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AN INVESTIGATION OF APPENDAGE DRAG

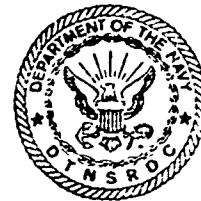
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RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084



AN INVESTIGATION OF APPENDAGE DRAG

by

MARC P. LASKY

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NOBENCLATURE

c	chord length
C_f	coefficient of flat plate friction
C_p	pressure drag coefficient
D	diameter
L	length of appendage
R_D	base resistance due to bluntness of trailing edge
R_f	flatplate frictional resistance
R_{INT}	added resistance due to intersection
R_p	pressure or separation resistance
R_{VA}	velocity augmented resistance
S	planform area of one side of appendage
S_D	projected area of base or trailing edge
t	thickness
t_D	thickness of base or trailing edge
v	velocity
α	cross flow angle (angle between hull and appendage)
ν	kinematic viscosity
ρ	mass density

ABSTRACT

The purpose of this report is to provide information about the resistance, interaction and scaling of appendages. A calculation procedure is developed that can be used to compute the Reynolds number dependent components of appendage drag. A correlation is made between the calculated values of drag and data obtained from bare hull and appended ship-model resistance tests. This correlation indicates that the mathematical model is an effective means of predicting the viscous drag of appendages and that the added drag due to pressure as well as interaction between appendages and the hull form is of a small order of magnitude.

ADMINISTRATIVE INFORMATION

This study was authorized under the Naval Ship Systems Command Exploratory Development Program in Hydrodynamics, Budget Project 32, and was funded under Subproject SF 35421, Task 1713.

INTRODUCTION

Ship appendages refer usually to elements outside the main hull, such as shafting, shaft supporting struts and bossings, power transmission pods and struts, bilge keels and control surfaces. It has been common practice to measure the drag of these appendages as the difference in drag when conducting resistance tests with a ship-model in the bare hull and the appended condition. These measurements provide a gross assessment of the total drag of appendages plus interaction effects for a particular design, but they do not give detailed drag data for each appendage, nor interactions between hull and appendages. The designer does not have sufficient information to improve designs where the combined drag is unduly high. Furthermore the extrapolation, from model to full-scale, of appendage drag is questionable at best.

A procedure for designing appendages was presented in 1953 by Philip Mandel¹. In his summary, Mandel states that scale effects of appendage-resistance "...are important not only in accounting for part of any discrepancies between model power predictions and full-scale results but also in establishing the validity of comparative model testing conducted for the purpose of evaluating competitive appendages. Fundamental studies and tests of individual appendages over a large range of Reynolds numbers are needed for this purpose." In 1957, E. P. Clement conducted such a study using appendages from a planing boat². Clement concluded that the resistance predictions based on previous model tests were too high by about 2.9% when they were compared with his tests. He further concluded that this error was a scale effect due to the fact that below a Reynolds number of 10^6 the extrapolator used with the Schoenherr friction line was not steep enough. In 1966, Hadler³ developed mathematical expressions for predicting the drag of planing boat appendages and used Clement's work to determine the accuracy of his method.

References are listed on page 55.

The present task would appear to be to verify if the works by Clement and Hadler can be applied to displacement type surface-ships. The major problem encountered in this area is in predicting the flow in way of the appendages. Whereas in a planing boat, it may be assumed that the flow is parallel to the bottom of the hull and has the same magnitude as the boat speed, this is not necessarily the case for displacement ships.

This report will discuss ways of estimating the magnitude and direction of the velocity in way of the appendages. Then a mathematical model will be developed for estimating the Reynolds number dependent drag of the following appendage components:*

1. Rudders,
2. Shaft support struts,
3. Stabilizer fins,
4. Intermediate and main shafts,
5. Sterntube bossings,
6. Intermediate and main strut barrels,
7. Bilge Keels, and
8. Skegs.

The results obtained from the mathematical model are then correlated with model test data and there is a discussion of the induced forces and the interaction between the appendages and the hull.

* It should be noted that although this report does not cover such appendages as power transmission pods or right angle drive units, information regarding these appendages may be found in References 4 and 5. It is hoped, that at a later date expressions will be developed for these appendages as there would appear to be quite a demand for this information in the future.

MATHEMATICAL EXPRESSIONS OF APPENDAGE DRAG

In the development of mathematical expressions that can predict the drag of the aforementioned appendages it was necessary to make assumptions so that the calculations could be made with relative ease and still be applicable. The first major assumption is that the appendages can be divided into their component parts, the drag of each component being calculated separately and therefore, the total appendage drag is equal to the sum of the drag of each appendage. The second major assumption is that the drag of the appendages is considered to be viscous in nature. (These assumptions will be discussed in further detail later in the text.) Other assumptions will be discussed for each case and specific references are noted next to each expression.

