0
4158	0.40	0.50	0.10	0.65	8.0
4159	0.40	0.50	0.10	0.65	10.0
4160	0.36	0.50	0.10	0.65	7.0
4161	0.44	0.50	0.10	0.65	7.0
4162	0.48	0.50	0.10	0.65	7.0
4163	0.52	0.50	0.10	0.65	7.0
4164	0.40	0.50	0.10	0.55	7.0
4165	0.40	0.50	0.10	0.60	7.0
4166	0.40	0.50	0.10	0.70	7.0
4167	0.40	0.00	0.10	0.65	7.0
4168	0.40	0.30	0.10	0.65	7.0
4169	0.40	0.70	0.10	0.65	7.0
4170	0.40	1.00	0.10	0.65	7.0
4171	0.40	0.50	0.00	0.65	7.0
4172	0.40	0.50	0.05	0.65	7.0
4173	0.40	0.50	0.15	0.65	7.0
4174	0.40	0.50	0.20	0.65	7.0
4175	0.40	0.50	0.10	0.60	5.0
4176	0.40	0.50	0.10	0.55	5.0
4177	0.34	0.50	0.10	0.65	7.0

forms as shown in Figure 1. The reason for this can be shown by the following relationship:

$$C_s = \frac{S}{\pi LD} \qquad [2]$$

where C_s is the wetted-surface coefficient,
S is the wetted surface,
L is the length, and
D is the maximum diameter.

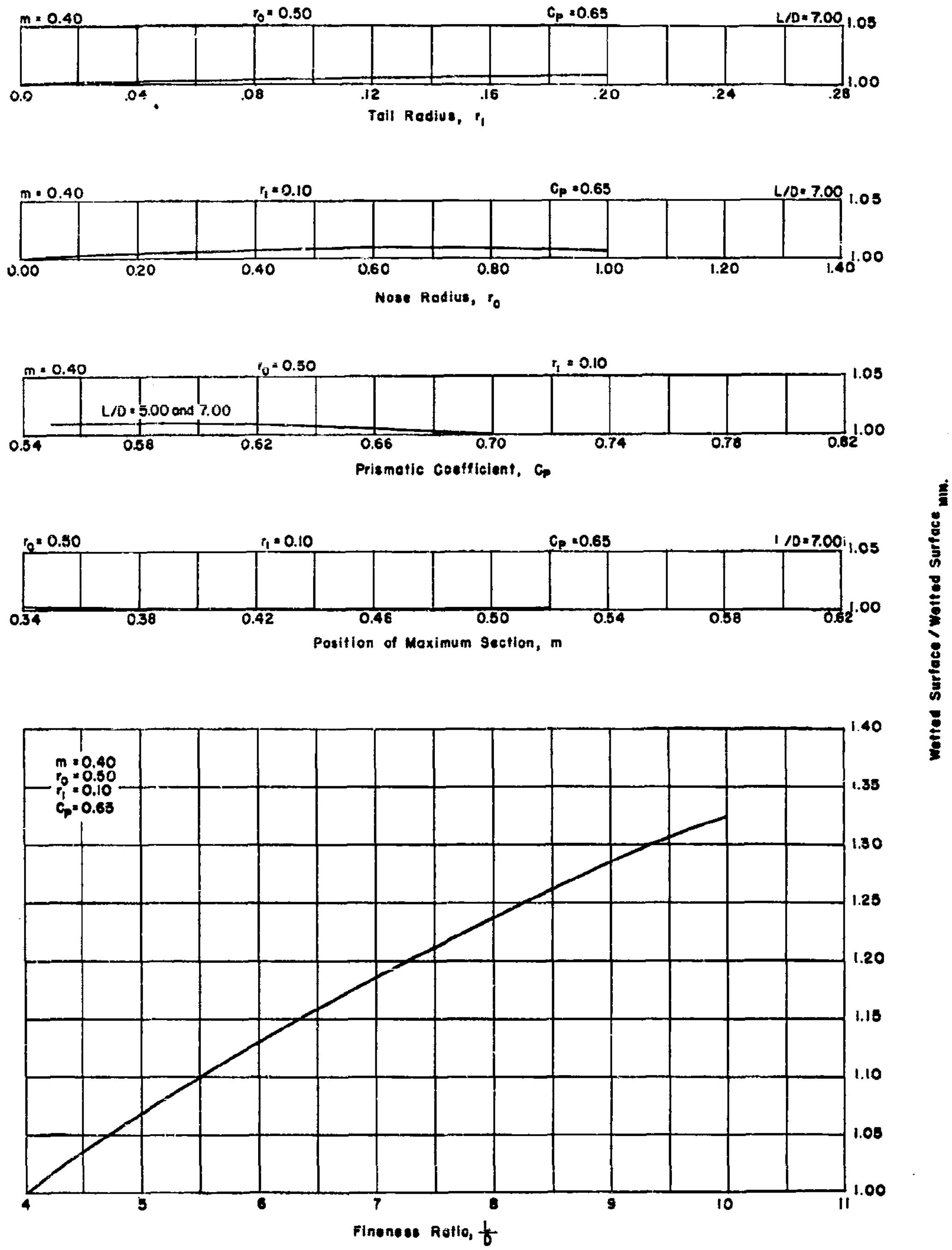


Figure 2 - Wetted-Surface Areas for Prototypes of Series 58 Compared on a Basis of Equal Volume

The wetted-surface areas have been calculated for bare-hull prototypes and are expressed as a ratio to the minimum for each geometrical parameter variation.

$$C_P = \frac{\nabla}{\frac{\pi L D^2}{4}} \quad [3]$$

where C_P is the prismatic coefficient and ∇ is the volume.

Let the fineness ratio L/D = n. Then

$$C_P = \frac{\nabla}{\frac{\pi L^3}{4n^2}} \quad [4]$$

or

$$L = \left(\frac{4n^2\nabla}{\pi C_P}\right)^{1/3} \quad [5]$$

Substituting Equation [5] in Equation [2] and transposing

$$S = C_S\left[\pi^{1/3}\, n^{1/3}\left(\frac{4\nabla}{C_P}\right)^{2/3}\right] \quad [6]$$

is obtained. This is the general expression for obtaining the wetted surface of all prototypes of Series 58. Now, if n and ∇ are taken to be constant and all the remaining constant terms are collected and denoted by K, then

$$S = \frac{KC_S}{(C_P)^{2/3}} \quad [7]$$

Substituting numerical values from Figure 1, for C_P = 0.55 and L/D = 7.00,

$$S = \frac{K \times 0.6954}{(0.55)^{2/3}} = 1.036\ K$$

and for C_P = 0.70 and L/D = 7.00,

$$S = \frac{K \times 0.8094}{(0.70)^{2/3}} = 1.027\ K$$

Thus there is only 0.9 percent difference in wetted-surface area between the C_P of 0.55 and the C_P of 0.70, a percentage that agrees with Figure 2. Or to summarize, the wetted-surface coefficient varies approximately as the two-thirds power of the prismatic coefficient in the range of values covered by Series 58.

The volumetric distribution on the series forms is shown in Figure 3 by curves of prismatic of the forebody, C_{PF}, prismatic of the afterbody, C_{PA}, and position of longitudinal center of buoyancy, LCB, versus each of the prescribed parameters for the series—with the exception of fineness ratio which does not alter these properties.

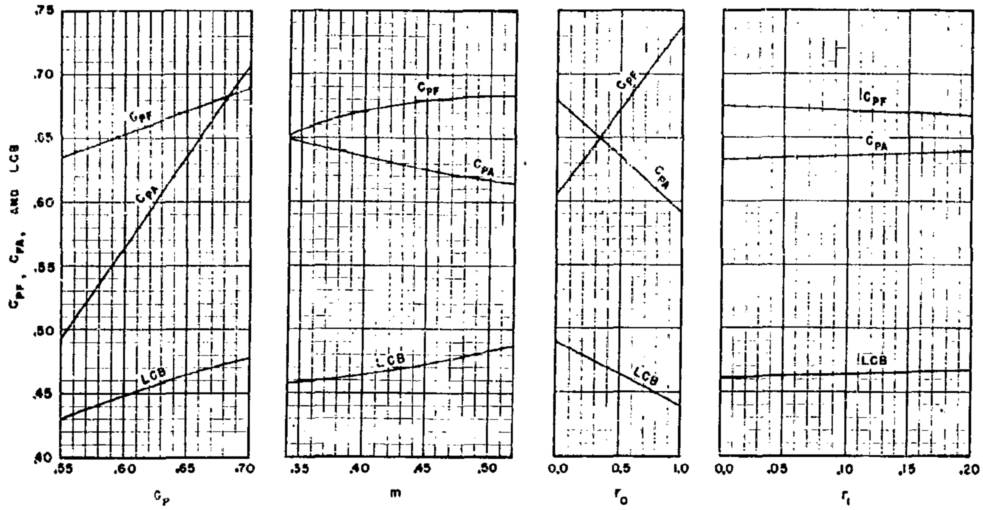


Figure 3 - The Variation of Forebody Prismatic Coefficient, Afterbody Prismatic Coefficient, and Longitudinal Center of Buoyancy for Series 58

DESCRIPTION OF MODELS

The models for the series were constructed in the model shop at the David Taylor Model Basin and were all 9 feet in length. All but two of the models were built of Honduras mahogany. Of the excepted two, one was made of Alaska yellow cedar and the other of sugar pine. Mahogany was selected as the preferred material for building the models since it was found to be more impervious to water and consequently the models constructed of mahogany maintained their dimensions within a few hundredths of an inch without cracking or checking, even when subjected to long periods of soaking.

The procedure for constructing the models was as follows: A block was assembled from glued lifts cut from planks; the block was then turned on a lathe and cut by a rotating cutting head which travelled along a longitudinal template defining the profile meridian of the form; a central cutout was provided in the model to accommodate an internal dynamometer and forward and after cutouts were made to accommodate the pads for securing the towing struts; the cutouts were covered by 1/8-inch-thick sheet-aluminum plates which were molded to fit the contours of the model.

The procedure for finishing the models was as follows: The mahogany was first sealed with marine wood sealer followed by paste wood filler and then rubbed with burlap or excelsior to remove the excess filler; after about 6 hours of drying time, the model was sprayed with Dupont 1991 lacquer sealer and then sanded with sandpaper moistened with soapy water until a smooth finish was obtained; a final coating of Dupont Dulux examel, Ra-190, exterior clear, was sprayed on the model and, when dry, was rubbed down with a rubbing compound. A photograph of a typical model is given in Figure 4.

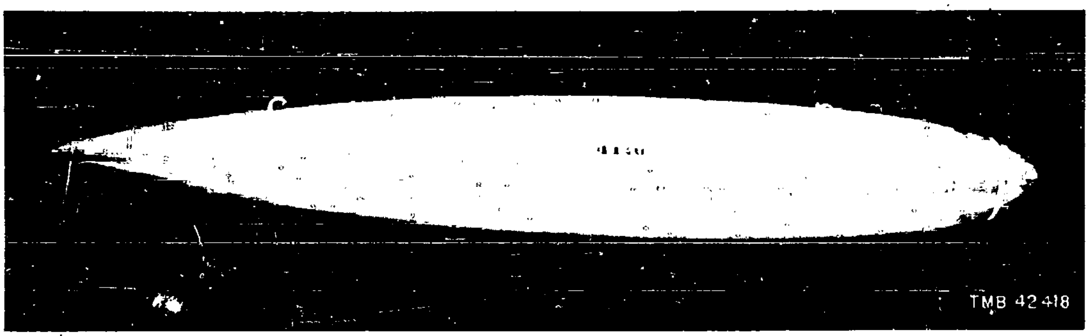


Figure 4 - A Typical Model of Series 58

TEST APPARATUS AND PROCEDURE

The "TMB Faired Towing Struts" were used to tow the series models in the deep-submergence condition. The assembly of each of the two towing struts consists of an internal supporting strut and an external fairing. The internal supporting strut is pin-connected to the model at one end and clamped to the floating girder of the resistance dynamometer at the other end. The external fairing is placed concentrically about the supporting strut to shield it completely from the flow. The fairing is free at the model end and is fixed to a pair of rails, which are rigidly mounted to the towing carriage, at the upper end.

The towing arrangement used for the tests is diagrammatically shown in Figure 5. Two struts were used because a single one of the existing struts did not have the torsional rigidity required to overcome the inherent dynamic instability of the bare-hull models at the test speeds comtemplated. The fairings of the struts were inserted into the model through deck-plate openings which had enough clearance to provide for the motion of the resistance dynamometer and for possible side deflection of the internal strut or fairing.

A resistance increase was expected due to the interference with the flow about the models caused by the presence of the towing struts. Consequently, it was necessary to construct a pair of dummy struts in order to determine the magnitude of this effect. The dummy-strut assembly is shown in Figure 6.

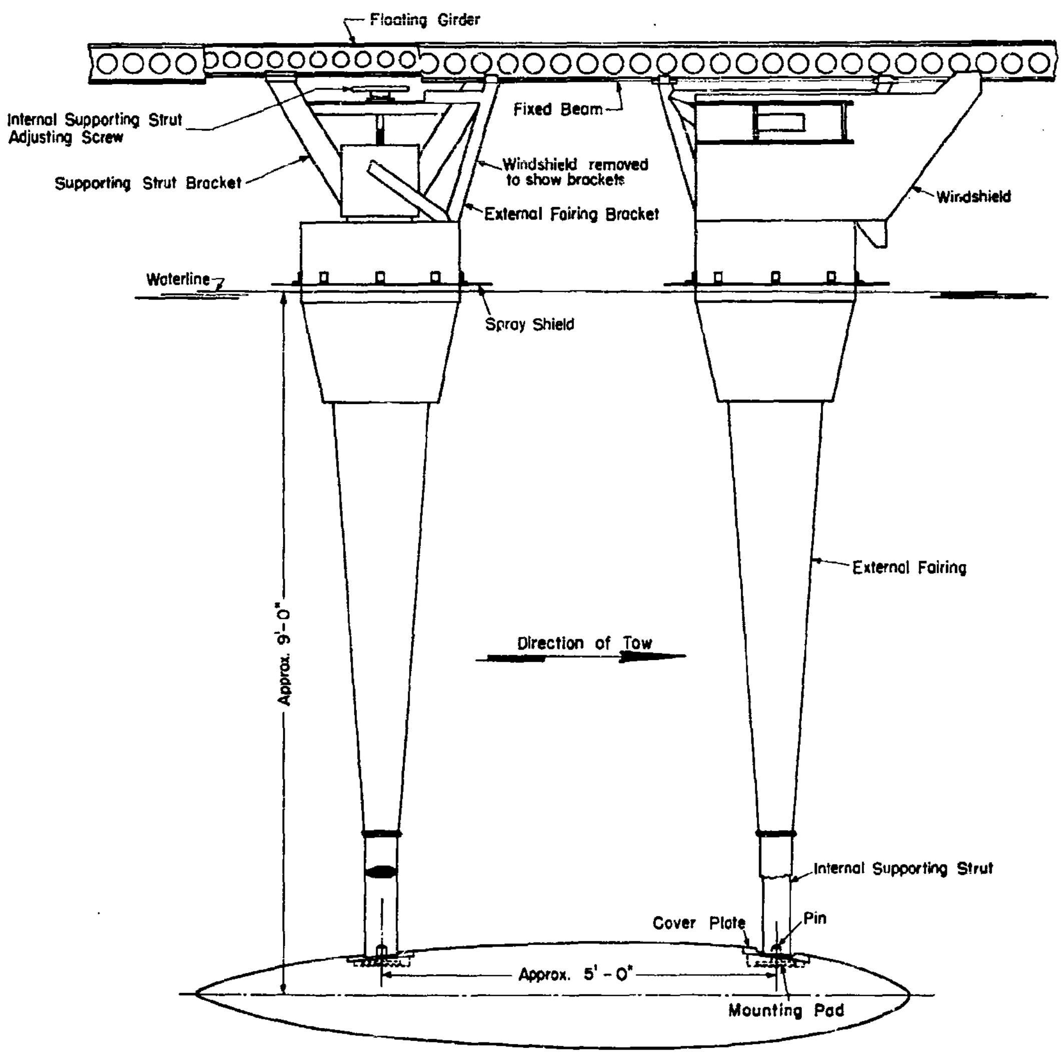


Figure 5 - Schematic Diagram of the Arrangement of the Model-Towing Apparatus

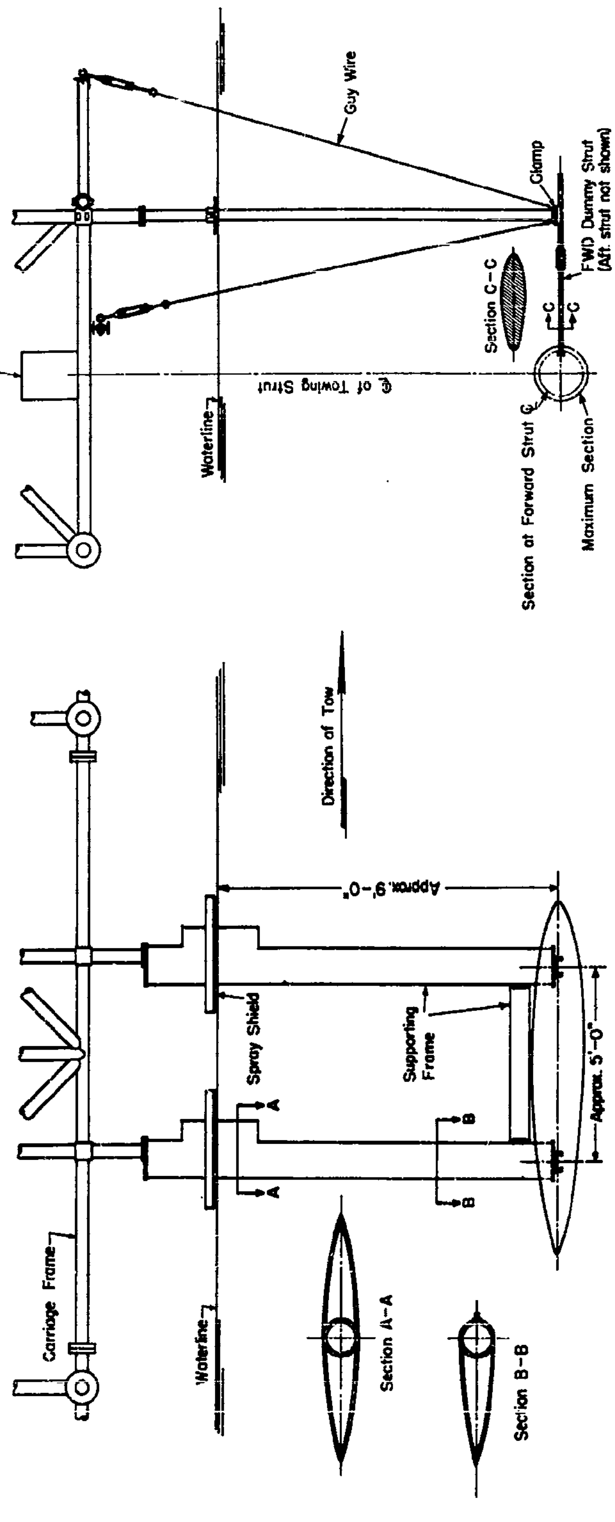


Figure 6 - Schematic Diagram of the Dummy-Strut Assembly

The dummy struts are supported by a frame which is parallel to the towing struts. The struts have the same cross section as the fairings of the towing struts. They project at right angles to the supporting frame and are inserted into the model in a manner similar to the fairings of the towing struts and, like the latter, are not attached to the model. The arrangement of placing the dummy struts at 90 degrees instead of 180 degrees to the towing struts was selected for two reasons: First, because of the impracticability of supporting dummy struts coming up to the bottom of the model, and second, because it was considered desirable to reproduce, in another plane, the original asymmetry in flow about the model caused by the towing struts. It was assumed from previous experience that there would be no measurable increase in resistance due to mutual interference in flow between each towing strut and dummy strut. The validity of this assumption is verified by the agreement in the results of tests of 9- and 15-foot geometrically similar streamlined bodies of revolution, which are discussed in a subsequent section of this report.

For the purpose of stimulating turbulence, the model was prepared for tests with a 1/2-inch-wide sand strip placed in the form of a circle, around the nose of the model at a distance of 1/20 of the length (of the model) from the nose. The strip was prepared by sprinkling 20- to 30-mesh sand on a thin adhesive coating.

The procedure used in the testing was as follows: The smooth bare hull was first towed at a range of steady-state speeds from 1 to 18 knots; the test was then repeated for the model equipped with the sand strip. The model with the sand strip was tested with the dummy struts inserted and then with the dummy struts removed but with the dummy-strut supporting frame down (in order to obtain the net effect of the dummy struts alone). The tests with the dummy struts in place extended only up to a speed of approximately 8.5 knots because the system was not stiff enough to maintain clearance between the dummy strut and the edge of the cutout in the model at higher speeds. Strut-interference tests were not conducted for all models since the small change in strut-interference coefficient from model to model permitted accurate interpolation and extrapolation.

The apparatus used to tow the models at the near-surface or snorkelling conditions consisted of a single towing strut, having a 4- by 1-inch ogival cross section, which was rigidly attached to the model at one end and to the floating girder of the resistance dynamometer at the other end. The strut had no external fairing, so that separate resistance tests of the strut were necessary to obtain the tare.

The procedure of testing was as follows: Each model, prepared with a sand strip, was towed at a range of steady-state speeds from 1 to 18 knots at each of three different depths of submergence. The depths were taken in small increments about what was considered to be a reasonable snorkelling depth based on information from other submarines. The strut was then towed alone over the same speed range at the appropriate depths to obtain the tare resistances.

Separate tests of the models to determine the additions in resistance due to sand-roughness and strut-interference effect were not made at the snorkelling conditions. The means used to assess these quantities are explained in the following section. Because of limitations in time, only four models, embodying the variation of prismatic coefficient at a fineness ratio of 7.0, were tested for near-surface resistance.

REDUCTION OF TEST DATA

The resistance-versus-speed values obtained from the tests of each model were reduced to nondimensional form by the method of Reference 3, as follows:

The total-resistance coefficient is defined as:

$$C_t = \frac{R_t}{\frac{\rho}{2} SV^2} \qquad [8]$$

where C_t is the total-resistance coefficient,
R_t is the total resistance,
ρ is the mass density, and
V is the speed.

The frictional-resistance coefficient is obtained from the Schoenherr formula

$$\frac{0.242}{\sqrt{C_f}} = \log_{10}(Re \cdot C_f) \qquad [9]$$

where C_f is the frictional-resistance coefficient,
Re is the Reynolds number, equal to $\frac{VL}{\nu}$,
V is the speed,
L is the overall length, and
ν is the kinematic viscosity of the basin water.

This is subtracted from the total-resistance coefficient to obtain the residual-resistance coefficient, or

$$C_t - C_f = C_r = \frac{R_r}{\frac{\rho}{2} SV^2} \qquad [10]$$

where C_r is the residual-resistance coefficient, and R_r is the residual resistance.

The residual-resistance coefficient values were then plotted against the Froude number, $\frac{V}{\sqrt{gL}}$, and irregularities due to obvious test-spot discrepancies faired out. The Froude number was selected as the speed parameter for fairing purposes even for the deep-submergence tests because, although the models for these tests were towed at considerable depth, a small amount of wave-making resistance, which varies with Froude number, remained.

As mentioned previously, for the majority of the models four resistance tests at deep submergence were made: A test of the smooth model, a test of the model with the sand strip for stimulating turbulence, a test of the model with the dummy-strut supporting frame alone, and a test of the model with the dummy struts inserted into the model. To illustrate how the data from these four tests are used to obtain the net residual-resistance coefficient, the data from the tests of Model 4165 are reproduced in Figure 7.

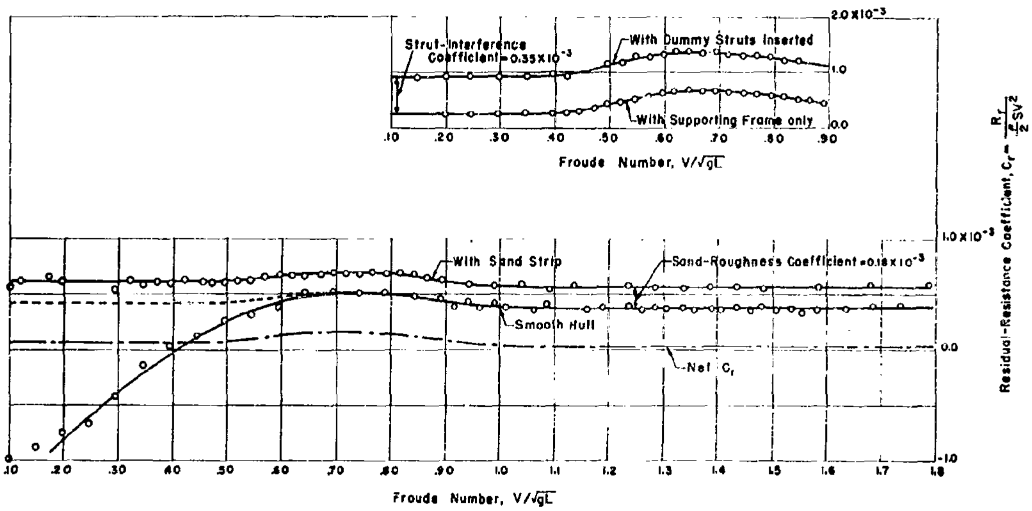


Figure 7 - Sample Residual-Resistance-Coefficient Curves

The data were derived from tests with Model 4165.

Examining first the results of the smooth-hull tests, it can be seen that below a Froude number of 0.7—corresponding to a Reynolds number of about 1.04×10^7—the C_r curve drops sharply and attains negative values below a Froude number 0.4. Since the C_r values were obtained by subtracting turbulent C_f values from the C_t data, the drop in the C_r curve indicates the presence of laminar flow over part of the body. This is verified by the C_r curve for the body when the sand strip is used to stimulate turbulence. Here the C_r curve is very nearly horizontal from low to high Froude numbers, except for the hump, which is known to be due to wave-making resistance. The C_r curve for the body with the sand strip is higher, however, even at high Froude numbers. This is considered to be due to the added resistance caused by the sand itself. It is noted that above a Froude number of 0.7 these two C_r curves are parallel. Thus, the difference between the C_r's in this area can be taken as representative of the correction needed to compensate for the added resistance of the sand. The curve for the smooth body can then be amended as shown by the broken line. The effect of the sand beyond that caused by turbulence stimulation will hereinafter be referred to as the "sand-roughness coefficient," $\frac{\Delta R_1}{\rho/2\ SV^2}$, where ΔR_1 is the resistance added by the sand.

If, now, the C_r curve for the model towed with the dummy-strut supporting frame alone in place and the curve for the model including the dummy struts are taken as a pair, it can be seen that these curves are also parallel. Consequently if the difference between these curves can be denoted as the "strut-interference coefficient," $\frac{\Delta R_2}{\rho/2\ SV^2}$, then the smooth-bare-hull C_r curve can be further corrected to obtain the net C_r curve which is shown in Figure 7. To summarize, net C_r = gross C_r minus sand-roughness coefficient minus strut-interference coefficient.

To illustrate the validity of the aforementioned procedure, the results of tests of two different-sized, geometrically similar streamlined bodies of revolution are shown as resistance coefficients in Figure 8. The test results are for a 9- and a 15-foot model of a TMB-EPH form of a fineness ratio of 5. As can be readily seen, after the respective sand-roughness and strut-interference coefficients are deducted from the C_t curves derived from the tests of each model, the net C_t curves, and consequently the net C_r curves, in the area outside of the wave-making hump are identical. The fact that the sand-roughness and strut-interference coefficients are quite different in magnitude for the two different sized models, (0.10×10^{-3} and 0.30×10^{-3}) for the 9-foot model and (0.05×10^{-3} and 0.05×10^{-3}) for the 15-foot model, and yet yield the same net C_r's, is an indication of the accuracy of

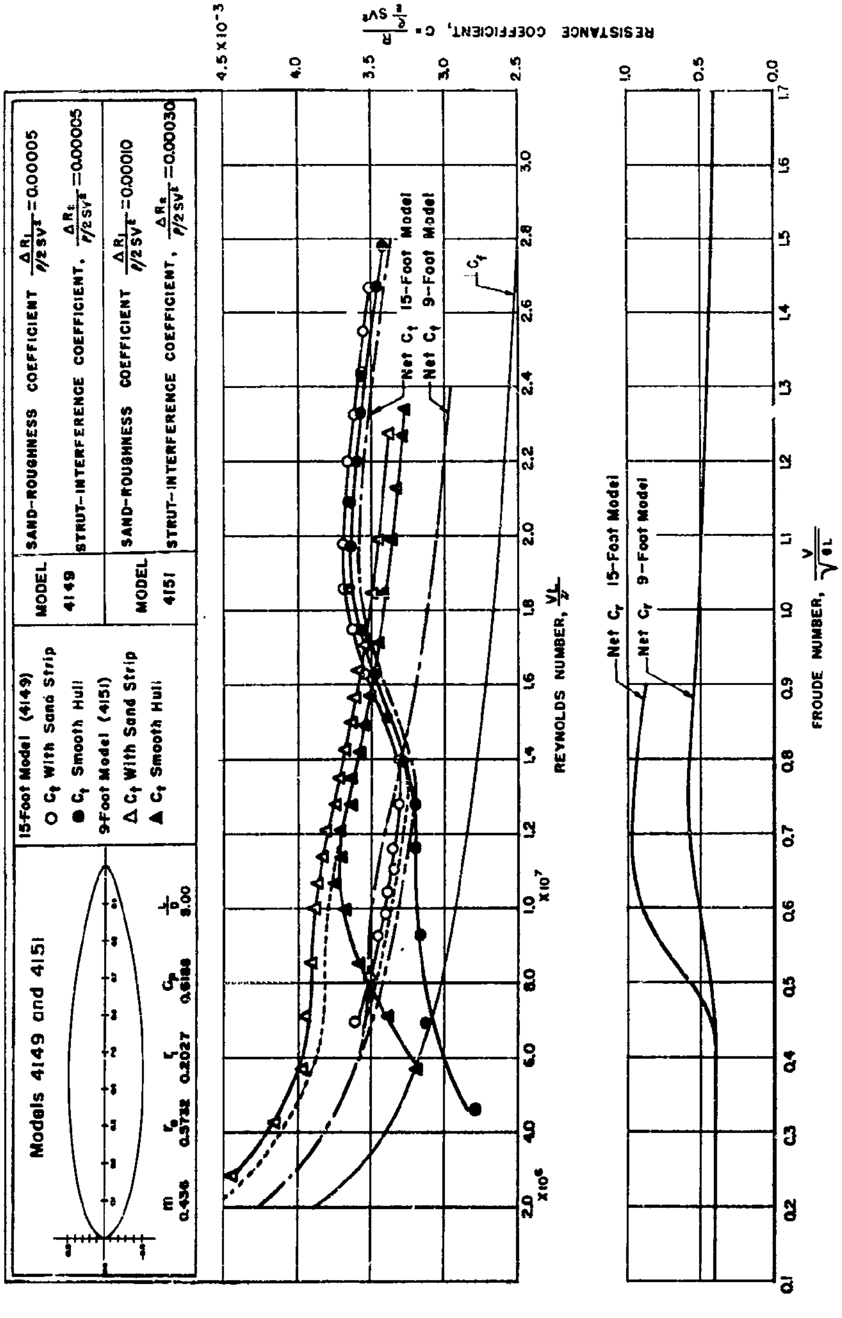


Figure 8 - Comparison of the Resistance Coefficients for 9- and 15-foot Geometrically Similar Models

The data were derived from tests of Model 4151, a 9-foot model, and Model 4149, a 15-foot model, both representing a TMB-EPH body of revolution.

the test procedure and analysis technique. Thus the results of the tests of the 9-foot models can be used quantitatively with the same confidence as those from tests of large models.

The method used to extrapolate the model data to obtain the effective horsepowers for geometrically similar prototypes for deep submergence is essentially the same as the method of Reference 3. The only difference is that C_r is considered to be constant and independent of Froude number. The assumption of the constancy of C_r for the deep submergence condition is based on the following reasoning: As will be shown subsequently, the results of tests of all models of Series 58 at deep submergence have indicated that the C_r's as defined by Equation [10] are sensibly constant over a range of Reynolds numbers from 2×10^6 to 2×10^7, with the exception of the small wavemaking hump. It is reasonable to assume, therefore, that if the C_r does not change over such a wide model range, where its dependency with Reynolds number should be most pronounced, there will be no further change in the extrapolation to full-scale Reynolds numbers, which are only removed from the highest model Reynolds number by a factor of the order of 10. Thus, the total effective horsepower is:

$$EHP_t = (C_r + C_f + \Delta C_f) \frac{\rho}{2} S V^3 \frac{(1.689)^3}{550} \qquad [11]$$

where C_r is the net residual-resistance coefficient corrected for the sand-roughness coefficient and the strut-interference coefficient,

C_f is obtained from the Schoenherr formula using the appropriate Reynolds number based on the full-scale speed and length and on a kinematic viscosity corresponding to a standard sea water of 3 percent salinity at a temperature of 59 F.,

ΔC_f is the roughness-allowance coefficient and is taken, for the purpose of this analysis, equal to 0.400×10^{-3} as recommended by the American Towing Tank Conference,*

ρ is the mass density of sea water at 59 F.,

S is the full-scale wetted-surface area,

V is the speed which, when knots are used, requires the conversion factor of 1.689, and

550 is the conversion factor of foot-lb per second to horsepower.

*Recent standardization trials have indicated that a roughness-allowance coefficient of 0.4×10^{-3} is somewhat low even for clean-bottom vessels treated with zinc chromate paint. Roughness-allowance coefficients for vessels treated with antifouling paints of hot or cold plastic are even higher. There are very little existing data on the roughness of submarine hulls. It is recommended, therefore, that when sufficient roughness data are available, they be applied to adjust the EHP values in this report, if more accurate ~~qualitative~~ results are desired. In general, the merit relationships will not be materially altered by a change of roughness-allowance coefficient.
quantitative

The method used to reduce the data from the model snorkelling tests was as follows: The strut tare resistances were faired against model speed and then cross-faired against depth. The appropriate faired tares were then subtracted from the test data values of gross resistance versus speed. The tares were small, amounting to only approximately 8 percent of the total measured resistance. The resultant data were used to compute C_r's using Equations [8] and [9] and these C_r's were then plotted against Froude number and faired. An examination of the C_r curves for each model revealed that, below a Froude number of approximately 0.25, the curves for all tested depths converged at a single constant value. The difference between this value and the net C_r for deep submergence was considered to be equal to the sum of the sand-roughness coefficient and the strut-interference coefficient for the snorkelling tests of the given model. This assumed coefficient was then deducted from the faired C_r curve values to obtain the net C_r-versus-Froude number curves. The EHP's were then computed by the method of Reference 3 using the net C_r's.

PRESENTATION OF DATA

The data derived from the deep-submergence resistance tests of Series 58 are presented in several different forms to facilitate immediate application for various purposes.

First, to permit an independent evaluation, the data are presented in Appendix 3 as total-resistance coefficients plotted against Reynolds number. Test spots are shown for the model tested, with and without sand strips. Values for the sand-roughness coefficient and the strut-interference coefficient are given on each set of curves. Data for the strut-interference coefficients are given in Appendix 4 in the form of C_r versus Froude number.

Secondly, the corrected, or net, C_r's plotted against Froude number are shown as curves in Appendix 5. These curves demonstrate that C_r is constant and independent of Reynolds' number at deep submergence, show the extent of the wave-making resistance at the depth tested, and permit calculations of the total-resistance coefficient, the effective horsepower, or various other comparative resistance coefficients. The constant values for the C_r taken from each of these curves are restated in Table 2.

To provide a means for readily obtaining the effective horsepower for various prototypes of each of the series forms, curves of effective horsepower versus immersed volume (or displacement in salt-water tons) are given for various even speeds in Appendix 6. The EHP's in these curves have been calculated for bare hull, to which a roughness-allowance coefficient of 0.4×10^{-3} has been added. Standard conditions of salt water at 59 F. were used.

TABLE 2

Net Residual-Resistance Coefficients for Series 58 Forms at Deep Submergence

Model	Net Coefficient	Model	Net Coefficient	Model	Net Coefficient
4154	0.58×10^{-3}	4162	0.17×10^{-3}	4170	0.18×10^{-3}
4155	0.36	4163	0.19	4171	0.13
4156	0.22	4164	0.37	4172	0.13
4157	0.13	4165	0.07	4173	0.13
4158	0.09	4166	0.28	4174	0.10
4159	0.075	4167	0.16	4175	0.32
4160	0.12	4168	0.14	4176	0.41
4161	0.15	4169	0.14	4177	0.16

Curves relating the lengths to the volumes of the prototypes are also given in Appendix 6.

The variation in EHP due to the change in geometrical parameters is shown by the use of "merit curves" in Figures 9 to 14. The EHP's used to construct these curves were calculated for prototypes having equal volumes, namely 60,000 cubic feet (corresponding to 1715 tons) of displaced salt water. In each curve, submerged EHP's for a given form are expressed as ratios to the minimum bare-hull EHP of the group of forms being compared. The ratios are average values for a speed range of 10 to 30 knots and apply to any speed in this range to within 1/2 of 1 percent, changing only because of the small variation of frictional resistance coefficient with Reynolds numbers. They also apply just as closely to any fixed volume comparison between volumes of 20,000 to 100,000 cubic feet. The ratios are, in each case, plotted against the geometrical parameter that is varied. Thus the advantage that can be gained, in terms of percent, by the variation of these parameters can be readily seen. The circle on each curve denotes the parent form.

The broken lines on the merit curves indicate the EHP—including a calculated added EHP due to the addition of horizontal and vertical control surfaces. The increase in EHP due to the addition of the control surfaces was estimated by the following empirical relationship:

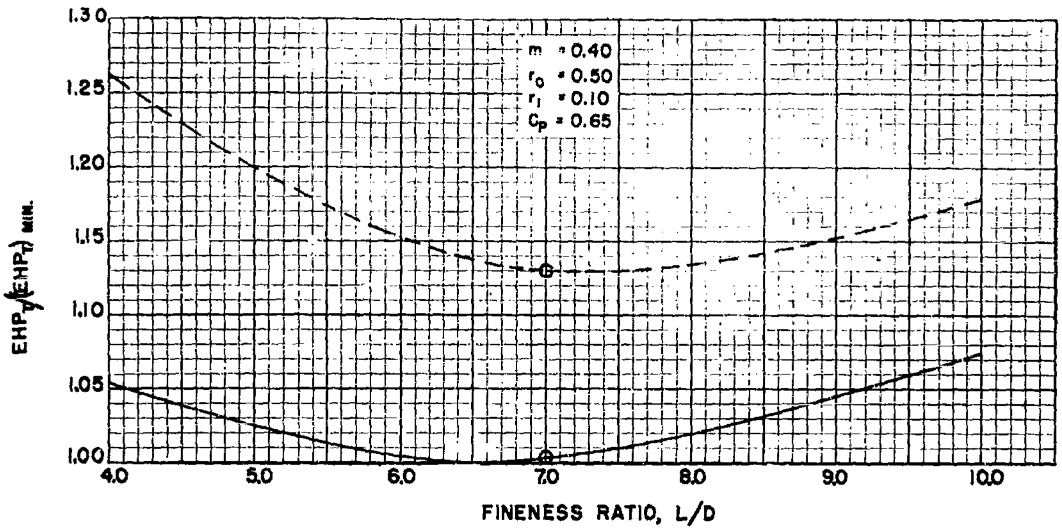


Figure 9 - Merit Curve Showing the Effect of the Variation of Fineness Ratio, L/D, on EHP

The EHP's were calculated for 60,000-cubic-foot prototype operating in salt water of 59 F. using a roughness-allowance coefficient of 0.4×10^{-3} and a C_r for the deeply submerged condition which has been corrected for sand-roughness and strut-interference effects. The EHP's are expressed as ratios to the minimum bare-hull EHP obtained in the given variation. The ratios are averaged over a speed range of 10 to 30 knots. The broken line includes a computed EHP for horizontal and vertical control surfaces. The circle denotes the parent form.

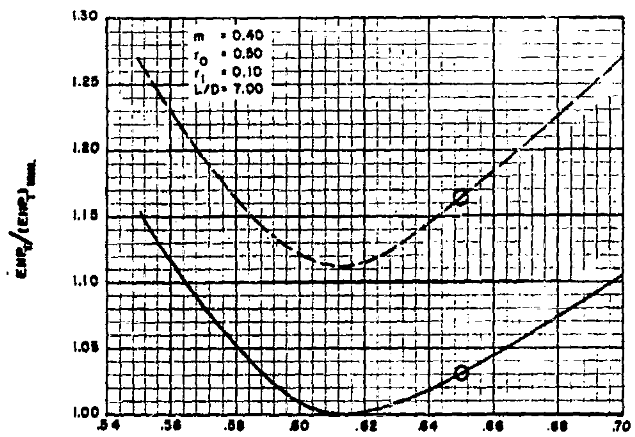


Figure 10 - Merit Curves Showing the Effect of Variation of Longitudinal Prismatic Coefficient, C_p, for an L/D of 7.0 on EHP

See note, Figure 9.

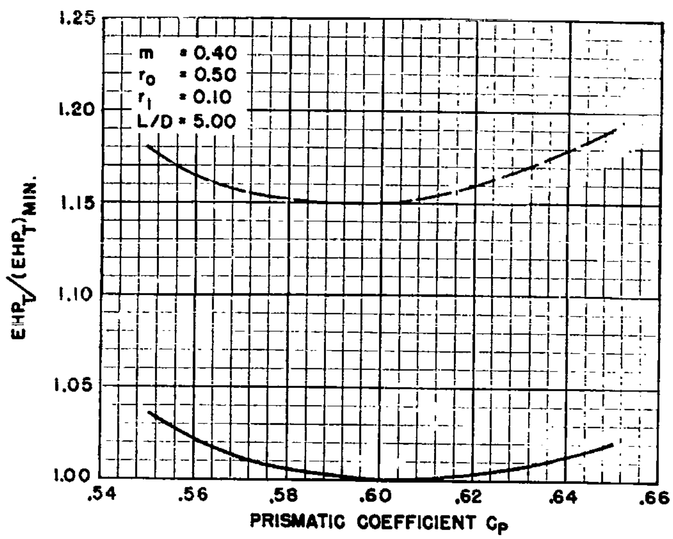


Figure 11 - Merit Curves Showing the Effect of Variation of Longitudinal Prismatic Coefficient, C_p, for an L/D of 5.0 on EHP

See note, Figure 9.

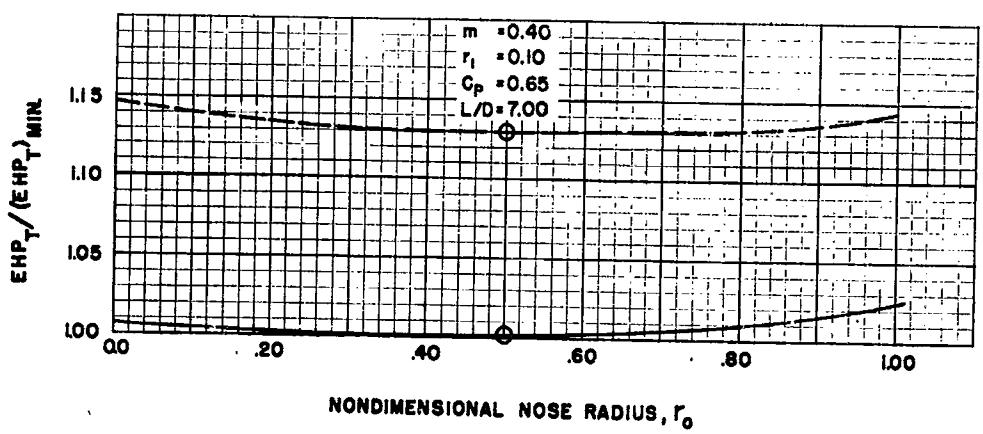


Figure 12 - Merit Curves Showing the Effect of Variation of Nose Radius, r_0, on EHP

See note, Figure 9.

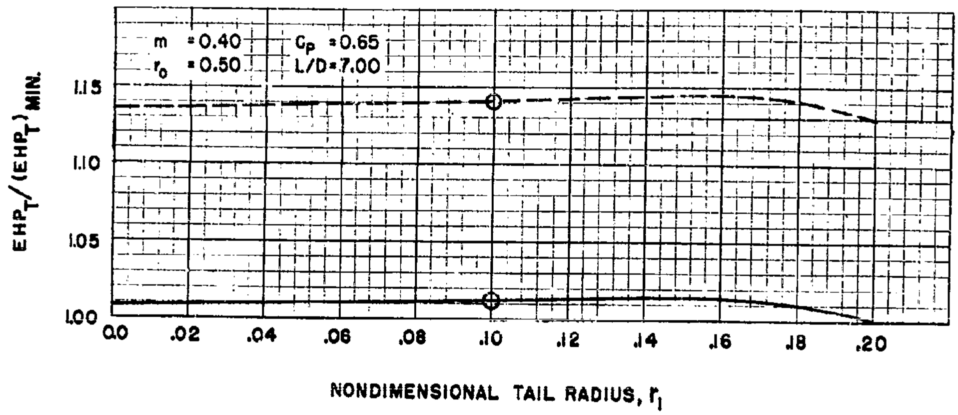


Figure 13 - Merit Curves Showing the Effect of Variation of Tail Radius, r_1, on EHP

See note, Figure 9.

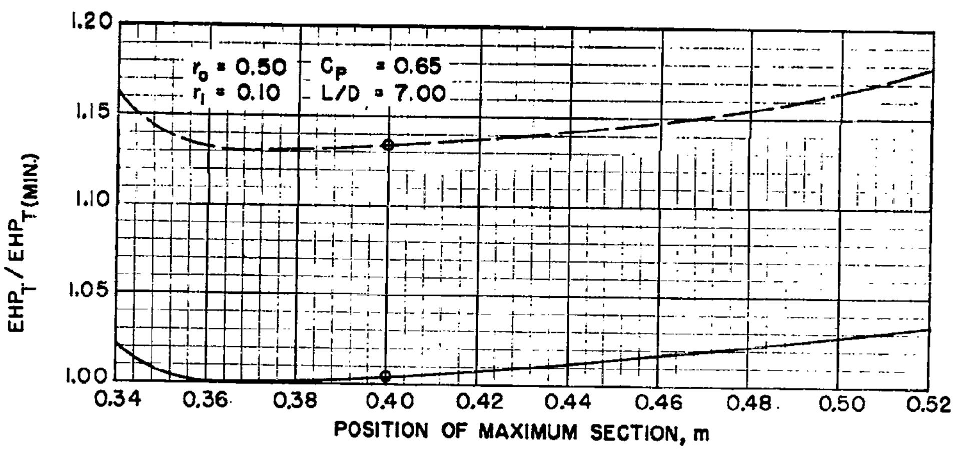


Figure 14 - Merit Curves Showing the Effect of Variation of Position of Maximum Section, m, on EHP

See note, Figure 9.

$$EHP_2 = EHP_1 \left[1 + 2.3 \frac{S_t}{S}\right] \qquad [12]$$

where EHP_2 is the effective horsepower for the bare-hull plus control surfaces,

EHP_1 is the bare-hull effective horsepower,

S_t is the wetted-surface area of the control surfaces,

S is the wetted-area of the bare-hull, and the factor

2.3 was obtained by averaging the results of tests to determine the separate resistances of various types of control surfaces when installed on different classes of submarines.

This empirical factor (2.3) combines the effects of several variables, such as the interference effect between the control surface and the hull, the use of a Reynolds number based on the length of the hull instead of a Reynolds number based on the length of the control surface, and differences in boundary-layer thicknesses or wakes in the neighborhood of the control surface. The resultant effect is a first approximation of the augmentation to the total resistance of the hull due to the addition of the control surfaces. This approximation, although not accurate enough for a quantitative appraisal, serves the purpose of showing the effects of the addition of control surface areas on the merit relationships of Series 58. Although this factor is high compared to control surfaces designed solely on resistance considerations, it is considered fairly representative of present practical control-surface design.

The required control-surface areas for the various forms are shown in Figure 15. The quantities given represent the total areas (both sides) of both horizontal and vertical control surfaces. These areas were predicted from the derivatives obtained from static-stability tests of Series 58 by the method of Reference 4. The basic assumptions used in the derivation were: A directional stability index (dimensional = -0.02 reciprocal second), a constant volume of 60,000 cubic feet, radii of gyration equal to those of prolate spheroids of the same length, and control surfaces having a span equal to the maximum diameter of the form under consideration.

The data derived from the resistance tests of models of Series 58 at the snorkelling conditions are presented in several ways. The net C_r's plotted against Froude number are shown in Appendix 7, as curves for each of the tested depth-to-diameter ratios. These C_r's permit the calculation of EHP's for any geometrically similar prototype within the given range of depth-to-diameter ratios. For comparison purposes, the EHP's have been calculated for 60,000-cubic-foot prototypes operating in salt water of 59 F. at an assumed depth of submergence of 20 feet to the top of the hull at the maximum diameter. These EHP's are shown plotted against speed for each prismatic coefficient in Figure 16 and as cross curves against prismatic coefficient for various even speeds in Figure 17. The EHP's of Figures 16 and 17 are expressed, in Table 3, as ratios to the minimum EHP for deep submergence for each given speed. The purpose of this is to show the magnitude of the snorkelling EHP in percentages which are referred to the same basis as used in Figure 10.

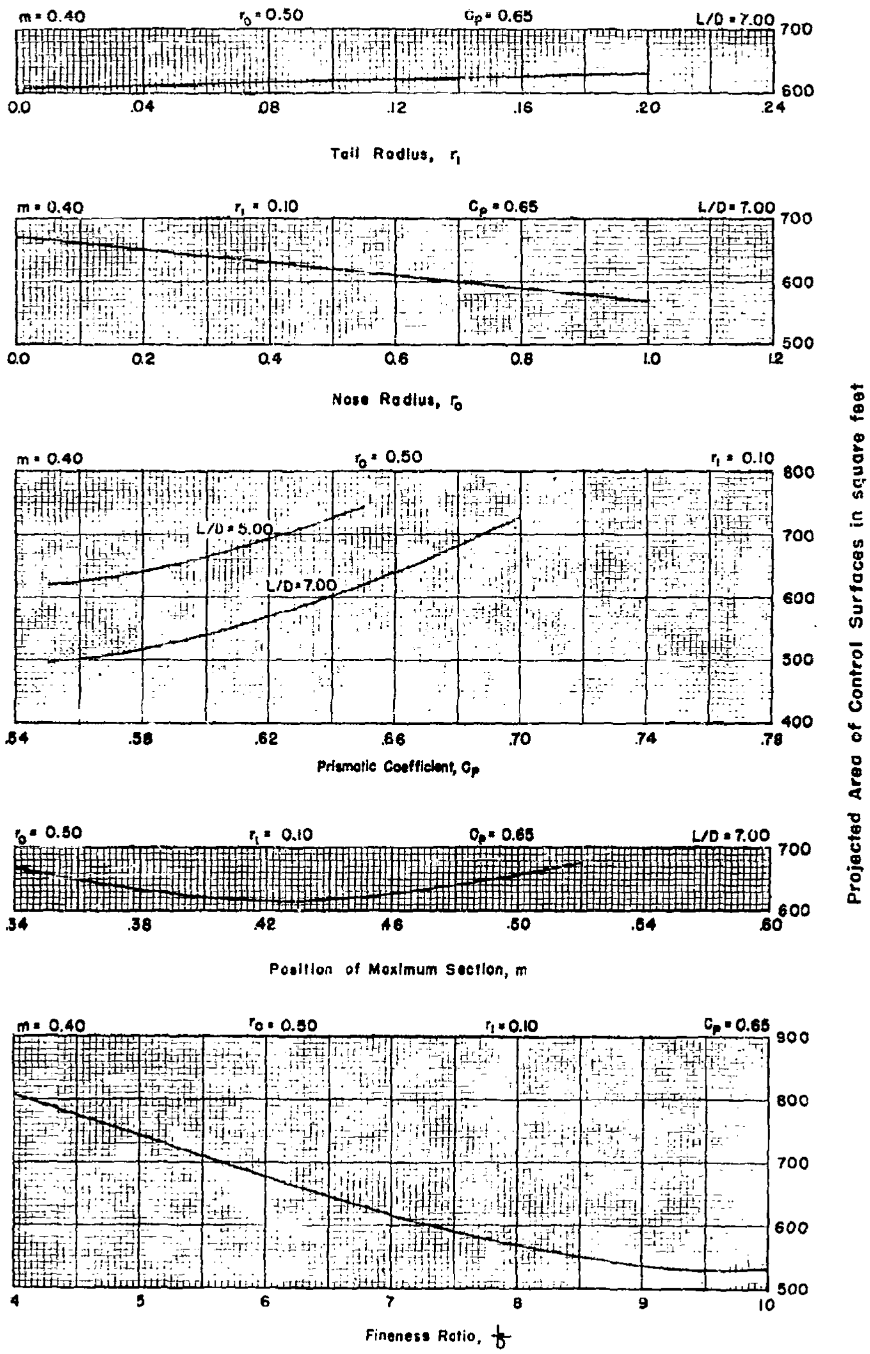


Figure 15 - The Total Control-Surface Area Requirements for 60,000-Cubic-Foot Prototypes of Series 58

The values are the total projected areas (both sides) for horizontal and vertical control surfaces which have been estimated by the method of Reference 4.

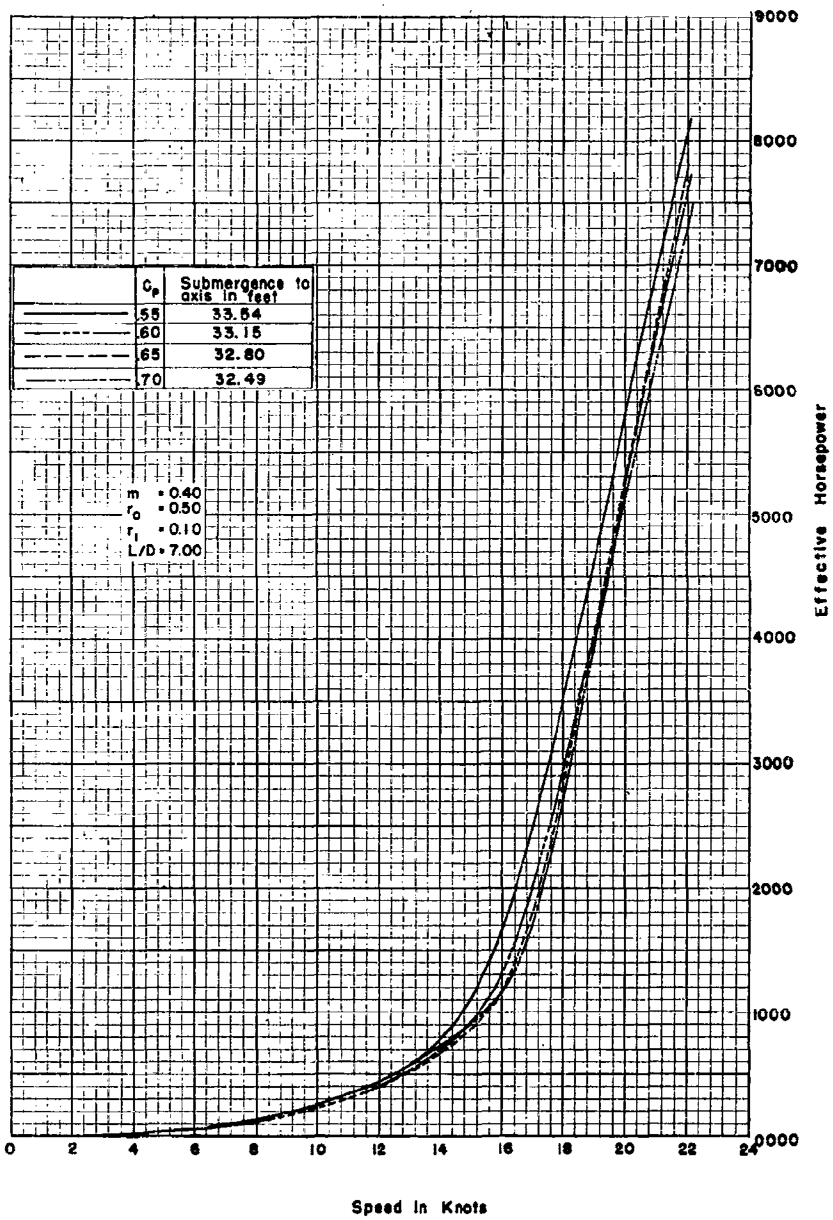


Figure 16 - Total Bare-Hull EHP versus Speed at Various Prismatic Coefficients for 60,000-Cubic-Foot Prototypes of Series 58 Operating at Snorkelling Depth

The EHP's have been calculated for a depth of submergence of 20 feet to the hull at the maximum diameter using a roughness-allowance coefficient of 0.4×10^{-3} and for standard conditions of salt water at 59 F.

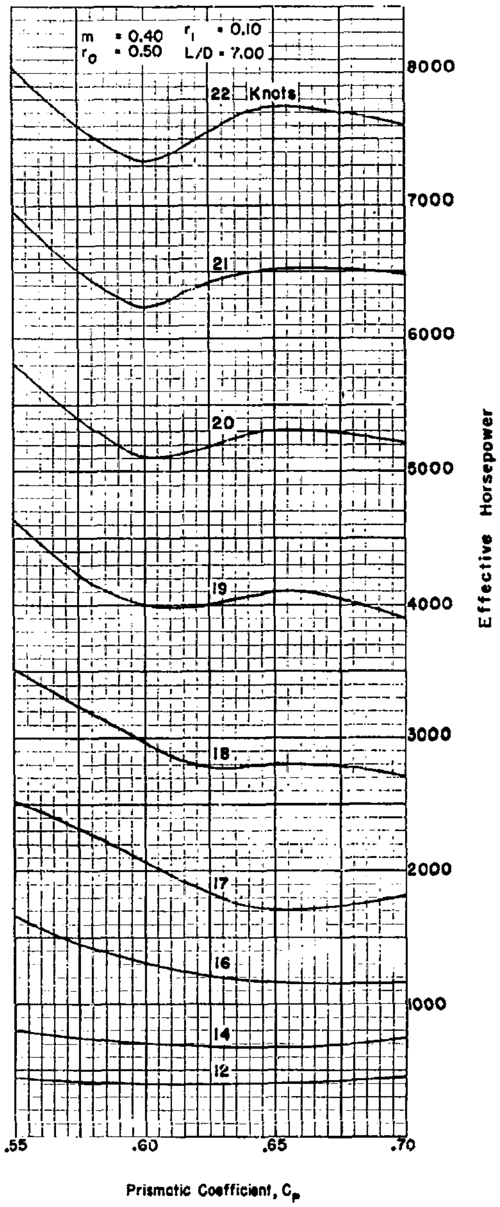


Figure 17 - Total Bare-Hull EHP versus Prismatic Coefficient at Various Even Speeds for 60,000-Cubic-Foot Prototype of Series 58 Operating at Snorkelling Depth

See note, Figure 16.

TABLE 3

Ratios of the EHP's at Snorkelling Condition to the Minimum EHP at Deep Submergence for the Series 58 Variation of Prismatic Coefficient at an L/D = 7.0

The EHP's have been calculated for 60,000-cubic-foot prototypes operating in salt water of 59 F. at an assumed depth of submergence of 20 feet to the top of the hull at the maximum diameter.

Speed in knots	EHP/EHP_{min}			
	C_p = 0.55	C_p = 0.60	C_p = 0.65	C_p = 0.70
12	1.179	1.074	1.060	1.149
14	1.325	1.190	1.129	1.246
16	1.886	1.490	1.319	1.305
18	2.852	2.415	2.278	2.195
20	3.483	3.067	3.177	3.120
22	3.657	3.333	3.521	3.457

DISCUSSION OF RESULTS

The range of the geometrical parameters selected for Series 58 is comparatively narrow; the forms chosen are principally those which might reasonably be used for the shape of external hulls for high-submerged-speed submarines. However, these forms may be applied to airships, high-speed torpedoes, airplane fuselages, sound domes, and numerous types of faired housings. Extension of the series to include the more radical shapes required for other applications has been deferred because of the limitation in time imposed on the first phases of the project. In spite of the fact that the series is restricted in scope, it is believed that Figures 9 to 14 will enable the selection of forms very near to the minimum EHP, within practical design limitations. It will be noted that, although all of the forms of Series 58 may be considered as being within the category of well streamlined shapes, substantial improvement in resistance can be made by the proper selection of geometrical parameters even for such shapes. Other things being equal, bodies of revolution having features such as parallel middle body or very blunt after bodies can be expected to have higher resistances than the bodies contained in Series 58.

The variations of the EHP with the geometrical parameters which are shown in Figures 9 to 14 apply in the strictest sense only to the particular parent that is being varied. It is reasonable to assume, however, that the resistances of other parent forms which are not too dissimilar will vary with change of parameter in very nearly the same manner. Consequently, although the subsequent discussion will strictly pertain only to the forms encompassed by the series, it will apply to other similar forms. The effects of the variation of each geometrical parameter on the EHP for deep submergence are separately discussed in the following paragraphs. The comparisons have been made on the basis of equal volume on the assumption that this quantity is of major importance in the design of submarines. The data in the appendices will, however, enable comparisons to be made—based on length, maximum section, or any other geometrical criterion which is suitable to a particular problem.

The effect of the variation of fineness ratio for constant volume is shown in Figure 9. It can be seen that the minimum bare-hull EHP occurs at an L/D of approximately 6.5. A saving of about 7.5 percent is effected by changing from an L/D of 10, which corresponds approximately to that of a conventional submarine design, to an L/D of 6.5. Figure 2 shows that for a constant volume of 60,000 cubic feet there is approximately a 32 percent reduction in bare-hull wetted-surface area in going from an L/D of 10 to one of 4.0. Since the wetted-surface area is indicative of the amount of frictional EHP, it is apparent that, below an L/D of 6.5, the rate of increase in residual EHP is greater than the decrease of the frictional EHP. This relationship is further demonstrated by Figure 18, in which the total, frictional, and residual horsepowers for a speed of 30 knots have been plotted for 60,000-cubic-foot prototypes of the various L/D's. The frictional EHP's increase almost linearly at a pronounced rate, whereas the residual EHP's tend to level off above an L/D of 8.0. The comparatively sharp increase in residual EHP* at the lower L/D's is probably caused by a thickened boundary layer due to the relatively greater positive pressure gradients over the afterbody of the blunter forms. The thicker boundary layers would result in a larger pressure defect over the tail and consequently an increased pressure drag. The effect of the addition of necessary control-surface area upon the location of the optimum L/D is small, only shifting it to approximately 7.0.

The variation of the prismatic coefficient at an L/D of 7.0 causes the most pronounced change in EHP of any of the parameters covered by the series. It can be seen from Figure 10 that the minimum-bare-hull EHP occurs at a C_p of approximately 0.61. The EHP at this point is approximately 15 percent lower than that of a C_p of 0.55, and 10 percent lower than that of a C_p of 0.70. The changes are almost entirely changes in residual EHP, since the bare-hull wetted areas for prototypes of equal volumes are almost equal. The

*The explanations offered in this report to account for the relative magnitudes of the residual EHP's for the various forms are based on a few preliminary observational experiments conducted in the circulating water channel of the Taylor Model Basin. More precise determination of the causes of form resistance on streamlined bodies will form the subject of future research.

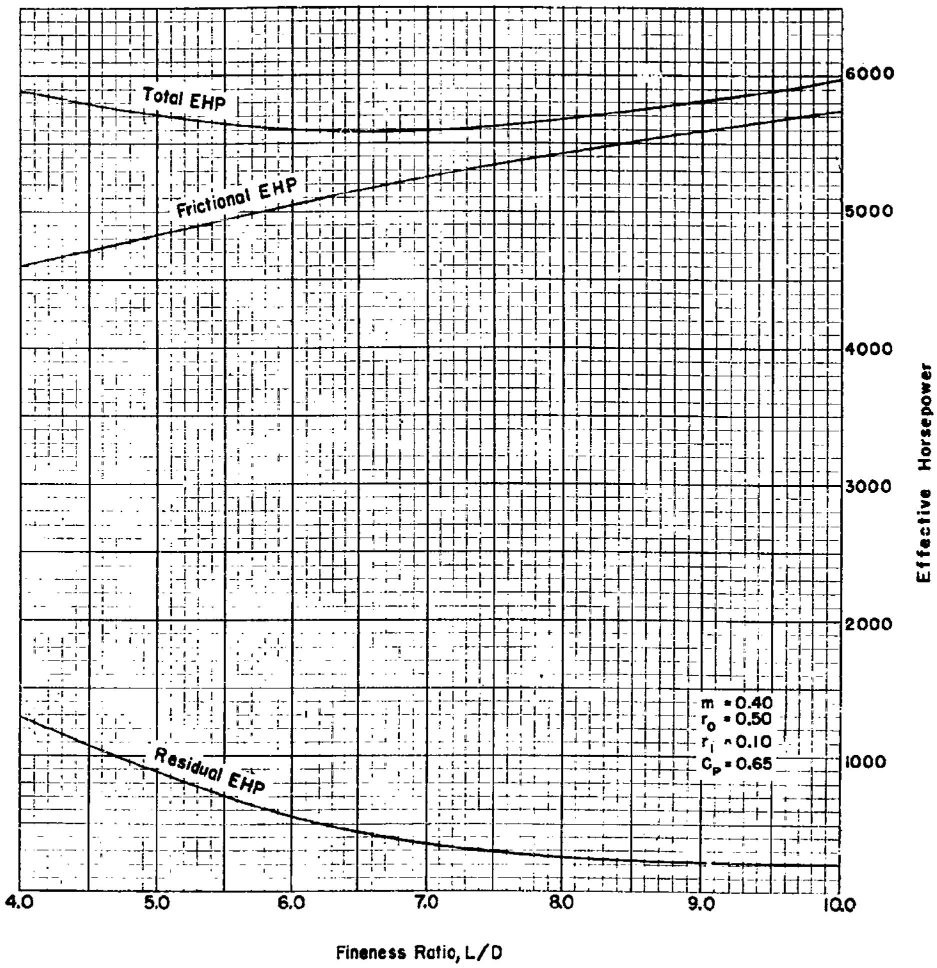


Figure 18 - The Relationship of Total, Frictional, and Residual EHP's for 60,000-Cubic-Foot Prototypes Derived From the L/D Variation of Series 58

The values are for a speed of 30 knots. The total and frictional EHP's include a roughness-allowance coefficient of 0.4×10^{-3}. The residual EHP's have been computed from net C_r's which are for deep submergence and are corrected for sand-roughness and strut-interference effects.

relatively large residual EHP on the C_p of 0.55 is probably caused by a rapid change of slope of the afterbody which produces adverse pressure gradients and consequently a thickened boundary layer. The addition of control surfaces does not materially alter the position of the optimum C_p.

The variation of EHP with C_p at an L/D of 5.0, shown in Figure 11, differs somewhat from that at an L/D of 7.0. Although the minimum occurs at nearly the same value, $C_p = 0.60$, the bare-hull EHP at a C_p of 0.55 is only 4 percent higher than the minimum. The different character of this curve is probably due to the fact that even at the optimum C_p for an L/D of 5.0, a substantial amount of form resistance exists. Consequently, since the boundary layer at the tail is already relatively thick, it is reasonable to expect that the thickness of the boundary layer would not be as sensitive to changes of form as is the case for an L/D of 7.0. The addition of control surfaces does not materially alter the position of the optimum C_p.

The effect of the variation of the nose radius is very small over the range of values tested and consequently the choice of this parameter is not critical. The nose radius of 0.5, used on the parent, appears to be most satisfactory and it does not seem to be advisable to use a nose radius greater than 0.8. The change of nose radius produces a substantial change in forebody and afterbody prismatic coefficient and in the position of the LCB as shown in Figure 3. The latter parameters could be substituted in place of the scale for nose radius in Figure 12 or used interchangeably, to show that these parameters have little effect on resistance over the range tested. The fact that the LCB can be moved quite considerably without much effect upon resistance gives the designer considerable latitude in making his choice of form. The additional resistance computed for tail surfaces does not alter the relative effects of the nose radius.

The variation of the tail radius over the range given in Figure 13 does not result in any significant changes of resistance. The tail radius of 0.2 appears to be most satisfactory for the parent, having a C_p of 0.65, because it results in a more gradual afterbody taper. This probably would not be true at lower C_p's. The addition of control surface areas does not alter the relative comparison of Figure 13.

The position of the maximum section, as shown in Figure 14, does not appear to be critical over the range covered by the series. For the parent used, the optimum position of the maximum section appears to be approximately 0.36. The change in bare-hull EHP is only 3 percent from an m of 0.36 to an m of 0.52. The addition of control surfaces does not materially alter the optimum position of the maximum section.

At snorkelling depths, the effect of the variation of geometrical parameters on EHP is more pronounced, since the effect of wave-making resistance due to surface proximity is also included. As seen in Figure 17 and in Table 3, the choice of the optimum C_p for snorkelling depends upon the speed that is contemplated. At speeds below 12 knots, the C_p for minimum EHP approaches the optimum C_p for deep submergence and consequently the choice of C_p for both conditions would be the same. At speeds of 14 to 17 knots, a C_p of approximately 0.65 would be more desirable for snorkelling, and if these speeds were contemplated, the relative advantage of using the best C_p for deep submergence or that for snorkelling would have to be considered in the design of the hull form. It is assumed that snorkelling speeds above 17 knots are impractical at the present time. It is nevertheless of interest to note the effect of C_p at higher speeds, since the optimum C_p for deep submergence is once more approached. It should be noted, from Table 3, that at a speed of 22 knots the bare hull EHP is of the order of 3 1/2 times the EHP at deep submergence.

The selection of the minimum resistance form must be done advisedly, even within the scope of the series. Since the variation of geometrical parameters has in each case been made from a common parent, the effects of each parameter are not necessarily additive. For example, the nose or tail radius most suitable for the parent form is not necessarily right for the body of optimum C_p. Furthermore, the optimum form may not be unique in that several combinations of the five parameters used in the series may result in equally good resistance forms.

Based on the preceding factors, considering also the effect of the addition of control surfaces, and assuming a design snorkelling speed below 12 knots, one possible optimum resistance form is one having an L/D of 7.0, a C_p of 0.61, an r_o of 0.5, an r_1 of 0.1 and an m of 0.36. The r_1 of 0.1 was selected, instead of the 0.2 indicated by the series results, because the latter value is not compatible with the other parameter changes. Since there are only small changes involved in going from a C_p of 0.61 to a C_p of 0.60 and from an m of 0.36 to an m of 0.40, Model 4165 with a serial of 4005016O-70 has a form that has a resistance of only approximately 1 percent higher than the selected minimum resistance form.

A comparison of the selected minimum resistance form from Series 58 with other existing streamlined bodies of revolution on the basis of equal volume reveals the following: The optimum form has approximately a 3 percent lower bare-hull EHP than the British R101 with an L/D = 5 (TMB Model 4184), and approximately a 6 percent lower bare-hull EHP than the TMB-EPH form with an L/D = 5 (TMB Model 4149). It is especially interesting to note that if the merit curves of Series 58 are entered with the geometrical parameters of the R101 and EPH forms mentioned in the foregoing, the EHP difference is identical to that obtained from the actual tests of these two models, i.e., 3 percent. Furthermore, if the R101 form is compared with the Series 58 form having the same geometrical parameters, the resistances are very nearly equal.

The selected optimum form from Series 58 is compared on an equal-volume basis to a conventional type of submarine in Figure 19. It can be seen that the conventional form has approximately 22 percent greater bare-hull EHP than the optimum form.

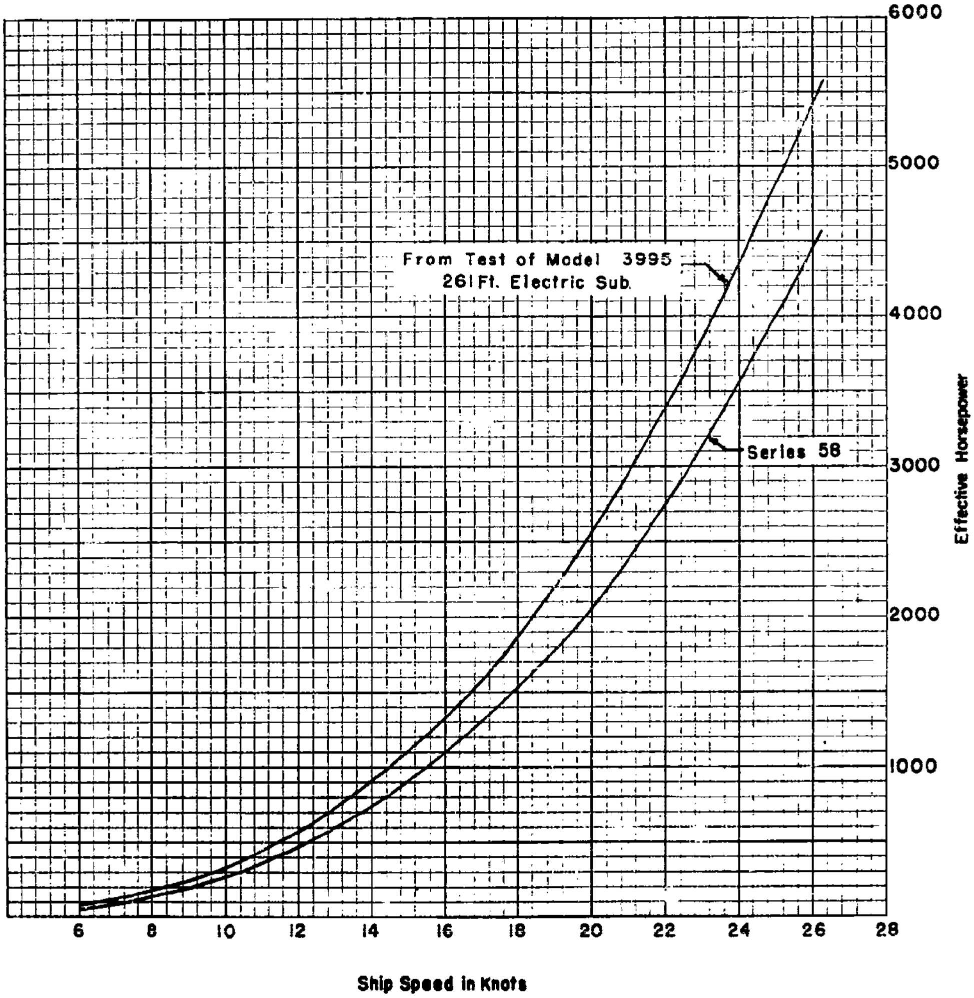


Figure 19 - Comparison of the Total Bare-Hull EHP of an Optimum Form from Series 58 to that of a Conventional Type of Submarine

The EHP for the optimum form was computed for a volume of 84,350 cubic feet equal to that of the conventional type. The values are for deep submergence in salt water of 59 F. using a roughness-allowance coefficient of 0.4×10^{-3}.

It should be emphasized that the optimum form suggested herein is based solely on the resistance performance, which includes the effects of the control surface area required for certain directional stability specifications. The effects of hull shape on propulsive performance will undoubtedly play an important part in the final selection of the optimum form. It is conceivable that the use of a form of lower fineness ratio or fuller afterbody than indicated for minimum resistance may improve the wake and thrust deduction so that a higher hull efficiency is obtained, which will result in a lower shaft horsepower than that obtained with the minimum resistance form. Furthermore, practical considerations such as machinery layout, military characteristics, etc. will also enter into the determination of the final form.

Programs to study the effect of variations in hull form on propulsive characteristics are being planned as an extension of the work with Series 58 and will form the subject of future reports.

CONCLUSIONS

The results of the experiments with Series 58 show that the submerged resistance of streamlined bodies of revolution, whose section area curves may be represented by sixth degree polynomials, will vary with changes in the geometrical parameters which are used to define these bodies. The EHP of equal-volume prototypes of Series 58, equipped with horizontal and vertical control surfaces, changes within the range of geometrical parameters covered by the series as follows:

1. Fineness ratio—The maximum change is approximately 12 percent and there is a minimum EHP at an L/D of 7.0.

2. Prismatic coefficient, L/D = 7.0—The maximum change is approximately 15 percent and there is a minimum EHP at a C_p of 0.61.

3. Prismatic coefficient, L/D = 5.0—The maximum change is approximately 4 percent and there is a minimum EHP at a C_p of 0.60.

4. Nose radius—The maximum change is approximately 2 percent and there is a minimum EHP at an r_0 of 0.5.

5. Tail radius—The maximum change is approximately 1 percent and there is no definite minimum EHP indicated.

6. Position of maximum section—The maximum change is approximately 5 percent and there is a minimum EHP at an m of 0.36.

A minimum resistance form based on the preceding relationships is one having an L/D of 7.0, a C_p of 0.61, an r_0 of 0.5, an r_1 of 0.1, and an m of 0.36.

PERSONNEL

The present series was selected jointly by L. Landweber and the author. The remaining work was carried out by the personnel of the Submarine and Torpedo Powering Section of the David Taylor Model Basin. The experimentation was conducted by F.S. Cauldwell, C.R. Olson, J. Posner, and W. Kopko, assisted by W. Gotthardt. The data were prepared and reduced by J.L. Beveridge assisted by A.D. Williams and T.M. Mahoney.

REFERENCES

1. BuShips CONF ltr C-SS/S1-2(420) of 8 July 1949 to TMB.

2. Landweber, L. and Gertler, M., "The Mathematical Formulation of Bodies of Revolution with Prescribed Geometrical Characteristics," TMB Report 719 (in preparation).

3. Gertler, Morton, "The Prediction of the Effective Horsepower of Ships by Methods in Use at the David Taylor Model Basin," TMB Report 576, December 1947.

4. Landweber, L. and Johnson, J.L., "A Method of Estimating the Dynamic Stability of a Body of Revolution with Tail Surfaces from Measurements of Bare Hull Static Characteristics," TMB CONF Report (in preparation).

APPENDIX 1

MEMORANDUM REVIEWING THE INFORMATION AVAILABLE ON
STREAMLINED BODIES OF REVOLUTION
PRIOR TO SERIES 58

IN REPLY ADDRESS:
DIRECTOR, DAVID TAYLOR
MODEL BASIN, USN.

REFER TO FILE:

C-SS/S1-2(5)
C-A9-17
(524:MG:or)
CONFIDENTIAL

NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON 7, D.C.

for PEACE and SAVINGS BONDS

3 May 1948

MEMORANDUM

To: Officer-in-Charge of Hydromechanics Department

Subj: Research TMB SRD 542/46 - Hydrodynamics of High-Submerged-Speed Submarines - Resistance of Streamline Forms.

Refs: (a) TMB Conference of 25 Mar 46 attended by Dr. Kennard, Mr. Landweber, Mr. Kirstein, Mr. Gertler, and Mr. Abkowitz of TMB.
(b) BuShips Conference of 30 Apr 46 attended by Captain Weaver, Comdr. Tilburne, and Mr. Neidermair of BuShips and Mr. Kirstein, Mr. Gertler and Mr. Abkowitz of TMB.
(c) TMB CONF ltr C-SS/S1-2(5), C-A9-17 of 3 Aug 46.
(d) "Modern Developments in Fluid Dynamics," by S. Goldstein, Volume II, Chapter XI, Section 2 (1939).

Encl: (A) Bibliography of the Resistance of Streamline Bodies of Revolution, dated 31 Jan 47.

1. The purpose of this memorandum is to review the steps taken by the David Taylor Model Basin in the basic research phases of the Program for Investigation of Hydrodynamics of High-Submerged-Speed Submarines, designated as Project SRD 542/46. In addition, general remarks concerning the state of available experimental data on streamline bodies of revolution are made and systematic series models are proposed for testing in order to further this knowledge. The discussion which follows is concerned only with the phase of the program which deals with factors affecting the resistance of these forms. Stability, controllability, and propulsion are not considered herein.

2. At the inception of the High-Submerged-Speed Submarine Program, a conference, Reference (a) was held, to determine the course of action to be taken. It was decided, at this time, that data obtained from wind-tunnel experiments on airship forms might be directly applicable to the ideal submarine form for exclusively submerged operation. It was suggested, therefore, that a complete bibliographical search on this subject matter be made before an experimental program of basin tests was planned.

3. Pursuant thereto, a detailed search of all available sources was made and the bibliography contained in Enclosure (A) was assembled. The bibliography has been divided into two categories; one of which is experimental and deals with the results of tests on

streamline bodies of revolution in wind tunnels, model basins, and on full-scale trials to obtain resistance and related data, and the second which contains papers by various authorities on hydrodynamics giving a theoretical treatment of the same subject matter.

4. A study made to determine the value of these experimental data revealed that in general one or more of the following conditions were present which rendered them unreliable as bases for the proposed program:

a. The values of total resistance coefficient ($C_t = \frac{R_t}{\rho/2 \; S \; V^2}$, where R_t is the total resistance, ρ is the mass density, S is the wetted surface area, and V is the speed at any given Reynolds number $\frac{VL}{\nu}$, where V is the speed, L is the overall length and ν is the kinematic viscosity) for the same model tested in different wind tunnels varied over a wide range. This was due to the various degrees of turbulence in these tunnels.

b. The curves of total resistance coefficient versus Reynolds number for the same model in the same wind tunnel varied greatly when different means were used to artificially stimulate turbulence. The curves did not converge at a given value as normally occurs when the drag experiments are conducted in water. The drag coefficients obtained from tests in an undisturbed air stream and those obtained from tests in an air stream with turbulence induced by wire grids placed at different positions relative to the model differed as much as 200 percent.

c. Most of the available wind tunnel data were obtained at low Reynolds numbers because of the small size of the model used and the low air speed. As a result, most of these data were obtained under conditions of either laminar or transitional flow.

d. The few wind tunnel tests made at high enough Reynolds numbers to ensure turbulence without the use of artificial stimulation produced too few experimental observations to discern a trend in the data.

e. As far as can be determined, there have been no tests of systematic series of streamline bodies of revolution conducted in the wind tunnels. The majority of the tests were made either on specific airship designs or isolated cases of streamlined bodies of revolution. Very little or no attempt was made to relate the effect of variables of size and shape to resistance.

f. The full-scale data available were obtained from deceleration tests and the approximations relied upon make these data unreliable for any basic study.

g. The model basin test results which are available are inadequate because of the use of small models, low towing speeds, and failure to take accurate temperature readings. As a result, most of these data were obtained under transitional flow conditions. The following excerpts from Reference (d) confirm some of the above mentioned statements:

"Before that date (1929) much experimental work had been conducted on streamline bodies, but (for lack of facilities as well as knowledge) the Reynolds numbers were as a rule so low that the results are of little practical value.

"In most of the fairly numerous experiments made to determine the effect of the variation of fineness ratio, the Reynolds number has been of the order of 10^5 or 10^6 so that the boundary layer has in all probability been partly laminar and partly turbulent.

"Other experiments have been unsatisfactory because the fineness ratio has been altered by the insertion of different lengths of cylindrical body between the nose and tail. It is not clear what purpose such tests are expected to serve, since, given a well-shaped nose and tail and junction between them, it seems that the introduction of a cylindrical portion must increase the drag."

5. The inadequacies of the existing data led the Taylor Model Basin to suggest to the Bureau of Ships in Reference (b) that systematic experiments of streamlined bodies of revolution be conducted. It was agreed in this conference that, although these forms might not be practical for submarine hulls, the information gained from tests of the bodies would provide valuable guides for submarine hull design and add much to the basic knowledge of the subject. As the outcome of this conference, provision for experiments on these forms were incorporated in paragraph 4a of Reference (c) as part of the general research program for the hydrodynamics of high-submerged-speed submarines.

6. The Taylor Model Basin has conducted submerged resistance tests on the bare hulls of several 20-foot submarine models. These models were towed at high enough speeds to ensure reliable data. It was noted that the value of residual resistance coefficient, $C_r = \frac{R}{\rho/2\ S\ V^2}$ where R is the residual resistance, was approximately the same for each model and equal to 0.0002. This suggests that, in streamline bodies having a length-diameter ratio of from 10 to 12, the prime factor which affects the resistance is the wetted surface area. It should be mentioned, however, that the volumes of these models were not the same.

7. The variables which are likely to affect the resistance of streamline bodies of revolution to the greatest extent expressed in non-dimensional form are: $\frac{h}{L}$, $\frac{D}{L}$, $\frac{S}{L^2}$, and $\frac{\forall}{L^3}$

where L is the overall length of the body,
h is the distance of the section of maximum diameter from the nose,
D is the diameter of the maximum section,
S is the wetted surface area, and
$\forall$ is the volume.

A systematic study of the effects of each of these variables can be made by a series of models which would vary one of the variables at a time while the others remain constant. Since the differences of wetted surface area would be accounted for in the non-dimensional coefficient, $C_t = \frac{R_t}{\rho/2\ S\ V^2}$, only the three remaining variables need be considered. Thus, if three models were used for each of the variations, the resultant series would be composed of 27 models. The number of models required might possibly be diminished by testing models at selected end points and determining whether the magnitude of the resistance changes warrant the testing of models at intermediate points.

8. Although it is true that the relationships which arise out of such a series may only be strictly accurate for the particular family of forms tested, it is believed that the general relationships will not deviate greatly in other similar families of reasonably streamline forms.

9. In addition to investigating the effects of the variables given above, it may be desirable to investigate details of shape such as curvature at the nose, curvature at the maximum section, curvature at the tail, and the slope of the longitudinal section at various points. Consequently, the family of forms chosen for the series work should also be able to define these variations.

10. A family of streamline bodies of revolution which apparently satisfies most requirements is being presently developed. The family is derived from the power series equation:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + \ldots a_nS^n$$

where y is the non-dimensional ordinate, Y/D,

x is the non-dimensional abscissa, X/L, and

a_1, a_2, a_3, etc. are arbitrary constants having numerical values which are dependent upon the limitations imposed on the basic equation.

The degree of the basic equation is chosen to accommodate the number of variables which are used to define the shape of the body. Typical features of shape which can be specified are: Curvature of the nose, maximum section, and tail; position of maximum section, and volume.

11. The lines of investigation suggested for the bodies comprising the proposed series are outlined as follows:

1. Resistance tests at zero angle of trim, for
   - a. Deep Submergence
   - b. Intermediate Depths
   - c. Surface
2. Resistance tests at various angles of trim, for
   - a. Deep Submergence
   - b. Intermediate Depths
   - c. Surface
3. Boundary layer studies, at
   - a. Deep Submergence
4. Point pressure studies, at
   - a. Deep Submergence
   - b. Intermediate Depths
   - c. Surface

Because of the amount of preparation and testing time required, it is proposed that the boundary layer and point pressure work be confined to only one or two selected models. It is also proposed to include tests of the series models equipped with various nose shapes designed for the purpose of improving surface performance without serious detrimental effect on submerged performance.

12. In addition to the tests of the hull forms, it is proposed that the design of appendages be studied in conjunction with the series models in the following manner:

1. Resistance of control surfaces
    a. Effect of size
    b. Effect of shape
    c. Effect of location
2. Resistance of conning tower assemblies
    a. Effect of size
    b. Effect of shape
    c. Effect of location
3. Resistance of sound domes
    a. Effect of size
    b. Effect of shape
    c. Effect of location

13. The details concerning the series models, the most practical sizes of models and the extent of the experiments will be determined as the work progresses.

M. GERTLER
Submarine and Torpedo
Powering Group

C-SS/S1-2(5)
C-A9-17

31 January 1946

ENCLOSURE (A)

BIBLIOGRAPHY OF THE RESISTANCE OF STREAMLINE BODIES OF REVOLUTION

EXPERIMENTAL

1. Jones, Williams, and Brown, "Tests on Two Streamline Bodies in the Compressed Air Tunnel," A.R.C. Reports and Memoranda No. 1710, 1936.

2. Simmons and Brown, "An Experimental Investigation of Boundary Layer Flow," A.R.C. Reports and Memoranda No. 1547, 1935.

3. Arnstein, Karl, "Some Design Aspects of Rigid Airships," Transactions of A.S.M.E., 1934.

4. Garland and Fulton, "Improving Airship Performance," Transactions of A.S.M.E., 1934.

5. Lyon, H.M., "A Study of Flow in the Boundary Layer of Streamline Bodies," A.R.C. Reports and Memoranda No. 1622, 1934.

6. Gehman, S.D. and Mallory, G.C., "Skin Friction of Various Surfaces," Journal of the Franklin Institute, Volume 216, No. 3, 1933.

7. Abbot, Ira H., "The Drag of Two Streamline Bodies as Affected by Protuberances and Appendages," N.A.C.A. Technical Report No. 450, 1933.

8. Freeman, Hugh B., "Pressure Distribution Measurements on the Hulls and Fins of a 1/40 Scale Model of the U.S. Airship Akron," N.A.C.A. Technical Report No. 443, 1933.

9. Freeman, Hugh B., "Force Measurements on a 1/40 Scale Model of the U.S. Airship Akron," N.A.C.A. Technical Report No. 432, 1932.

10. Freeman, Hugh B., "Measurements of Flow in the Boundary Layer of a 1/40 Scale Model of the U.S. Airship Akron," N.A.C.A. Technical Report No. 430, 1932.

11. Klemperer, W., "Windkanalversuche an Einem Zeppelin-Luftschiff-Modell." Abhandlungen airs der Aerodynamischen Institut an der Technischen Hochschule, Aachen, 1932.

12. Lyon, H.M., "The Effect of Turbulence on the Drag of Airship Models," A.R.C. Reports and Memoranda No. 1511, 1932.

13. Upson, R.H. and Klikoff, W.A., "Application of Practical Hydrodynamics to Airship Design," N.A.C.A. Technical Report No. 405, 1932.

14. Abbot, Ira H., "Airship Model Tests in the Variable Density Wind Tunnel," N.A.C.A. Technical Report No. 394, 1931.

15. Thompson, F.L. and Kirschbaum, H.W., "The Drag Characteristics of Several Airships Determined by Deceleration Tests," N.A.C.A Technical Report No. 397, 1931.

16. Dryden, H.L. and Kuethe, A.M., "Effect of Turbulence in Wind Tunnel Measurements," N.A.C.A. Technical Report No. 342, 1930.

C-SS/S1-2(5)
C-A9-17

17. Owen and Hutton, "Investigation of the Boundary Layers and the Drags of Two Streamline Bodies," A.R.C. Reports and Memoranda No. 1271, 1930.

18. von Kármán, T., "Berechnung der Druckvertichung an Luftschiffkorfrern," Translated in N.A.C.A. Technical Memorandum No. 574, 1930.

19. Simmons, "Experiments Relating to the Flow in the Boundary Layer of an Airship Model," A.R.C. Reports and Memoranda No. 1268, 1930.

20. Blakemore, Boyle, and Meadowcroft, "Design, Construction and Handling of Nonrigid Airships," Transactions of the A.S.M.E., 1929.

21. Zahm, A.F., Smith, R.H., and Louden, F.A., "Drag of C-Class Airship Hulls of Various Fineness Ratios," N.A.C.A. Technical Report No. 291, 1928.

22. Arnstein, Karl, "Development of Large Commercial Rigid Airships," Transactions of A.S.M.E., 1927-1928.

23. Ackeret, J., "Removing Boundary Layer by Suction," N.A.C.A. Technical Memorandum No. 395, 1927.

24. Hemke, Paul E., "Measurement of Pressure Through Tubes in Pressure Distribution Tests," N.A.C.A. Technical Report No. 270, 1927.

25. Higgins, G.J., "Tests of the N.P.L. Airship Models in the Variable Density Wind Tunnel," N.A.C.A. Technical Note No. 264, 1927.

26. Havill, Clinton H., "The Drag of Airships - Drag of Bare Hulls - II," N.A.C.A. Technical Note No. 248, 1926.

27. Havill, Clinton H., "The Drag of Airships - I," N.A.C.A. Technical Note No. 247, 1926.

28. Schrenk, Oscar, "Experiments With a Sphere From Which the Boundary Layer is Removed by Suction," N.A.C.A. Technical Memorandum No. 388, 1926.

29. Crowley, J.W., Jr., and DeFrance, S.J., "Pressure Distribution on the C-7 Airship," N.A.C.A. Technical Report No. 223, 1925.

30. Tuckerman, L.B., "Water Model Tests for Semi-Rigid Airships," N.A.C.A. Technical Report No. 211, 1925.

31. Zahm, A.F., "Air Forces, Moments and Damping on Model of Fleet Airship Shenandoah," N.A.C.A. Technical Report No. 215, 1925.

32. Crocco, G.A., "Effect of Ratio Between Volume and Surface Area of Airships," N.A.C.A. Technical Memorandum No. 280, 1924.

33. Durr, L., "The American Airship ZR-3," N.A.C.A. Technical Memorandum No. 286, 1924.

34. Zahm, A.F., Smith, R.H., and Hill, G.C., "The Drag of "C" Class Airship Hull with Varying Length of Cylindrical Midships," N.A.C.A. Technical Report No. 138, 1922.

35. Jones, R. and Bell, A.H., "The Pressure Distribution over a Model of the Hull of Airship R. 33," A.R.C. Reports and Memoranda No. 801 (Ae. 55), 1922.

C-SS/S1-2(5)
C-A9-17

36. Frazer, R.A. and Gadd, A.G., "The Prediction of the Resistance of Rigid Airship R. 33," A.R.C. Reports and Memoranda No. 827, 1922.

37. Jones, Williams, and Bell, "Experiments on Model of a Rigid Airship of New Design," A.R.C. Reports and Memoranda No. 802, 1921-1922.

38. Pannell, J.R., Frazer, R.A., and Bateman, H., "Experiments on Rigid Airship R. 32 - Part III, Measurement of Resistance and Airspeed," A.R.C. Reports and Memoranda No. 813 (Ae. 64), 1921.

39. Munk, M., "The Drag of Zeppelin Airships," N.A.C.A. Technical Report No. 117, 1921.

40. Riabouchinsky, D.P., "On the Resistance of Spheres and Ellipsoids in Wind Tunnels," N.A.C.A. Technical Note No. 44, 1921.

41. Jones, R. and Williams, "Experiments on a Model of Rigid Airship R. 38," A.R.C. Reports and Memoranda No. 799 (Ae. 54), 1920.

42. Jones, R., Williams, D.H., and Bell, A.H., "Experiments on a Model of Rigid Airship R. 29," A.R.C. Reports and Memoranda No. 714, 1920.

43. Pannell, J.R., "Preliminary Experiments on Non-Rigid Airship S.S.E. 3 100,000 with a Consideration of the Performance Data of Various Types of S.S. Airships," A.R.C. Reports and Memoranda No. 693, 1920.

44. Stahl, Frederick, "Rigid Airships," N.A.C.A. Technical Memoranda No. 237, 1920.

45. Pannell, J.R. and Jones, R., "Resistance Experiments on Four Models of Proposed Non-Rigid Airship Envelopes," A.R.C. Reports and Memoranda No. 646, 1920-21.

46. Pannell, J.R., Jones, R. and Pell, G.N., "The Prediction from Model Experiments of the Resistance of an Airship of the 23 Class," A.R.C. Reports and Memoranda No. 619, 1919-1920.

47. Jones and Williams, "The Distribution of Pressure Over the Surface of Airship Model U721 Together with a Comparison With the Pressure Over a Spheroid," A.R.C. Reports and Memoranda No. 600, 1918-1919.

48. Pannell, J.R. and Jones, R., "Experiments in a Wind Channel on Elongated Bodies of Approximately Streamline Form," A.R.C. Reports and Memoranda No. 564, 1918.

49. Pannell, J.R.,and Jones, R., "Experiments on a Model of a Modified Form of the N.S. Non-Rigid Airship," A.R.C. Reports and Memoranda No. 482, 1918.

50. Pannell, J.R. and Jones, R., "Experiments on a Model of the 23 Class Airship," A.R.C. Reports and Memoranda No. 456, 1918.

51. Pannell, J.R. and Campbell, N.R., "The Variation of the Resistance of Rigid Airships Models with the Scale and the Wind Speed," A.R.C. Reports and Memoranda No. 302, 1916.

52. Relf, E.F., "An Estimation of the Variation of the Drag Coefficient of a Rigid Airship Form from Model Size to Full Scale," A.R.C. Reports and Memoranda No. 245, 1916.

C-SE/S1-2(5)
C-A9-17

53. Wieselsberger, Z.F., "Experiments on Model Balloons and the Resistance of Various Kinds of Surfaces," Flugtechnik, U. Motorl, September 1915.

54. Fukrmann, G., "Theoretische and Experimentelle Untersuchungen an Ballonmodellen" Jarbuch Motorlufschiff-Studiengesellschaft, Berlin Springer, 1911-1912.

THEORETICAL

55. Goldstein, S., "Modern Developments in Fluid Dynamics," Vol. II, Chapter XI Entitled, "Flow Past Solid Bodies of Revolution," 1938.

56. Clauser, Milton and Clauser Francis, "The Effect of Curvature on the Transition from Laminar to Turbulent Boundary Layer," N.A.C.A. Technical Note No. 613, 1937.

57. Gurjienko, G., "Universal Logarithmic Law of Velocity Distribution as Applied to the Investigation of Boundary Layer and Drag of Streamline Bodies at Large Reynolds Number," N.A.C.A. Technical Memorandum No. 842, 1937.

58. Munk, M., "The Computation of Apparent Mass of Dirigibles," Journal of Aeronautical Sciences, Vol. 2, No. 3, May 1935.

59. "The Boundary Layer and Skin Friction For a Figure of Revolution at Large Reynolds Numbers," Daniel Gugenheim Airship Institute, Akron, Ohio, No. 2, 1935.

60. Fediaevsky, C.C., "The Boundary Layer and the Drag of a Body of Revolution at Large Reynolds Number," Journal of Aeronautical Sciences, Vol. 3, No. 1, September 1935.

61. Kaplan, Karl, "Potential Flow Abo t Elongated Bodies of Revolution," N.A.C.A. Technical Report No. 516, 1935.

62. Moore, N.B., "Application of Kármán Logarithmic Law to Prediction of Airship Hull Drag," Journal of Aeronautical Sciences, Vol. 2, No. 1, January 1935.

63. Smith, R.H., "Longitudinal Potential Flow About an Arbitrary Body of Revolution with Application to the Airship Akron," Journal of the Aeronautical Sciences, Vol. 3, No. 1, September 1935.

64. Lyon, H.M., "The Drag of Streamline Bodies," Aircraft Engineering, September 1934.

65. Dryden, Murnagham and Bateman, "Hydrodynamics," Chapter II Section 20 Entitled, "Flow about an Obstacle Whose Surface is one of Revolution," 1932.

66. Lotz, I., "Calculation of Potential Flow Past Airship Bodies in Yaw," N.A.C.A. Technical Memorandum No. 675, 1932.

67. Havelock, T.H., "The Wave Resistance of an Ellipsoid," Proceedings of the Royal Society of London, 1931.

68. Benndorf, H., "Motion of a Solid Body in a Liquid with Friction," Physik 2, 1930.

69. Jones, B.M., "Skin Friction and Drag of Streamline Bodies," A.R.C. Reports and Memoranda No. 1199, 1929.

C-SS/S1-2(5)
C-A9-17

70. "Sur une Formule pour le calcul de la Resistance d'un solid dans un Fluide Parfait Incompressible," Comptes Rendu, 189, 1929.