THE APPENDAGE COMPONENTS

The appendages considered herein are broken down into the following groups:

- Group I = Rudders, struts, and stabilizer fins;
- Group II = Stern tube bossings, intermediate shafts, main shafts, and intermediate strut barrels;
- Group III = Main strut barrels;
- Group IV = Bilge keels and skegs.

Groups I and II are treated as two-dimensional surfaces, Group III is treated like a body of revolution and Group IV is treated similar to a flat plate friction plane.

VELOCITY - MAGNITUDE AND DIRECTION

In the preliminary design stage, more often than not, the designer can only approximate the velocity at the stern. At present there are no simple

methods for predicting the flow in way of a ship's appendages. The Douglass Aircraft Company, Inc. has developed a computer program for calculating potential flow about arbitrary three-dimensional bodies (Reference 6). The Douglass program has been used successfully in several cases to predict the flow about ship hulls. There has been some success in predicting the pressure distribution over a bow-mounted sonar dome.⁷ However, in the early stages of this project, an attempt was made to predict the flow at the stern of a ship, and it was concluded that this method was too expensive, time consuming, and necessitated information which might not necessarily be available to the user during the preliminary design stage of the hull.

For simplicity, if we restrict this investigation to ships with multiscrew propulsion systems that have some type of transom stern with a relatively flat bottom, we may then assume that the wake fraction, for this type of ship, will normally range from zero to eight percent. Therefore, we may use as the local velocity in way of the appendage, the freestream velocity or modify it by a wake fraction (based on data for a similar ship which has previously been tested). It is felt that in terms of percentages, the error due to this assumption would be approximately 0 to 8 percent (at most) of the velocity as measured from a wake survey.*

As for the direction of the local velocity, it is assumed that the struts, skegs, bilge keels, stabilizer fins and rudders align with the flow. Further, the direction of flow past cylindrical bodies such as shafts, sterntube bossings, strut barrels, and fairwaters is assumed to be parallel to the hull and that there is no transverse crossflow. Therefore, the direction of the flow over these appendages can be estimated to be the angle they make (locally) with the hull.

* This assumes that the velocity error will be no greater than the wake fraction for the hull form.

THE FRICTION FORMULATION

The Schoenherr friction line, (Reference 8), has been used for all friction calculations on the appendages. The numerical values of C_f derived from the Schoenherr formula apply to the viscous component of flat surfaces whereas other friction lines commonly used by naval architects in determining the frictional resistance of ships might incorporate various degrees of a form factor.

Therefore, since the Schoenherr formulation is considered to be a baseline, the expressions used to calculate appendage drag will relate the geometric parameters of the appendage to the corresponding flat plate friction coefficient.

The Schoenherr friction formula may be simplified by the following expression:

$$C_f = 1/(3.46 \log_{10}(Rn) - 5.6)^2 \quad (1)$$

This approximation is considered to be within ± 2 percent of the standard Schoenherr formulation.

The formulations are for turbulent flow. However, a correction should be made to account for the fact that the appendages experience a local flow which may be laminar up to a point and then becomes turbulent afterward. The following are the expressions which have been used to obtain the coefficient of friction for all work discussed in this report:

$$C_{f_{\text{Laminar}}} = 1.327/\sqrt{Rn} \quad (2a)$$

$$C_{f_{\text{Turbulent}}} = \frac{0.242}{\sqrt{C_f}} + \log_{10}(Rn \cdot C_f), \quad (2b)$$

$$C_{F_{\text{Transition}}} = C_{F_{\text{Turbulent}}} - \frac{A}{Rn}, \quad (2c)$$

$$\text{where } A = \frac{(C_{F_{\text{Turbulent}}} - C_{F_{\text{Laminar}}}) Rn}{\left(\begin{array}{l} \text{all taken at the chosen} \\ \text{Reynolds number at transition} \end{array} \right)}$$

It will be shown later that for the present work on appendages, an appropriate Reynolds number for transition is approximately 5×10^4 . Figures 1 and 2 are provided to facilitate the user in obtaining Reynolds numbers and friction coefficients. Figure 1 presents a graphical solution for obtaining Reynolds numbers; a sample problem is shown by the indicated arrows. Figure 2 presents curves of the friction coefficient previously discussed. Transition curves from laminar to turbulent flow are given for $Rn_{\text{Transition}} = 5 \times 10^4$; 1×10^5 and 5×10^5 . Conditions where "forced turbulence" would be used correspond to the case where the turbulent curve is used for all Reynolds numbers and would be generated by using $Rn_{\text{Transition}} = 0.0$.