71. Bickley, W.G., "The Influence of Vortices Upon the Resistance Experienced by Solids Moving Through a Liquid," Proceedings of the Royal Society of London, A119, 1928.

72. Taylor, G.I., "The Energy of a Body Moving in an Infinite Fluid with an Application to Airships," Proceedings of the Royal Society of London A120, 1928.

73. Millikan, Clark B., "The Boundary Layer and Skin Friction for a Figure of Revolution," Journal of Applied Mechanics, APM 54-3, 1932.

74. Jones, R., "The Distribution of Normal Pressures on a Prolate Spheroid," Philosophical Transactions, 226, 1927.

75. Zahm, A.F., "Flow and Drag Formulas for Simple Quadrics," N.A.C.A. Technical Report No. 253, 1926.

76. Ames, J.S., "A Resume of the Advances in Theoretical Aeronautics Made by Max M. Munk," N.A.C.A. Technical Report No. 213, 1925.

77. "Reaction en Regime Permanent d'un Fluide Incompressible Parfait sur un Solide Immerge," Comptes Rend 181, 1925.

78. "Sur Quelques Cos de Mouvements Irrotationnels a Trois Dimensions," Comptes Rend 181, 1925.

79. Swaim, L.M., "On the Turbulent Wake Behind a Body of Revolution," Proceedings of the Royal Society of London, A125, 1925.

80. Burgess, C.P., "A Method of Determining the Dimensions and Horsepower of an Airship for any Given Performance," N.A.C.A. Technical Note No. 194, 1924.

81. Maatz, H., "Recent Researches in Airship Construction Part I - Forces of Flow on a Moving Airship and the Effect of Control Surfaces," N.A.C.A. Technical Memorandum, 1924.

82. Munk, Max M., "Note on the Pressure Distribution over the Hull of Elongated Airships with Circular Cross-Section," N.A.C.A. Technical Note No. 192, 1924.

83. Munk, Max M., "Remarks on the Pressure Distribution over the Surface of an Ellipsoid, Moving Translationally through a Perfect Fluid," N.A.C.A. Technical Note No. 196, 1924.

84. Weiselsburger, C., "Air Forces Exerted on Streamline Bodies with Round or Square Cross Sections When Placed Obliquely to the Air Stream," N.A.C.A. Technical Memorandum No. 267, 1924.

85. Munk, Max M., "The Aerodynamic Forces on Airship Hulls," N.A.C.A. Technical Report No. 184, 1923.

86. Taylor, G.I., "The Motion of Ellipsoidal Particles in a Viscous Fluid," Proceedings of the Royal Society of London, A103, 1923.

APPENDIX 2

TABLES OF OFFSETS FOR SERIES 58

The Nondimensional Abscissas and Ordinates, the Dimensional Abscissas and Ordinates for a 9-foot Model, and other Geometrical Particulars are Given for Each Form of Series 58 in the Following Pages.

Model 4154

Serial 40050165-40

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1439	3.885
.04	4.32	.2059	5.559
.06	6.48	.2537	6.850
.08	8.64	.2934	7.922
.10	10.80	.3272	8.834
.12	12.96	.3565	9.626
.14	15.12	.3818	10.309
.16	17.28	.4037	10.900
.18	19.44	.4226	11.410
.20	21.60	.4388	11.848
.22	23.76	.4526	12.220
.24	25.92	.4641	12.531
.26	28.08	.4737	12.790
.28	30.24	.4815	13.001
.30	32.40	.4878	13.171
.32	34.56	.4925	13.298
.34	36.72	.4959	13.389
.36	38.88	.4982	13.451
.38	41.04	.4996	13.489
.40	43.20	.5000	13.500
.42	45.36	.4997	13.492
.44	47.52	.4986	13.462
.46	49.68	.4968	13.414
.48	51.84	.4944	13.349
.50	54.00	.4917	13.276
.52	56.16	.4882	13.181
.54	58.32	.4844	13.079
.56	60.48	.4799	12.957
.58	62.64	.4749	12.822
.60	64.80	.4692	12.668
.62	66.96	.4629	12.498
.64	69.12	.4557	12.304
.66	71.28	.4478	12.091
.68	73.44	.4388	11.848
.70	75.60	.4287	11.575
.72	77.76	.4174	11.270
.74	79.92	.4046	10.924
.76	82.08	.3905	10.544
.78	84.24	.3744	10.109
.80	86.40	.3566	9.628
.82	88.56	.3368	9.094
.84	90.72	.3146	8.494
.86	92.88	.2901	7.833
.88	95.04	.2630	7.101
.90	97.20	.2330	6.291
.92	99.36	.2000	5.400
.94	101.52	.1635	4.415
.96	103.68	.1230	3.321
.98	105.84	.0771	2.082
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

Where $a_1 = + \ 1.000000$

$a_2 = + \ 2.149653$

$a_3 = - \ 17.773496$

$a_4 = + \ 36.716580$

$a_5 = - \ 33.511285$

$a_6 = + \ 11.418548$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7887$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4644$

Model Particulars:

Length, ft	9.000
Diameter, ft	2.250
Nose radius, ft	0.2813
Tail radius, ft	0.0563
Wetted surface, ft^2	50.18
Volume, ft^3	23.26
Longitudinal center of buoyancy, ft from nose	4.180

Model 4155 Serial 40050165-50

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1439	3.108
.04	4.32	.2059	4.447
.06	6.48	.2537	5.480
.08	8.64	.2934	6.337
.10	10.80	.3272	7.068
.12	12.96	.3565	7.700
.14	15.12	.3818	8.247
.16	17.28	.4037	8.720
.18	19.44	.4226	9.128
.20	21.60	.4388	9.478
.22	23.76	.4526	9.776
.24	25.92	.4641	10.025
.26	28.08	.4737	10.232
.28	30.24	.4815	10.400
.30	32.40	.4878	10.536
.32	34.56	.4925	10.638
.34	36.72	.4959	10.711
.36	38.88	.4982	10.761
.38	41.04	.4996	10.791
.40	43.20	.5000	10.800
.42	45.36	.4997	10.794
.44	47.52	.4986	10.770
.46	49.68	.4968	10.731
.48	51.84	.4944	10.679
.50	54.00	.4917	10.621
.52	56.16	.4882	10.545
.54	58.32	.4844	10.463
.56	60.48	.4799	10.366
.58	62.64	.4749	10.258
.60	64.80	.4692	10.135
.62	66.96	.4629	9.999
.64	69.12	.4557	9.843
.66	71.28	.4478	9.672
.68	73.44	.4388	9.478
.70	75.60	.4287	9.260
.72	77.76	.4174	9.016
.74	79.92	.4046	8.739
.76	82.08	.3905	8.435
.78	84.24	.3744	8.087
.80	86.40	.3566	7.703
.82	88.56	.3368	7.275
.84	90.72	.3146	6.795
.86	92.88	.2901	6.266
.88	95.04	.2630	5.681
.90	97.20	.2330	5.033
.92	99.36	.2000	4.320
.94	101.52	.1635	3.532
.96	103.68	.1230	2.657
.98	105.84	.0771	1.665
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 2.149653$

$a_3 = - \ 17.773496$

$a_4 = + \ 36.716580$

$a_5 = - \ 33.511285$

$a_6 = + \ 11.418548$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7810$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4644$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.800
Nose radius, ft	0.1800
Tail radius, ft	0.0360
Wetted surface, ft^2	39.75
Volume, ft^3	14.89
Longitudinal center of buoyancy, ft from nose	4.180

Model 4156

Serial 40050165-60

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1439	2.590
.04	4.32	.2059	3.706
.06	6.48	.2537	4.567
.08	8.64	.2934	5.281
.10	10.80	.3272	5.890
.12	12.96	.3565	6.417
.14	15.12	.3818	6.872
.16	17.28	.4037	7.267
.18	19.44	.4226	7.607
.20	21.60	.4388	7.898
.22	23.76	.4526	8.147
.24	25.92	.4641	8.354
.26	28.08	.4737	8.527
.28	30.24	.4815	8.667
.30	32.40	.4878	8.780
.32	34.56	.4925	8.865
.34	36.72	.4959	8.926
.36	38.88	.4982	8.968
.38	41.04	.4996	8.993
.40	43.20	.5000	9.000
.42	45.36	.4997	8.995
.44	47.52	.4986	8.975
.46	49.68	.4968	8.942
.48	51.84	.4944	8.899
.50	54.00	.4917	8.851
.52	56.16	.4882	8.788
.54	58.32	.4844	8.719
.56	60.48	.4799	8.638
.58	62.64	.4749	8.548
.60	64.80	.4692	8.446
.62	66.96	.4629	8.332
.64	69.12	.4557	8.203
.66	71.28	.4478	8.060
.68	73.44	.4388	7.898
.70	75.60	.4287	7.717
.72	77.76	.4174	7.513
.74	79.92	.4046	7.283
.76	82.08	.3905	7.029
.78	84.24	.3744	6.739
.80	86.40	.3566	6.419
.82	88.56	.3368	6.062
.84	90.72	.3146	5.663
.86	92.88	.2901	5.222
.88	95.04	.2630	4.734
.90	97.20	.2330	4.194
.92	99.36	.2000	3.600
.94	101.52	.1635	2.943
.96	103.68	.1230	2.114
.98	105.84	.0771	1.388
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + 1.000000$

$a_2 = + 2.149653$

$a_3 = - 17.773496$

$a_4 = + 36.716580$

$a_5 = - 33.511285$

$a_6 = + 11.418548$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7766$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4644$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.500
Nose radius, ft	0.1250
Tail radius, ft	0.0250
Wetted surface, ft^2	32.94
Volume, ft^3	10.34
Longitudinal center of buoyancy, ft from nose	4.180

Model 4157 Serial 40050165-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1439	2.220
.04	4.32	.2059	3.177
.06	6.48	.2537	3.914
.08	8.64	.2934	4.527
.10	10.80	.3272	5.048
.12	12.96	.3565	5.500
.14	15.12	.3818	5.891
.16	17.28	.4037	6.229
.18	19.44	.4226	6.520
.20	21.60	.4388	6.770
.22	23.76	.4526	6.983
.24	25.92	.4641	7.160
.26	28.08	.4737	7.309
.28	30.24	.4815	7.429
.30	32.40	.4878	7.526
.32	34.56	.4925	7.599
.34	36.72	.4959	7.651
.36	38.88	.4982	7.687
.38	41.04	.4996	7.708
.40	43.20	.5000	7.714
.42	45.36	.4997	7.710
.44	47.52	.4986	7.693
.46	49.68	.4968	7.665
.48	51.84	.4944	7.628
.50	54.00	.4917	7.586
.52	56.16	.4882	7.532
.54	58.32	.4844	7.474
.56	60.48	.4799	7.404
.58	62.64	.4749	7.327
.60	64.80	.4692	7.239
.62	66.96	.4629	7.142
.64	69.12	.4557	7.031
.66	71.28	.4478	6.909
.68	73.44	.4388	6.770
.70	75.60	.4287	6.614
.72	77.76	.4174	6.440
.74	79.92	.4046	6.242
.76	[illegible]08	.3905	6.025
.78	84.24	.3744	5.776
.80	86.40	.3566	5.502
.82	88.56	.3368	5.196
.84	90.72	.3146	4.854
.86	92.88	.2901	4.476
.88	95.04	.2630	4.058
.90	97.20	.2330	3.595
.92	99.36	.2000	3.086
.94	101.52	.1635	2.523
.96	103.68	.1230	1.898
.98	105.84	.0771	1.190
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 2.149653$

$a_3 = - \ 17.773496$

$a_4 = + \ 36.716580$

$a_5 = - \ 33.511285$

$a_6 = + \ 11.418548$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7744$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4644$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	28.15
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.180

Model 4158 Serial 40050165-80

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1439	1.943
.04	4.32	.2059	2.780
.06	6.48	.2537	3.425
.08	8.64	.2934	3.961
.10	10.80	.3272	4.417
.12	12.96	.3565	4.813
.14	15.12	.3816	5.154
.16	17.28	.4037	5.450
.18	19.44	.4226	5.705
.20	21.60	.4388	5.924
.22	23.76	.4526	6.110
.24	25.92	.4641	6.265
.26	28.08	.4737	6.395
.28	30.24	.4815	6.548
.30	32.40	.4878	6.585
.32	34.56	.4925	6.649
.34	36.72	.4959	6.695
.36	38.88	.4982	6.726
.38	41.04	.4996	6.745
.40	43.20	.5000	6.750
.42	45.36	.4997	6.746
.44	47.52	.4986	6.731
.46	49.68	.4968	6.707
.48	51.84	.4944	6.674
.50	54.00	.4917	6.638
.52	56.16	.4882	6.591
.54	58.32	.4844	6.539
.56	60.48	.4799	6.479
.58	62.64	.4749	6.411
.60	64.80	.4692	6.334
.62	66.96	.4629	6.249
.64	69.12	.4557	6.152
.66	71.28	.4478	6.045
.68	73.44	.4388	5.924
.70	75.60	.4287	5.787
.72	77.76	.4174	5.635
.74	79.92	.4046	5.462
.76	82.08	.3905	5.272
.78	84.24	.3744	5.054
.80	86.40	.3566	4.814
.82	88.56	.3368	4.547
.84	90.72	.3146	4.247
.86	92.88	.2901	3.916
.88	95.04	.2630	3.551
.90	97.20	.2330	3.146
.92	99.36	.2000	2.700
.94	101.52	.1635	2.207
.96	103.68	.1230	1.661
.98	105.84	.0771	1.041
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 2.149653$

$a_3 = - \ 17.773496$

$a_4 = + \ 36.716580$

$a_5 = - \ 33.511285$

$a_6 = + \ 11.418548$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7727$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4644$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.125
Nose radius, ft	0.0703
Tail radius, ft	0.0141
Wetted surface, ft^2	24.58
Volume, ft^3	5.815
Longitudinal center of buoyancy, ft from nose	4.180

Model 4159 Serial 4005016 5-100

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1439	1.554
.04	4.32	.2059	2.224
.06	6.48	.2537	2.740
.08	8.64	.2934	3.169
.10	10.80	.3272	3.534
.12	12.96	.3565	3.850
.14	15.12	.3818	4.123
.16	17.28	.4037	4.360
.18	19.44	.4226	4.564
.20	21.60	.4388	4.739
.22	23.76	.4526	4.888
.24	25.92	.4641	5.012
.26	28.08	.4737	5.116
.28	30.24	.4815	5.200
.30	32.40	.4878	5.268
.32	34.56	.4925	5.319
.34	36.72	.4959	5.358
.36	38.88	.4982	5.381
.38	41.04	.4996	5.396
.40	43.20	.5000	5.400
.42	45.36	.4997	5.397
.44	47.52	.4986	5.385
.46	49.68	.4968	5.365
.48	51.84	.4944	5.340
.50	54.00	.4917	5.310
.52	56.16	.4882	5.273
.54	58.32	.4844	5.232
.56	60.48	.4799	5.183
.58	62.64	.4749	5.129
.60	64.80	.4692	5.067
.62	66.96	.4629	4.999
.64	69.12	.4557	4.922
.66	71.28	.4478	4.836
.68	73.44	.4388	4.739
.70	75.60	.4287	4.630
.72	77.76	.4174	4.508
.74	79.92	.4046	4.370
.76	82.08	.3905	4.217
.78	84.24	.3744	4.044
.80	86.40	.3566	3.851
.82	88.56	.3368	3.637
.84	90.72	.3146	3.398
.86	92.88	.2901	3.133
.88	95.04	.2630	2.840
.90	97.20	.2330	2.516
.92	99.36	.2000	2.160
.94	101.52	.1635	1.766
.96	103.68	.1230	1.328
.98	105.84	.0771	0.833
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

Where $a_1 = + \ 1.000000$

$a_2 = + \ 2.149653$

$a_3 = - \ 17.773496$

$a_4 = + \ 36.716580$

$a_5 = - \ 33.511285$

$a_6 = + \ 11.418548$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7717$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4644$

Model Particulars:

Length, ft	9.000
Diameter, ft	0.9000
Nose radius, ft	0.0450
Tail radius, ft	0.0090
Wetted surface, ft^2	19.64
Volume, ft^3	3.722
Longitudinal center of buoyancy, ft from nose	4.180

Model 4160 Serial 3605016 5-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1454	2.243
.04	4.32	.2094	3.231
.06	6.48	.2593	4.001
.08	8.64	.3009	4.642
.10	10.80	.3363	5.189
.12	12.96	.3669	5.661
.14	15.12	.3932	6.067
.16	17.28	.4156	6.412
.18	19.44	.4347	6.707
.20	21.60	.4508	6.955
.22	23.76	.4641	7.160
.24	25.92	.4749	7.327
.26	28.08	.4833	7.457
.28	30.24	.4898	7.557
.30	32.40	.4915	7.583
.32	34.56	.4977	7.679
.34	36.72	.4995	7.707
.36	38.88	.5000	7.714
.38	41.04	.4995	7.707
.40	43.20	.4982	7.687
.42	45.36	.4961	7.654
.44	47.52	.4934	7.612
.46	49.68	.4902	7.563
.48	51.84	.4867	7.509
.50	54.00	.4827	7.447
.52	56.16	.4785	7.383
.54	58.32	.4741	7.315
.56	60.48	.4693	7.241
.58	62.64	.4642	7.162
.60	64.80	.4588	7.079
.62	66.96	.4529	6.988
.64	69.12	.4465	6.889
.66	71.28	.4394	6.779
.68	73.44	.4315	6.657
.70	75.60	.4225	6.519
.72	77.76	.4125	6.364
.74	79.92	.4010	6.187
.76	82.08	.3882	5.989
.78	84.24	.3736	5.764
.80	86.40	.3569	5.507
.82	88.56	.3381	5.216
.84	90.72	.3170	4.891
.86	92.88	.2931	4.522
.88	95.04	.2665	4.112
.90	97.20	.2366	3.650
.92	99.36	.2034	3.138
.94	101.52	.1665	2.569
.96	103.68	.1252	1.931
.98	105.84	.0782	1.207
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 3.321200$

$a_3 = - \ 24.678776$

$a_4 = + \ 50.896065$

$a_5 = - \ 45.840700$

$a_6 = + \ 15.302158$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7758$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4594$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft²	28.20
Volume, ft³	7.595
Longitudinal center of buoyancy, ft from nose	4.135

Model 4161 Serial 44050165-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1428	2.203
.04	4.32	.2029	3.130
.06	6.48	.2488	3.839
.08	8.64	.2868	4.425
.10	10.80	.3191	4.923
.12	12.96	.3472	5.357
.14	15.12	.3715	5.732
.16	17.28	.3927	6.059
.18	19.44	.4113	6.346
.20	21.60	.4274	6.594
.22	23.76	.4419	6.818
.24	25.92	.4533	6.994
.26	28.08	.4637	7.154
.28	30.24	.4716	7.276
.30	32.40	.4794	7.396
.32	34.56	.4855	7.491
.34	36.72	.4901	7.562
.36	38.88	.4937	7.617
.38	41.04	.4967	7.663
.40	43.20	.4985	7.691
.42	45.36	.4997	7.710
.44	47.52	.5000	7.714
.46	49.68	.4997	7.710
.48	51.84	.4987	7.694
.50	54.00	.4970	7.668
.52	56.16	.4947	7.633
.54	58.32	.4916	7.585
.56	60.48	.4880	7.529
.58	62.64	.4834	7.458
.60	64.80	.4784	7.381
.62	66.96	.4720	7.282
.64	69.12	.4649	7.173
.66	71.28	.4571	7.052
.68	73.44	.4475	6.904
.70	75.60	.4370	6.742
.72	77.76	.4251	6.559
.74	79.92	.4117	6.352
.76	82.08	.3967	6.121
.78	84.24	.3800	5.863
.80	86.40	.3672	5.665
.82	88.56	.3405	5.253
.84	90.72	.3176	4.900
.86	92.88	.2923	4.510
.88	95.04	.2645	4.081
.90	97.20	.2338	3.607
.92	99.36	.2004	3.092
.94	101.52	.1636	2.524
.96	103.68	.1230	1.898
.98	105.84	.0770	1.188
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 1.214218$

$a_3 = - \ 12.683118$

$a_4 = + \ 26.981999$

$a_5 = - \ 25.571605$

$a_6 = + \ 9.058511$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7742$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4707$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	28.14
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.237

Model 4162 Serial 4805016 5-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1418	2.188
.04	4.32	.2005	3.093
.06	6.48	.2448	3.777
.08	8.64	.2812	4.339
.10	10.80	.3120	4.814
.12	12.96	.3388	5.227
.14	15.12	.3621	5.587
.16	17.28	.3824	5.900
.18	19.44	.4003	6.176
.20	21.60	.4161	6.420
.22	23.76	.4299	6.633
.24	25.92	.4420	6.819
.26	28.08	.4526	6.983
.28	30.24	.4617	7.123
.30	32.40	.4697	7.247
.32	34.56	.4764	7.350
.34	36.72	.4823	7.441
.36	38.88	.4871	7.515
.38	41.04	.4912	7.579
.40	43.20	.4944	7.628
.42	45.36	.4969	7.666
.44	47.52	.4985	7.691
.46	49.68	.4997	7.710
.48	51.84	.5000	7.714
.50	54.00	.4997	7.710
.52	56.16	.4986	7.693
.54	58.32	.4967	7.663
.56	60.48	.4941	7.623
.58	62.64	.4906	7.569
.60	64.80	.4861	7.500
.62	66.96	.4807	7.417
.64	69.12	.4742	7.316
.66	71.28	.4663	7.194
.68	73.44	.4573	7.055
.70	75.60	.4462	6.884
.72	77.76	.4350	6.711
.74	79.92	.4215	6.503
.76	82.08	.4062	6.267
.78	84.24	.3890	6.002
.80	86.40	.3697	5.704
.82	88.56	.3484	5.375
.84	90.72	.3247	5.010
.86	92.88	.2986	4.607
.88	95.04	.2699	4.164
.90	97.20	.2383	3.677
.92	99.36	.2038	3.144
.94	101.52	.1660	2.561
.96	103.68	.1246	1.922
.98	105.84	.0777	1.199
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = +\ 1.000000$

$a_2 = +\ 0.444725$

$a_3 = -\ 8.919726$

$a_4 = +\ 20.564463$

$a_5 = -\ 20.948573$

$a_6 = +\ 7.859120$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7742$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4783$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	28.14
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.304

Model 4163 Serial 5205016 5-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1411	2.177
.04	4.32	.1985	3.063
.06	6.48	.2414	3.724
.08	8.64	.2764	4.264
.10	10.80	.3060	4.721
.12	12.96	.3314	5.113
.14	15.12	.3535	5.454
.16	17.28	.3729	5.753
.18	19.44	.3901	6.019
.20	21.60	.4051	6.250
.22	23.76	.4185	6.457
.24	25.92	.4303	6.639
.26	28.08	.4409	6.802
.28	30.24	.4502	6.946
.30	32.40	.4585	7.074
.32	34.56	.4658	7.187
.34	36.72	.4724	7.288
.36	38.88	.4781	7.376
.38	41.04	.4831	7.454
.40	43.20	.4875	7.521
.42	45.36	.4912	7.579
.44	47.52	.4943	7.626
.46	49.68	.4967	7.663
.48	51.84	.4985	7.691
.50	54.00	.4996	7.708
.52	56.16	.5000	7.714
.54	58.32	.4996	7.708
.56	60.48	.4983	7.688
.58	62.64	.4961	7.654
.60	64.80	.4930	7.606
.62	66.96	.4887	7.540
.64	69.12	.4832	7.455
.66	71.28	.4764	7.350
.68	73.44	.4681	7.222
.70	75.60	.4584	7.072
.72	77.76	.4469	6.895
.74	79.92	.4336	6.690
.76	82.08	.4185	6.457
.78	84.24	.4012	6.190
.80	86.40	.3817	5.889
.82	88.56	.3600	5.554
.84	90.72	.3356	5.178
.86	92.88	.3087	4.763
.88	95.04	.2790	4.305
.90	97.20	.2462	3.799
.92	99.36	.2103	3.245
.94	101.52	.1710	2.638
.96	103.68	.1277	1.970
.98	105.84	.0789	1.217
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = - \ 0.139160$

$a_3 = - \ 6.590919$

$a_4 = + \ 17.669802$

$a_5 = - \ 19.810192$

$a_6 = + \ 7.870480$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7746$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4868$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	28.16
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.381

Model 4164 Serial 40050155-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1407	2.171
.04	4.32	.1981	3.056
.06	6.48	.2415	3.726
.08	8.64	.2774	4.280
.10	10.80	.3084	4.758
.12	12.96	.3358	5.181
.14	15.12	.3601	5.556
.16	17.28	.3820	5.894
.18	19.44	.4016	6.197
.20	21.60	.4192	6.468
.22	23.76	.4349	6.710
.24	25.92	.4489	6.926
.26	28.08	.4610	7.113
.28	30.24	.4715	7.275
.30	32.40	.4802	7.409
.32	34.56	.4874	7.520
.34	36.72	.4929	7.605
.36	38.88	.4969	7.666
.38	41.04	.4993	7.703
.40	43.20	.5000	7.714
.42	45.36	.4993	7.703
.44	47.52	.4970	7.668
.46	49.68	.4931	7.608
.48	51.84	.4878	7.526
.50	54.00	.4810	7.421
.52	56.16	.4729	7.296
.54	58.32	.4634	7.150
.56	60.48	.4525	6.981
.58	62.64	.4404	6.795
.60	64.80	.4271	6.590
.62	66.96	.4126	6.366
.64	69.12	.3970	6.125
.66	71.28	.3804	5.869
.68	73.44	.3629	5.599
.70	75.60	.3445	5.315
.72	77.76	.3255	5.022
.74	79.92	.3059	4.720
.76	82.08	.2858	4.409
.78	84.24	.2655	4.096
.80	86.40	.2449	3.778
.82	88.56	.2244	3.462
.84	90.72	.2040	3.147
.86	92.88	.1840	2.839
.88	95.04	.1643	2.535
.90	97.20	.1451	2.239
.92	99.36	.1263	1.949
.94	101.52	.1073	1.655
.96	103.68	.0869	1.341
.98	105.84	.0618	0.953
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$$

where $a_1 = +\ 1.000000$

$a_2 = -\ 0.475347$

$a_3 = +\ 0.601504$

$a_4 = -\ 8.564671$

$a_5 = +\ 12.426215$

$a_6 = -\ 4.987703$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.6954$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4295$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	25.28
Volume, ft^3	6.427
Longitudinal center of buoyancy, ft from nose	3.866

Model 4165 Serial 40050160-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1423	2.195
.04	4.32	.2020	3.117
.06	6.48	.2476	3.820
.08	8.64	.2855	4.405
.10	10.80	.3179	4.905
.12	12.96	.3462	5.341
.14	15.12	.3710	5.724
.16	17.28	.3930	6.063
.18	19.44	.4123	6.361
.20	21.60	.4260	6.573
.22	23.76	.4439	6.849
.24	25.92	.4565	7.043
.26	28.08	.4674	7.211
.28	30.24	.4765	7.352
.30	32.40	.4841	7.469
.32	34.56	.4900	7.560
.34	36.72	.4944	7.628
.36	38.88	.4976	7.677
.38	41.04	.4994	7.705
.40	43.20	.5000	7.714
.42	45.36	.4995	7.707
.44	47.52	.4978	7.680
.46	49.68	.4950	7.637
.48	51.84	.4911	7.577
.50	54.00	.4864	7.504
.52	56.16	.4806	7.415
.54	58.32	.4739	7.312
.56	60.48	.4665	7.197
.58	62.64	.4580	7.066
.60	64.80	.4486	6.921
.62	66.96	.4384	6.764
.64	69.12	.4273	6.593
.66	71.28	.4154	6.409
.68	73.44	.4026	6.212
.70	75.60	.3890	6.002
.72	77.76	.3743	5.775
.74	79.92	.3588	5.536
.76	82.08	.3422	5.280
.78	84.24	.3245	5.007
.80	86.40	.3059	4.720
.82	88.56	.2861	4.414
.84	90.72	.2652	4.092
.86	92.88	.2429	3.748
.88	95.04	.2193	3.383
.90	97.20	.1941	2.995
.92	99.36	.1672	2.580
.94	101.52	.1383	2.134
.96	103.68	.1065	1.643
.98	105.84	.0699	1.078
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 0.837153$

$a_3 = - \ 8.585996$

$a_4 = + \ 14.075954$

$a_5 = - \ 10.542535$

$a_6 = + \ 3.215422$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7374$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4484$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	26.81
Volume, ft^3	7.011
Longitudinal center of buoyancy, ft from nose	4.036

Model 4166 Serial 40050170-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1455	2.245
.04	4.32	.2097	3.235
.06	6.48	.2596	4.005
.08	8.64	.3010	4.644
.10	10.80	.3362	5.187
.12	12.96	.3664	5.653
.14	15.12	.3922	6.051
.16	17.28	.4141	6.389
.18	19.44	.4327	6.676
.20	21.60	.4483	6.917
.22	23.76	.4611	7.114
.24	25.92	.4716	7.276
.26	28.08	.4799	7.404
.28	30.24	.4865	7.506
.30	32.40	.4915	7.583
.32	34.56	.4950	7.637
.34	36.72	.4974	7.674
.36	38.88	.4990	7.699
.38	41.04	.4998	7.711
.40	43.20	.5000	7.714
.42	45.36	.4998	7.711
.44	47.52	.4994	7.705
.46	49.68	.4986	7.693
.48	51.84	.4978	7.680
.50	54.00	.4968	7.665
.52	56.16	.4958	7.649
.54	58.32	.4945	7.629
.56	60.48	.4930	7.606
.58	62.64	.4912	7.579
.60	64.80	.4890	7.545
.62	66.96	.4862	7.501
.64	69.12	.4825	7.444
.66	71.28	.4780	7.375
.68	73.44	.4723	7.287
.70	75.60	.4651	7.176
.72	77.76	.4565	7.043
.74	79.92	.4460	6.881
.76	82.08	.4333	6.685
.78	84.24	.4185	6.457
.80	86.40	.4010	6.187
.82	88.56	.3807	5.874
.84	90.72	.3573	5.513
.86	92.88	.3306	5.101
.88	95.04	.3004	4.635
.90	97.20	.2663	4.109
.92	99.36	.2280	3.518
.94	101.52	.1853	2.859
.96	103.68	.1376	2.123
.98	105.84	.0837	1.291
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = +\ 1.000000$

$a_2 = +\ 3.462153$

$a_3 = -\ 26.960996$

$a_4 = +\ 59.35721$

$a_5 = -\ 56.48003$

$a_6 = +\ 19.62167$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.8094$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4781$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	29.42
Volume, ft^3	8.179
Longitudinal center of buoyancy, ft from nose	4.303

Model 4167

Serial 40000165-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.0643	0.992
.04	4.32	.1231	1.899
.06	6.48	.1763	2.720
.08	8.64	.2243	3.461
.10	10.80	.2673	4.124
.12	12.96	.3057	4.717
.14	15.12	.3397	5.241
.16	17.28	.3695	5.701
.18	19.44	.3955	6.102
.20	21.60	.4178	6.446
.22	23.76	.4367	6.738
.24	25.92	.4527	6.985
.26	28.08	.4657	7.185
.28	30.24	.4763	7.349
.30	32.40	.4844	7.474
.32	34.56	.4907	7.571
.34	36.72	.4951	7.639
.36	38.88	.4980	7.683
.38	41.04	.4996	7.708
.40	43.20	.5000	7.714
.42	45.36	.4996	7.708
.44	47.52	.4985	7.691
.46	49.68	.4968	7.665
.48	51.84	.4948	7.634
.50	54.00	.4924	7.597
.52	56.16	.4897	7.555
.54	58.32	.4870	7.514
.56	60.48	.4839	7.466
.58	62.64	.4807	7.417
.60	64.80	.4772	7.363
.62	66.96	.4732	7.301
.64	69.12	.4687	7.231
.66	71.28	.4635	7.151
.68	73.44	.4574	7.057
.70	75.60	.4502	6.946
.72	77.76	.4416	6.813
.74	79.92	.4314	6.656
.76	82.08	.4194	6.471
.78	84.24	.4053	6.253
.80	86.40	.3888	5.999
.82	88.56	.3696	5.702
.84	90.72	.3476	5.363
.86	92.88	.3222	4,971
.88	95.04	.2933	4.525
.90	97.20	.2606	4.021
.92	99.36	.2237	3.451
.94	101.52	.1823	2.813
.96	103.68	.1359	2.097
.98	105.84	.0830	1.281
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$$

Where $a_1 = 0.000000$

$a_2 = + 11.337153$

$a_3 = - 50.335996$

$a_4 = + 91.950954$

$a_5 = - 78.042535$

$a_6 = + 25.090422$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7688$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4899$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0000
Tail radius, ft	0.0184
Wetted surface, ft^2	27.95
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.410

Model 4168 Serial 40030165-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1187	1.831
.04	4.32	.1775	2.739
.06	6.48	.2259	3.485
.08	8.64	.2679	4.133
.10	10.80	.3046	4.700
.12	12.96	.3371	5.201
.14	15.12	.3655	5.639
.16	17.28	.3914	6.039
.18	19.44	.4120	6.357
.20	21.60	.4305	6.642
.22	23.76	.4464	6.887
.24	25.92	.4596	7.091
.26	28.08	.4705	7.259
.28	30.24	.4794	7.396
.30	32.40	.4865	7.506
.32	34.56	.4918	7.588
.34	36.72	.4956	7.646
.36	38.88	.4982	7.687
.38	41.04	.4996	7.708
.40	43.20	.5000	7.714
.42	45.36	.4996	7.708
.44	47.52	.4985	7.691
.46	49.68	.4968	7.665
.48	51.84	.4946	7.631
.50	54.00	.4920	7.591
.52	56.16	.4888	7.541
.54	58.32	.4854	7.489
.56	60.48	.4815	7.429
.58	62.64	.4772	7.363
.60	64.80	.4724	7.288
.62	66.96	.4670	7.205
.64	69.12	.4610	7.113
.66	71.28	.4541	7.006
.68	73.44	.4463	6.886
.70	75.60	.4374	6.748
.72	77.76	.4272	6.591
.74	79.92	.4156	6.412
.76	82.08	.4023	6.207
.78	84.24	.3871	5.972
.80	86.40	.3698	5.705
.82	88.56	.3503	5.405
.84	90.72	.3282	5.064
.86	92.88	.3034	4.681
.88	95.04	.2756	4.252
.90	97.20	.2444	3.771
.92	99.36	.2098	3.237
.94	101.52	.1713	2.643
.96	103.68	.1283	1.979
.98	105.84	.0795	1.227
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$$

where $a_1 = + \ 0.600000$

$a_2 = + \ 5.824657$

$a_3 = - \ 30.798496$

$a_4 = + \ 58.810329$

$a_5 = - \ 51.323785$

$a_6 = + \ 16.887297$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7732$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4746$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0551
Tail radius, ft	0.0184
Wetted surface, ft^2	28.11
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.272

Model 4169

Serial 40070165-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1654	2.552
.04	4.32	.2308	3.561
.06	6.48	.2787	4.300
.08	8.64	.3168	4.888
.10	10.80	.3488	5.381
.12	12.96	.3748	5.783
.14	15.12	.3974	6.131
.16	17.28	.4166	6.428
.18	19.44	.4330	6.681
.20	21.60	.4469	6.895
.22	23.76	.4587	7.077
.24	25.92	.4687	7.231
.26	28.08	.4769	7.358
.28	30.24	.4836	7.461
.30	32.40	.4891	7.546
.32	34.56	.4932	7.609
.34	36.72	.4963	7.657
.36	38.88	.4984	7.690
.38	41.04	.4996	7.708
.40	43.20	.5000	7.714
.42	45.36	.4997	7.710
.44	47.52	.4986	7.693
.46	49.68	.4968	7.665
.48	51.84	.4944	7.628
.50	54.00	.4914	7.582
.52	56.16	.4876	7.523
.54	58.32	.4833	7.457
.56	60.48	.4783	7.380
.58	62.64	.4726	7.292
.60	64.80	.4660	7.190
.62	66.96	.4587	7.077
.64	69.12	.4505	6.951
.66	71.28	.4413	6.809
.68	73.44	.4311	6.651
.70	75.60	.4199	6.478
.72	77.76	.4073	6.284
.74	79.92	.3935	6.071
.76	82.08	.3782	5.835
.78	84.24	.3614	5.576
.80	86.40	.3429	5.290
.82	88.56	.3226	4.977
.84	90.72	.3005	4.636
.86	92.88	.2763	4.263
.88	95.04	.2498	3.854
.90	97.20	.2210	3.410
.92	99.36	.1896	2.925
.94	101.52	.1553	2.396
.96	103.68	.1176	1.814
.98	105.84	.0746	1.151
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.400000$

$a_2 = - \ 1.525347$

$a_3 = - \ 4.748496$

$a_4 = + \ 14.622829$

$a_5 = - \ 15.698785$

$a_6 = + \ 5.949797$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7750$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4542$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.1286
Tail radius, ft	0.0184
Wetted surface, ft^2	28.17
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.088

Model 4170 Serial 40100165-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1931	2.979
.04	4.32	.2640	4.073
.06	6.48	.3124	4.820
.08	8.64	.3491	5.386
.10	10.80	.3778	5.829
.12	12.96	.4008	6.184
.14	15.12	.4196	6.474
.16	17.28	.4352	6.715
.18	19.44	.4481	6.914
.20	21.60	.4589	7.080
.22	23.76	.4679	7.219
.24	25.92	.4754	7.335
.26	28.08	.4816	7.430
.28	30.24	.4868	7.511
.30	32.40	.4910	7.575
.32	34.56	.4943	7.626
.34	36.72	.4968	7.665
.36	38.88	.4986	7.693
.38	41.04	.4997	7.710
.40	43.20	.5000	7.714
.42	45.36	.4997	7.710
.44	47.52	.4986	7.693
.46	49.68	.4968	7.665
.48	51.84	.4943	7.626
.50	54.00	.4909	7.574
.52	56.16	.4867	7.509
.54	58.32	.4817	7.432
.56	60.48	.4758	7.341
.58	62.64	.4689	7.234
.60	64.80	.4612	7.116
.62	66.96	.4523	6.978
.64	69.12	.4424	6.826
.66	71.28	.4316	6.654
.68	73.44	.4194	6.471
.70	75.60	.4062	6.267
.72	77.76	.3917	6.043
.74	79.92	.3760	5.801
.76	82.08	.3591	5.540
.78	84.24	.3408	5.258
.80	86.40	.3212	4.956
.82	88.56	.3002	4.632
.84	90.72	.2778	4.286
.86	92.88	.2541	3.920
.88	95.04	.2286	3.527
.90	97.20	.2017	3.112
.92	99.36	.1729	2.668
.94	101.52	.1422	2.194
.96	103.68	.1088	1.679
.98	105.84	.0707	1.091
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 2.000000$

$a_2 = - \ 7.037847$

$a_3 = + \ 14.789004$

$a_4 = - \ 18.517796$

$a_5 = + \ 11.019965$

$a_6 = - \ 2.253328$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7744$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4389$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.1837
Tail radius, ft	0.0184
Wetted surface, ft^2	28.15
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	3.950

Model 4171

Serial 40050065-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1443	2.226
.04	4.32	.2068	3.191
.06	6.48	.2550	3.934
.08	8.64	.2951	4.553
.10	10.80	.3292	5.079
.12	12.96	.3587	5.534
.14	15.12	.3841	5.926
.16	17.28	.4060	6.264
.18	19.44	.4248	6.554
.20	21.60	.4408	6.801
.22	23.76	.4544	7.011
.24	25.92	.4657	7.185
.26	28.08	.4750	7.329
.28	30.24	.4825	7.444
.30	32.40	.4885	7.537
.32	34.56	.4930	7.606
.34	36.72	.4962	7.656
.36	38.88	.4984	7.690
.38	41.04	.4996	7.708
.40	43.20	.5000	7.714
.42	45.36	.4997	7.710
.44	47.52	.4987	7.694
.46	49.68	.4971	7.670
.48	51.84	.4950	7.637
.50	54.00	.4925	7.599
.52	56.16	.4894	7.551
.54	58.32	.4859	7.497
.56	60.48	.4818	7.433
.58	62.64	.4771	7.361
.60	64.80	.4718	7.279
.62	66.96	.4657	7.185
.64	69.12	.4587	7.077
.66	71.28	.4508	6.955
.68	73.44	.4417	6.815
.70	75.60	.4314	6.656
.72	77.76	.4196	6.474
.74	79.92	.4062	6.267
.76	82.08	.3911	6.034
.78	84.24	.3739	5.769
.80	86.40	.3546	5.471
.82	88.56	.3330	5.138
.84	90.72	.3088	4.764
.86	92.88	.2819	4.349
.88	95.04	.2520	3.888
.90	97.20	.2190	3.379
.92	99.36	.1827	2.819
.94	101.52	.1428	2.203
.96	103.68	.0992	1.531
.98	105.84	.0517	0.798
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = +\ 1.000000$

$a_2 = +\ 2.449653$

$a_3 = -\ 19.962385$

$a_4 = +\ 42.424913$

$a_5 = -\ 39.761285$

$a_6 = +\ 13.849103$

Wetted Surface Coefficient = $\frac{S}{\pi L D}$

= 0.7718

Longitudinal Center of Buoyancy = $\frac{X}{L}$

= 0.4618

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0000
Wetted surface, ft^2	28.06
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.156

Model 4172 Serial 4005(005)65-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1441	2.223
.04	4.32	.2064	3.184
.06	6.48	.2543	3.923
.08	8.64	.2942	4.539
.10	10.80	.3282	5.064
.12	12.96	.3576	5.517
.14	15.12	.3830	5.909
.16	17.28	.4049	6.247
.18	19.44	.4237	6.537
.20	21.60	.4398	6.785
.22	23.76	.4535	6.997
.24	25.92	.4649	7.173
.26	28.08	.4744	7.319
.28	30.24	.4820	7.437
.30	32.40	.4881	7.531
.32	34.56	.4928	7.603
.34	36.72	.4961	7.654
.36	38.88	.4983	7.688
.38	41.04	.4996	7.708
.40	43.20	.5000	7.714
.42	45.36	.4997	7.710
.44	47.52	.4986	7.693
.46	49.68	.4969	7.666
.48	51.84	.4947	7.633
.50	54.00	.4921	7.592
.52	56.16	.4888	7.541
.54	58.32	.4851	7.484
.56	60.48	.4809	7.420
.58	62.64	.4760	7.344
.60	64.80	.4705	7.259
.62	66.96	.4643	7.163
.64	69.12	.4572	7.054
.66	71.28	.4493	6.932
.68	73.44	.4402	6.792
.70	75.60	.4301	6.636
.72	77.76	.4185	6.457
.74	79.92	.4054	6.255
.76	82.08	.3908	6.029
.78	84.24	.3742	5.773
.80	86.40	.3556	5.486
.82	88.56	.3349	5.167
.84	90.72	.3117	4.809
.86	92.88	.2861	4.414
.88	95.04	.2575	3.973
.90	97.20	.2261	3.488
.92	99.36	.1915	2.955
.94	101.52	.1535	2.368
.96	103.68	.1118	1.725
.98	105.84	.0657	1.014
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$$

Where $a_1 = + 1.000000$

$a_2 = + 2.299653$

$a_3 = - 18.867941$

$a_4 = + 39.570746$

$a_5 = - 36.636285$

$a_6 = + 12.633825$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7732$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4631$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0092
Wetted surface, ft^2	28.11
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.168

Model 4173 Serial 4005(015)65-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1438	2.219
.04	4.32	.2055	3.171
.06	6.48	.2530	3.903
.08	8.64	.2925	4.513
.10	10.80	.3262	5.033
.12	12.96	.3554	5.483
.14	15.12	.3807	5.874
.16	17.28	.4026	6.212
.18	19.44	.4215	6.503
.20	21.60	.4378	6.755
.22	23.76	.4517	6.969
.24	25.92	.4634	7.151
.26	28.08	.4731	7.299
.28	30.24	.4810	7.421
.30	32.40	.4874	7.520
.32	34.56	.4923	7.595
.34	36.72	.4958	7.649
.36	38.88	.4982	7.687
.38	41.04	.4995	7.707
.40	43.20	.5000	7.714
.42	45.36	.4996	7.708
.44	47.52	.4985	7.691
.46	49.68	.4966	7.662
.48	51.84	.4942	7.625
.50	54.00	.4912	7.579
.52	56.16	.4876	7.523
.54	58.32	.4836	7.461
.56	60.48	.4790	7.390
.58	62.64	.4737	7.309
.60	64.80	.4680	7.221
.62	66.96	.4615	7.120
.64	69.12	.4542	7.008
.66	71.28	.4463	6.886
.68	73.44	.4373	6.747
.70	75.60	.4274	6.594
.72	77.76	.4163	6.423
.74	79.92	.4039	6.232
.76	82.08	.3901	6.019
.78	84.24	.3747	5.781
.80	86.40	.3576	5.517
.82	88.56	.3386	5.224
.84	90.72	.3175	4.899
.86	92.88	.2940	4.536
.88	95.04	.2683	4.139
.90	97.20	.2397	3.698
.92	99.36	.2081	3.211
.94	101.52	.1729	2.668
.96	103.68	.1334	2.058
.98	105.84	.0871	1.344
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$$

where $a_1 = +\ 1.000000$

$a_2 = +\ 1.999653$

$a_3 = -\ 16.679052$

$a_4 = +\ 33.862413$

$a_5 = -\ 30.386285$

$a_6 = +\ 10.203269$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7760$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4657$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0276
Wetted surface, ft^2	28.21
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.192

Model 4174 Serial 40050265-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1436	2.216
.04	4.32	.2051	3.164
.06	6.48	.2523	3.893
.08	8.64	.2916	4.499
.10	10.80	.3252	5.017
.12	12.96	.3543	5.466
.14	15.12	.3795	5.855
.16	17.28	.4014	6.193
.18	19.44	.4204	6.486
.20	21.60	.4367	6.738
.22	23.76	.4508	6.955
.24	25.92	.4626	7.137
.26	28.08	.4724	7.288
.28	30.24	.4805	7.413
.30	32.40	.4870	7.514
.32	34.56	.4920	7.591
.34	36.72	.4956	7.646
.36	38.88	.4981	7.685
.38	41.04	.4995	7.707
.40	43.20	.5000	7.714
.42	45.36	.4996	7.708
.44	47.52	.4984	7.690
.46	49.68	.4965	7.660
.48	51.84	.4939	7.620
.50	54.00	.4908	7.572
.52	56.16	.4871	7.515
.54	58.32	.4828	7.449
.56	60.48	.4780	7.375
.58	62.64	.4726	7.292
.60	64.80	.4667	7.201
.62	66.96	.4601	7.099
.64	69.12	.4527	6.985
.66	71.28	.4448	6.863
.68	73.44	.4358	6.724
.70	75.60	.4260	6.573
.72	77.76	.4151	6.404
.74	79.92	.4031	6.219
.76	82.08	.3898	6.014
.78	84.24	.3750	5.786
.80	86.40	.3586	5.533
.82	88.56	.3405	5.253
.84	90.72	.3204	4.943
.86	92.88	.2982	4.601
.88	95.04	.2735	4.220
.90	97.20	.2462	3.799
.92	99.36	.2159	3.331
.94	101.52	.1818	2.805
.96	103.68	.1430	2.206
.98	105.84	.0960	1.481
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 1.849653$

$a_3 = - \ 15.584607$

$a_4 = + \ 31.008246$

$a_5 = - \ 27.261285$

$a_6 = + \ 8.987991$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7772$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4671$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0367
Wetted surface, ft^2	28.25
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.204

Model 4175

Serial 40050160-50

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1423	3.074
.04	4.32	.2020	4.363
.06	6.48	.2476	5.348
.08	8.64	.2855	6.167
.10	10.80	.3179	6.867
.12	12.96	.3462	7.478
.14	15.12	.3710	8.014
.16	17.28	.3930	8.489
.18	19.44	.4123	8.906
.20	21.60	.4260	9.202
.22	23.76	.4439	9.588
.24	25.92	.4565	9.860
.26	28.08	.4674	10.096
.28	30.24	.4765	10.292
.30	32.40	.4841	10.457
.32	34.56	.4900	10.584
.34	36.72	.4944	10.679
.36	38.88	.4976	10.748
.38	41.04	.4994	10.787
.40	43.20	.5000	10.800
.42	45.36	.4995	10.789
.44	47.52	.4978	10.752
.46	49.68	.4950	10.692
.48	51.84	.4911	10.608
.50	54.00	.4864	10.506
.52	56.16	.4806	10.381
.54	58.32	.4739	10.236
.56	60.48	.4665	10.076
.58	62.64	.4580	9.893
.60	64.80	.4486	9.690
.62	66.96	.4384	9.469
.64	69.12	.4273	9.230
.66	71.28	.4154	8.973
.68	73.44	.4026	8.696
.70	75.60	.3890	8.402
.72	77.76	.3743	8.085
.74	79.92	.3588	7.750
.76	82.08	.3422	7.392
.78	84.24	.3245	7.009
.80	86.40	.3059	6.607
.82	88.56	.2861	6.180
.84	90.72	.2652	5.728
.86	92.88	.2429	5.247
.88	95.04	.2193	4.737
.90	97.20	.1941	4.193
.92	99.36	.1672	3.612
.94	101.52	.1383	2.987
.96	103.68	.1065	2.300
.98	105.84	.0699	1.510
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 0.837153$

$a_3 = - \ 8.585996$

$a_4 = + \ 14.075954$

$a_5 = - \ 10.542535$

$a_6 = + \ 3.215422$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7426$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4484$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.800
Nose radius, ft	0.1800
Tail radius, ft	0.0360
Wetted surface, ft^2	37.79
Volume, ft^3	13.74
Longitudinal center of buoyancy, ft from nose	4.036

Model 4176 Serial 40050155-50

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1407	3.039
.04	4.32	.1981	4.279
.06	6.48	.2415	5.216
.08	8.64	.2774	5.992
.10	10.80	.3084	6.661
.12	12.96	.3358	7.253
.14	15.12	.3601	7.778
.16	17.28	.3820	8.251
.18	19.44	.4016	8.675
.20	21.60	.4192	9.055
.22	23.76	.4349	9.394
.24	25.92	.4489	9.696
.26	28.08	.4610	9.958
.28	30.24	.4715	10.184
.30	32.40	.4802	10.372
.32	34.56	.4874	10.528
.34	36.72	.4929	10.647
.36	38.88	.4969	10.733
.38	41.04	.4993	10.785
.40	43.20	.5000	10.800
.42	45.36	.4993	10.785
.44	47.52	.4970	10.735
.46	49.68	.4931	10.651
.48	51.84	.4878	10.536
.50	54.00	.4810	10.390
.52	56.16	.4729	10.215
.54	58.32	.4634	10.009
.56	60.48	.4525	9.774
.58	62.64	.4404	9.513
.60	64.80	.4271	9.225
.62	66.96	.4126	8.912
.64	69.12	.3970	8.575
.66	71.28	.3804	8.217
.68	73.44	.3629	7.839
.70	75.60	.3445	7.441
.72	77.76	.3255	7.031
.74	79.92	.3059	6.607
.76	82.08	.2858	6.173
.78	84.24	.2655	5.735
.80	86.40	.2449	5.290
.82	88.56	.2244	4.847
.84	90.72	.2040	4.406
.86	92.88	.1840	3.974
.88	95.04	.1643	3.549
.90	97.20	.1451	3.134
.92	99.36	.1263	2.728
.94	101.52	.1073	2.318
.96	103.68	.0869	1.877
.98	105.84	.0618	1.335
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 + a_6 x^6$$

where $a_1 = +\ 1.000000$

$a_2 = -\ 0.475347$

$a_3 = +\ 0.601504$

$a_4 = -\ 8.564671$

$a_5 = +\ 12.426215$

$a_6 = -\ 4.987703$

Wetted Surface Coefficient $= \dfrac{S}{\pi L D}$

$= 0.7012$

Longitudinal Center of Buoyancy $= \dfrac{X}{L}$

$= 0.4295$

Model Particulars:

Length, ft	9.000
Diameter, ft	1.800
Nose radius, ft	0.1800
Tail radius, ft	0.0360
Wetted surface, ft^2	35.69
Volume, ft^3	12.60
Longitudinal center of buoyancy, ft from nose	3.866

Model 4177

Serial 34050165-70

X/L	X in inches	Y/D	Y in inches
0.00	0.00	0.0000	0.000
.02	2.16	.1463	2.257
.04	4.32	.2115	3.263
.06	6.48	.2627	4.053
.08	8.64	.3054	4.712
.10	10.80	.3418	5.273
.12	12.96	.3729	5.754
.14	15.12	.3995	6.164
.16	17.28	.4222	6.514
.18	19.44	.4413	6.808
.20	21.60	.4571	7.053
.22	23.76	.4700	7.251
.24	25.92	.4801	7.407
.26	28.08	.4879	7.527
.28	30.24	.4935	7.614
.30	32.40	.4973	7.673
.32	34.56	.4994	7.705
.34	36.72	.5000	7.714
.36	38.88	.4995	7.706
.38	41.04	.4978	7.680
.40	43.20	.4954	7.644
.42	45.36	.4923	7.596
.44	47.52	.4888	7.541
.46	49.68	.4848	7.480
.48	51.84	.4806	7.414
.50	54.00	.4763	7.348
.52	56.16	.4717	7.278
.54	58.32	.4672	7.209
.56	60.48	.4625	7.136
.58	62.64	.4578	7.063
.60	64.80	.4528	6.986
.62	66.96	.4475	6.904
.64	69.12	.4418	6.817
.66	71.28	.4355	6.719
.68	73.44	.4285	6.611
.70	75.60	.4206	6.490
.72	77.76	.4116	6.351
.74	79.92	.4013	6.191
.76	82.08	.3892	6.005
.78	84.24	.3756	5.794
.80	86.40	.3597	5.550
.82	88.56	.3416	5.270
.84	90.72	.3209	4.951
.86	92.88	.2974	4.588
.88	95.04	.2708	4.178
.90	97.20	.2409	3.717
.92	99.36	.2073	3.198
.94	101.52	.1696	2.617
.96	103.68	.1274	1.966
.98	105.84	.0792	1.222
1.00	108.00	0.0000	0.000

Formula:

$$y^2 = a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6$$

where $a_1 = + \ 1.000000$

$a_2 = + \ 4.041346$

$a_3 = - \ 29.154650$

$a_4 = + \ 60.478948$

$a_5 = - \ 54.459319$

$a_6 = + \ 18.093685$

Wetted Surface Coefficient $= \frac{S}{\pi L D}$

$= 0.7770$

Longitudinal Center of Buoyancy $= \frac{X}{L}$

$= 0.4577$

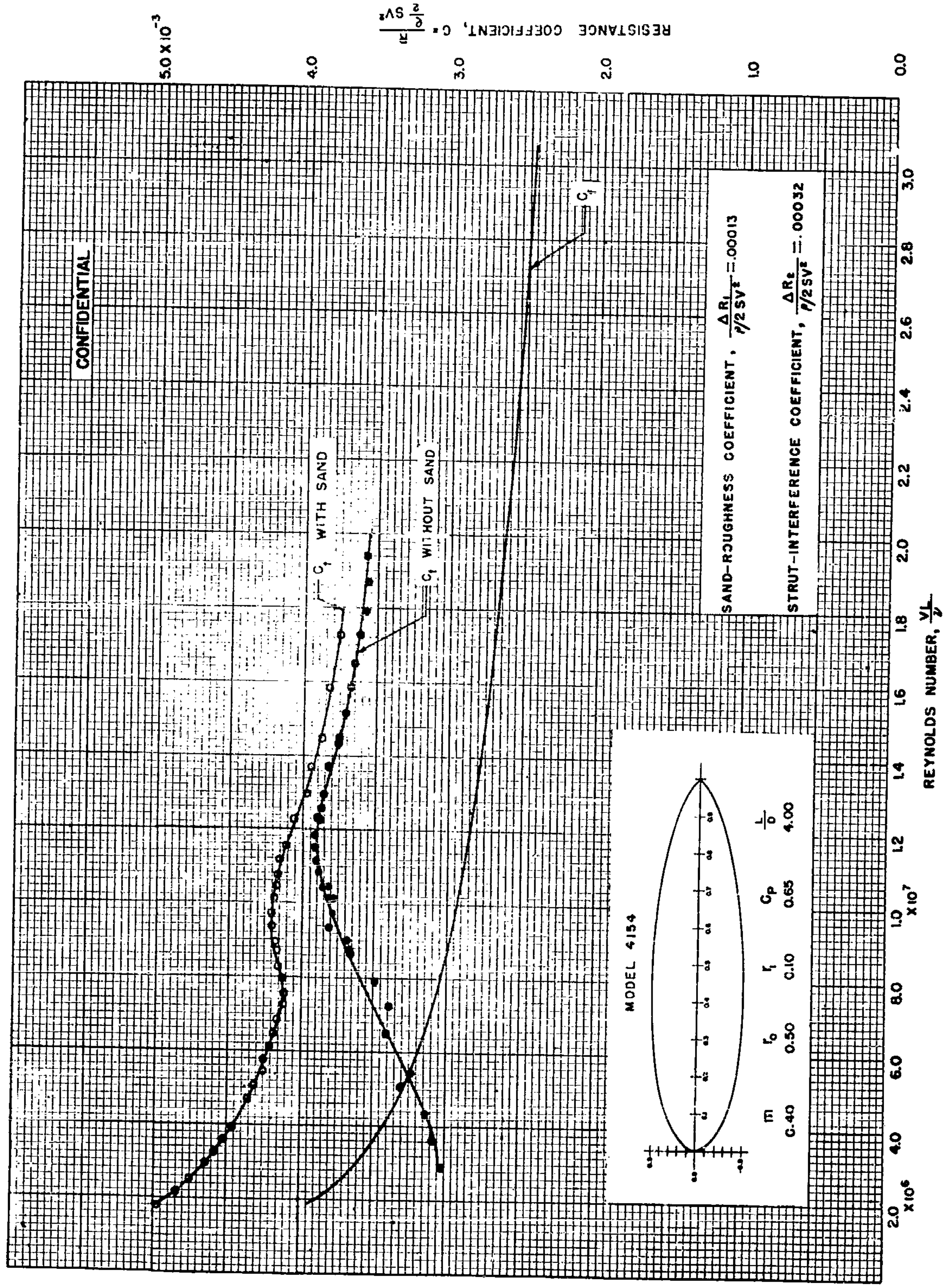
Model Particulars:

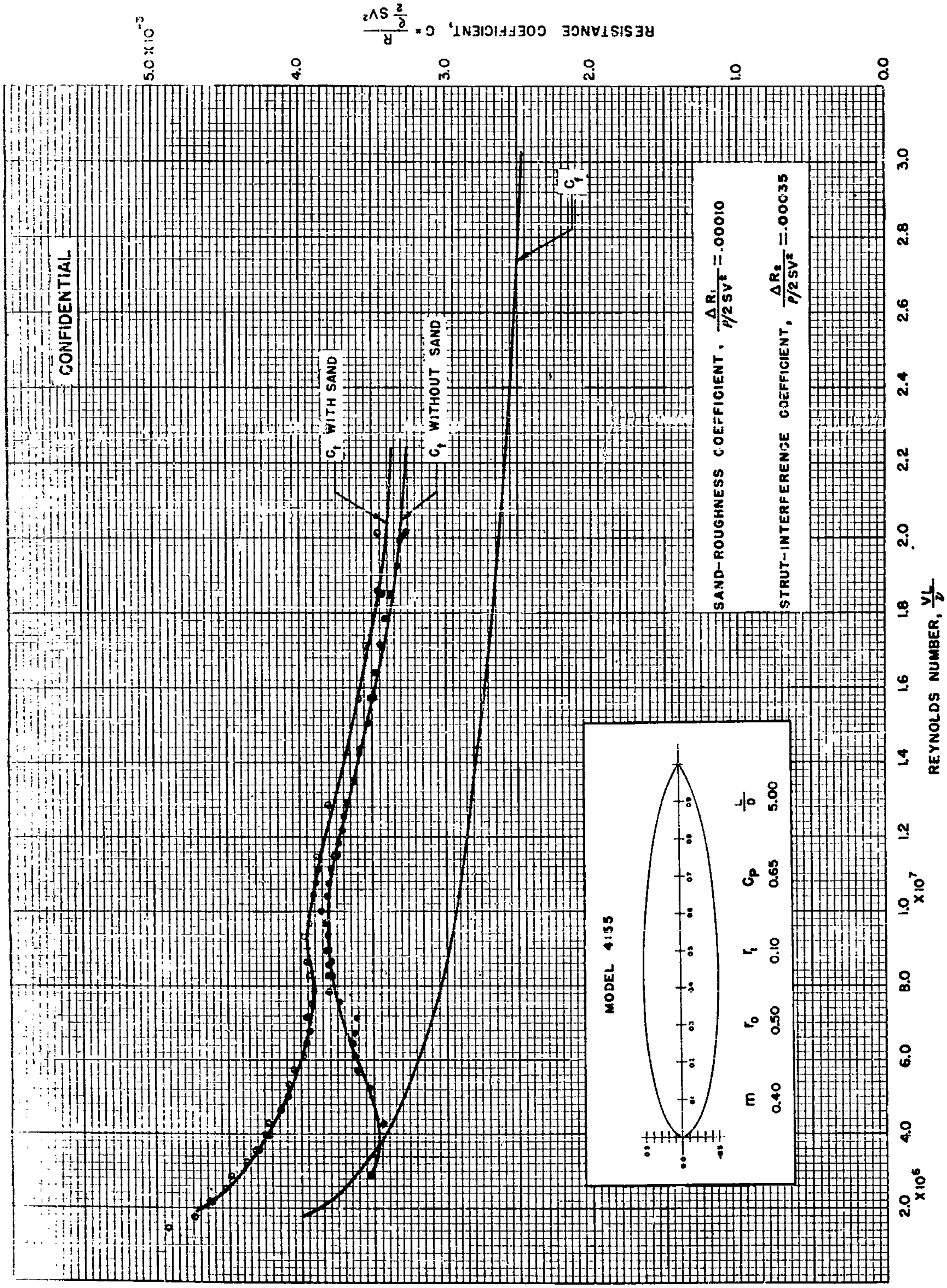
Length, ft	9.000
Diameter, ft	1.286
Nose radius, ft	0.0918
Tail radius, ft	0.0184
Wetted surface, ft^2	28.25
Volume, ft^3	7.595
Longitudinal center of buoyancy, ft from nose	4.119

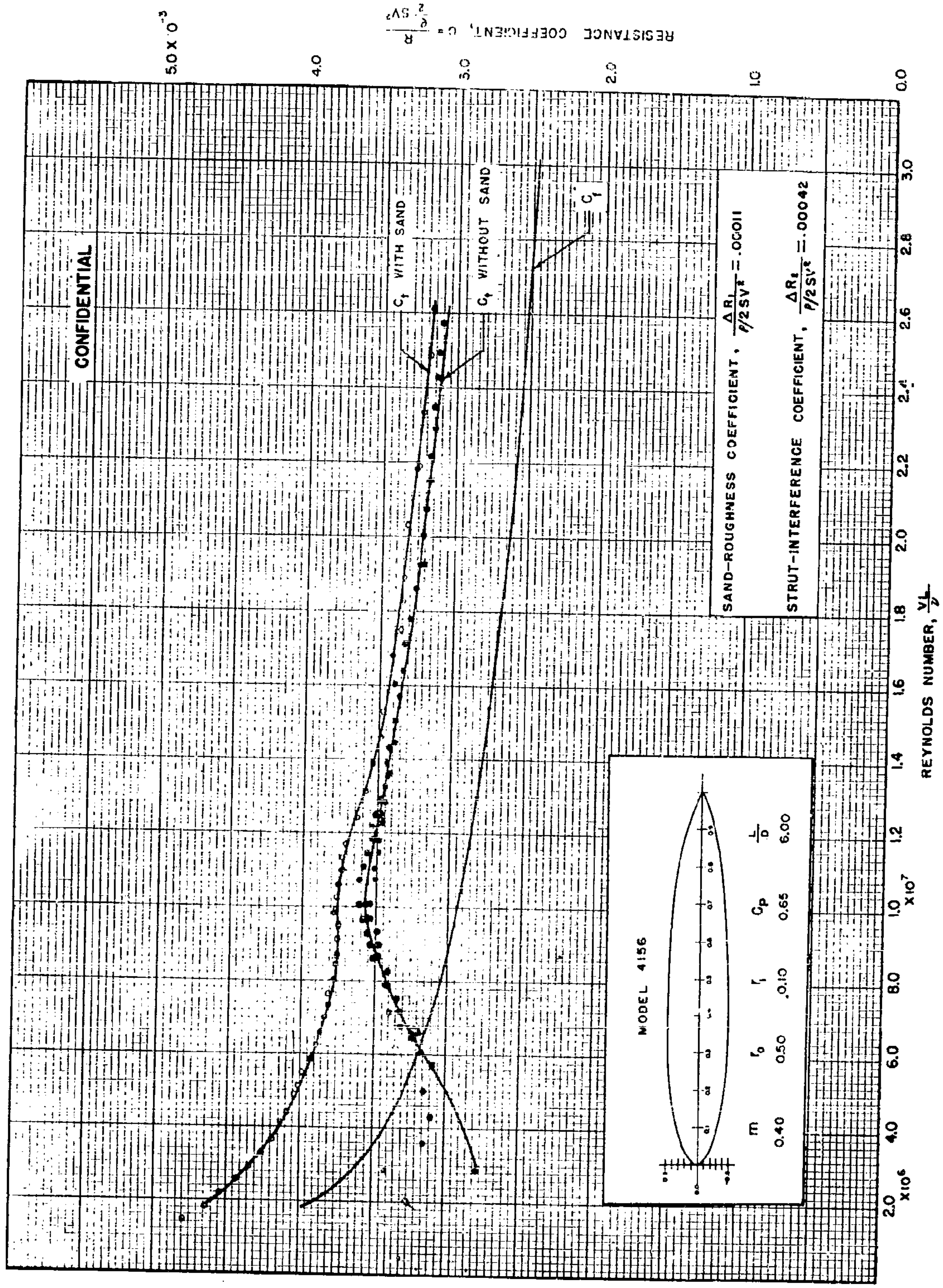
APPENDIX 3

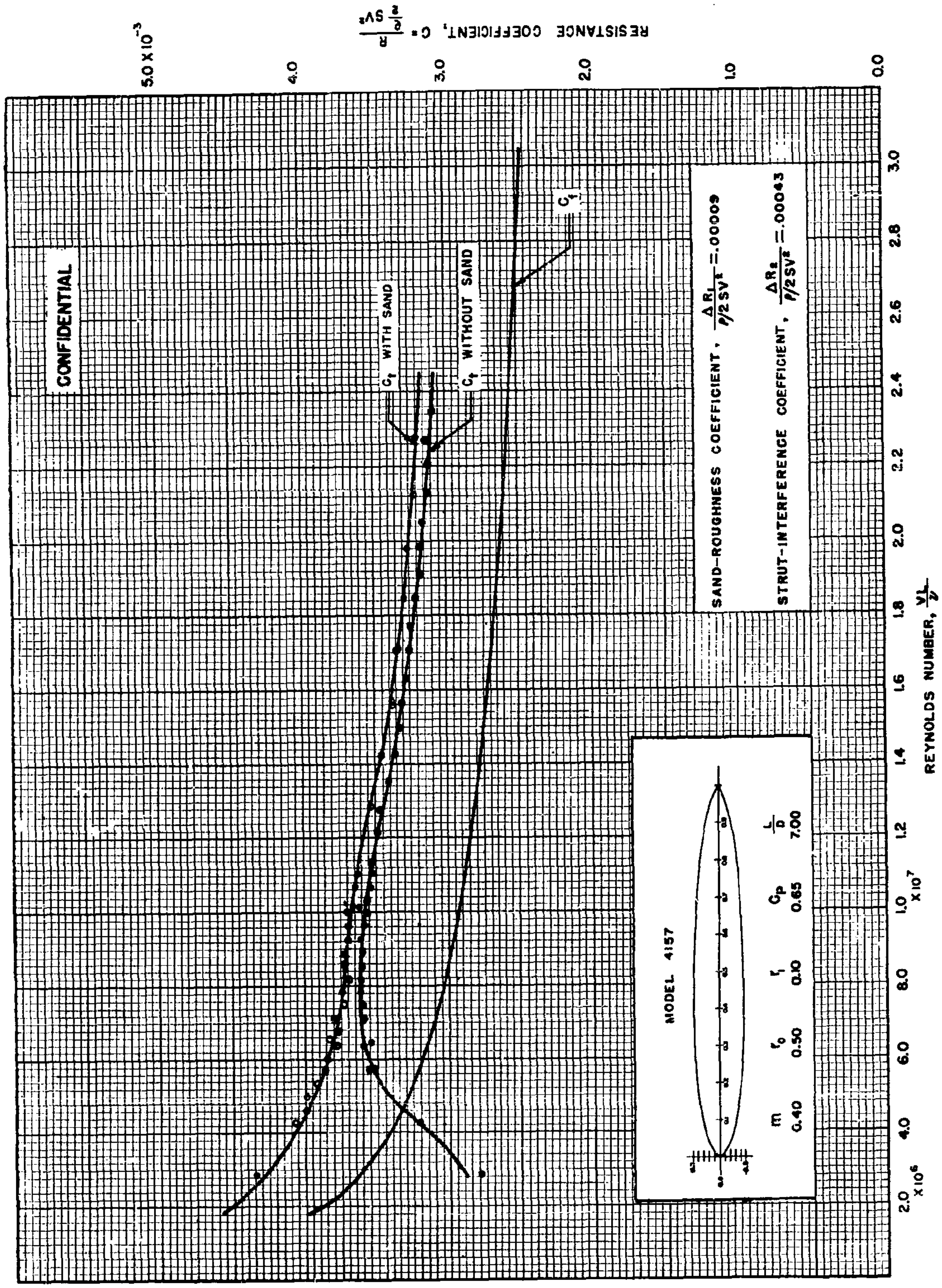
TOTAL-RESISTANCE COEFFICIENTS DERIVED FROM TESTS OF MODELS OF SERIES 58 AT DEEP SUBMERGENCE PLOTTED AGAINST REYNOLDS NUMBERS

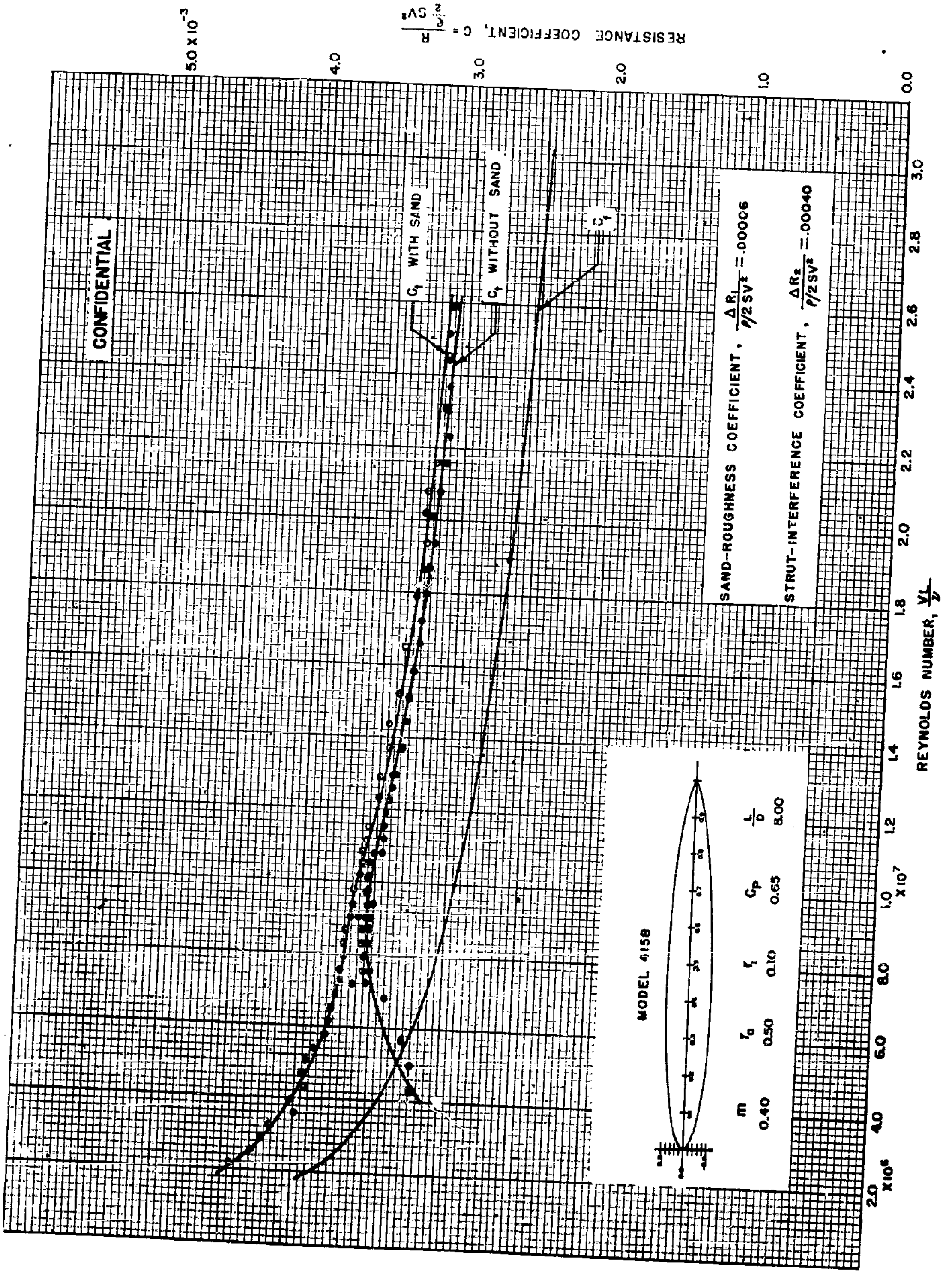
Test Spots are Shown for Each Model Tested With and Without Sand Strips. The Values for Sand Roughness Coefficient and Strut Interference Coefficient are Given on Each Set of Curves.

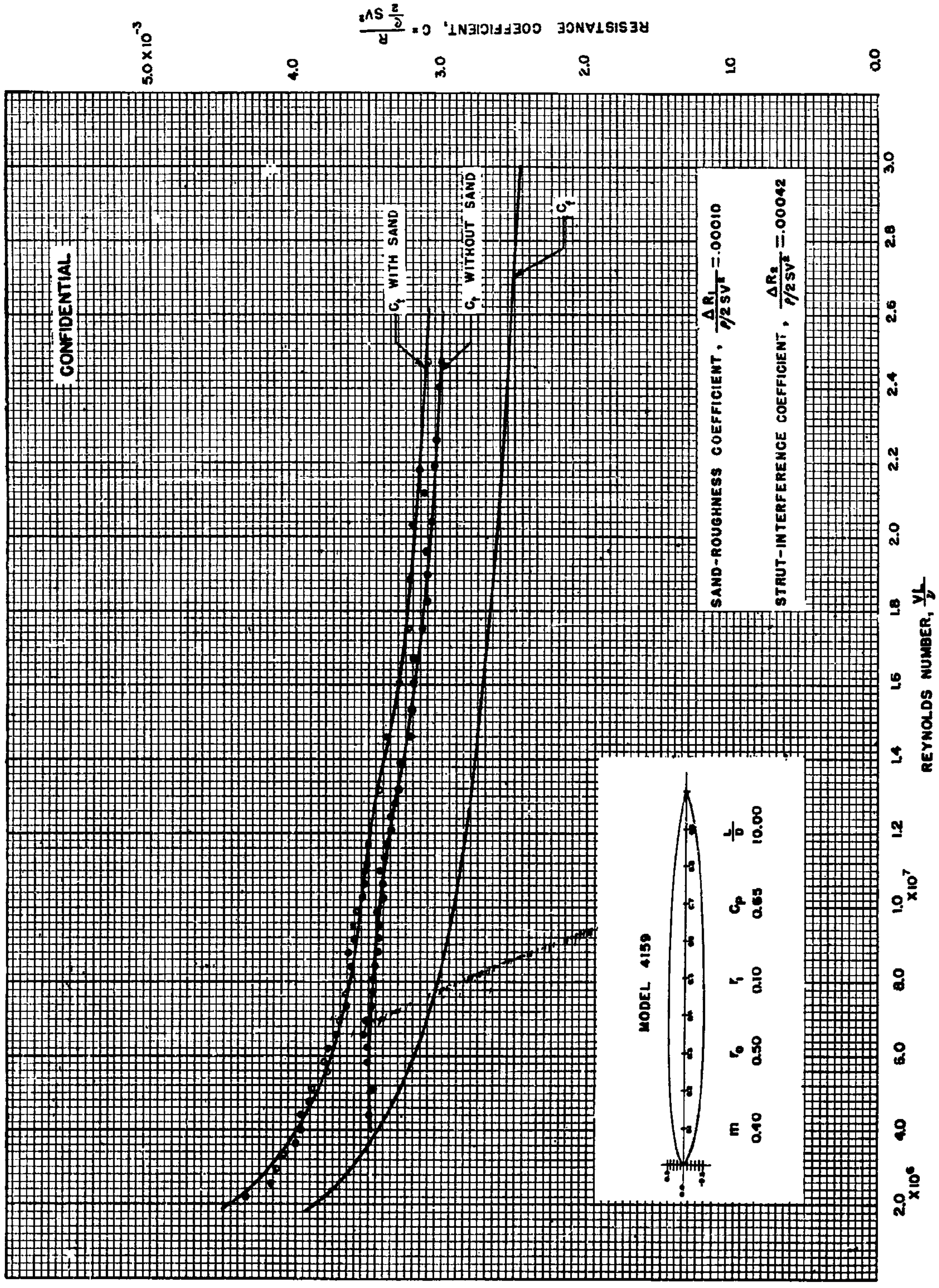

RESISTANCE COEFFICIENT, C = R / (ρ/2 S V²)
5.0 x 10⁻³
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, ΔR₁ / (ρ/2 S V²) = .00013
STRUT-INTERFERENCE COEFFICIENT, ΔR₂ / (ρ/2 S V²) = .00032
MODEL 4154
m 0.40
r₀ 0.50
r₁ 0.10
Cₚ 0.65
L/D 4.00
2.0 x 10⁶
4.0
6.0
8.0
1.0 x 10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, VL/ν

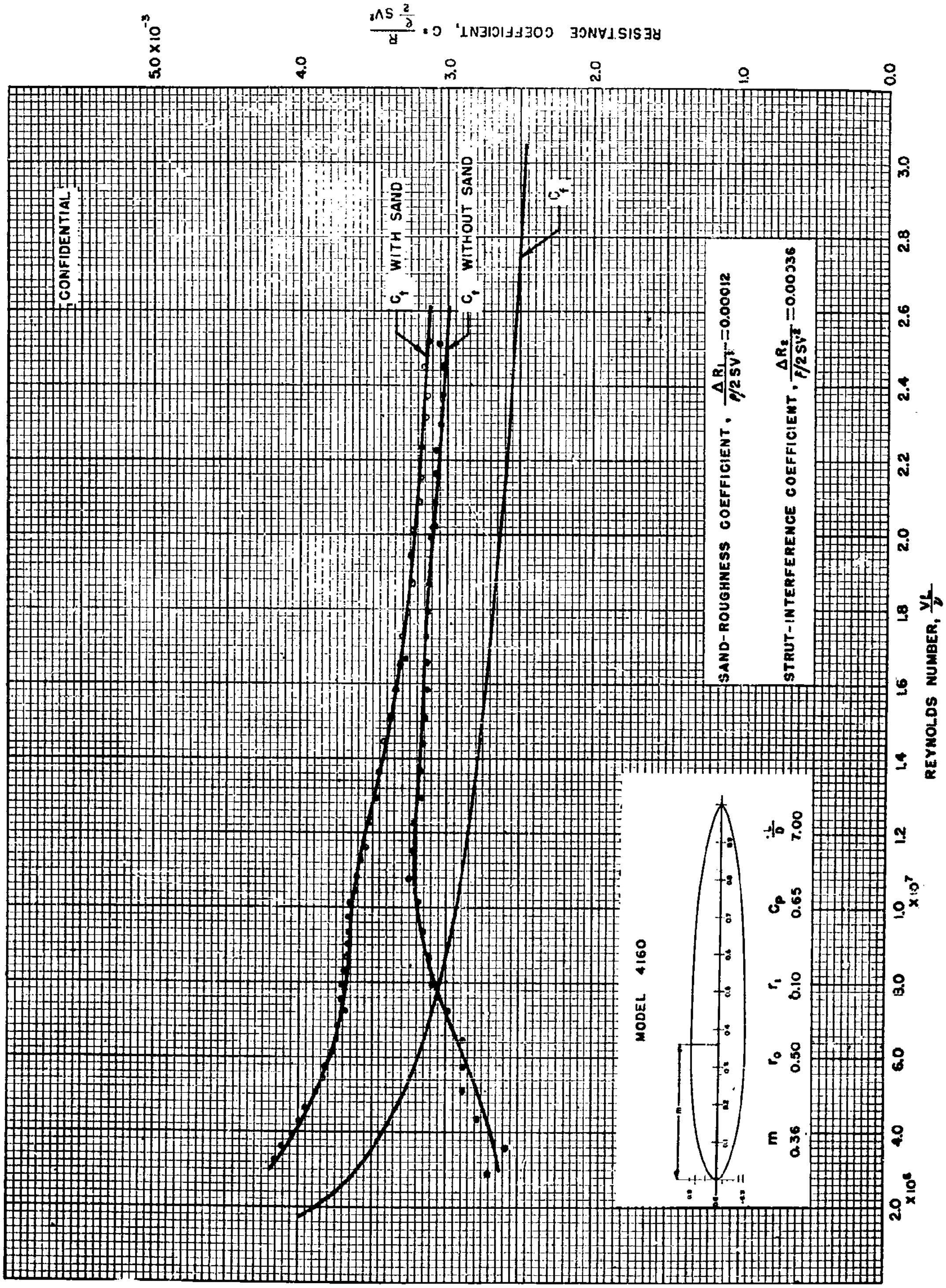

CONFIDENTIAL
RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} S V^2}$
5.0×10^{-3}
4.0
3.0
2.0
1.0
0.0
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2\, S V^2} = .00010$
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2\, S V^2} = .00035$
MODEL 4155
m 0.40
r_0 0.50
r_1 0.10
C_p 0.65
$\frac{L}{D}$ 5.00
REYNOLDS NUMBER, $\frac{VL}{\nu}$
2.0 $\times 10^6$
4.0
6.0
8.0
1.0 $\times 10^7$
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

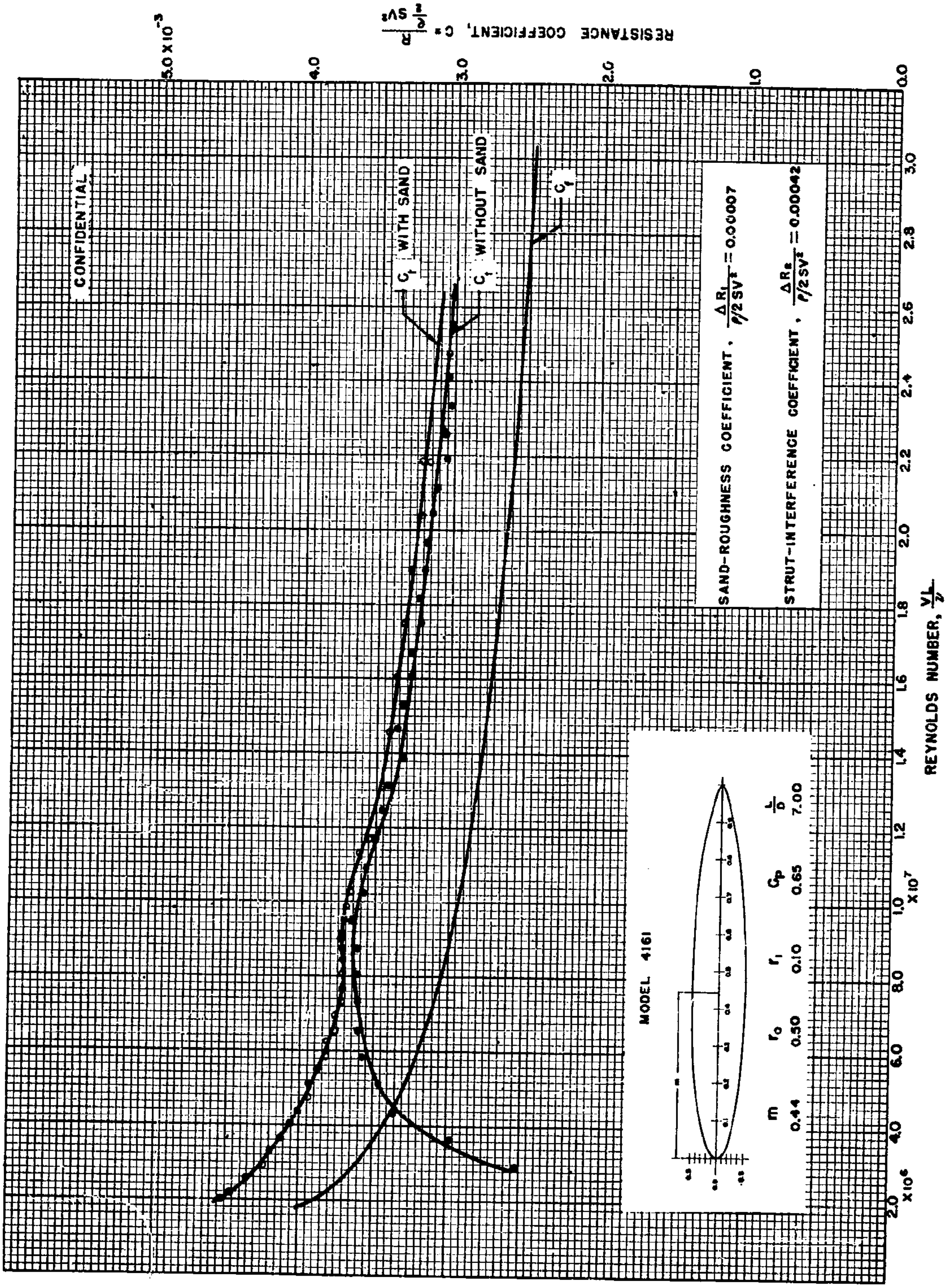

CONFIDENTIAL
RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 S V^2}$ = .00011
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 S V^2}$ = .00042
MODEL 4156
m 0.40
r_o 0.50
r_1 0.10
C_p 0.65
L/D 6.00
REYNOLDS NUMBER, VL/ν
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

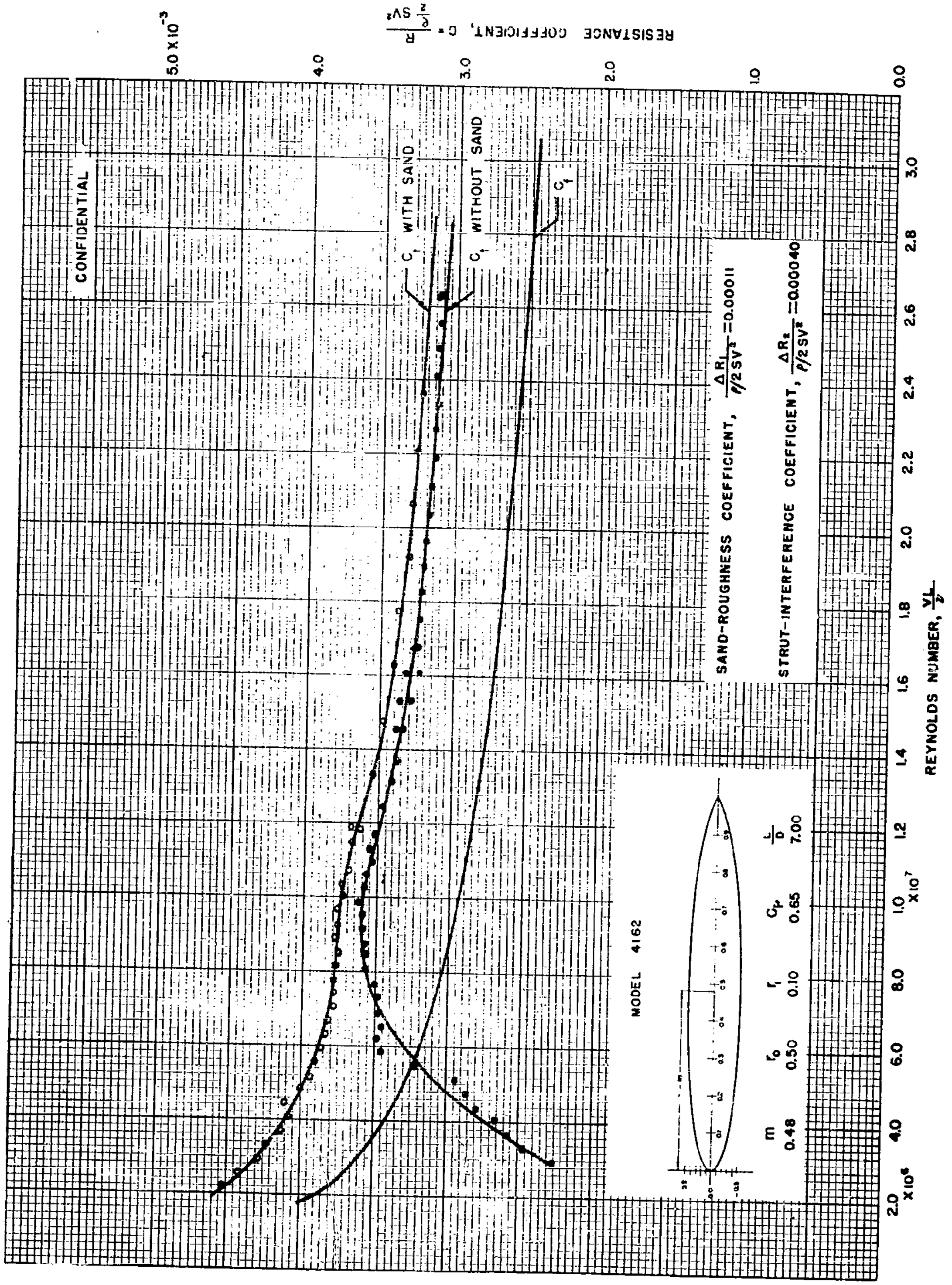

RESISTANCE COEFFICIENT, C = R/(ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
Ct WITH SAND
Ct WITHOUT SAND
Cf
SAND-ROUGHNESS COEFFICIENT, ΔR1/(ρ/2 SV²) = .00009
STRUT-INTERFERENCE COEFFICIENT, ΔR2/(ρ/2 SV²) = .00043
MODEL 4157
m 0.40
r0 0.50
r1 0.10
Cp 0.65
L/D 7.00
REYNOLDS NUMBER, VL/ν
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

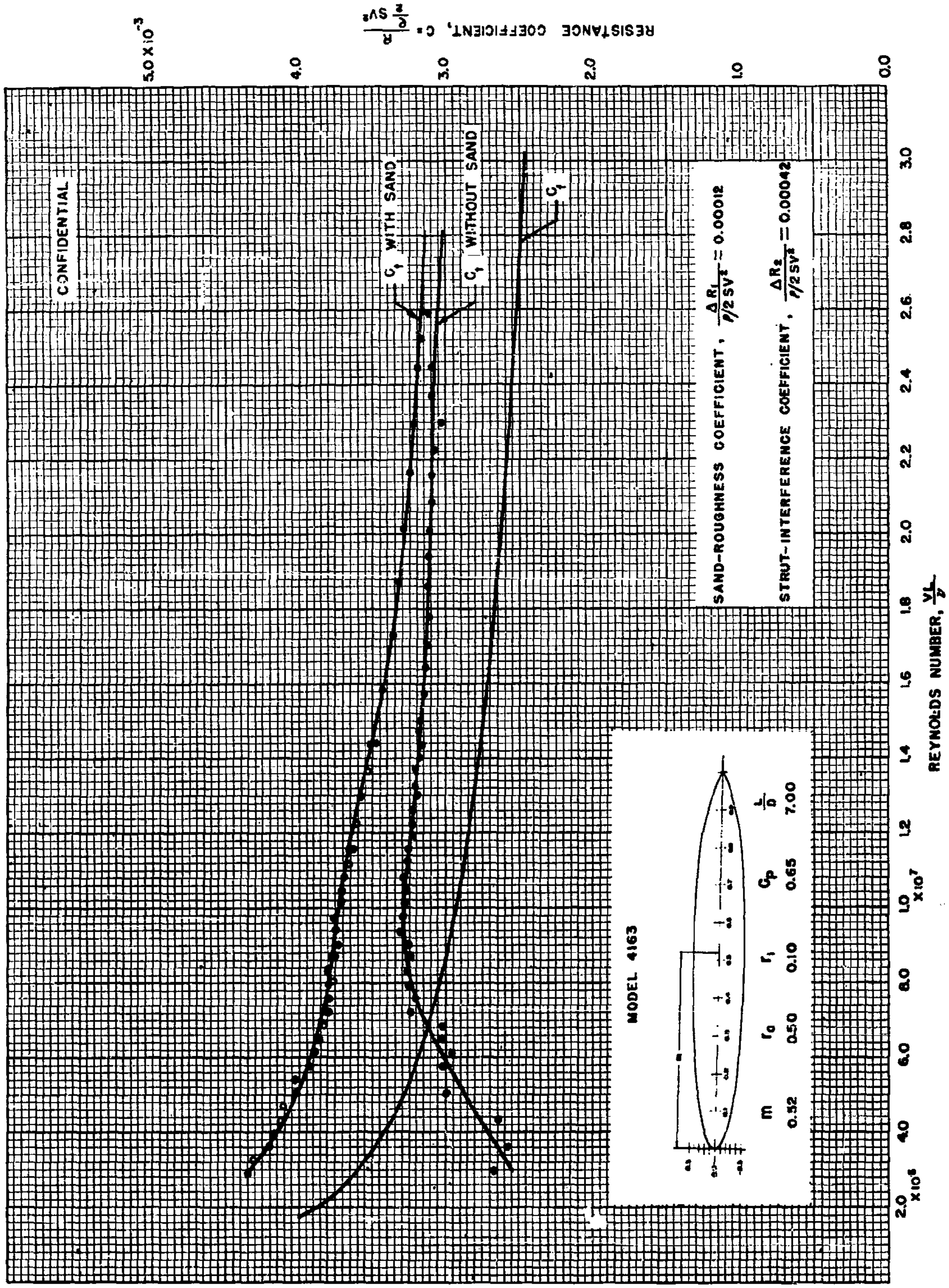

RESISTANCE COEFFICIENT, C = $\frac{R}{\frac{\rho}{2} S V^2}$
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 S V^2} = .00006$
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 S V^2} = .00040$
MODEL 4158
m 0.40
r_a 0.50
r_t 0.10
C_p 0.65
$\frac{L}{D}$ 8.00
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, $\frac{VL}{\nu}$

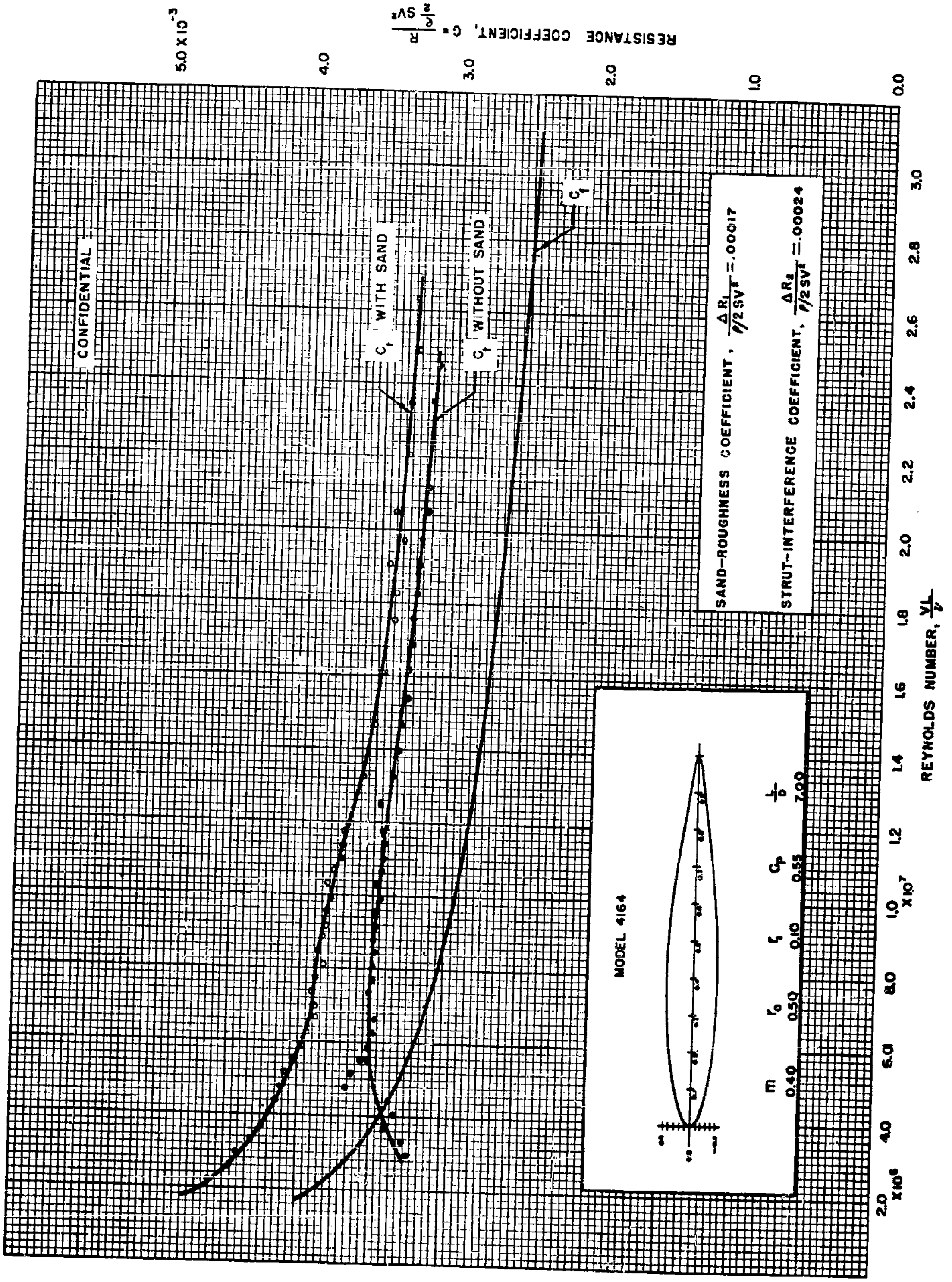

CONFIDENTIAL
RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
REYNOLDS NUMBER, VL/ν
Cₜ WITH SAND
Cₜ WITHOUT SAND
Cf
SAND-ROUGHNESS COEFFICIENT, ΔR₁ / (ρ/2 SV²) = .00010
STRUT-INTERFERENCE COEFFICIENT, ΔR₂ / (ρ/2 SV²) = .00042
MODEL 4159
m 0.40
r₀ 0.50
r₁ 0.10
Cp 0.65
L/D 10.00