GROUP I - RUDDERS, STRUTS AND STABILIZER FINS

Group I appendages, as considered herein, are assumed to have streamline sections with a maximum thickness located at 30 to 50 percent of the chord length. They are treated as two-dimensional surfaces which for appendages aligned with the flow appears to be acceptable. This is because experimental work for rudders, for example; reference 10, has shown that the effects of aspect ratio, sweepangle; and tip ending are small for zero angle of attack. Furthermore, it is also assumed that there is no ventilation or cavitation. With all of these simplifying assumptions taken into consideration the total drag can be derived as the sum of the various components usually considered in two-dimensional foil prediction. Expressions for these components such as flat plate friction resistance (R_F),

resistance due to velocity augmentation (R_{VA}), pressure or separation resistance (R_P), added resistance due to an intersection with the hull or a strut barrel (R_{INT}) and the base drag due to a bluntness of the trailing edge (R_B) are presented below.

Reynolds Number Used to Obtain C_F

The Reynolds number used for Group I appendages is a function of velocity, kinematic viscosity and chord length* or,

$$Re = Vc/\nu, \quad (3)$$

Flat Plate Friction Resistance

The expression used to obtain the flat plate friction resistance is as follows:

$$R_F = 1/2 \rho S V^2 (2C_F), \quad (4)$$

Resistance Due to Velocity Augmentation

The mean average velocity around a symmetrical foil section is higher than that of the undisturbed flow. The added resistance due to this velocity augmentation is given by:

$$R_{VA} = \rho 1/2 S V^2 (2C_F) (2t/c), \quad (5)$$

Pressure or Separation Resistance

The pressure or separation resistance is a component originating due to the lack of pressure recovery associated with boundary layer thickness and/

* For the work presented in this report, the maximum chord length was used when the drag of tapered appendage was to be calculated.

or separation along the afterbody of foil and strut sections. The expression for approximating the pressure drag is given as follows:

$$R_p = 1/2 \rho S V^2 (2C_F) 60 (t/c)^4; \quad (6)$$

Added Resistance Due to Intersection with Hull or Strut Barrel

The added resistance due to an intersection of any of these appendages with another surface will be treated as if it were an intersection with a flat wall. It is speculated that, "when a wing or strut adjoins a wall (or an end plate), the boundary layers of both; the wind and the wall, join each other. Subjected to the pressure gradient along the rear of the foil section; the boundary layer is further retarded; and additional pressure drag (i.e., interference drag) arises."¹¹ It should be noted that for very thin sections ($t/c < .08$, this interference drag might become negative. The expression for estimating this drag component is given below:

$$R_{INT} = 1/2 \rho V^2 t^2 \left[0.75 (t/c) - 0.0003/(t/c)^2 \right] \quad (7)$$

Base Drag Due to Bluntness of Trailing Edge

The base drag of foil section with blunt trailing edges may be approximated with the following expression.

$$R_B = 1/2 \rho S_B V^2 \left[0.135/3 \sqrt{C_F(c/t_B)} \right] \quad (8)$$

GROUP II - SHAFTING, STERN TUBE BOSSINGS AND INTERMEDIATE STRUT BARRELS

In order to estimate the drag of the shafting, it was necessary to divide this appendage into the following sections: (1) Intermediate shaft (between the stern tube bossing and the intermediate strut barrel), and (2) main shaft (between the intermediate strut barrel and the main

strut barrel). The resistance components of Group II appendages are the frictional resistance (R_f) and the pressure resistance corrected for crossflow (R_p).

Friction Resistance and Reynolds Number

The Reynolds number used in estimating the frictional drag is based on the appendage length along the longitudinal axis. Therefore,

$$Re = \frac{VL}{\nu} \quad (9)$$

where

L = length of appendage along the longitudinal axis (for stern tube bossings, the length is taken to the intersection with the hull along the shaft centerline).

The friction resistance may be determined by the following expression.

$$R_f = \frac{1}{2} \rho L D V^2 \pi C_f \quad (10)$$

Pressure Resistance Corrected for Crossflow

The expression used to estimate the pressure drag has been taken from a derivation proposed by Hoerner (reference 11). The general form of the equation is:

$$R_p = \frac{1}{2} \rho L D V^2 C_p \sin^3 \alpha \quad (11)$$

The pressure drag coefficient (C_p) may be further defined for non-cavitating and cavitating flows. The proposed definition of C_p follows from work presented in reference 11, page 10-8, Figure 15a. This figure presents drag coefficients as a function of cavitation number for flows that are

above and below the critical Reynolds number for separation. The parameters used to describe the flow are Reynolds number (Rn) and cavitation number (σ),

$$Rn = \frac{VD_c}{\nu} \quad (12)$$

$$\sigma = (P_{\text{ambi}} - P_{\text{vap}}) / (1/2 \rho V^2) \quad (13)$$

where

P_{ambi} = ambient pressure acting at the centroid of the appendage,

P_{vap} = vapor pressure of the surrounding fluid.

The expressions for the pressure drag coefficient represent the aforementioned curves in reference 11 in polynomial form and are given below for various flow conditions.

$$Rn < 5 \times 10^5 \quad \text{and } \sigma > 2.5,$$

$$C_p = 1.17$$

$$Rn > 5 \times 10^5 \quad \text{and } \sigma > 2.5,$$

$$C_p = 0.50$$

Non-Cavitating Flows

$$Rn < 5 \times 10^5 \quad \text{and } \sigma < 2.5,$$

$$C_p = .5 + .5\sigma - .052 \sigma^2 + .046 \sigma^3 - .061 \sigma^4 + .014 \sigma^5,$$

$$Rn > 5 \times 10^5 \quad \text{and } 2.1 < \sigma < 2.5,$$

$$C_p = 6.125 - 2.25 \sigma,$$

$$Rn > 5 \times 10^5 \quad \text{and } \sigma < 2.1,$$

$$C_p = .5 + .5\sigma - .039 \sigma^2 + .006 \sigma^3.$$

Cavitating Flows

GROUP III - MAIN STRUT BARRELS

The components of a main strut barrel are:

- (a) strut barrel,
- (b) propeller hub,
- (c) fairwater.

These components together are considered one unit.

The components of resistance for these appendages are friction resistance (R_f), pressure resistance corrected for crossflow (R_p) and the base drag due to the bluntness of the fairwater trailing tip (R_b). The expressions used to estimate the resistance due to friction and pressure are the same as the ones for Group II appendages (Equations (9) through (13)).

Base Drag Due to Bluntness of Fairwater-Ending

According to Hoerner, the base drag of three dimensional bodies very similar to the fairwater (projectiles, fuselages and ellipsoids for example) is found to depend largely on the length of the forebody, its surface conditions, and the ratio of base to body diameter. The expression used to estimate the resistance due to the bluntness of the fairwater-ending is:

$$R_b = \frac{\rho}{2} V^2 \frac{\pi}{4} D^2 [0.029 (D_b/D)^3 / (2\sqrt{C_F(L/D)})] \quad (14)$$

where

- D = maximum diameter of appendage,
- D_b = diameter of base (see above),
- L = length of appendage along the longitudinal axis if blunt or rounded trailing end, use the extended length i.e., the length the appendage would be if it were not blunt.

GROUP IV - BILGE KEELS AND SKEGS

The resistance of bilge keels and skegs is treated similar to the drag of a flat plate. This assumes that these appendages are aligned with the flow. It should be noted that, generally, skegs are considered as an integral part of the bare hull form and not as a separate appendage. The expression for estimating the resistance of this group of appendages is,

$$R = \frac{1}{2} S V^2 C_F, \quad (15)$$

where

S = wetted surface area of the appendage minus the wetted surface area of that part of the hull that has been covered up by the appendage. By taking the wetted surface in this manner, the loss of bare hull friction drag due to a net loss of wetted surface on the bare hull can be compensated for.

The Reynolds number to be used to obtain the flat plate friction coefficient is a function of the velocity, length of appendage, and kinematic viscosity, as follows:

$$Re = \frac{VL}{\nu} \quad (16)$$

"APPEND" A COMPUTER PROGRAM OF THE MATHEMATICAL MODEL

The expressions derived in the previous section for calculating the drag of various appendages have been used as the basis for a computer routine named APPEND. Details of the computer program are presented in Appendices I through III with the routine/algorithm in Fortran presented in Appendix I, input format and output format in Appendices II and III, respectively.

CORRELATION OF THE MATHEMATICAL MODEL WITH MODEL TESTS

In the presentation of any calculation method, it would be most desirable if the expressions could be proven out by experimental data. For the case of appendages, this would involve the testing of various sizes (scale effect), shapes, and combinations with one another (interactions). However, it was not possible to conduct such an experimental program for this study. It was necessary, therefore, to simulate a data base which could substitute for the test program.