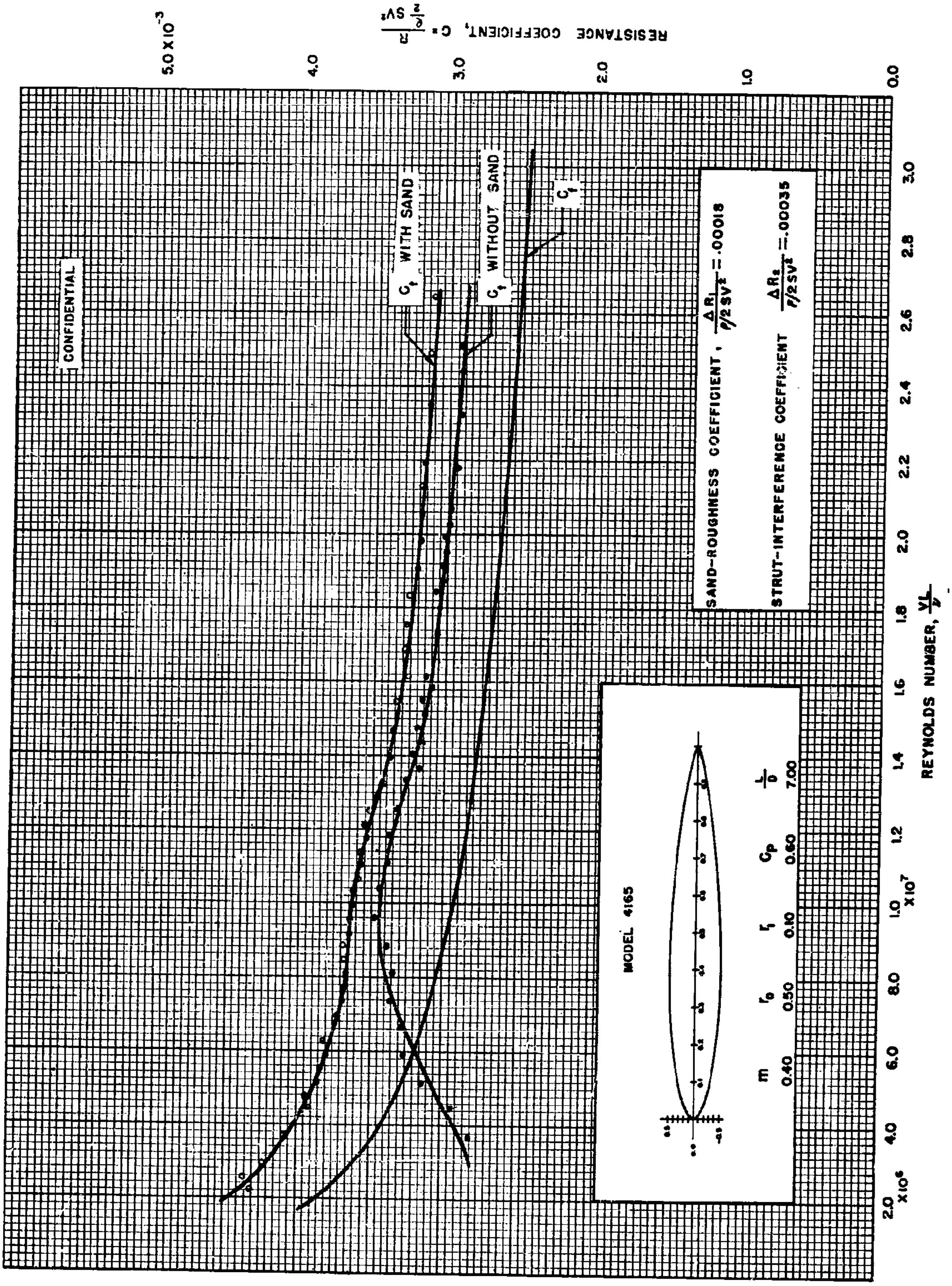

RESISTANCE COEFFICIENT, C = R/(ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
Cf WITH SAND
Cf WITHOUT SAND
Cf
SAND-ROUGHNESS COEFFICIENT, ΔR1/(ρ/2 SV²) = 0.00012
STRUT-INTERFERENCE COEFFICIENT, ΔR2/(ρ/2 SV²) = 0.00036
MODEL 4160
m 0.36
r0 0.50
r1 0.10
Cp 0.65
L/D 7.00
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, VL/ν

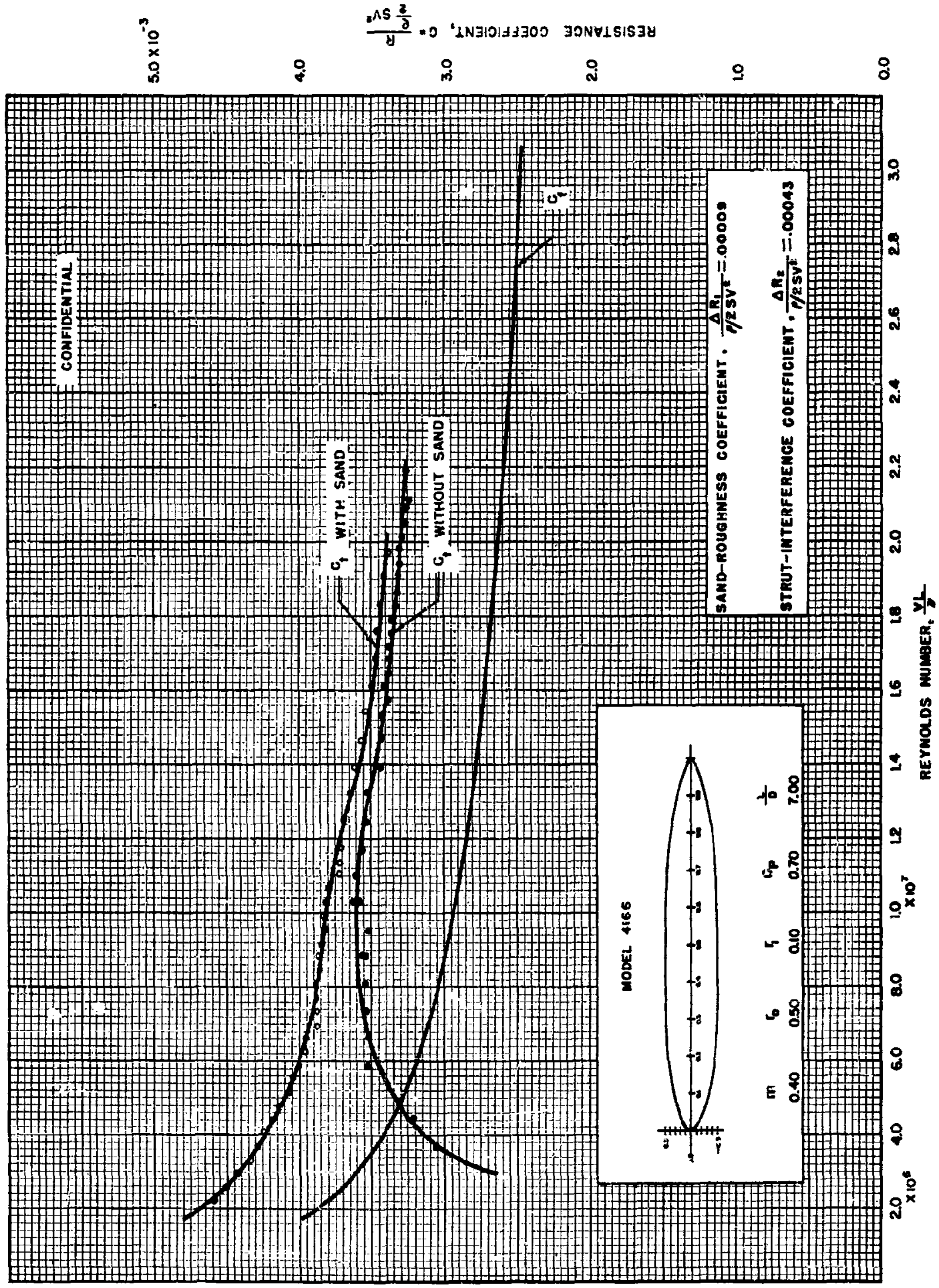

CONFIDENTIAL
RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, ΔR₁ / (ρ/2 SV²) = 0.00007
STRUT-INTERFERENCE COEFFICIENT, ΔR₂ / (ρ/2 SV²) = 0.00042
MODEL 4161
m 0.44
r_o 0.50
r_1 0.10
C_p 0.65
L/D 7.00
REYNOLDS NUMBER, VL/ν
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

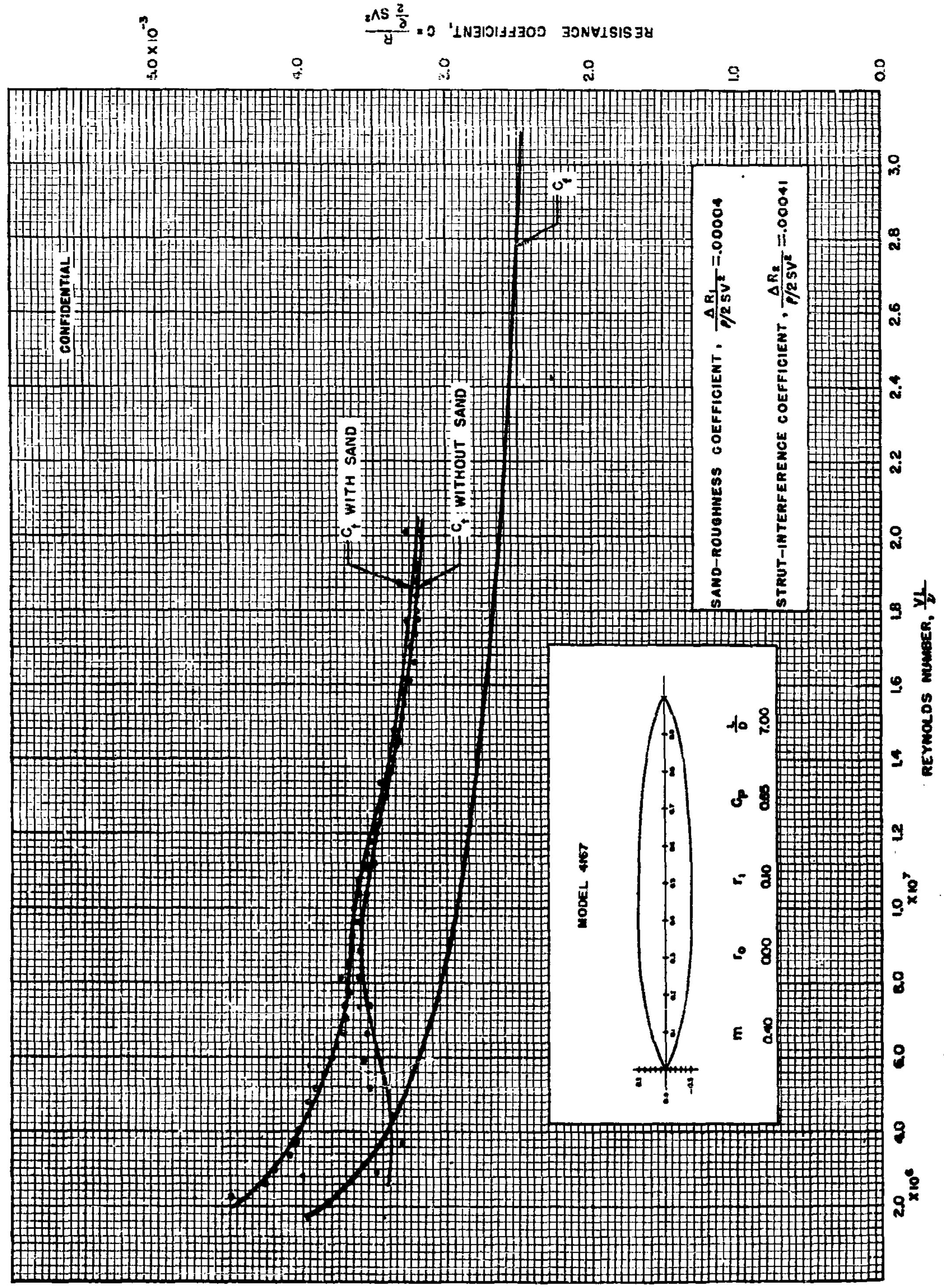

CONFIDENTIAL
RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} SV^2}$
REYNOLDS NUMBER, $\frac{VL}{\nu}$
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2\, SV^2} = 0.00011$
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2\, SV^2} = 0.00040$
MODEL 4162
m 0.48
r_0 0.50
r_1 0.10
C_p 0.65
$\frac{L}{D}$ 7.00

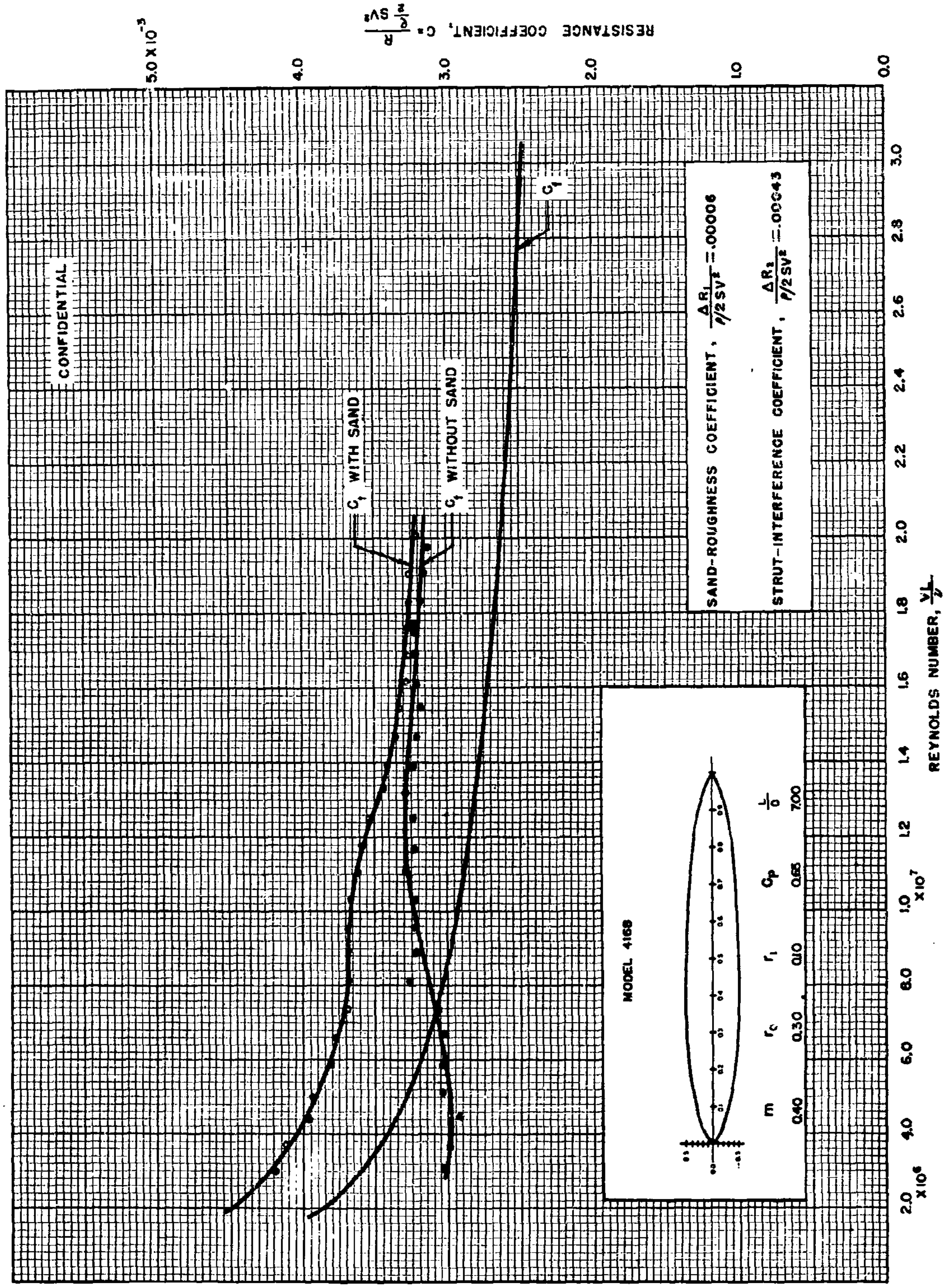

RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
Cf WITH SAND
Cf WITHOUT SAND
Cf
SAND-ROUGHNESS COEFFICIENT, ΔR1 / (ρ/2 SV²) = 0.00012
STRUT-INTERFERENCE COEFFICIENT, ΔR2 / (ρ/2 SV²) = 0.00042
MODEL 4163
m 0.52
ra 0.50
r1 0.10
Cp 0.65
L/D 7.00
2.0 X 10⁶
4.0
6.0
8.0
1.0 X 10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, VL/ν

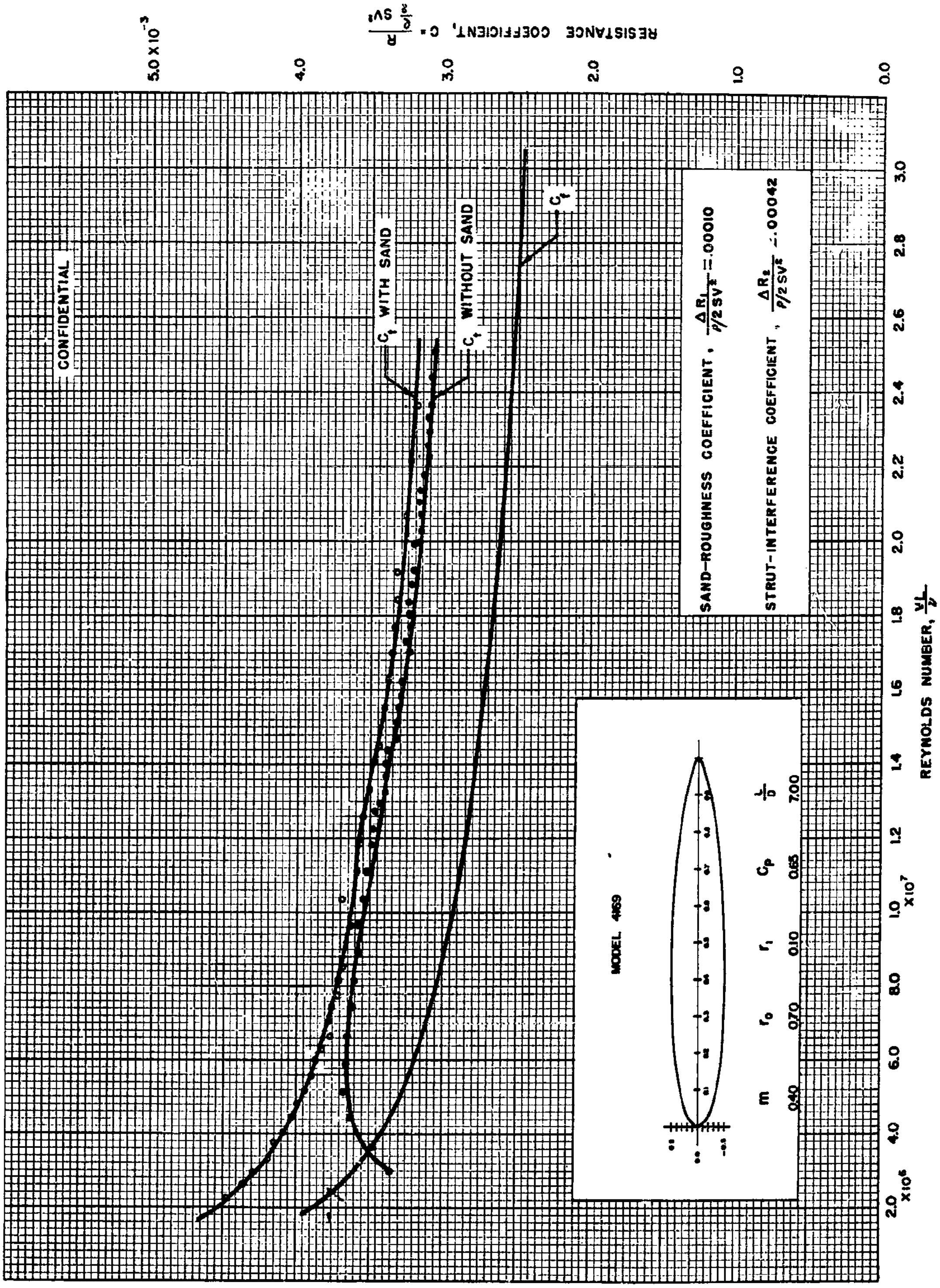

CONFIDENTIAL
RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} S V^2}$
5.0 X 10^{-3}
4.0
3.0
2.0
1.0
0.0
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 S V^2}$ = .00017
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 S V^2}$ = .00024
MODEL 4164
m 0.40
r_0 0.50
r_1 0.10
C_p 0.55
$\frac{L}{D}$ 7.00
REYNOLDS NUMBER, $\frac{VL}{\nu}$
2.0 X10^6
4.0
6.0
8.0
1.0 X10^7
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

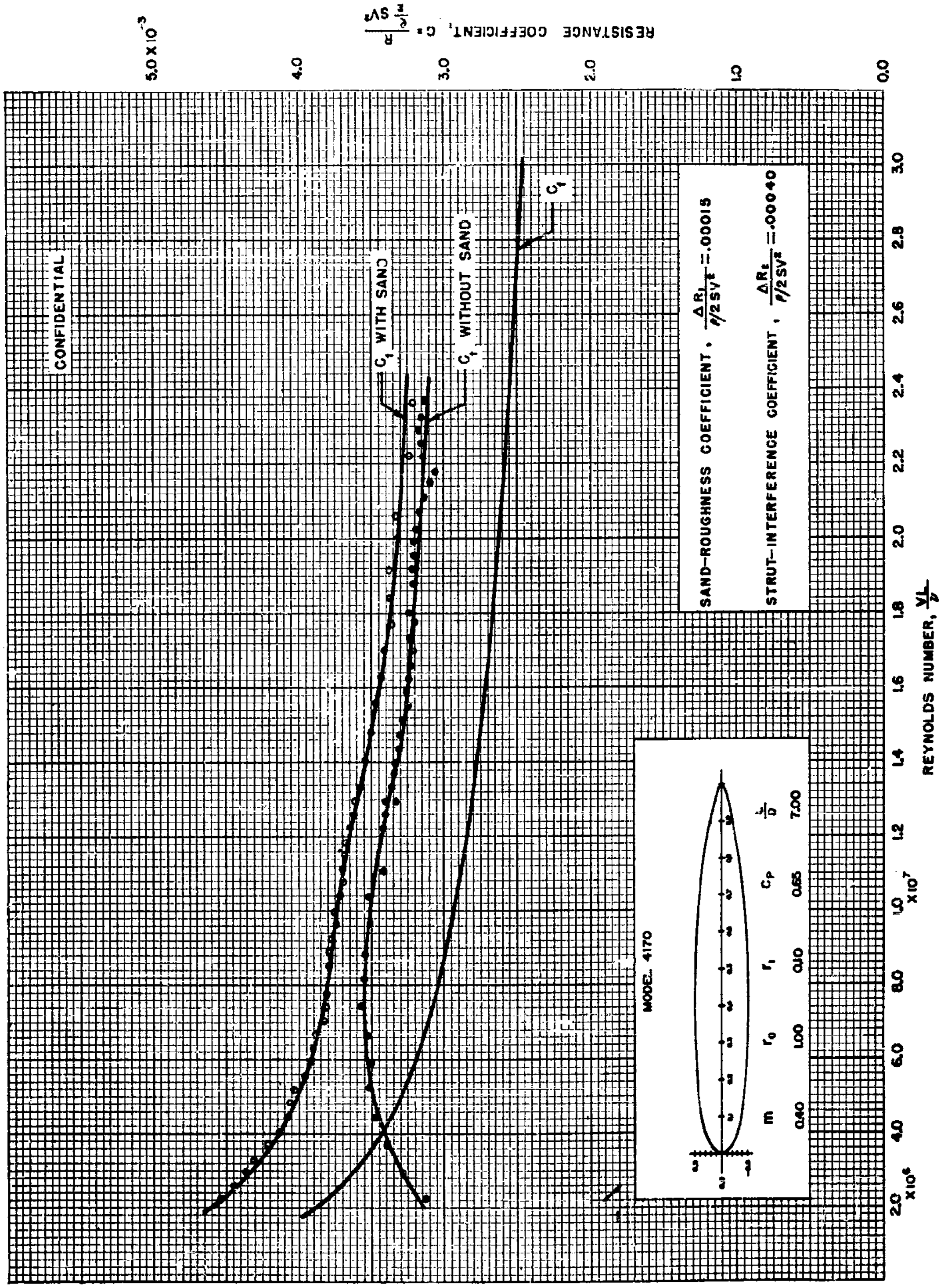

CONFIDENTIAL
RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, ΔR₁ / (ρ/2 SV²) = .00018
STRUT-INTERFERENCE COEFFICIENT ΔR₂ / (ρ/2 SV²) = .00035
MODEL 4165
m 0.40
r₀ 0.50
r₁ 0.10
Cp 0.60
L/D 7.00
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, VL/ν

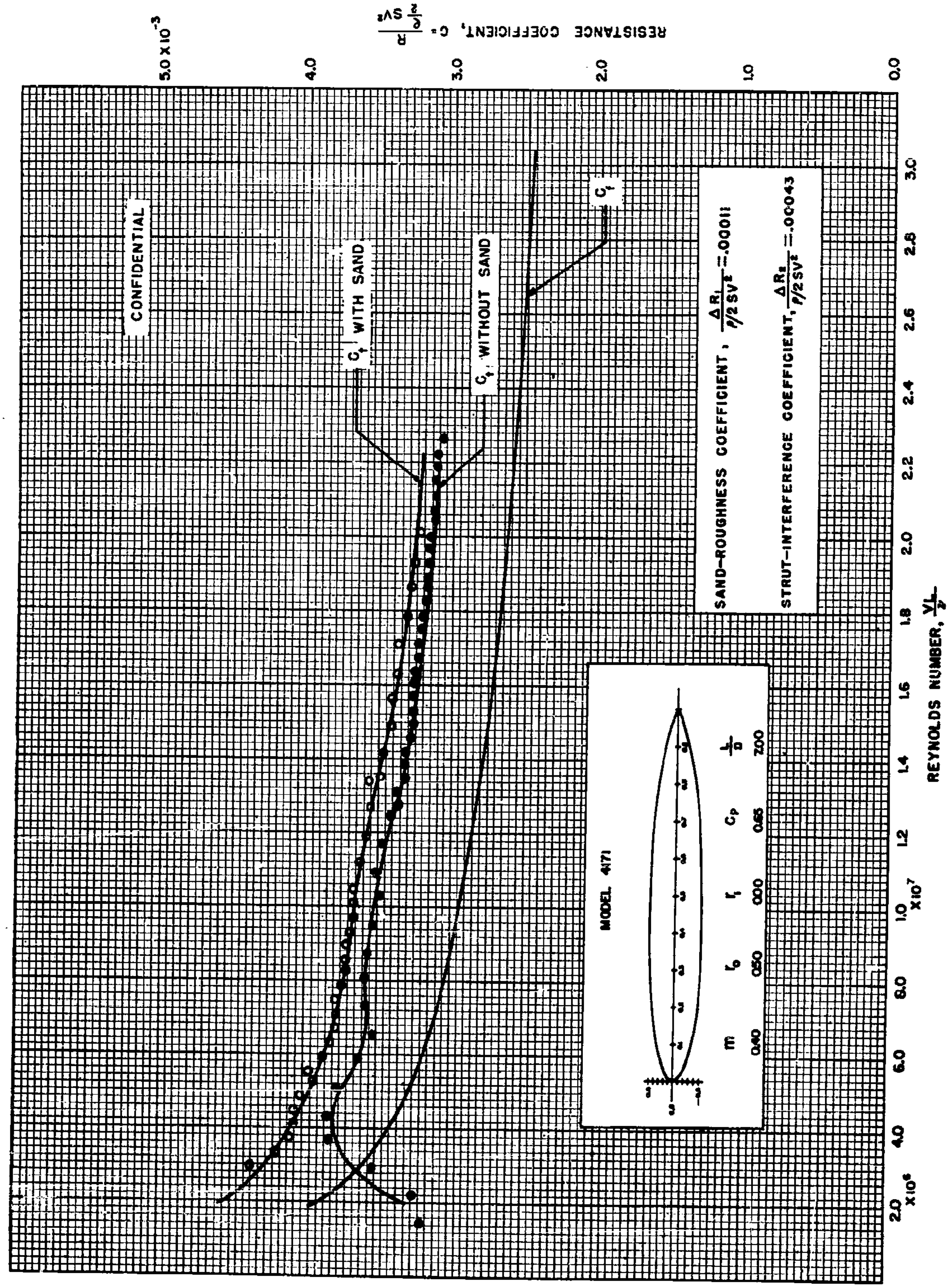

RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} SV^2}$
5.0 X 10^{-3}
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
C_f WITH SAND
C_f WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 SV^2} = .00009$
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 SV^2} = .00043$
MODEL 4166
m 0.40
r_o 0.50
r_1 0.10
C_p 0.70
$\frac{L}{D}$ 7.00
2.0 X10^6
4.0
6.0
8.0
1.0 X10^7
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, $\frac{VL}{\nu}$

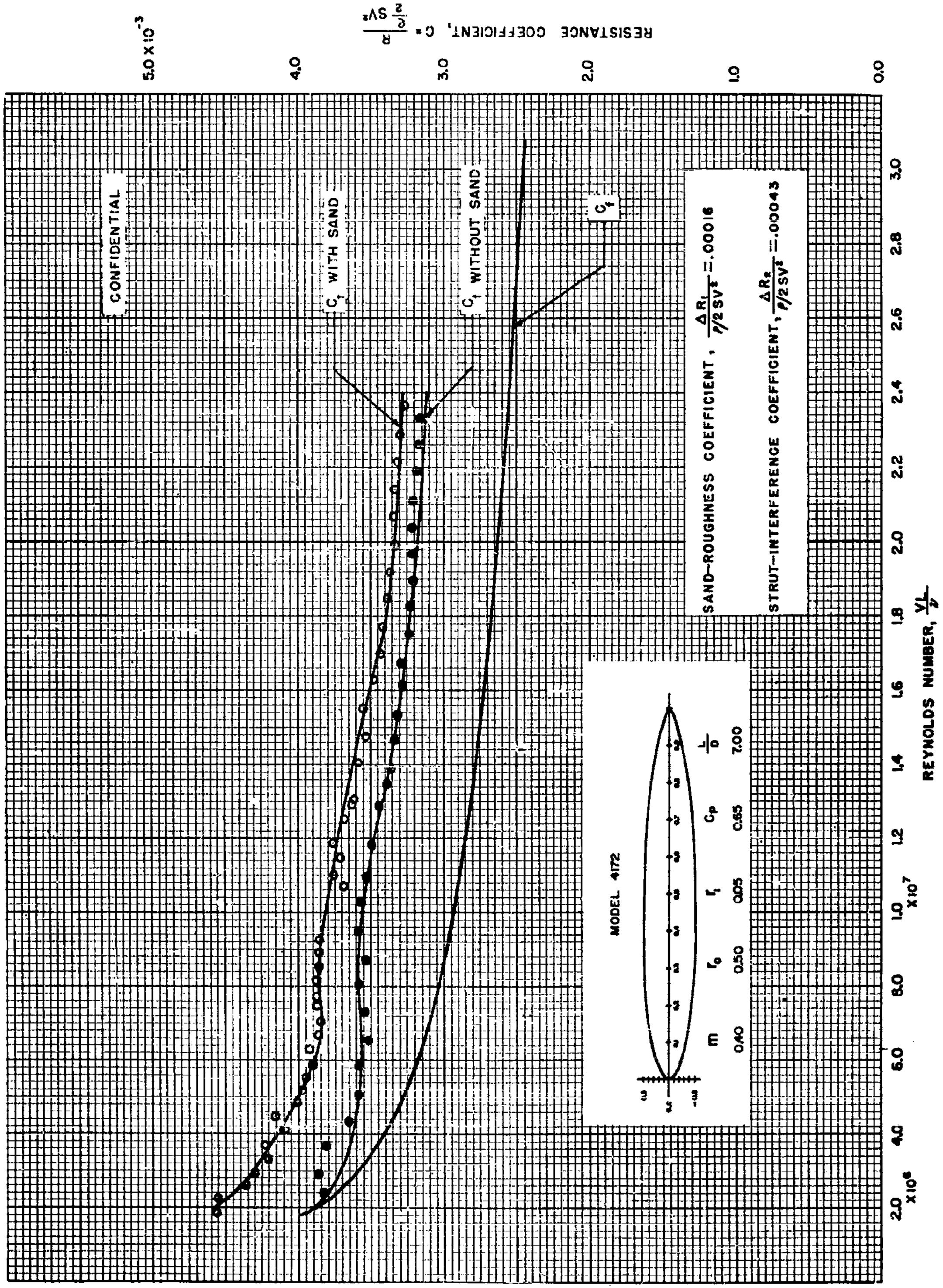

RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} SV^2}$
5.0 X 10^-3
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 SV^2}$ = .00004
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 SV^2}$ = .00041
m r0 r1 Cp L/D
0.40 0.00 0.10 0.65 7.00
2.0 X10^6 4.0 6.0 8.0 1.0 X10^7 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0
REYNOLDS NUMBER, $\frac{VL}{\nu}$

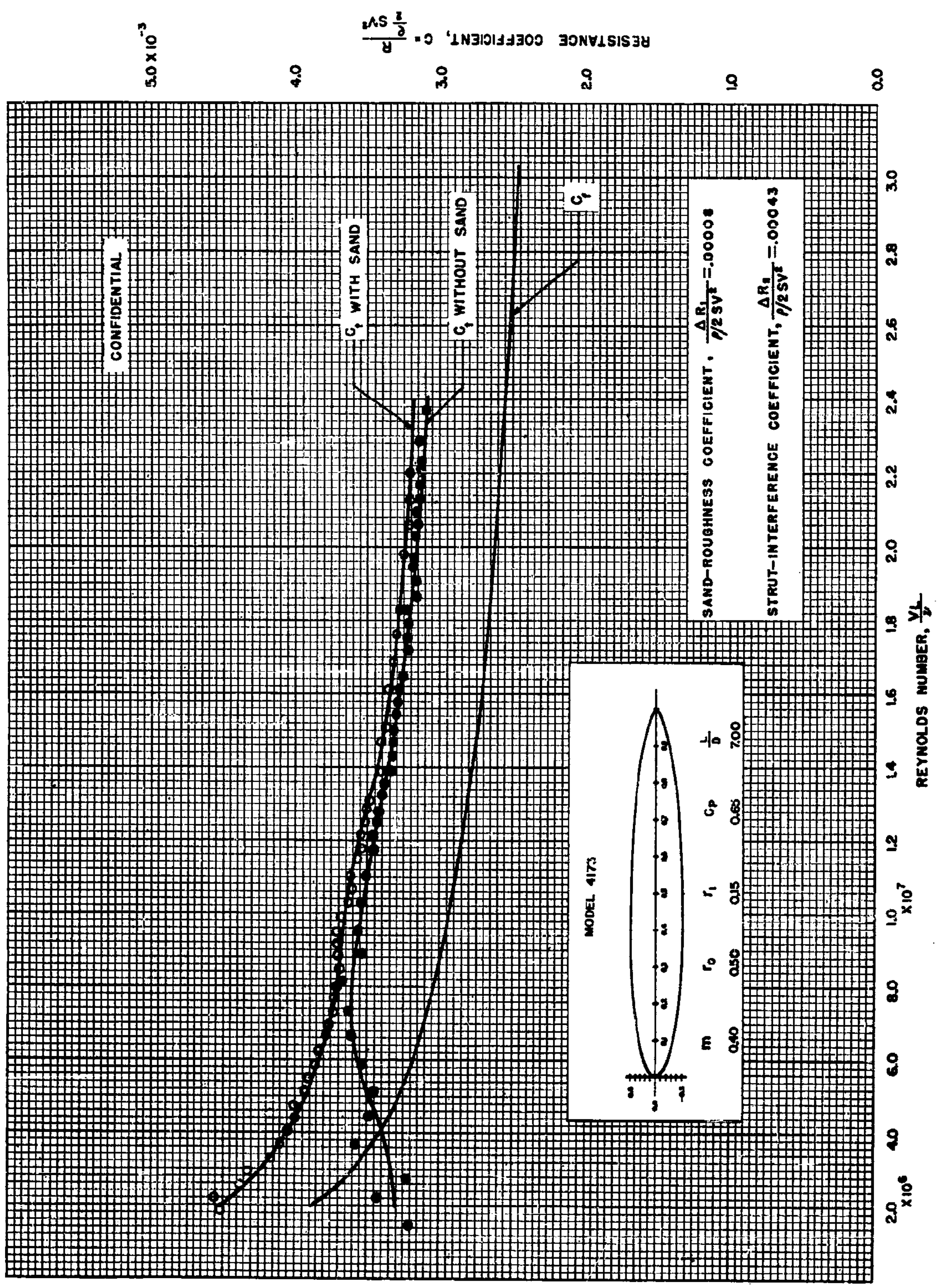

RESISTANCE COEFFICIENT, C = $\frac{R}{\frac{\rho}{2} SV^2}$
5.0 X 10^{-3}
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
C_f WITH SAND
C_f WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 SV^2}$ = .00006
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 SV^2}$ = .00043
MODEL 4168
m r_c r_1 C_p L/D
0.40 0.30 0.10 0.65 7.00
2.0 X10^6
4.0
6.0
8.0
1.0 X10^7
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, $\frac{VL}{\nu}$

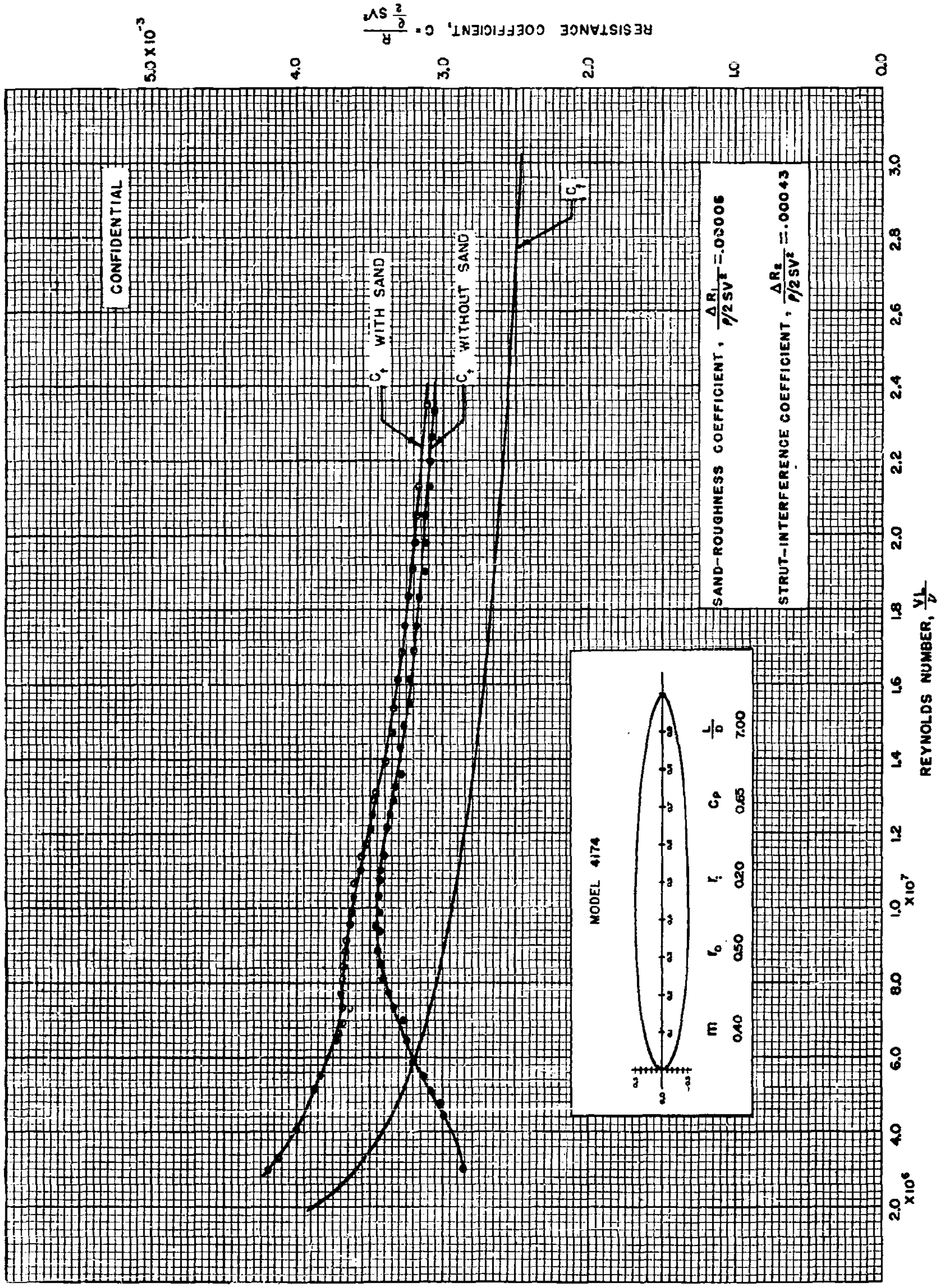

RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 x 10⁻³
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
Ct WITH SAND
Ct WITHOUT SAND
Cf
SAND-ROUGHNESS COEFFICIENT, ΔR₁ / (ρ/2 SV²) = .00010
STRUT-INTERFERENCE COEFFICIENT, ΔR₂ / (ρ/2 SV²) = .00042
MODEL
REYNOLDS NUMBER, VL/ν
2.0 x10⁶
4.0
6.0
8.0
1.0 x10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

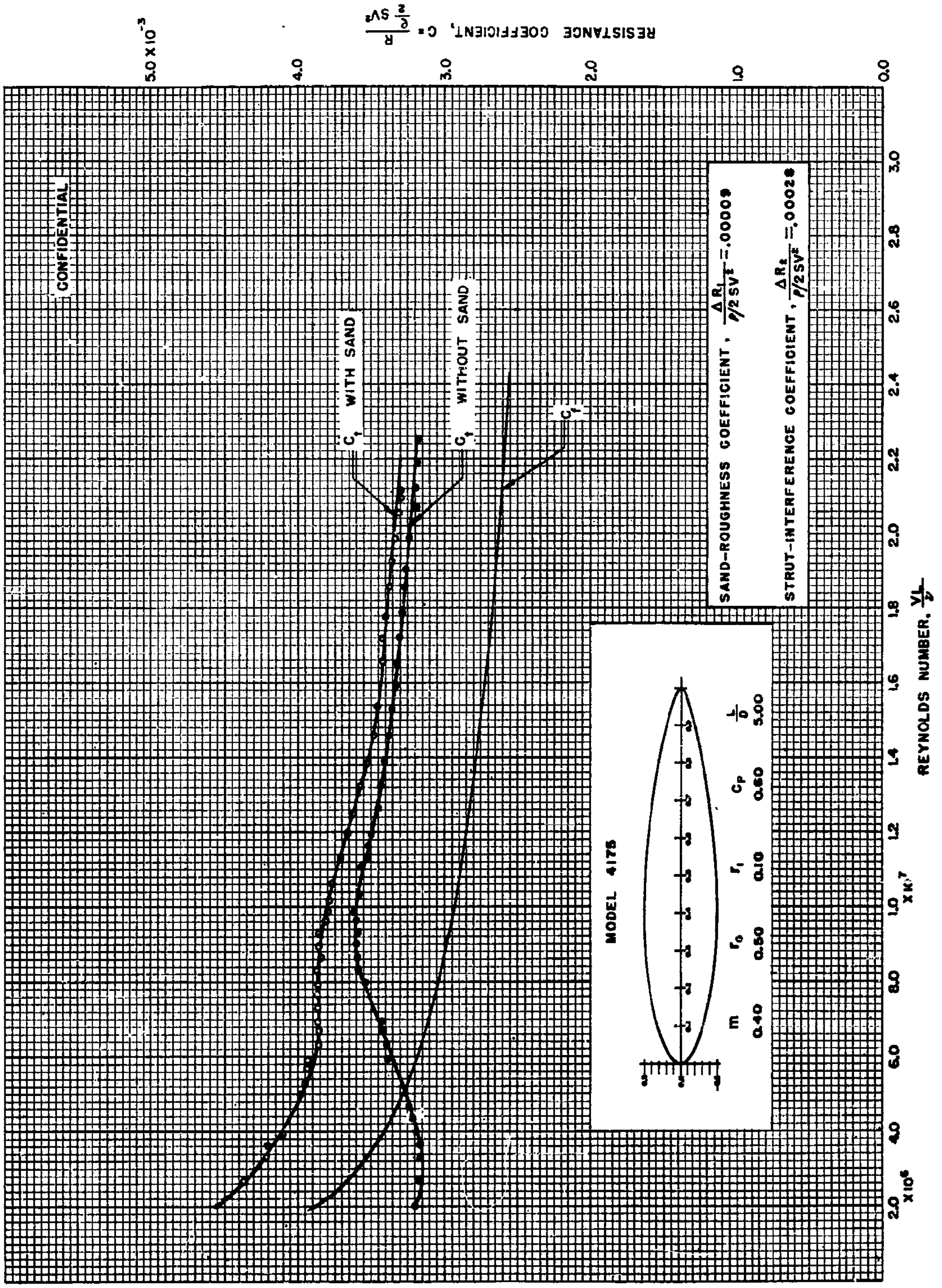

RESISTANCE COEFFICIENT, C = R/(ρ/2 SV²)
REYNOLDS NUMBER, VL/ν
CONFIDENTIAL
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, ΔR₁/(ρ/2 SV²) = .00015
STRUT-INTERFERENCE COEFFICIENT, ΔR₂/(ρ/2 SV²) = .00040
MODEL 4170
m r₀ r₁ Cp L/D
0.40 1.00 0.10 0.65 7.00

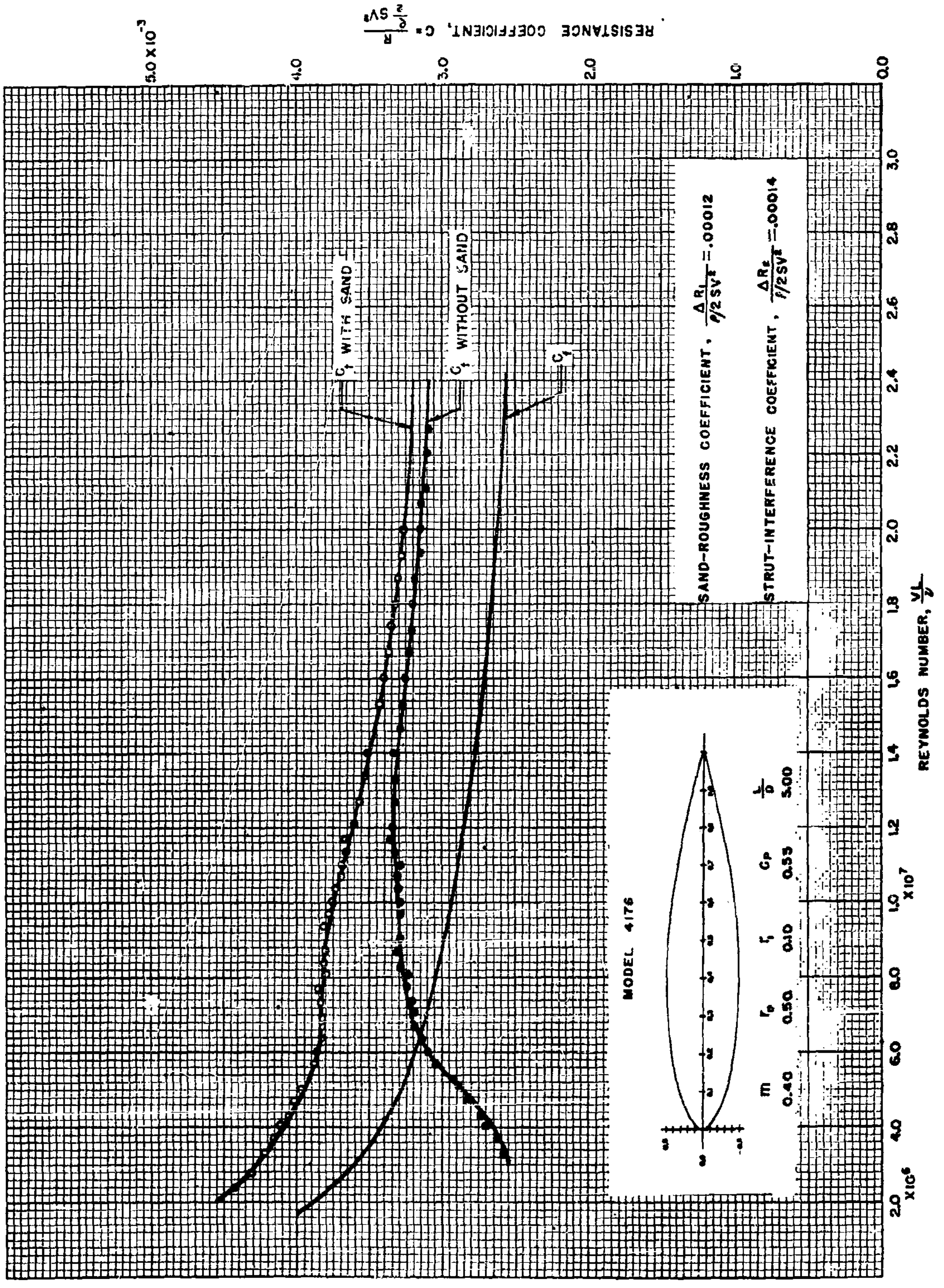

CONFIDENTIAL
RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} S V^2}$
5.0 X 10^-3
4.0
3.0
2.0
1.0
0.0
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2\, S V^2} = .00011$
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_s}{\rho/2\, S V^2} = .00043$
MODEL 4171
m 0.40
r_0 0.50
r_1 0.00
C_p 0.65
L/D 7.00
REYNOLDS NUMBER, $\frac{VL}{\nu}$
2.0 X10^6
4.0
6.0
8.0
1.0 X10^7
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

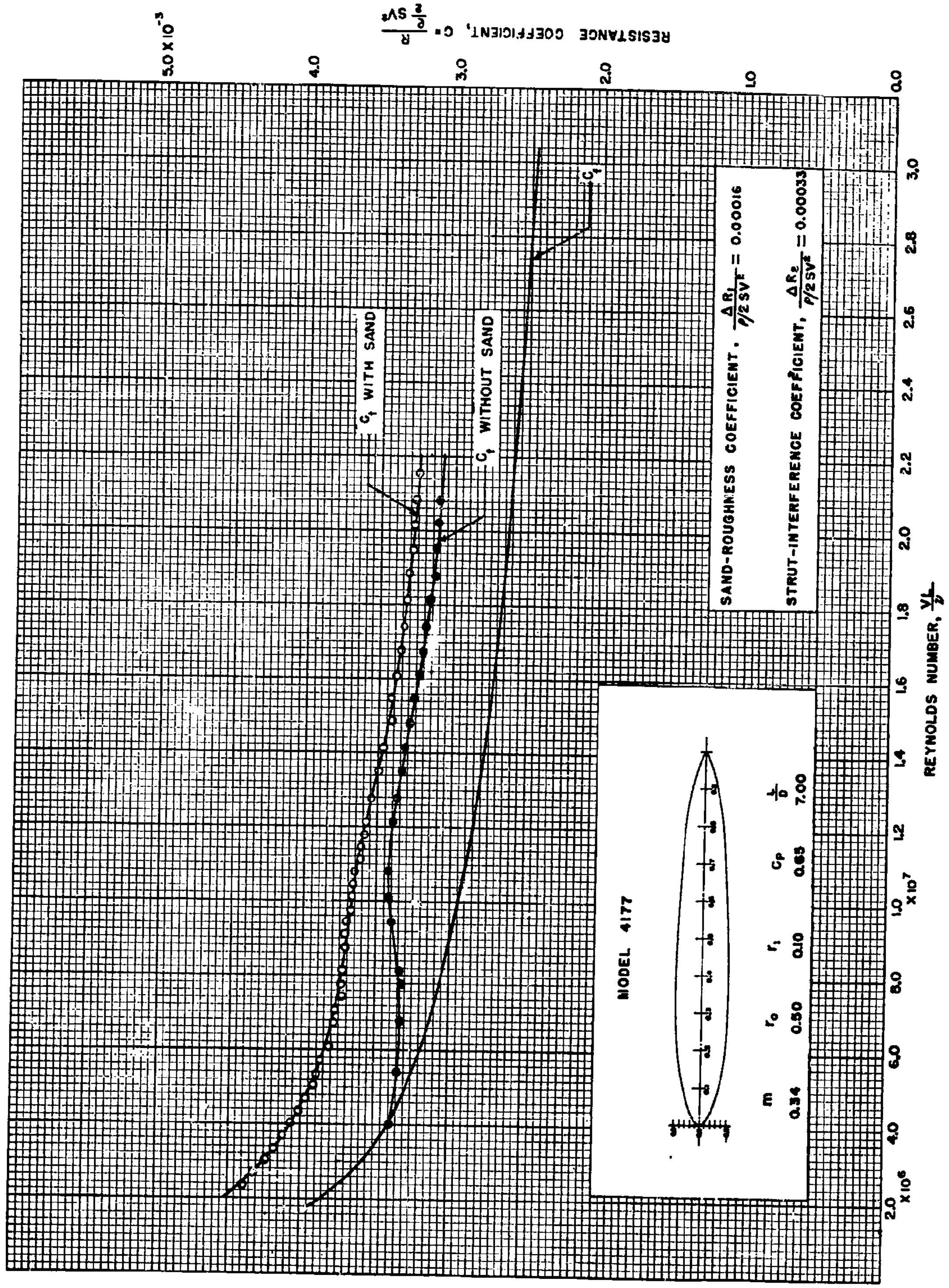

CONFIDENTIAL
RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} SV^2}$
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
C_f WITH SAND
C_f WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2\, SV^2} = .00016$
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2\, SV^2} = .00043$
MODEL 4172
m 0.40
r_0 0.50
r_1 0.05
C_p 0.65
$\frac{L}{D}$ 7.00
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, $\frac{VL}{\nu}$


RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
Cₜ WITH SAND
Cₜ WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, ΔR₁ / (ρ/2 SV²) = .00008
STRUT-INTERFERENCE COEFFICIENT, ΔR₂ / (ρ/2 SV²) = .00043
MODEL 4173
m 0.40
r₀ 0.50
r₁ 0.15
Cₚ 0.65
L/D 7.00
2.0 X10⁶
4.0
6.0
8.0
1.0 X10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, VL/ν


RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} S V^2}$
5.0 X 10^{-3}
4.0
3.0
2.0
1.0
0.0
CONFIDENTIAL
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 S V^2}$ =.00006
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 S V^2}$ =.00043
MODEL 4174
m 0.40
r_o 0.50
r_i 0.20
C_p 0.65
$\frac{L}{D}$ 7.00
2.0 X10^6
4.0
6.0
8.0
1.0 X10^7
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, $\frac{VL}{\nu}$


CONFIDENTIAL
RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 X 10⁻³
4.0
3.0
2.0
1.0
0.0
REYNOLDS NUMBER, VL/ν
2.0 X 10⁶
4.0
6.0
8.0
1.0 X 10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Ct WITH SAND
Ct WITHOUT SAND
Cf
MODEL 4175
m 0.40
r0 0.50
r1 0.10
Cp 0.60
L/D 5.00
SAND-ROUGHNESS COEFFICIENT, ΔR1 / (ρ/2 SV²) = .00009
STRUT-INTERFERENCE COEFFICIENT, ΔR2 / (ρ/2 SV²) = .00028

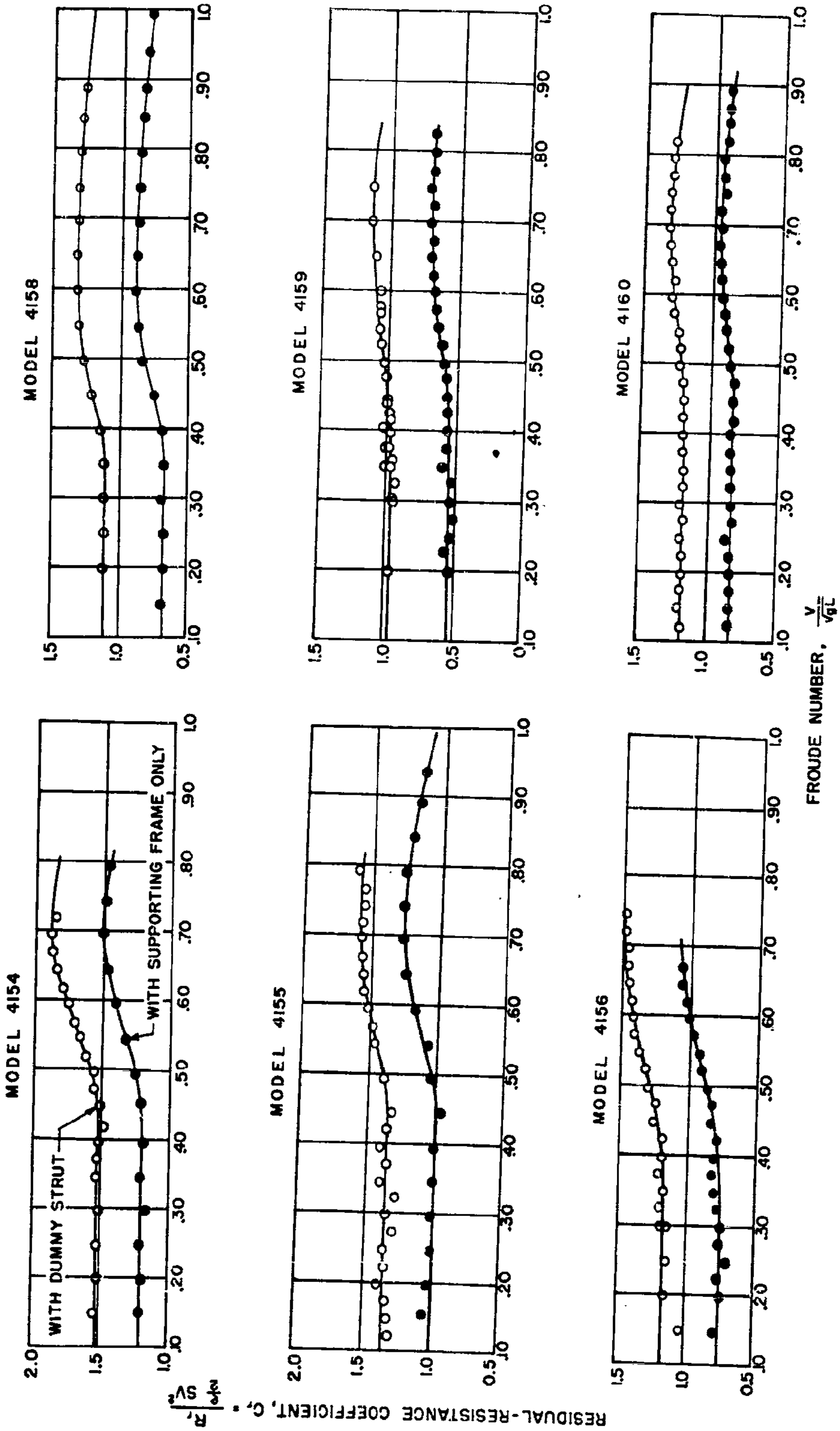

RESISTANCE COEFFICIENT, $C = \frac{R}{\frac{\rho}{2} S V^2}$
5.0 X 10^-3
4.0
3.0
2.0
1.0
0.0
C_t WITH SAND
C_t WITHOUT SAND
C_f
SAND-ROUGHNESS COEFFICIENT, $\frac{\Delta R_1}{\rho/2 S V^2}$ = .00012
STRUT-INTERFERENCE COEFFICIENT, $\frac{\Delta R_2}{\rho/2 S V^2}$ = .00014
MODEL 4176
m 0.40
r_0 0.50
r_1 0.10
C_p 0.55
$\frac{L}{D}$ 5.00
REYNOLDS NUMBER, $\frac{VL}{\nu}$
2.0 X10^6
4.0
6.0
8.0
1.0 X10^7
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

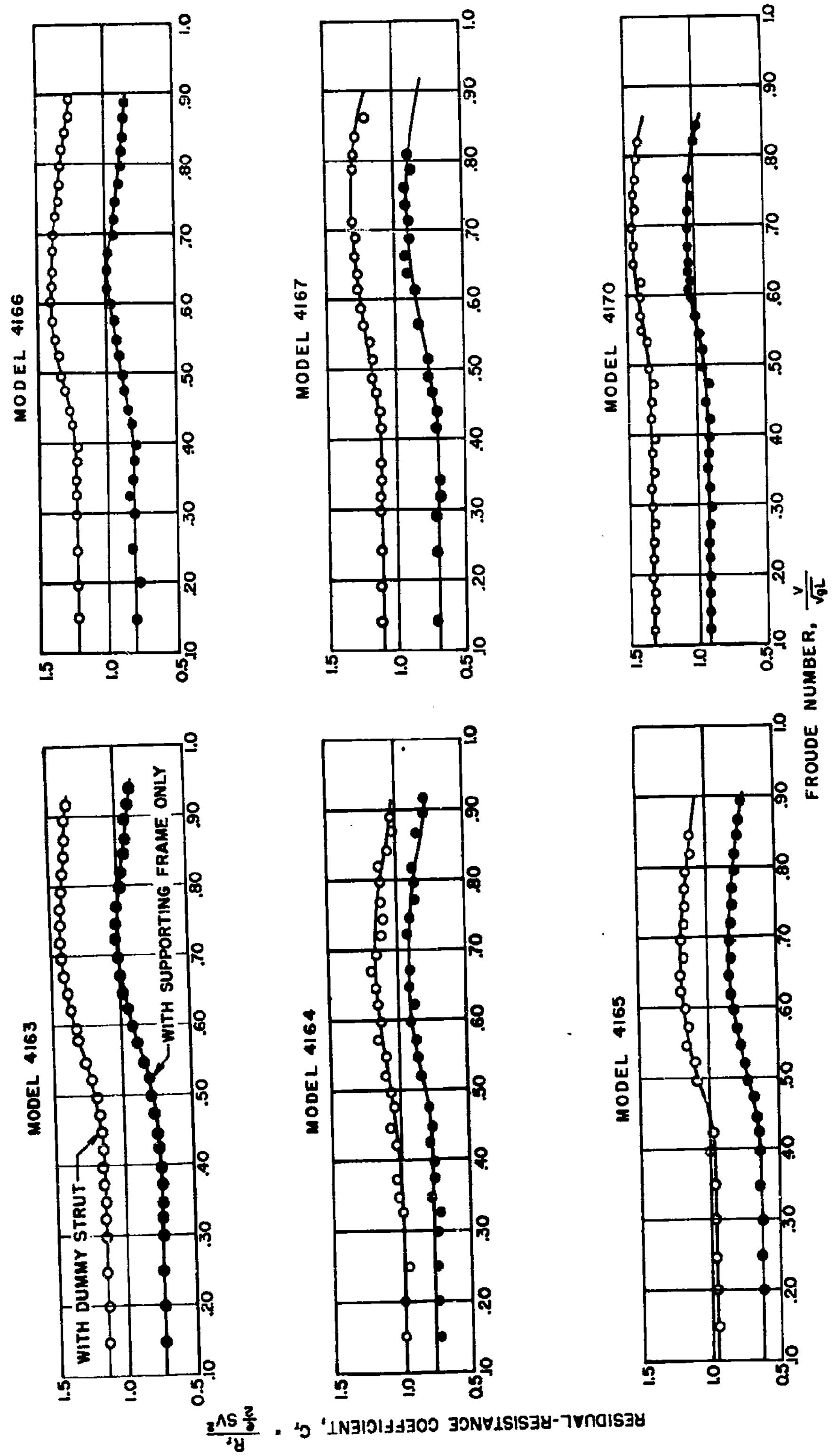

RESISTANCE COEFFICIENT, C = R / (ρ/2 SV²)
5.0 x 10⁻³
4.0
3.0
2.0
1.0
0.0
Ct WITH SAND
Ct WITHOUT SAND
Cf
SAND-ROUGHNESS COEFFICIENT, ΔR₁ / (ρ/2 SV²) = 0.00016
STRUT-INTERFERENCE COEFFICIENT, ΔR₂ / (ρ/2 SV²) = 0.00033
MODEL 4177
m r₀ r₁ Cp L/D
0.34 0.50 0.10 0.65 7.00
2.0 x 10⁶
4.0
6.0
8.0
1.0 x 10⁷
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
REYNOLDS NUMBER, VL/ν

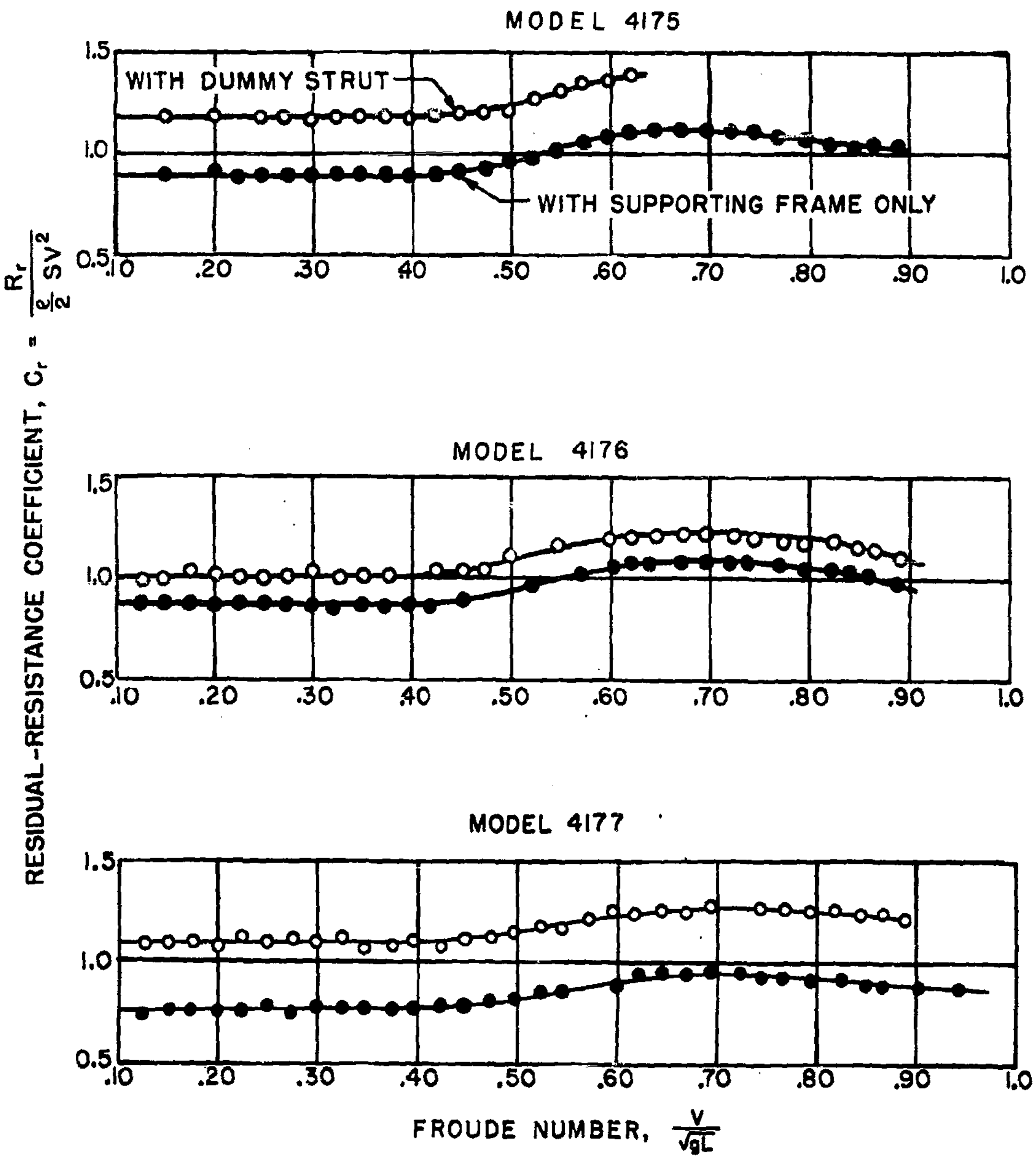
APPENDIX 4

RESIDUAL-RESISTANCE COEFFICIENT CURVES USED TO DETERMINE THE STRUT CORRECTION COEFFICIENTS

The Strut Interference Correction is Obtained by Deducting the Coefficients for the Model with Dummy-Strut Supporting Frame Alone in Place from the Coefficients for the Model with the Dummy Struts Inserted.


MODEL 4158
MODEL 4159
MODEL 4160
MODEL 4154
MODEL 4155
MODEL 4156
WITH DUMMY STRUT
WITH SUPPORTING FRAME ONLY
FROUDE NUMBER, $\frac{V}{\sqrt{gL}}$
RESIDUAL-RESISTANCE COEFFICIENT, $C_r = \frac{R_r}{\frac{\rho}{2} S V^2}$

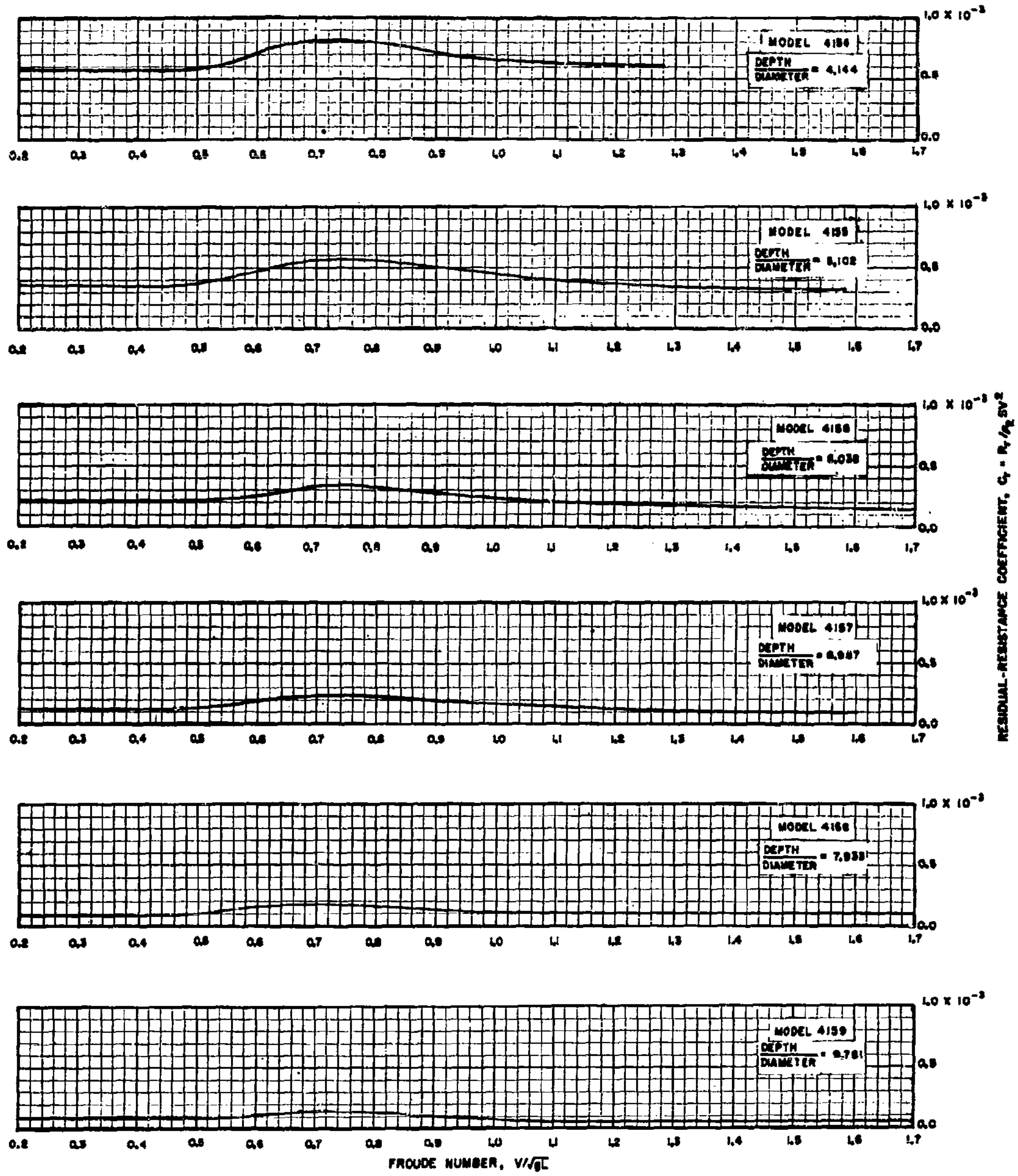

MODEL 4166
MODEL 4167
MODEL 4170
MODEL 4163
MODEL 4164
MODEL 4165
WITH DUMMY STRUT
WITH SUPPORTING FRAME ONLY
FROUDE NUMBER, $\frac{V}{\sqrt{gL}}$
RESIDUAL-RESISTANCE COEFFICIENT, $C_r = \frac{R_r}{\frac{\rho}{2} S V^2}$

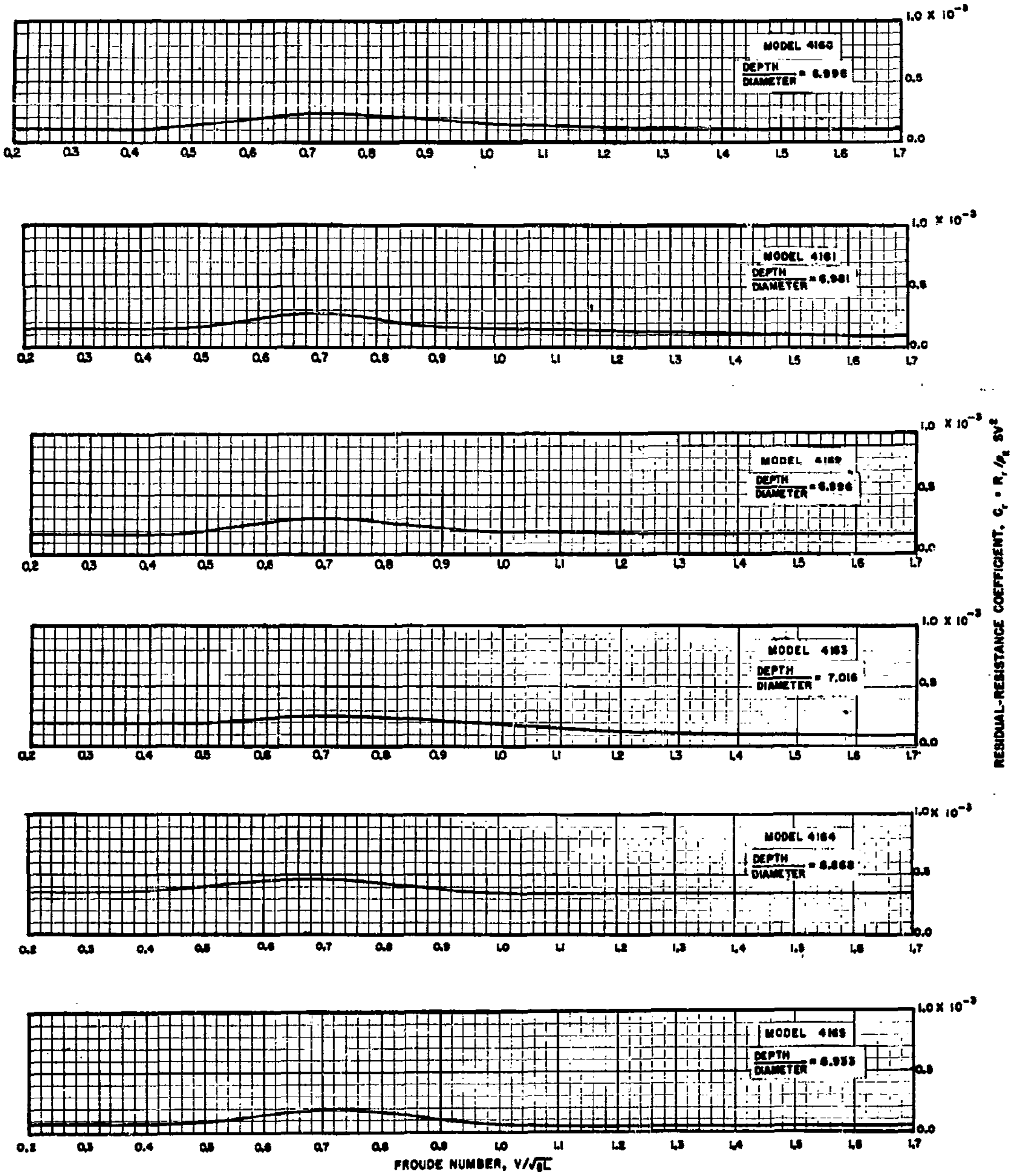

MODEL 4175
WITH DUMMY STRUT
WITH SUPPORTING FRAME ONLY
MODEL 4176
MODEL 4177
1.5
1.0
0.5
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
RESIDUAL-RESISTANCE COEFFICIENT, $C_r = \frac{R_r}{\frac{\rho}{2} S V^2}$
FROUDE NUMBER, $\frac{V}{\sqrt{gL}}$

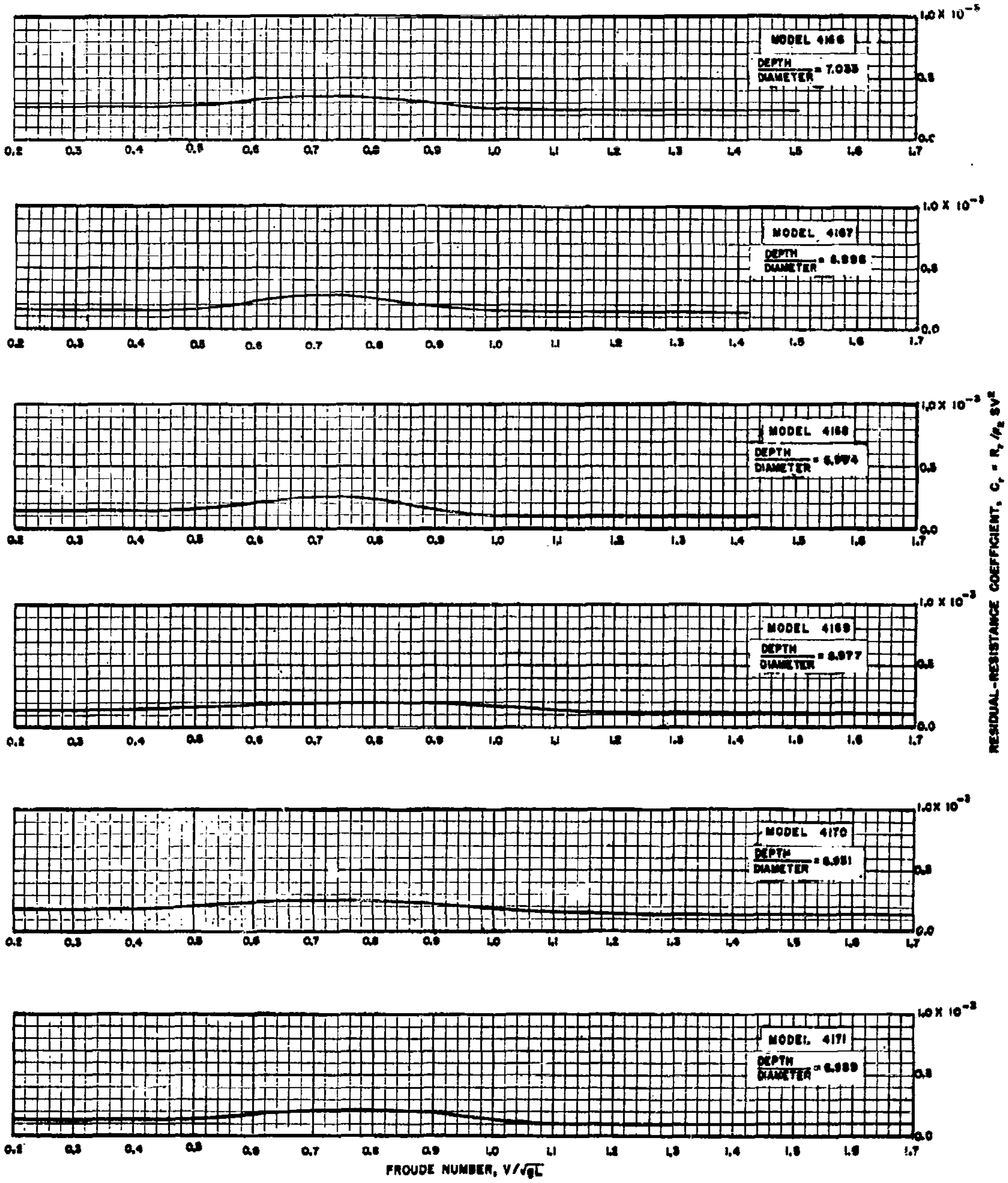
APPENDIX 5

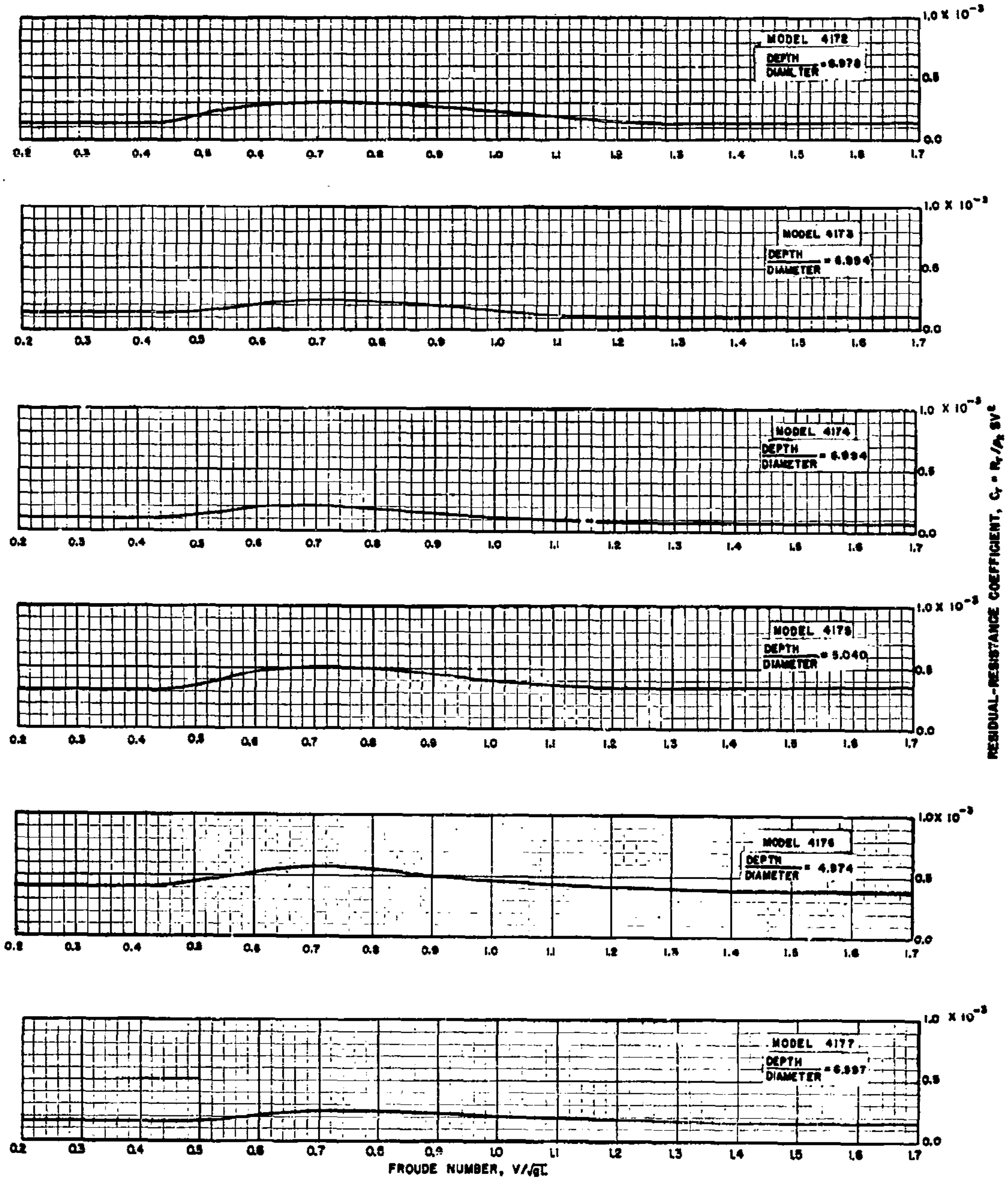
NET RESIDUAL-RESISTANCE COEFFICIENTS FOR DEEP SUBMERGENCE PLOTTED AGAINST FROUDE NUMBER

The Net Residual-Resistance Coefficients are Obtained by Deducting the Sand Roughness Coefficient and Strut Interference Coefficient from the Gross Residual-Resistance Coefficient Obtained from Tests of the Model with the Sand Strip but Without the Dummy Strut or Supporting Strut in Place.


MODEL 4154
DEPTH/DIAMETER = 4.144
MODEL 4155
DEPTH/DIAMETER = 5.102
MODEL 4156
DEPTH/DIAMETER = 6.038
MODEL 4157
DEPTH/DIAMETER = 6.987
MODEL 4158
DEPTH/DIAMETER = 7.933
MODEL 4159
DEPTH/DIAMETER = 9.781
1.0 X 10⁻³
0.5
0.0
FROUDE NUMBER, V/√gL
RESIDUAL-RESISTANCE COEFFICIENT


MODEL 4161
MODEL 4163
DEPTH / DIAMETER = 7.016
MODEL 4164
1.0 X 10^-3
0.5
0.0
FROUDE NUMBER, V/√gL
RESIDUAL-RESISTANCE COEFFICIENT

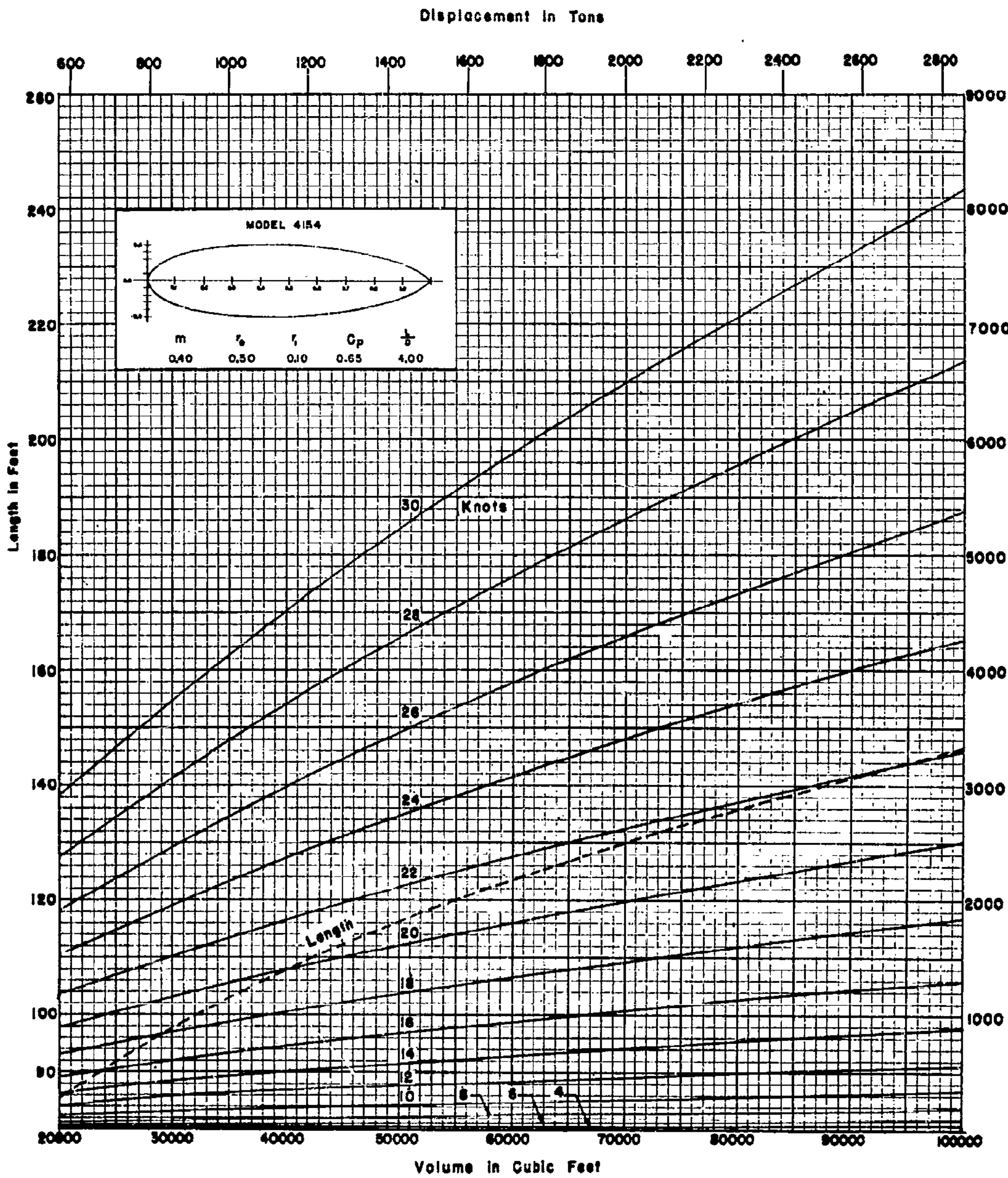

MODEL 4166
DEPTH/DIAMETER = 7.035
MODEL 4167
DEPTH/DIAMETER
MODEL 4168
DEPTH/DIAMETER
MODEL 4169
DEPTH/DIAMETER = 6.977
MODEL 4170
DEPTH/DIAMETER = 6.951
MODEL 4171
DEPTH/DIAMETER
1.0 X 10⁻³
0.5
0.0
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
RESIDUAL-RESISTANCE COEFFICIENT, $C_r = R_r / \frac{\rho}{2} S V^2$
FROUDE NUMBER, $V/\sqrt{gL}$


MODEL 4172
MODEL 4173
MODEL 4174
MODEL 4175
DEPTH/DIAMETER = 5.040
MODEL 4176
DEPTH/DIAMETER = 4.974
MODEL 4177
1.0 X 10⁻³
0.5
0.0
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
FROUDE NUMBER, V/√gL
RESIDUAL-RESISTANCE COEFFICIENT

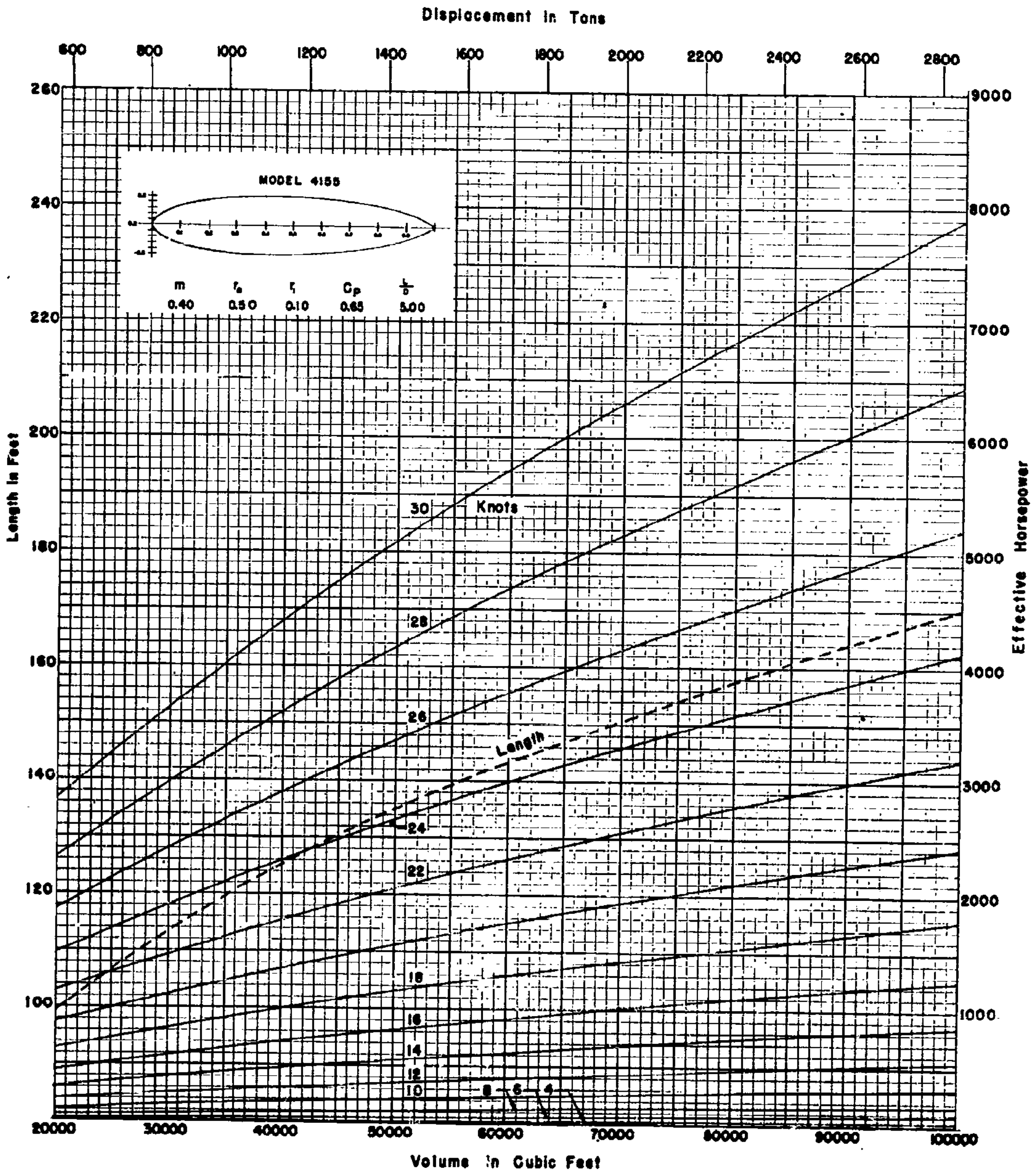
APPENDIX 6

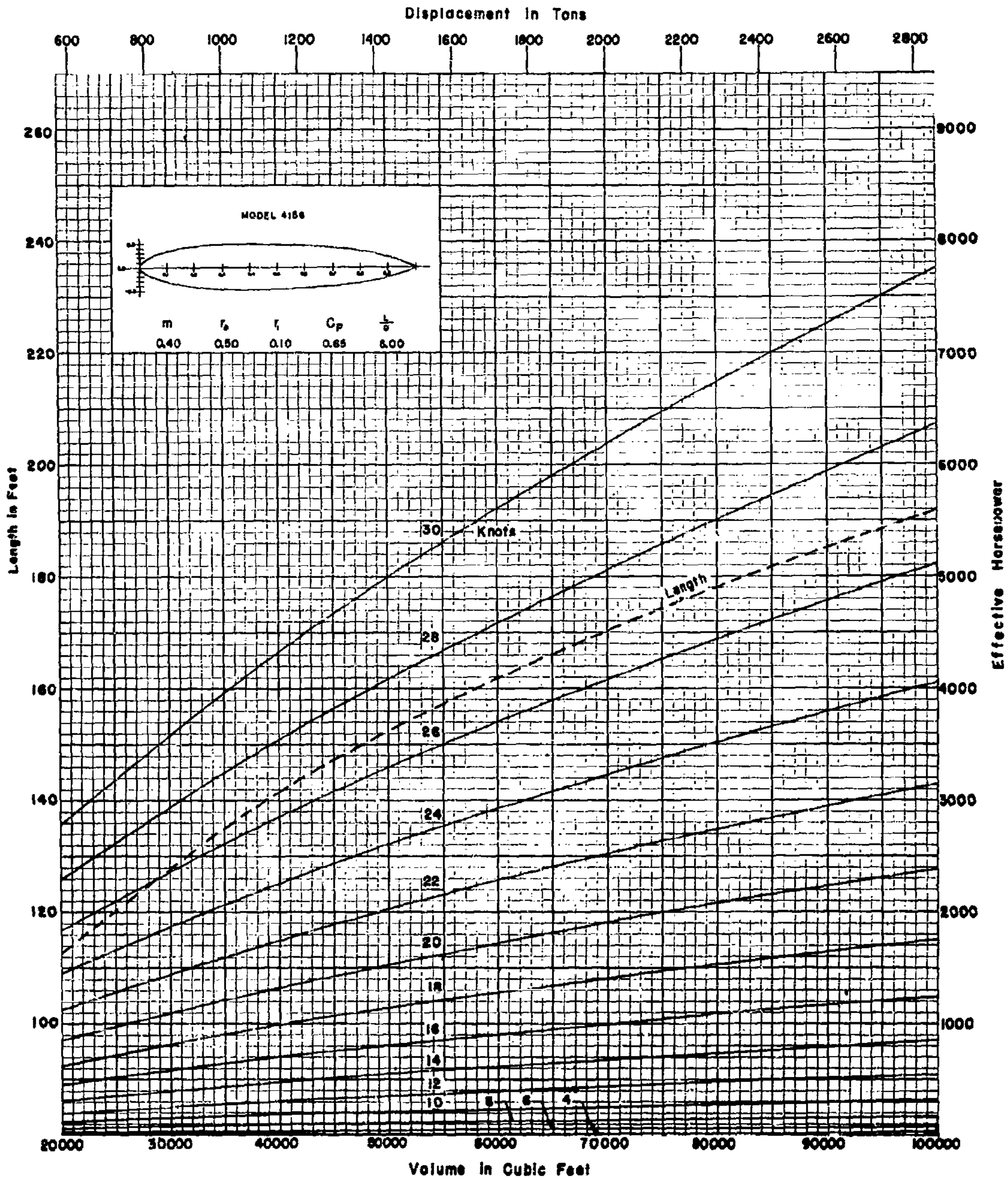
TOTAL BARE HULL EFFECTIVE HORSEPOWER VERSUS VOLUME AT VARIOUS EVEN SPEEDS FOR PROTOTYPES OF SERIES 58 OPERATING AT DEEP SUBMERGENCE.

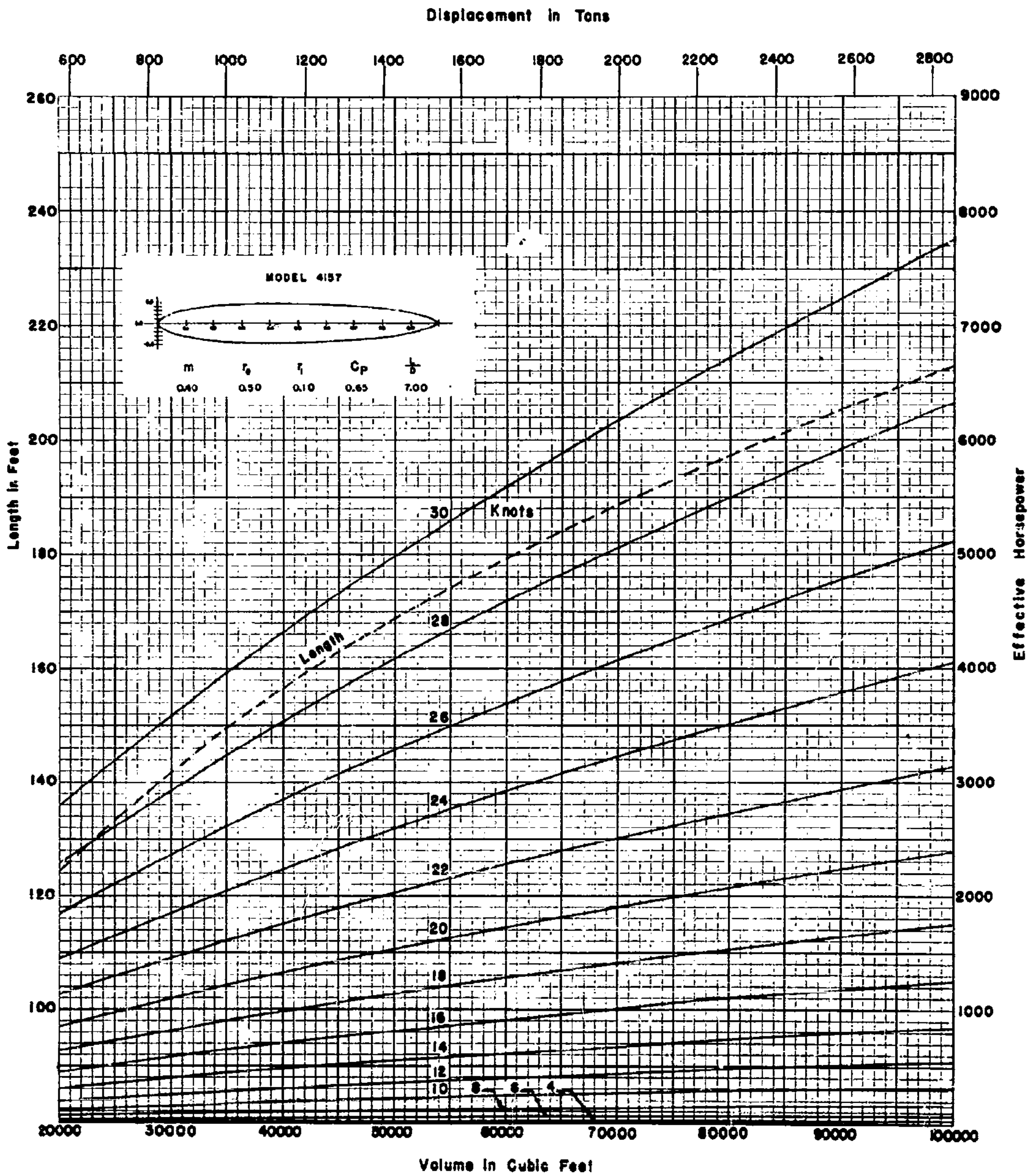
The EHP's Have Been Calculated using the Net C_r for Deep Submergence and a Roughness Allowance Coefficient of 0.4×10^{-3} for Standard Conditions of Salt Water at 59 F. A Curve of Length Versus Volume is Also Shown.

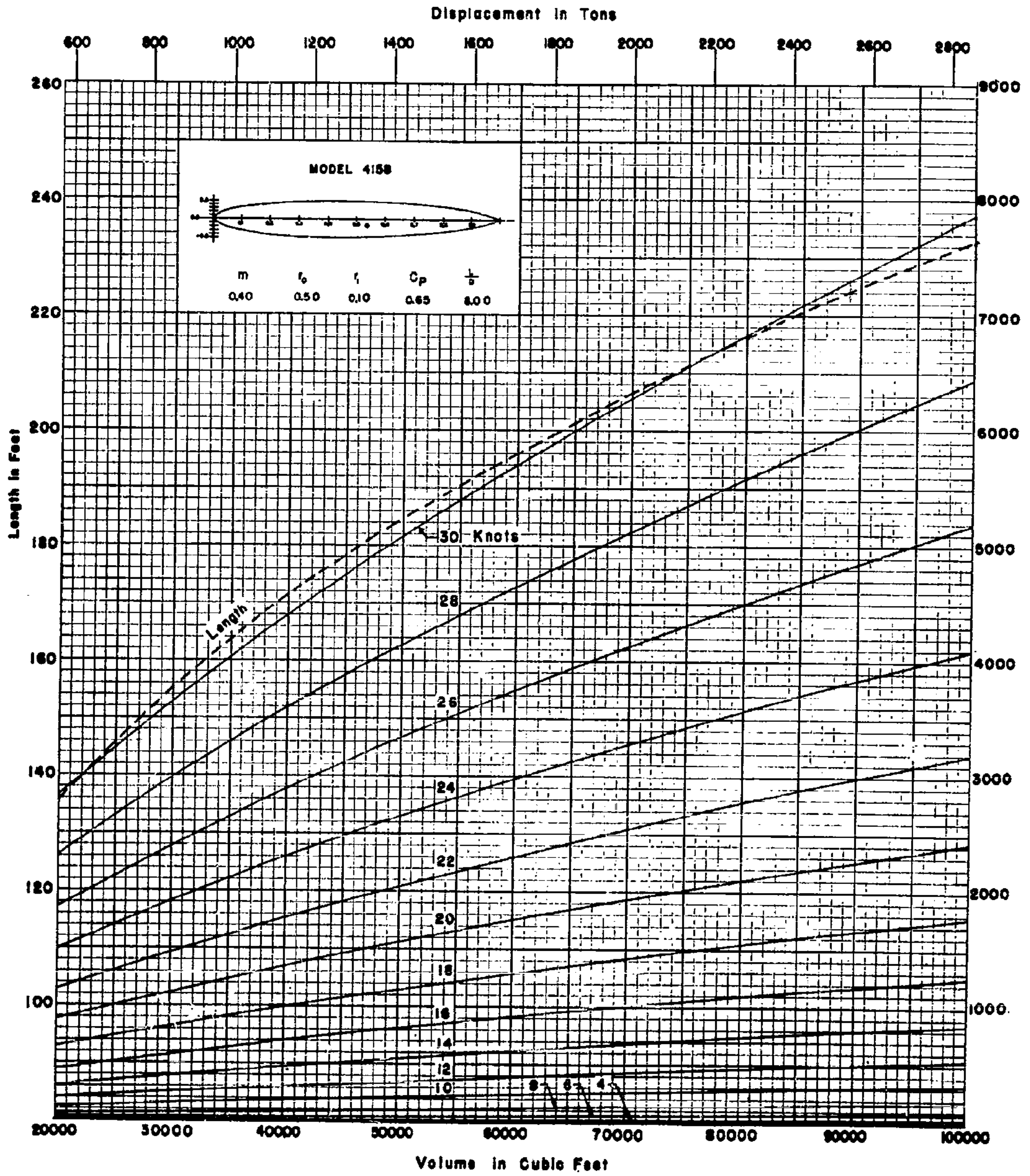


Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4154
m
0.40
r_e
0.50
r_i
0.10
C_p
0.65
$\frac{L}{D}$
4.00
Length in Feet
260
240
220
200
180
160
140
120
100
80
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
30
Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
Volume in Cubic Feet
20000
30000
40000
50000
60000
70000
80000
90000
100000

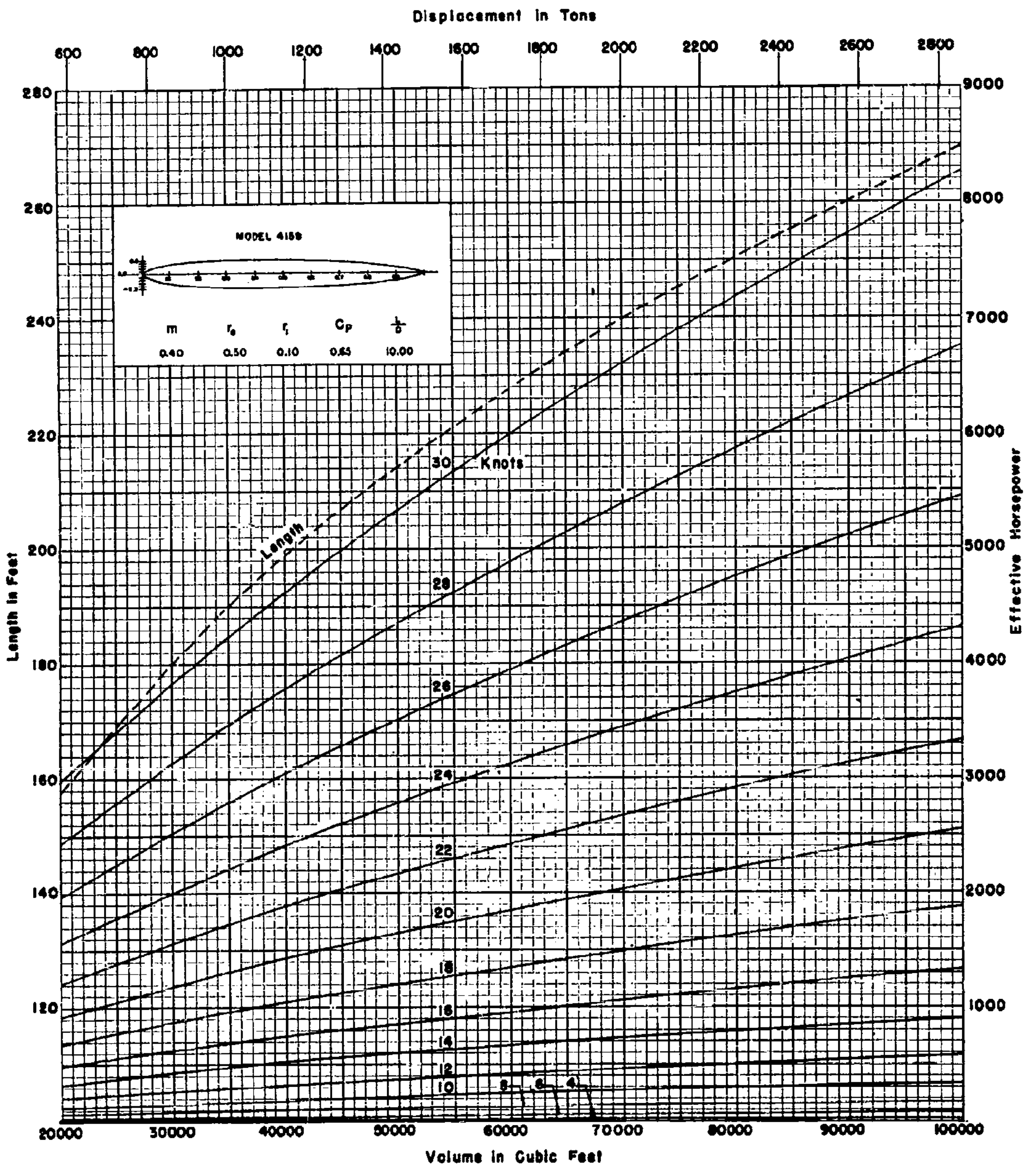

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4155
m 0.40
r_e 0.50
r_f 0.10
C_p 0.65
$\frac{L}{D}$ 5.00
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
30 Knots
28
26
Length
24
22
18
16
14
12
10
8
6
4
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

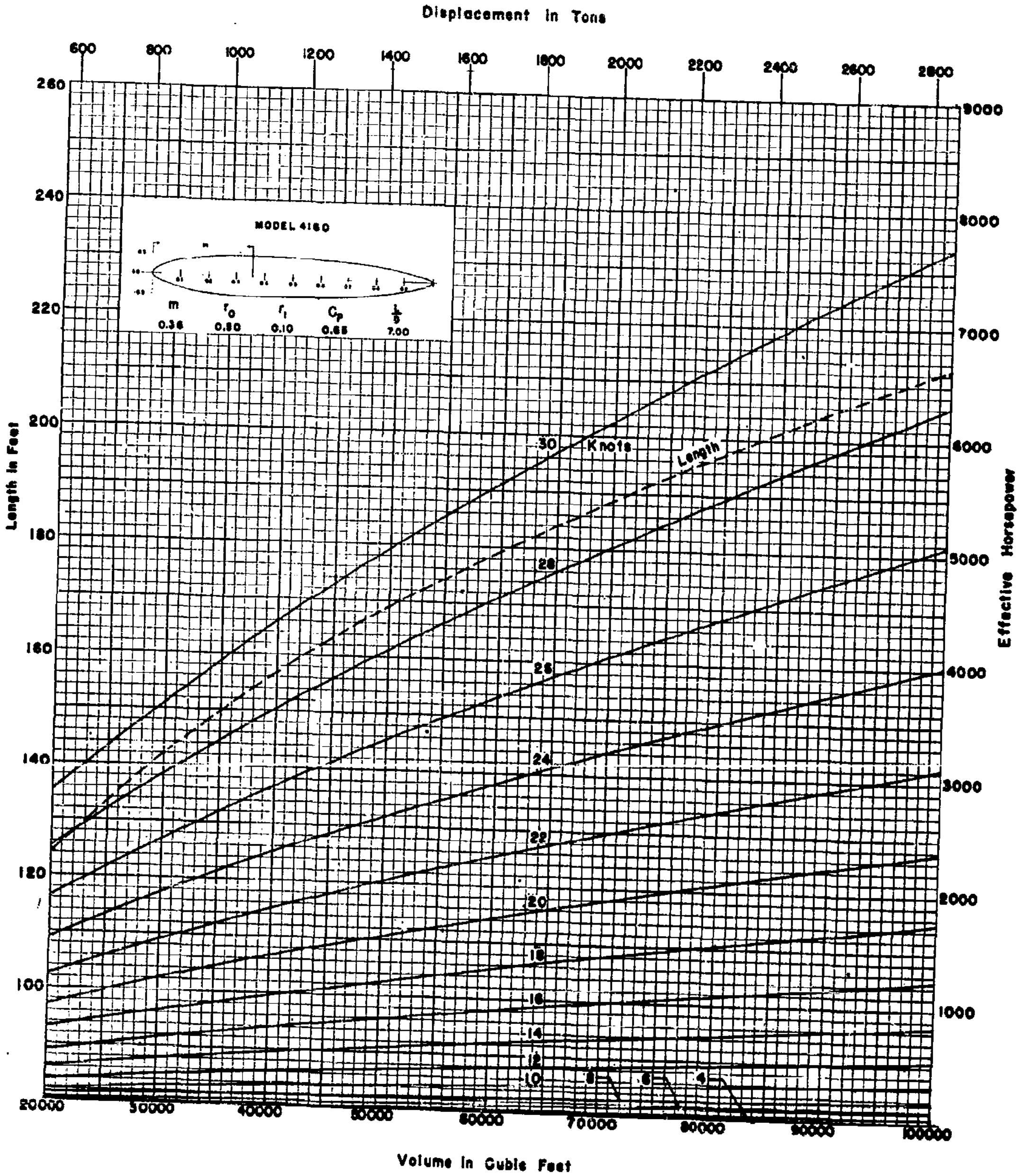

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
MODEL 4156
m
r_e
r_i
C_p
$\frac{L}{D}$
0.40
0.50
0.10
0.65
6.00
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

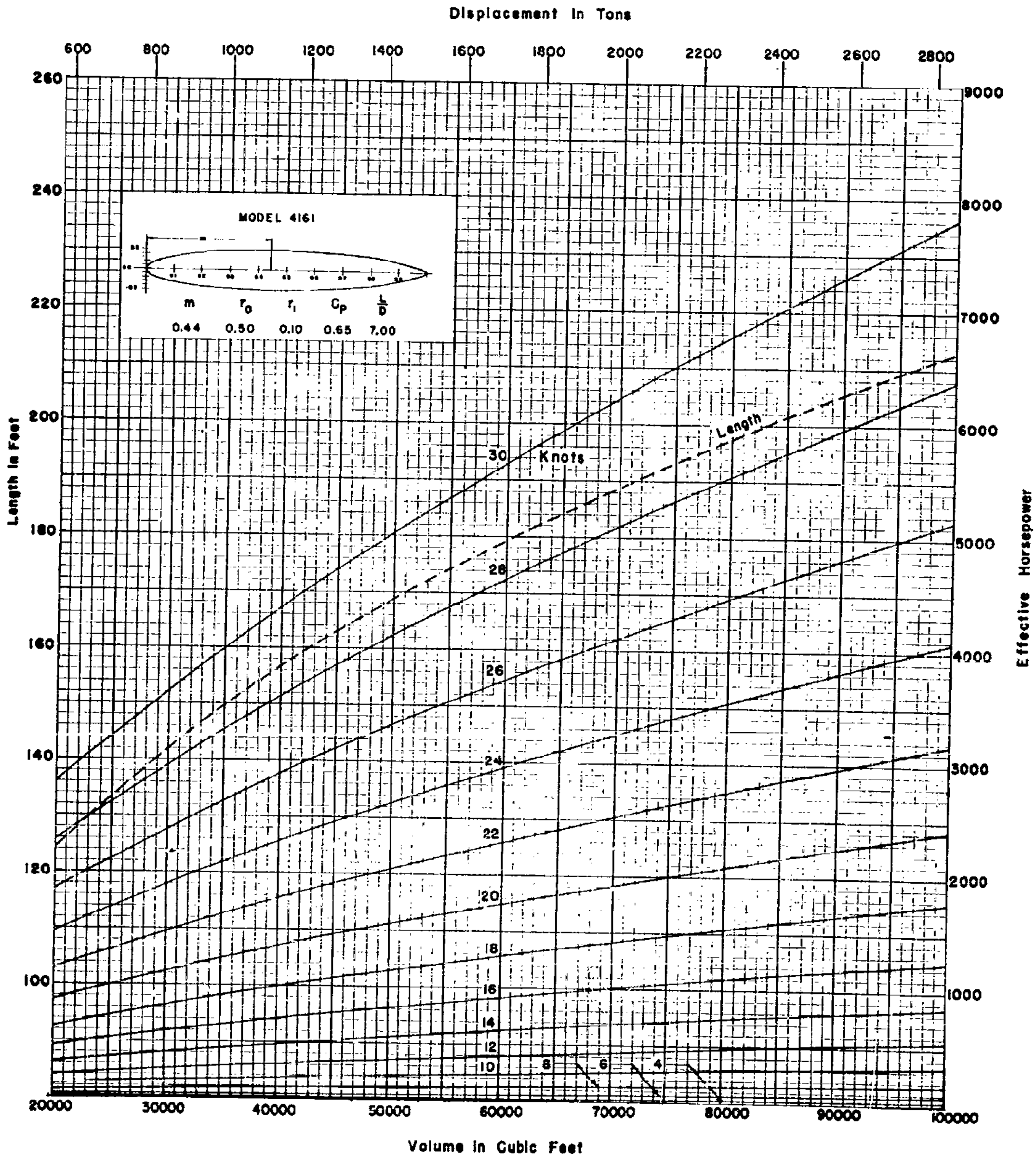

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4157
m
0.40
0.50
0.10
0.65
7.00
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
Length in Feet
Effective Horsepower
Volume in Cubic Feet



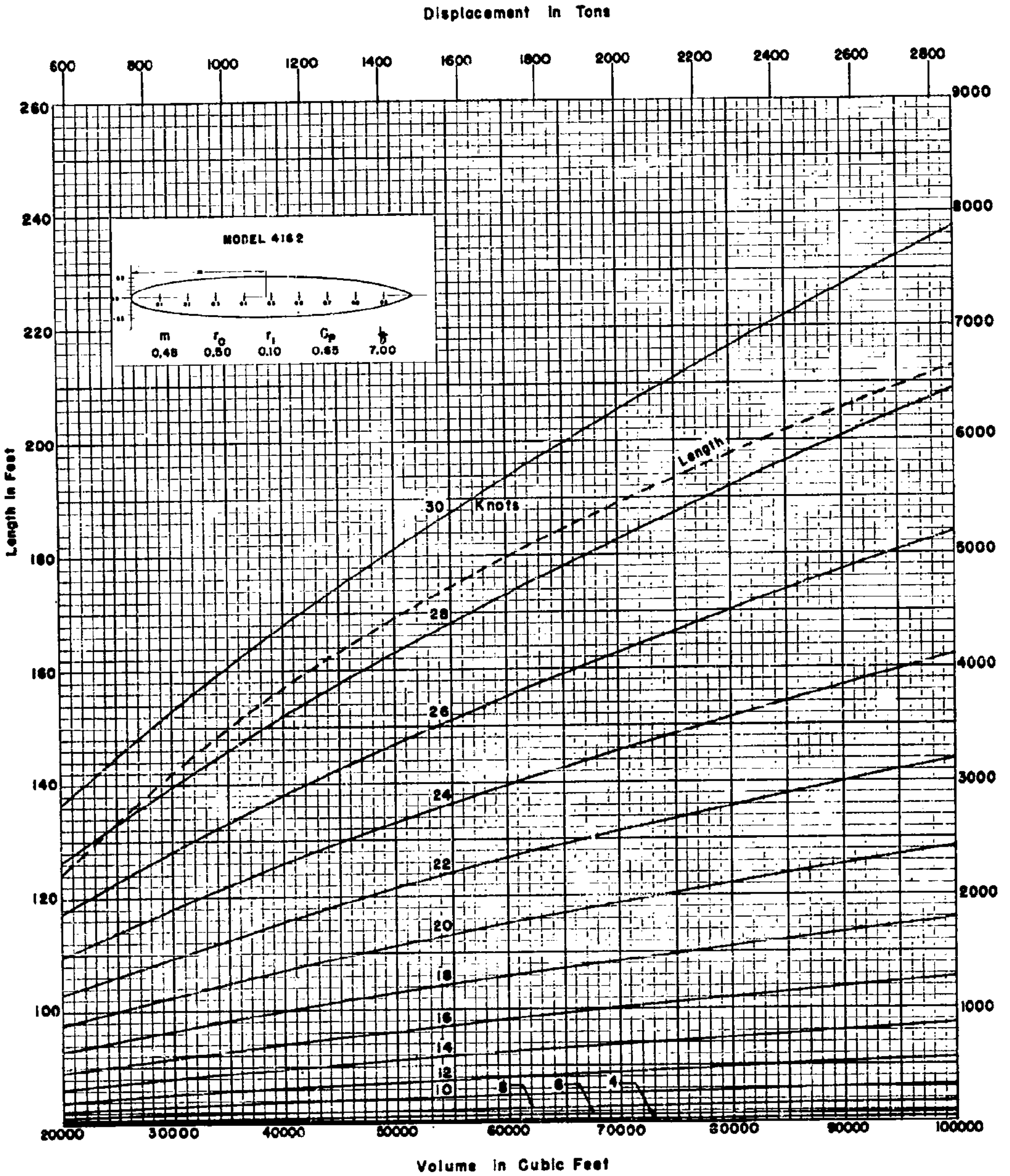
Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4158
m 0.40
r_0 0.50
r_1 0.10
C_p 0.65
L/D 8.00
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

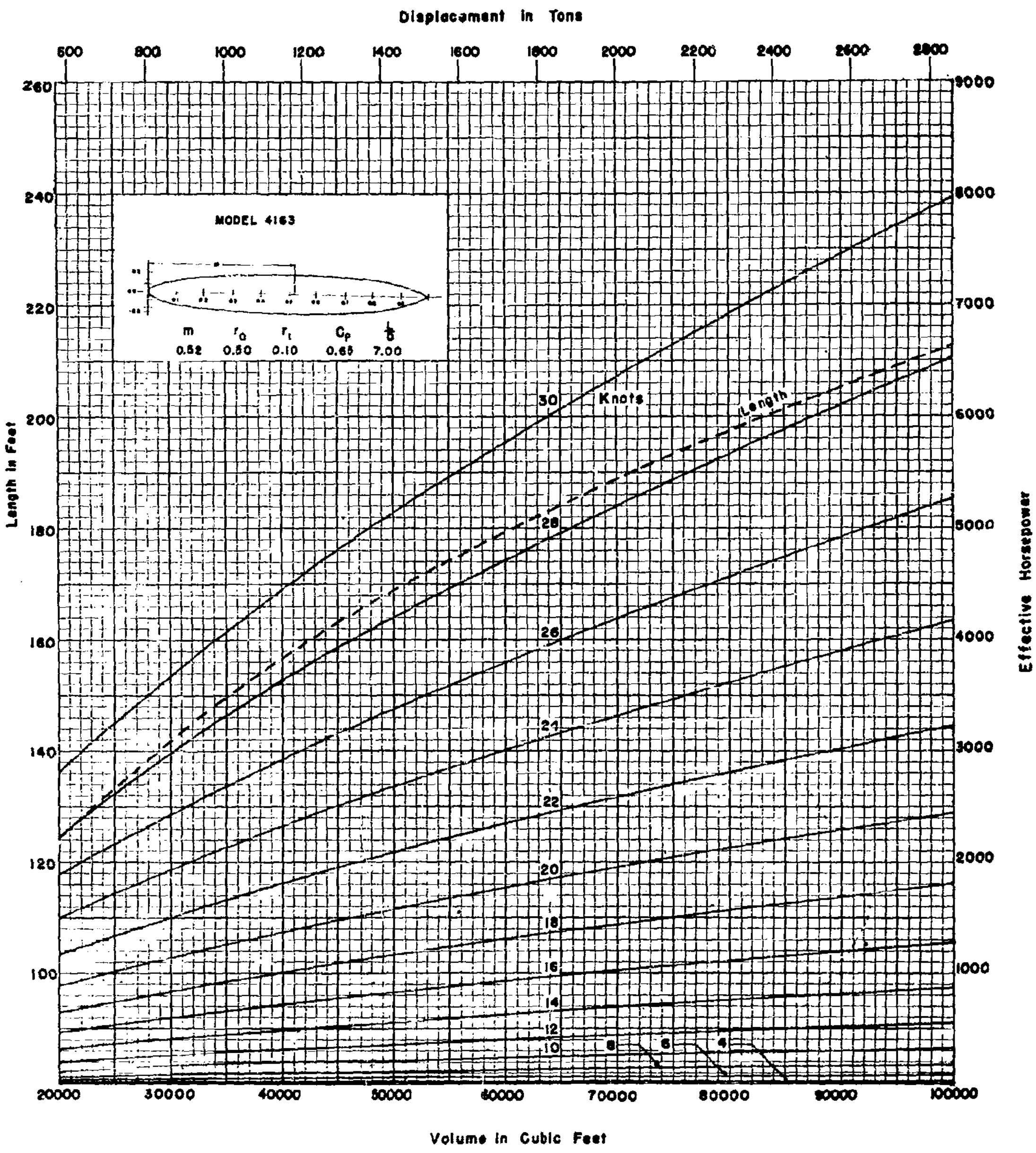

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4159
m
0.40
r_e
0.50
r_i
0.10
C_p
0.65
$\frac{L}{D}$
10.00
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
280
260
240
220
200
180
160
140
120
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

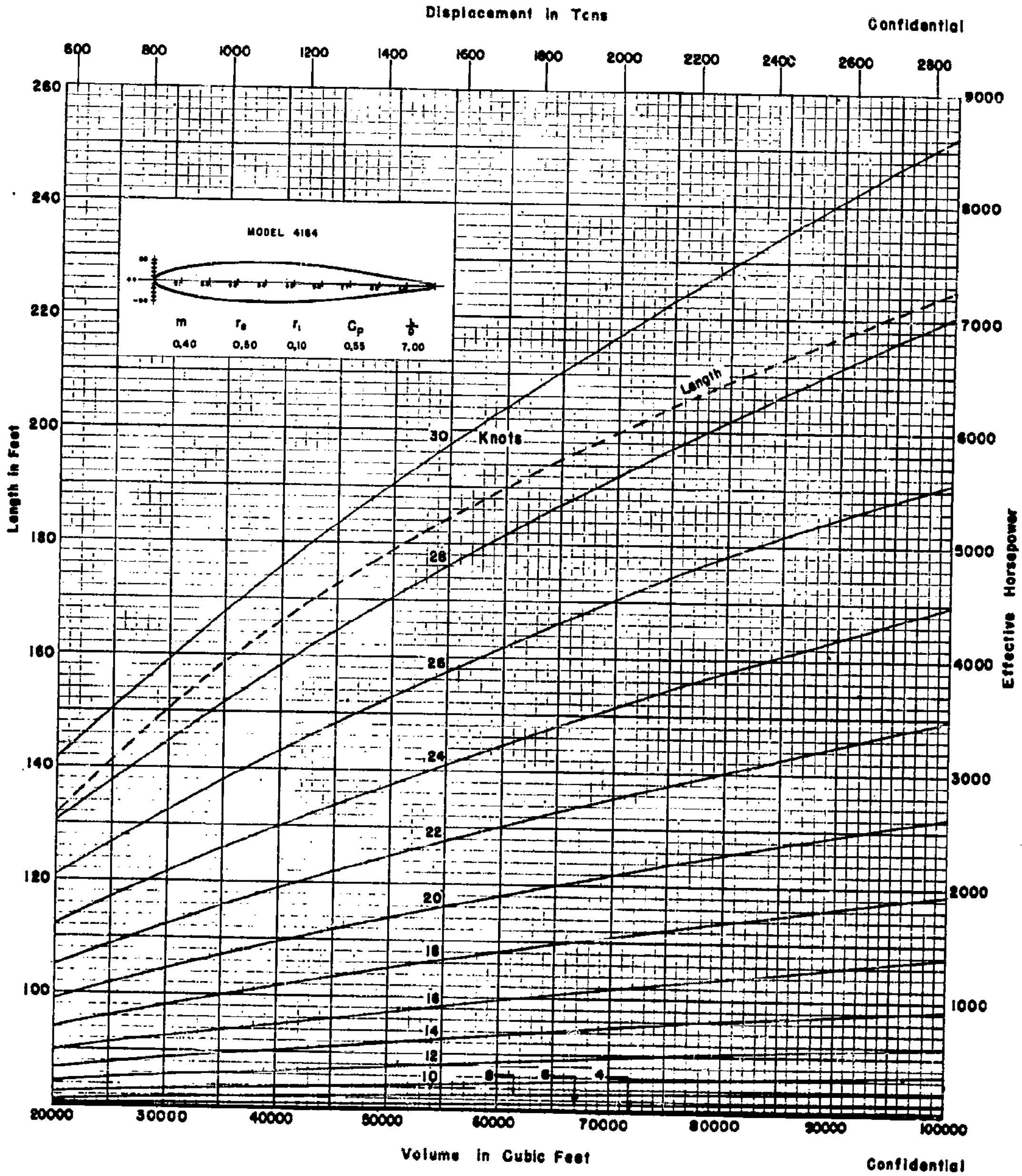

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4160
m
r_0
r_1
C_p
$\frac{L}{D}$
0.36
0.80
0.10
0.65
7.00
30 Knots
Length
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet



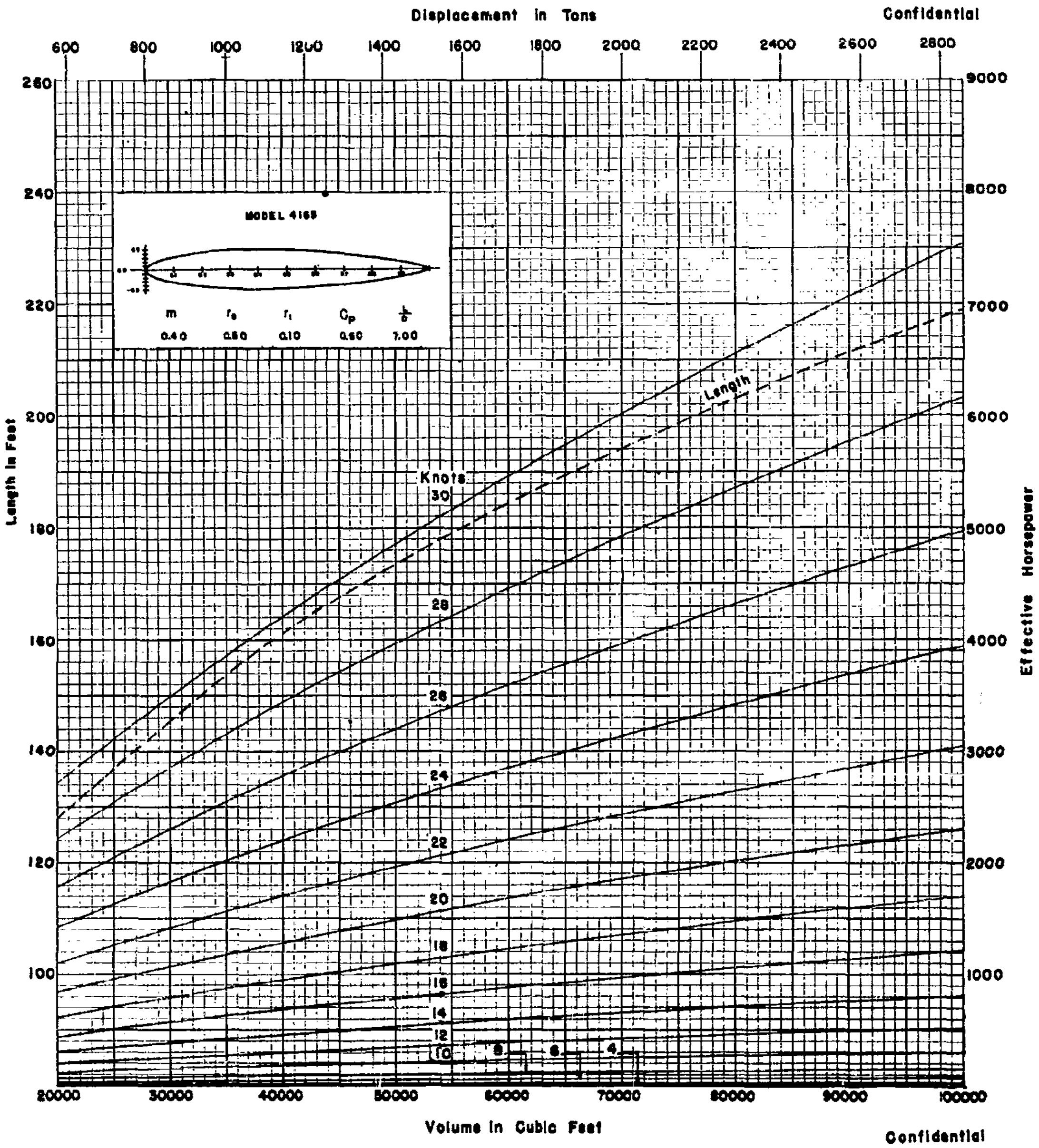
Displacement In Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4161
m
r_0
r_1
C_p
$\frac{L}{D}$
0.44
0.50
0.10
0.65
7.00
Length In Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
30 Knots
Length
28
26
24
22
20
18
16
14
12
10
8
6
4
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet


Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4162
m 0.48
r_0 0.50
r_1 0.10
C_p 0.65
L/D 7.00
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
Effective Horsepower
Volume in Cubic Feet

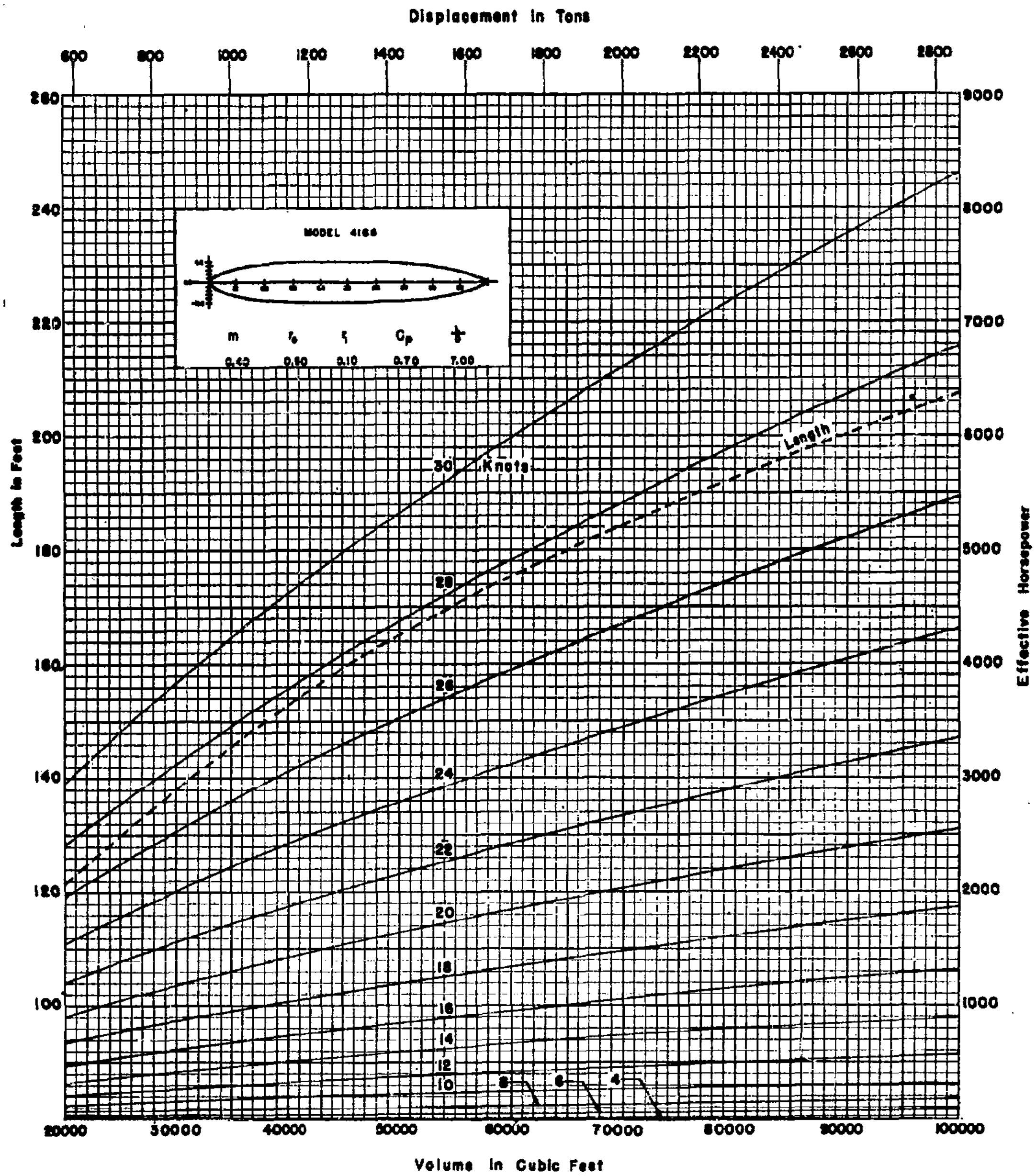

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4163
m 0.52
r_a 0.50
r_t 0.10
C_p 0.65
L/D 7.00
Knots
Length
30
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
Effective Horsepower
Volume in Cubic Feet
20000
30000
40000
50000
60000
70000
80000
90000
100000

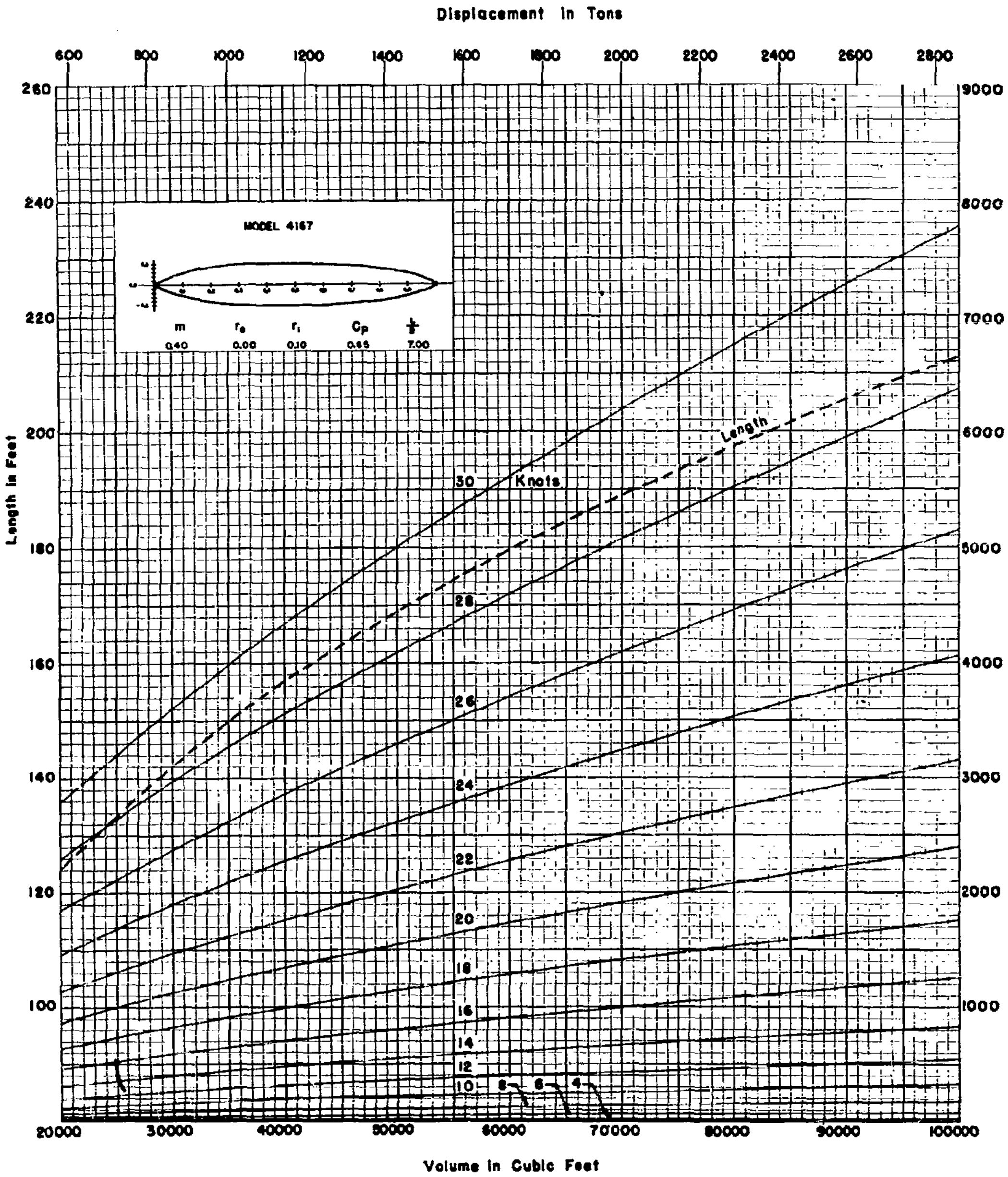


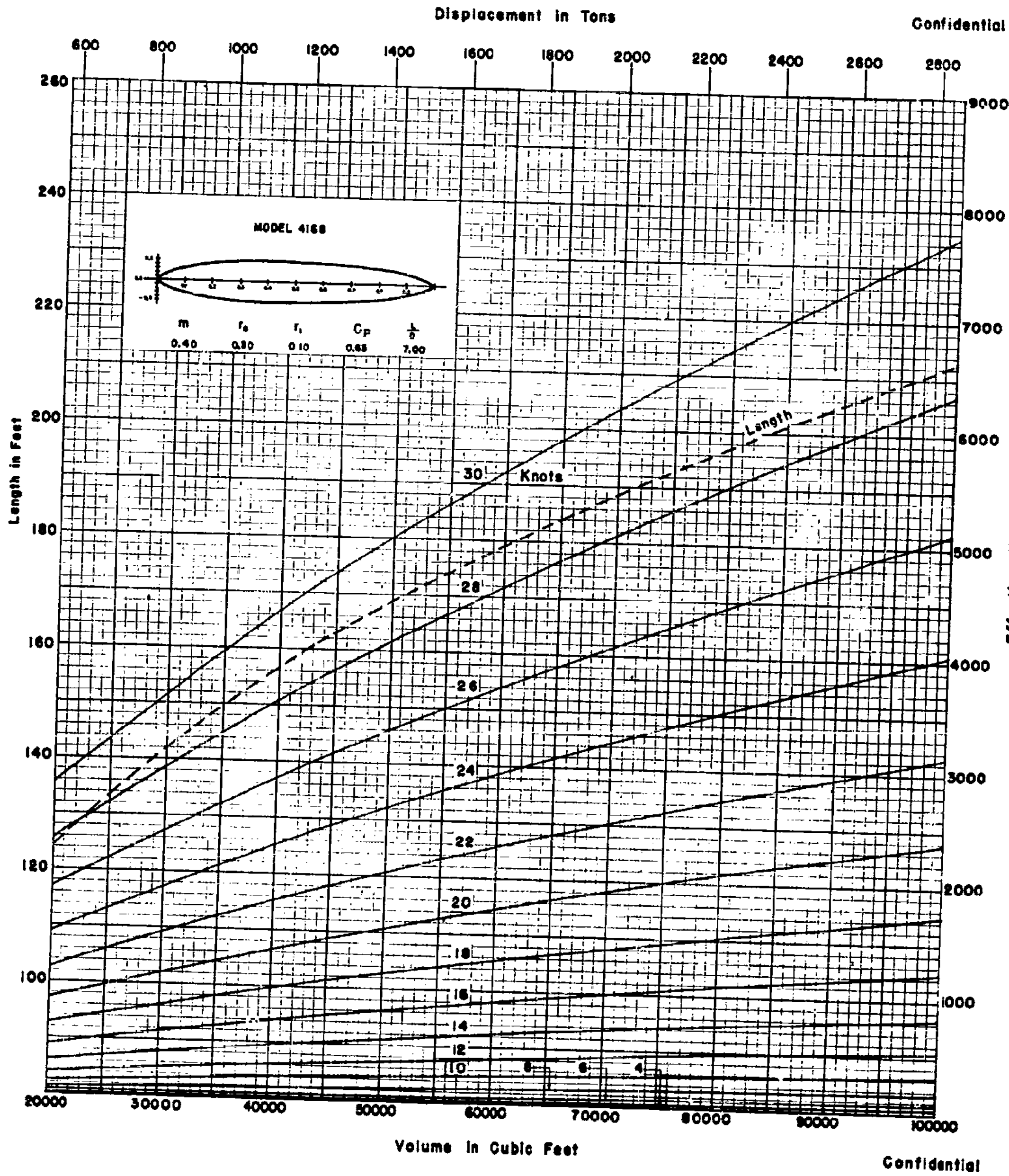
Displacement in Tons
Confidential
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4164
m
0.40
r_e
0.50
r_i
0.10
C_p
0.55
7.00
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet
Confidential



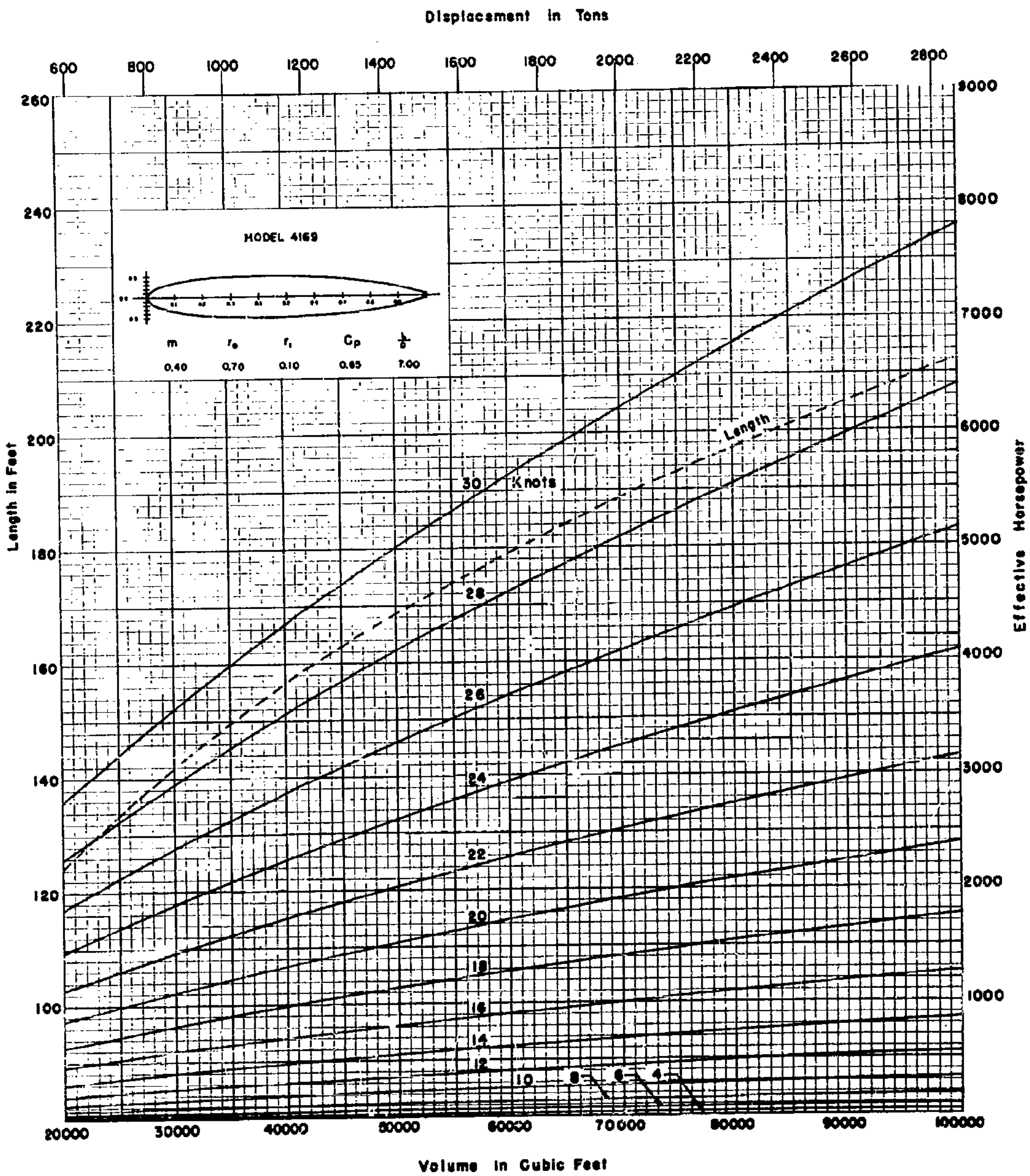
Displacement in Tons
Confidential
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4165
m
0.40
0.60
0.10
0.60
7.00
Length
Knots
30
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet
Confidential

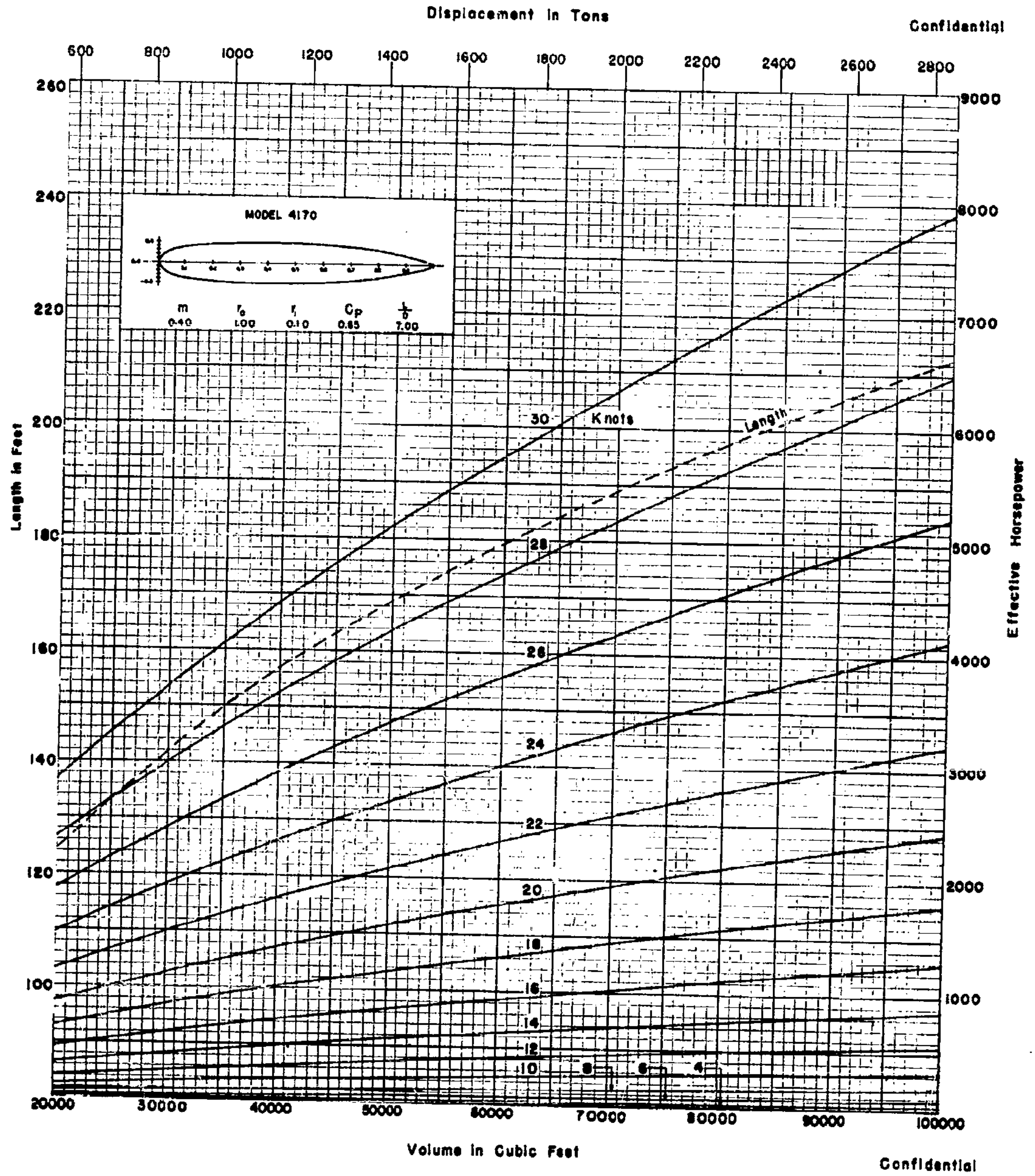

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4166
m
0.60
0.50
0.10
C_p
0.70
7.00
Length in Feet
280
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
Volume in Cubic Feet
20000
30000
40000
50000
60000
70000
80000
90000
100000


Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4167
m
0.40
0.00
0.10
Cp
0.65
7.00
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

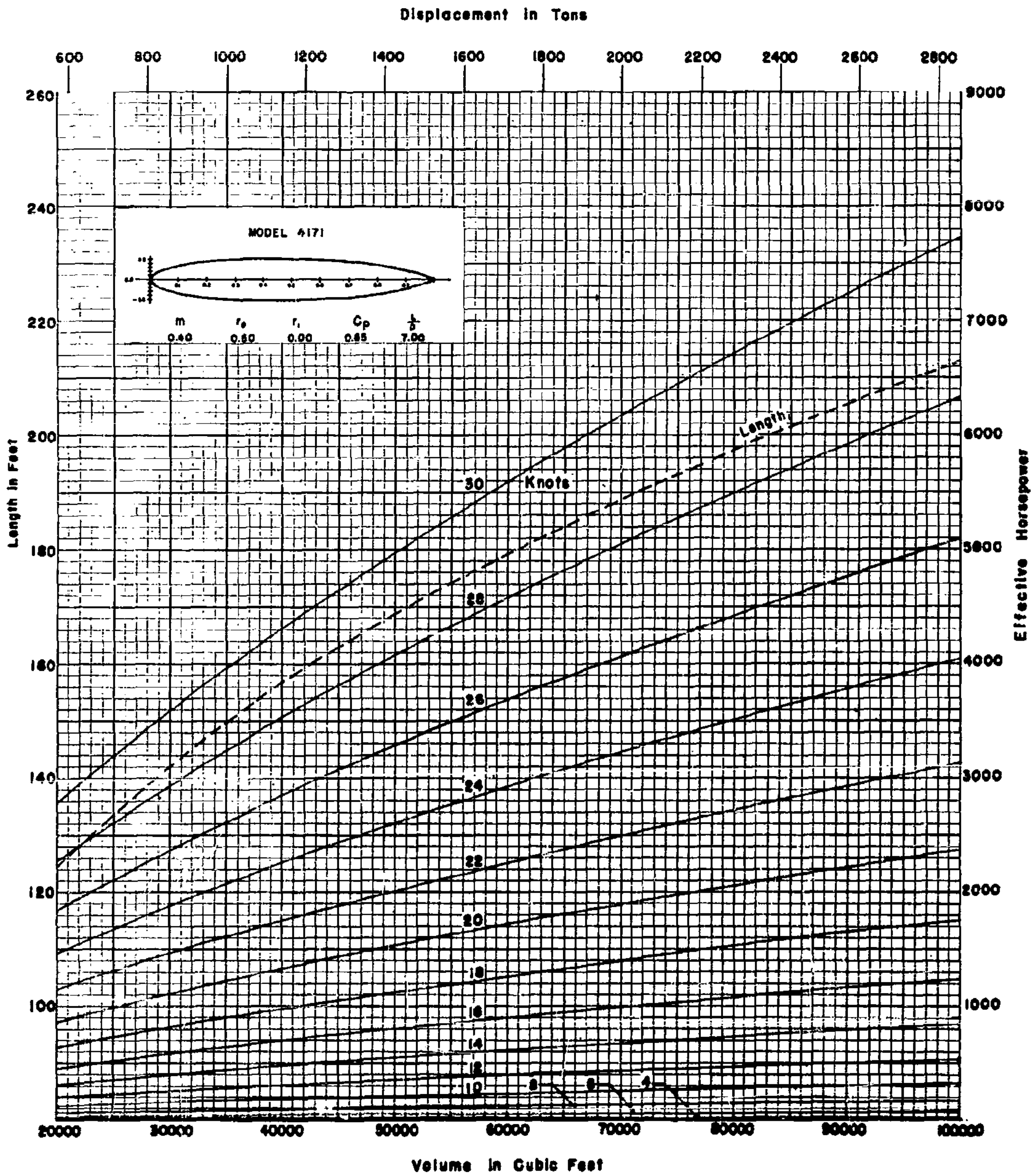


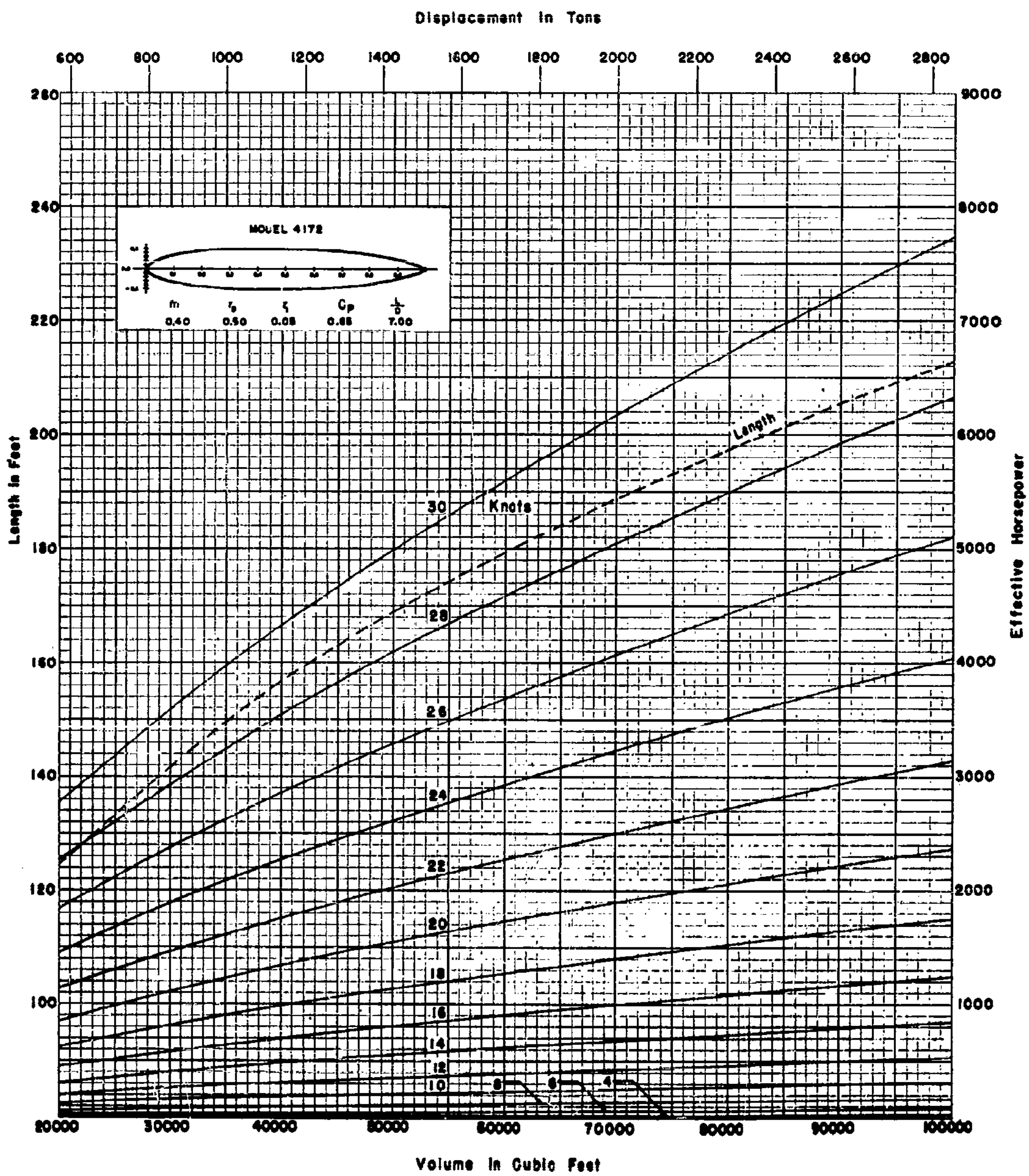
Displacement in Tons
Confidential
600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
MODEL 4168
m 0.40
Cp 0.65
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
Length in Feet
Effective Horsepower
Volume in Cubic Feet
Confidential

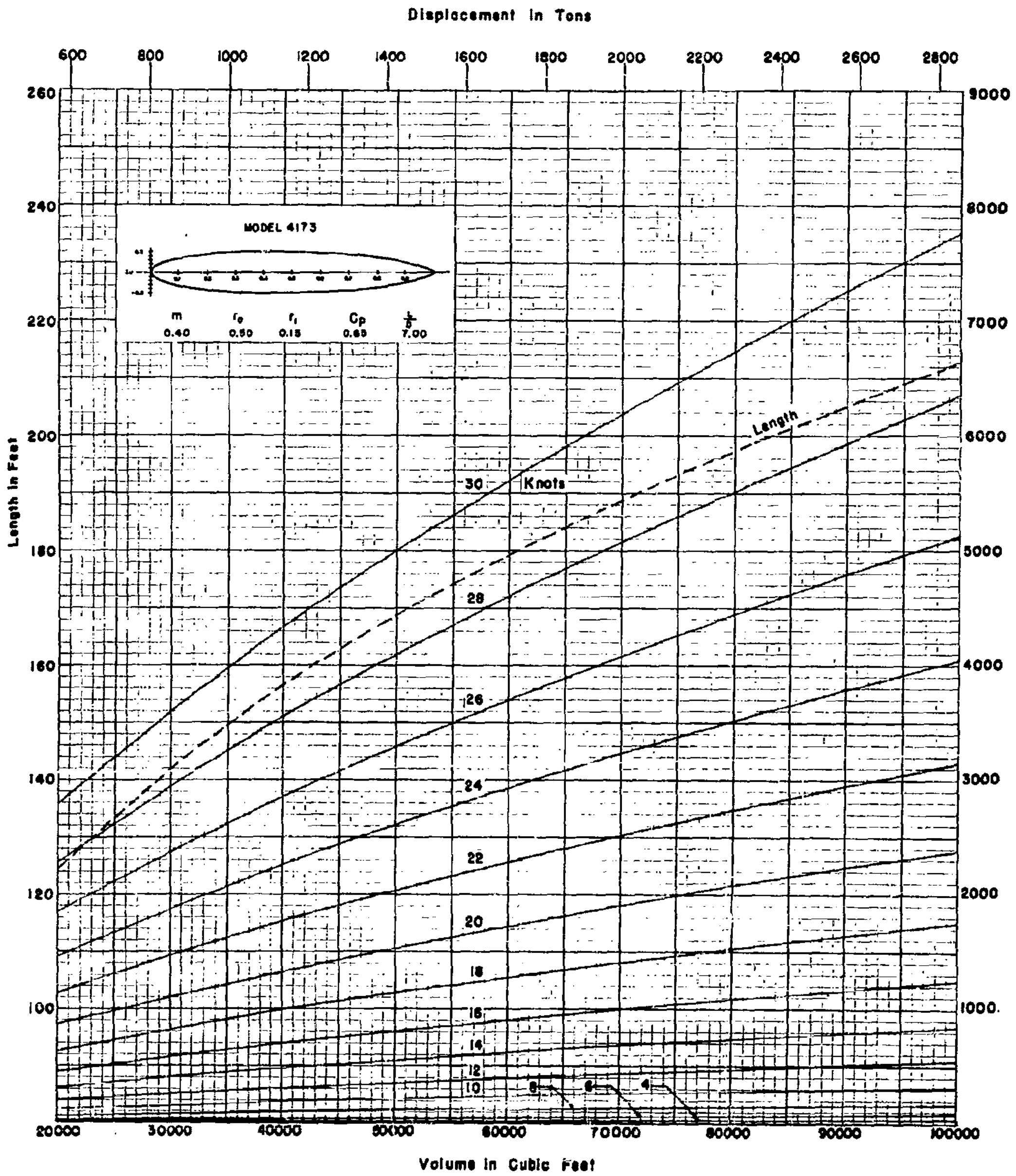

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4169
m 0.40
r_e 0.70
r_i 0.10
C_p 0.65
L/D 7.00
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

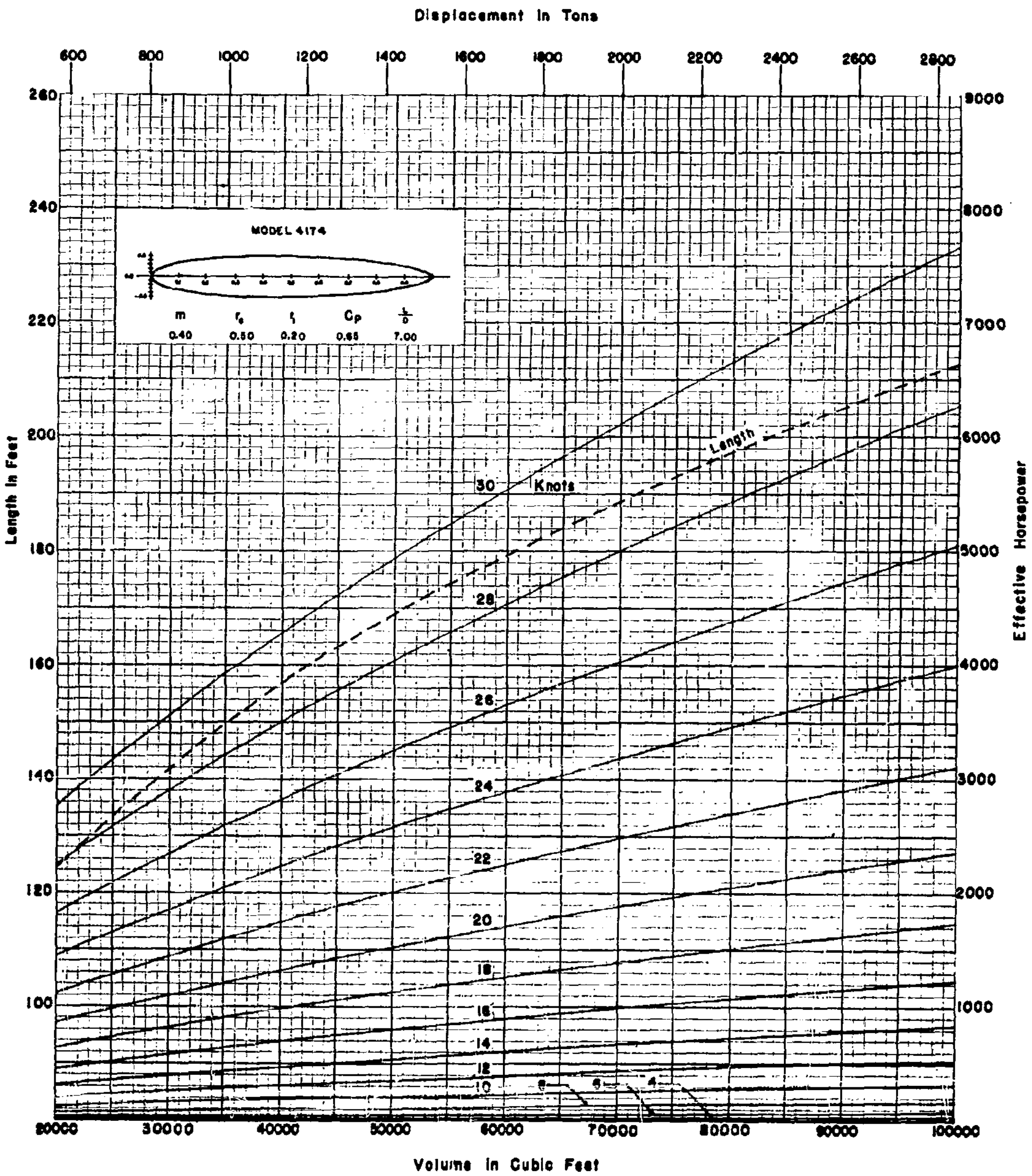


Displacement in Tons
Confidential
600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
MODEL 4170
m 0.40
r_0 1.00
r_1 0.10
C_p 0.65
L/D 7.00
30 Knots
Length
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260 240 220 200 180 160 140 120 100
Effective Horsepower
9000 8000 7000 6000 5000 4000 3000 2000 1000
20000 30000 40000 50000 60000 70000 80000 90000 100000
Volume in Cubic Feet
Confidential

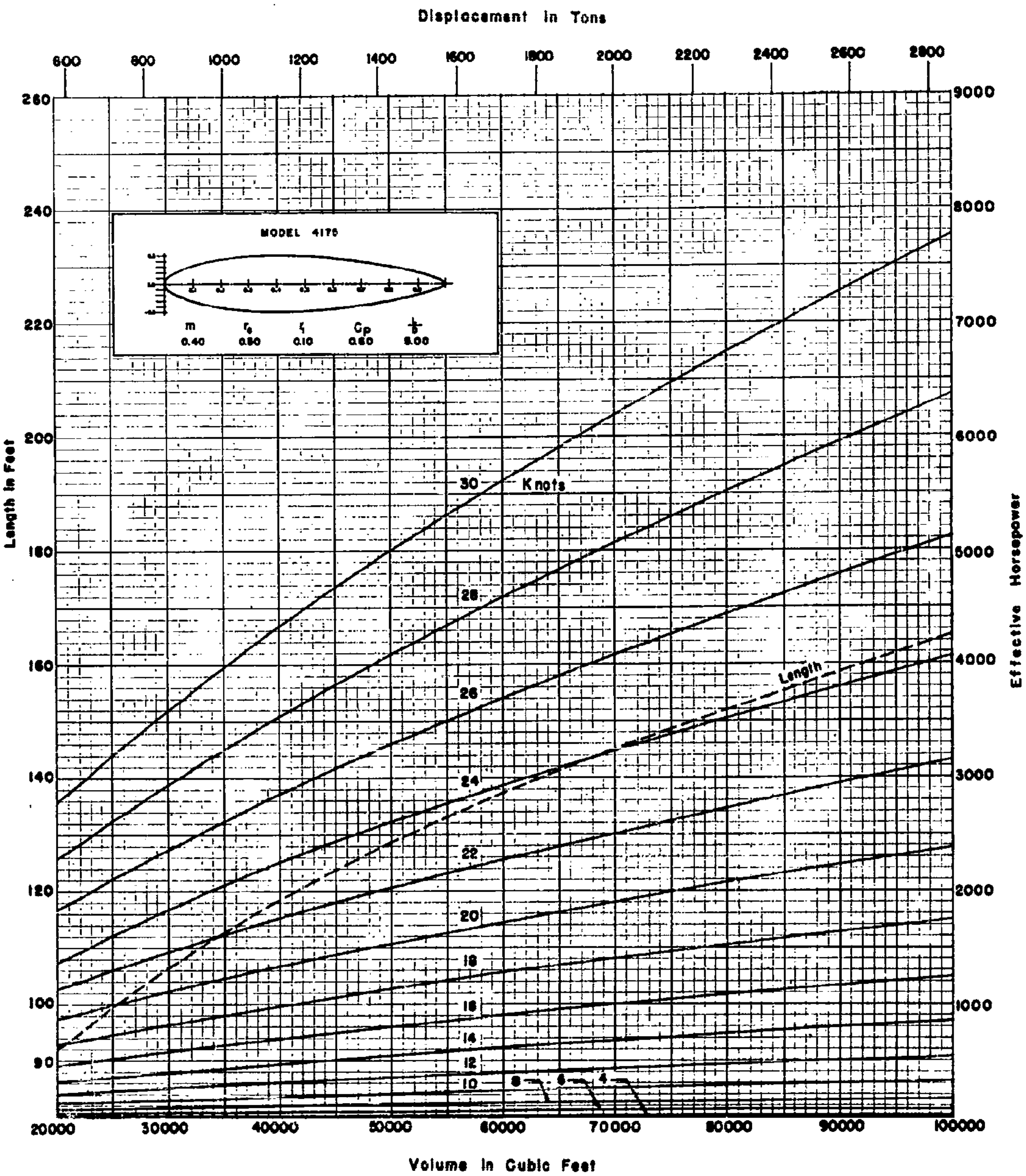

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Length in Feet
Effective Horsepower
MODEL 4171
m
0.40
0.50
0.00
Cp
0.65
7.00
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
Volume in Cubic Feet
20000
30000
40000
50000
60000
70000
80000
90000
100000

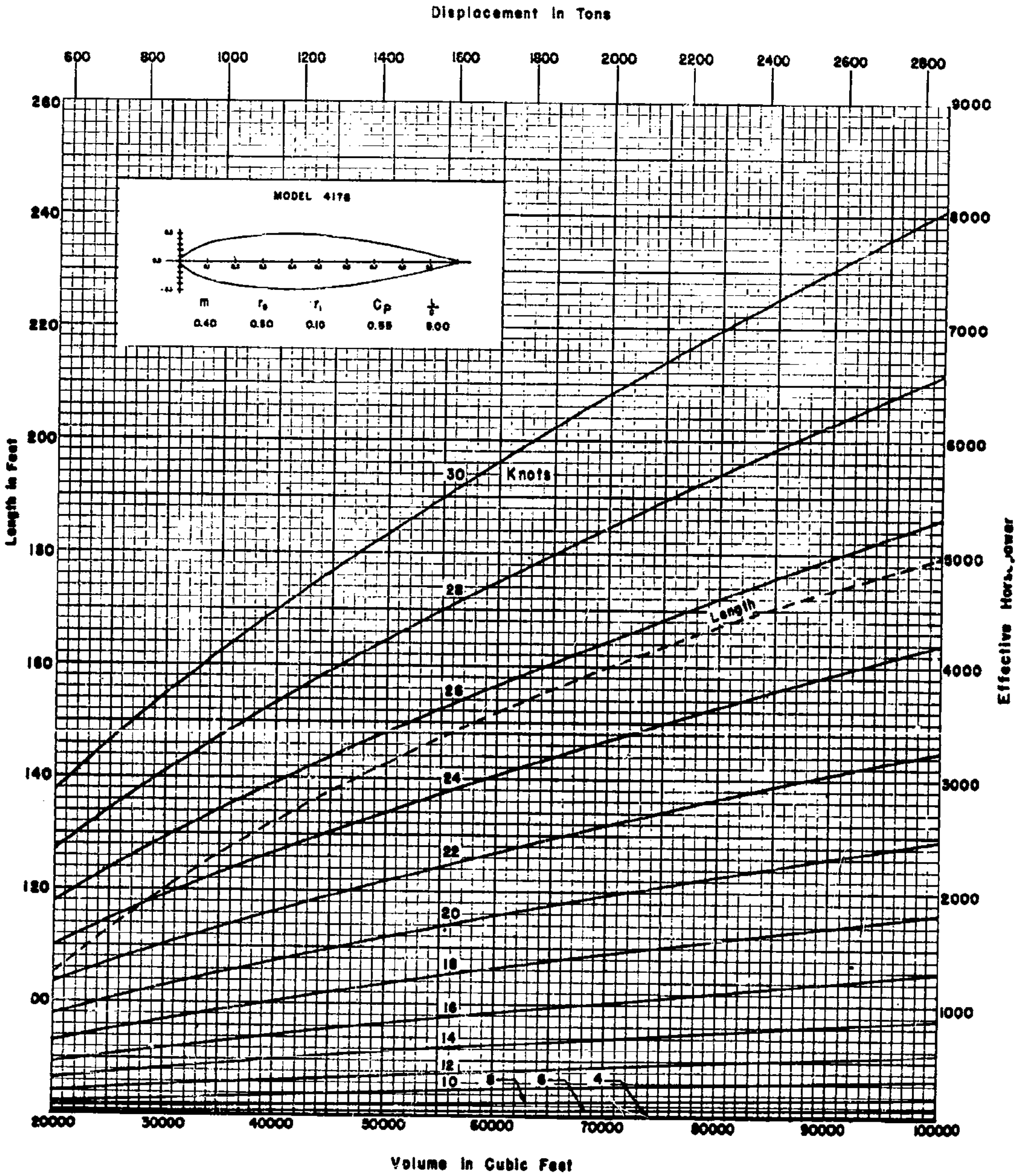

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4172
m 0.40
Cp
L/D 7.00
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

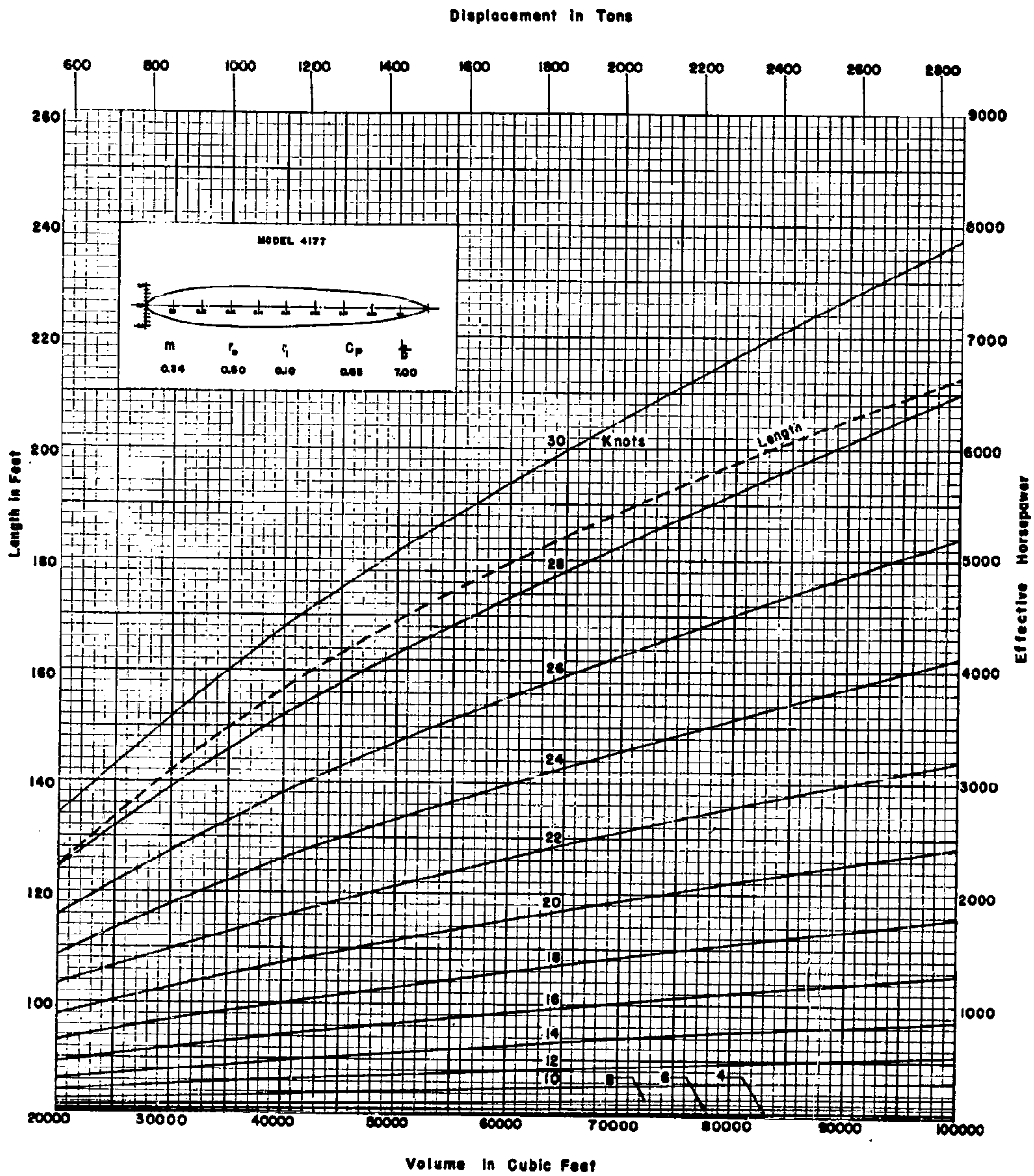

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4173
m 0.40
r_e 0.50
r_r 0.15
C_p 0.65
L/D 7.00
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet



Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4174
m
0.40
0.50
0.20
0.65
7.00
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
Length
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

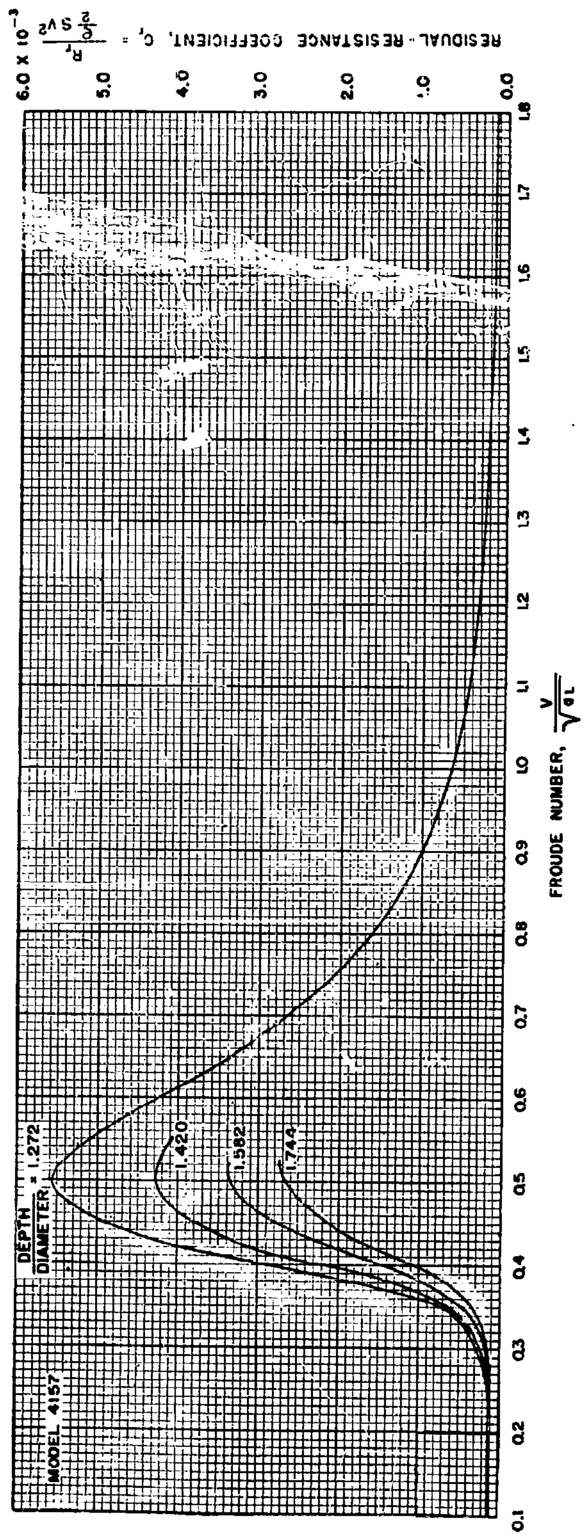

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4170
m 0.40
r_e 0.50
r_t 0.10
C_p 0.60
$\frac{L}{D}$ 5.00
Length in Feet
Effective Horsepower
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
Volume in Cubic Feet
20000
30000
40000
50000
60000
70000
80000
90000
100000

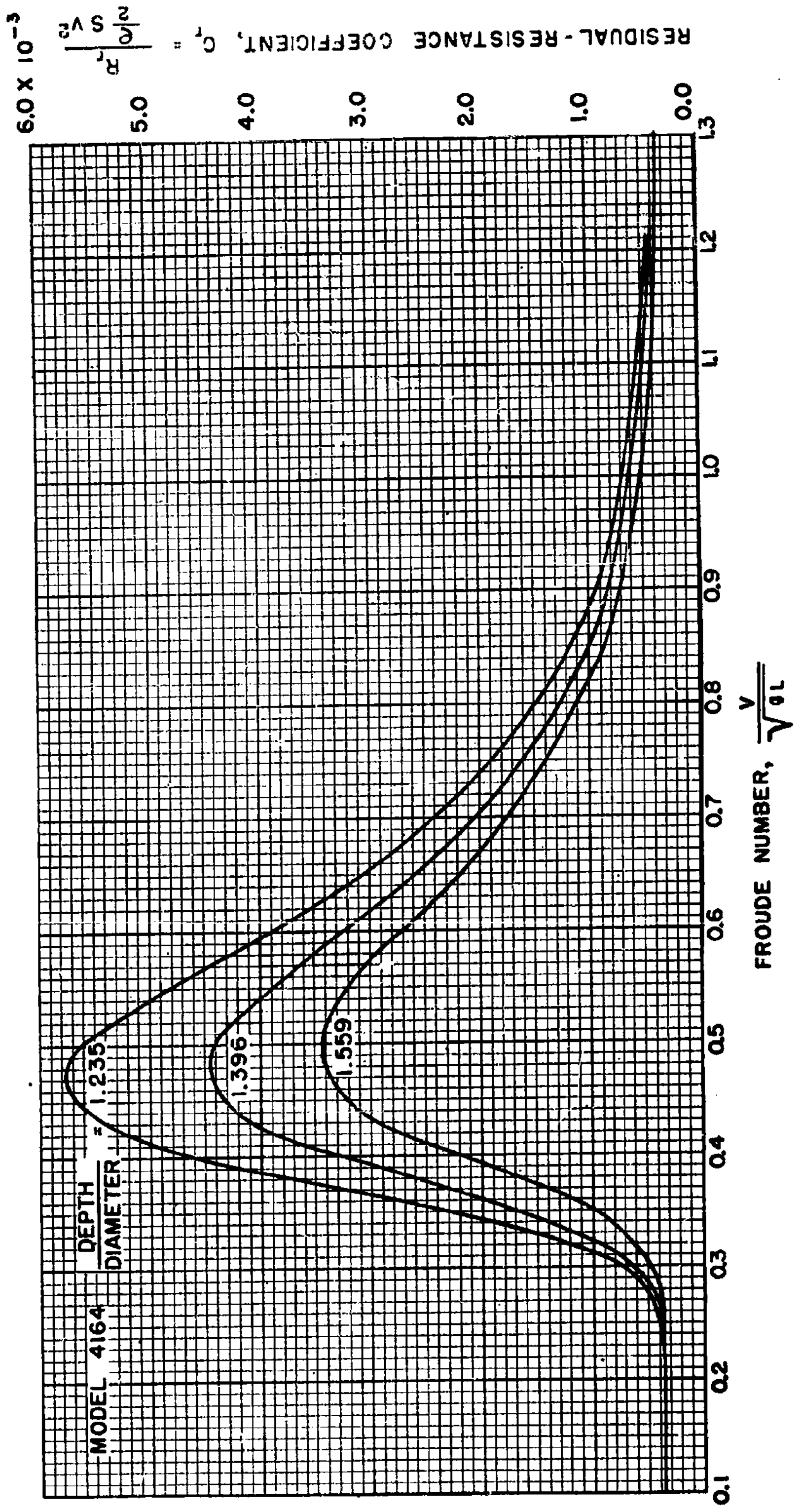

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4178
m 0.40
r_e 0.50
r_i 0.10
C_p 0.55
8.00
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
30 Knots
28
26
24
22
20
18
16
14
12
10
8
6
4
Length
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

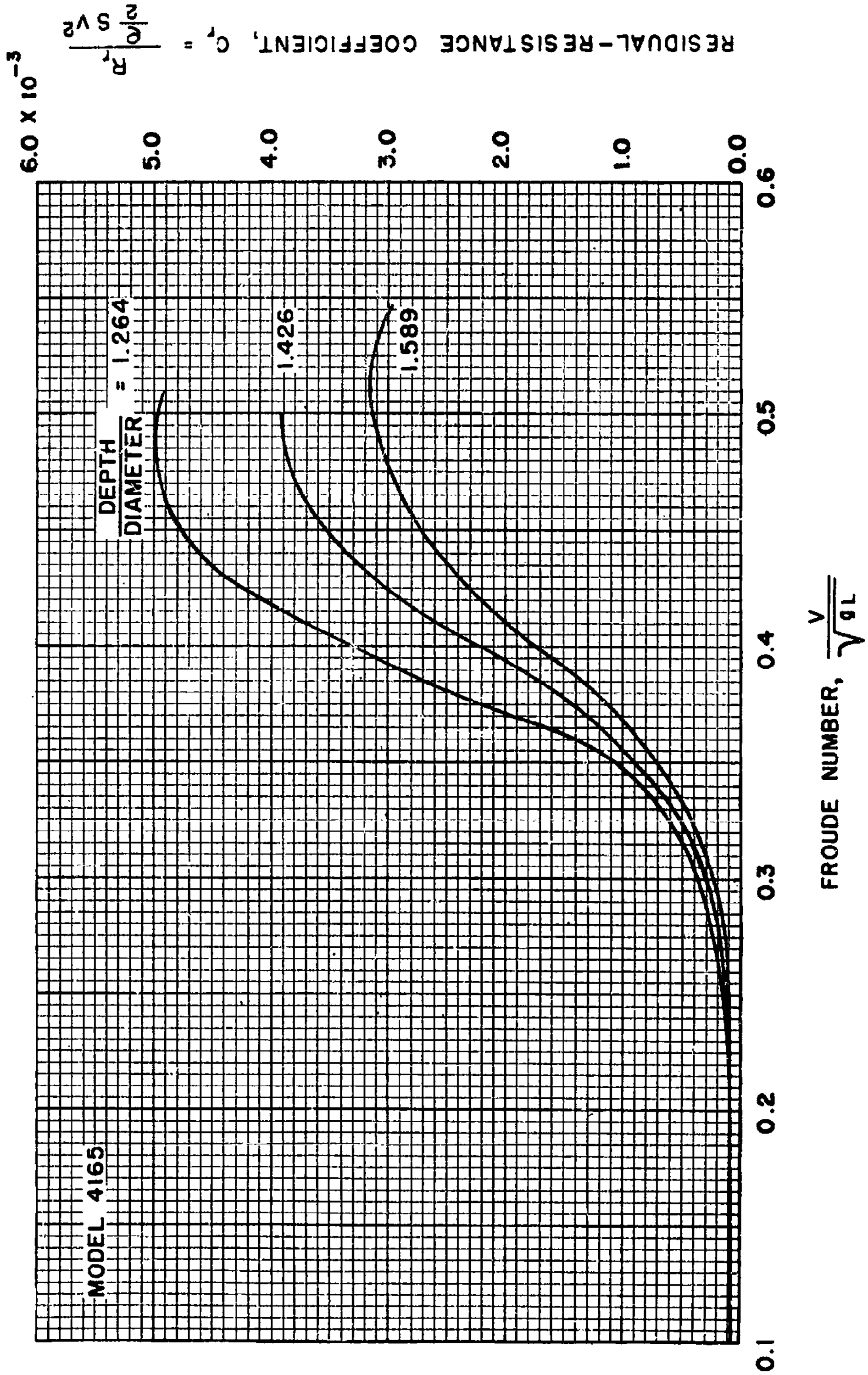

Displacement in Tons
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
MODEL 4177
m
0.34
0.60
0.18
Cp
0.65
7.00
30 Knots
Length
28
26
24
22
20
18
16
14
12
10
8
6
4
Length in Feet
260
240
220
200
180
160
140
120
100
Effective Horsepower
9000
8000
7000
6000
5000
4000
3000
2000
1000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Volume in Cubic Feet

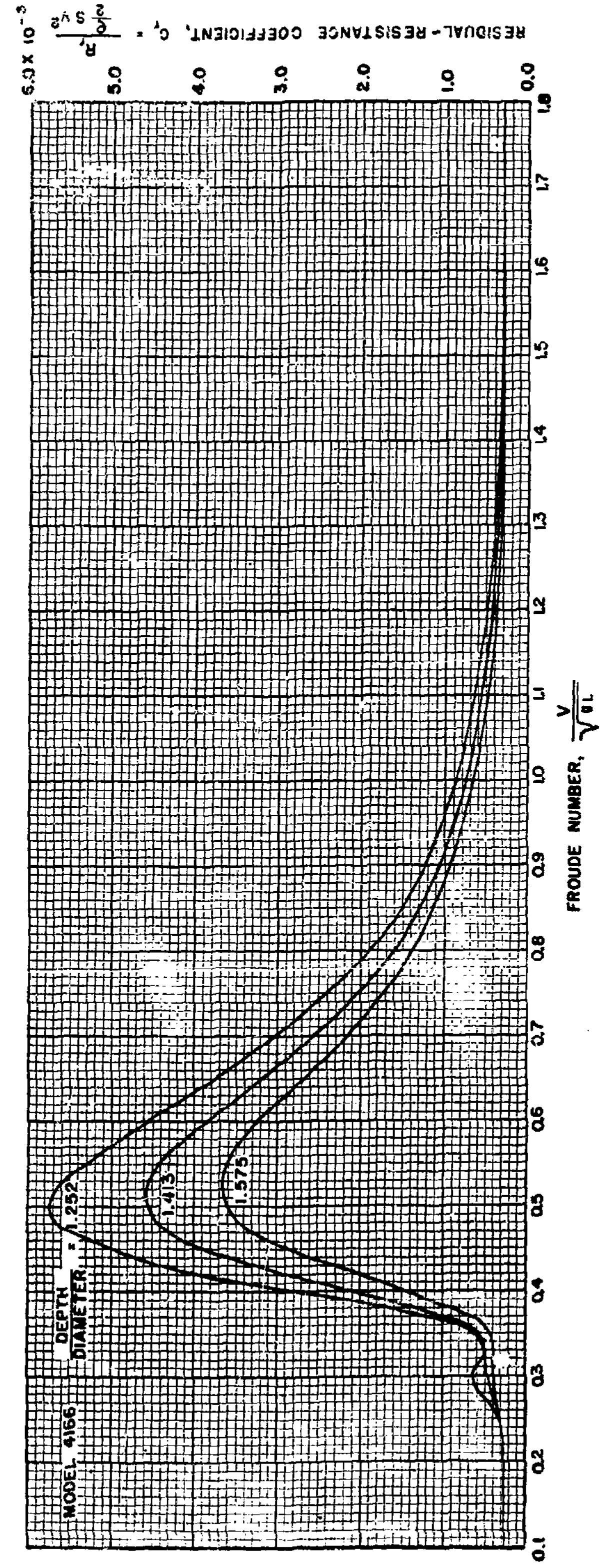
APPENDIX 7

NET RESIDUAL-RESISTANCE COEFFICIENTS FOR SNORKELLING DEPTHS PLOTTED AGAINST FROUDE NUMBER


RESIDUAL-RESISTANCE COEFFICIENT, $C_r = \frac{R_r}{\frac{\rho}{2} S V^2}$
6.0 x 10^{-3}
5.0
4.0
3.0
2.0
1.0
0.0
FROUDE NUMBER, $\frac{V}{\sqrt{gL}}$
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
MODEL 4157
DEPTH / DIAMETER = 1.272
1.420
1.582
1.744


RESIDUAL-RESISTANCE COEFFICIENT, $C_r = \frac{R_r}{\frac{\rho}{2} S V^2}$
6.0 X 10^{-3}
5.0
4.0
3.0
2.0
1.0
0.0
MODEL 4164
$\frac{\text{DEPTH}}{\text{DIAMETER}}$ = 1.235
1.396
1.559
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
FROUDE NUMBER, $\frac{V}{\sqrt{gL}}$


RESIDUAL-RESISTANCE COEFFICIENT, $C_r = \frac{R_r}{\frac{\rho}{2} S V^2}$
6.0 X 10^-3
5.0
4.0
3.0
2.0
1.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
FROUDE NUMBER, $\frac{V}{\sqrt{gL}}$
DEPTH/DIAMETER = 1.264
1.426
1.589
MODEL 4165


RESIDUAL-RESISTANCE COEFFICIENT, $C_r = \frac{R_r}{\frac{\rho}{2} S V^2}$
6.0 x 10^{-3}
5.0
4.0
3.0
2.0
1.0
0.0
FROUDE NUMBER, $\frac{V}{\sqrt{gL}}$
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
MODEL 4166
$\frac{\text{DEPTH}}{\text{DIAMETER}}$ = 1.252
1.413
1.575

CADO CONTROL NO: 104 650 | US CLASSIFICATION: [redacted] | * ATI NO: 86 476 | OA NO:

U

TITLE: [illegible]
of Streamlined Bodies of Revolution [illegible]
[illegible]
Appendixes [illegible] April 1950 [illegible]

over

AUTHOR(S): [illegible]

ORIGINATING AGENCY: [illegible]

FOREIGN TITLES: (N.A.) 2 [illegible]

AD-A800 144

PUBLISHED BY: (Same) 9 5

PUBLISHING NO.:

TRANSLATED BY: NTIS, auth: (N.A.) USNSRDC ltr. 17Feb72

TRANSLATION NO:

PREVIOUSLY CATALOGED AS:

AIR FORCE-WPAFB-L-27 NOV 50 150M

CADO FORM NO. 5C — LIBRARY CARD

SCP-4 Authority: DOD DIR 5200.10, 29 June 60

U SCP-4, AUTH: DOD DIR 5200.10, 29 June 60 (RB no. 109)

Public Release per Bill Bush 3/12/92

P20/4 STREAMLINE SHAPE & BOUNDARY LAYER FLOW