The decision was made to make use of the results of previous model tests conducted by the Naval Ship Research and Development Center. This method involved the selection of fourteen ship-models that had been tested in the bare hull and appended modes for resistance. The drag of the appendages as a group was then obtained from the difference in resistance of the two modes and compared to the results obtained by using the expressions presented herein. A fairing of the data has been made in order to facilitate general comparisons.

A BRIEF DESCRIPTION OF THE SHIP-MODELS

In general, the fourteen ship-models chosen for this study were of the twin screw propulsion type and represent three basic hull forms with

transom type sterns. Tables I and II present a more detailed description of the hull forms and their appendages.

PRESENTATION OF MODEL DATA

As stated previously, it is most desirable to present some experimental data in order to verify a mathematical model. Keeping in mind that the mathematical model presented herein is supposed to represent the Reynolds number dependent components of the appendage drag, then the data should be presented in such a manner so as to describe visually the answers to the following questions. First, and most important, are the expressions able to predict within a reasonable tolerance the Reynolds number dependent drag of the various appendages; and second, what are the possible sources of error inherent to the mathematical model and how can they be compensated for? The data are presented, therefore, in two ways in order to determine if the answers to the above questions are just a function of the individual appendage suit in question or if there are general trends which can be applied to any appendage suit.

Figure 3 presents the values of appendage drag (in coefficient form) as calculated from the mathematical model using both a friction line based on forced turbulence at the lower Reynolds numbers and on a transition Reynolds number equal to 5×10^4 (these friction lines may be seen in Figure 2). Also presented in Figure 3 are the appendage drag data obtained from model tests as previously described. The differences in model appendage drag coefficient for various hull forms of the same designation, e.g. three 3-D forms, are due to differences in the models not readily apparent from the descriptive parameters listed in Tables I and II. The predicted values of Reynolds number dependent appendage resistance appear to be in close agreement with the model data except where "humps" appear. To further investigate this phenomena, Figure 4 has been prepared. It presents the difference between the calculated values

TABLE I

The Hull Forms

Hull Coefficient	Name of Coefficient*	TYPE 1**	TYPE 2	TYPE 3
C_B	Block Coefficient	.61	.66	.48
C_P	Longitudinal Prismatic Coefficient	.63	.67	.59
C_X	Maximum Section Coefficient	.97	.99	.81
C_{WP}	Waterplane Coefficient	.78	.84	.73
C_{PF}	Forebody Prismatic Coefficient	.60	.67	.56
C_{PA}	Afterbody Prismatic Coefficient	.67	.67	.62
C_{PE}	Entrance Prismatic Coefficient	.60	.65	.58
C_{PR}	Run Prismatic Coefficient	.66	.67	.59
C_{VP}	Vertical Prismatic Coefficient	.78	.79	.65
C_{VPA}	Afterbody Vertical Prismatic Coefficient	.72	.69	.62
C_{VPF}	Forebody Vertical Prismatic Coefficient	.88	.93	.78
C_{WPF}	Forebody Waterplane Coefficient	.66	.72	.58
C_{WPA}	Afterbody Waterplane Coefficient	.90	.96	.96

* Formulae for the hull coefficients may be found in Reference 12.

** The numerical values for the hull coefficients for each hull type are the average values for all the designs used.

TABLE II
The Appendage Suits

HULL FORM TYPE	APPEN- DAGE SUIT TYPE	RUDDERS	STRUTS	STABI- LIZER FINS	SHAFTS	STERNTUBE BOSSINGS	STRUT BARRELS	BILGE KEELS	SKEGS
MAIN INTER*									
1	A	1	4	-	2	-	2	-	-
1	A	1	4	-	2	-	2	-	-
1	B	2	4	-	2	-	2	-	-
1	B	2	4	-	2	-	2	-	-
2	B	2	4	-	2	-	2	-	-
1	C	2	4	-	2	-	2	-	-
2	D	2	4	-	2	-	2	-	-
3	D	2	4	-	2	-	2	-	-
3	D	2	4	-	2	-	2	-	-
3	D	2	4	-	2	-	2	-	-
3	E	2	4	-	2	-	2	-	-
3	F	2	4	4	2	-	2	-	-
3	G	2	4	-	2	-	2	-	-
3	H	2	4	4	2	-	2	-	-

* INTER is the abbreviation used to signify an intermediate appendage. Its location normally being approximately halfway down the length of the propeller shaft.

(using the transition Reynolds number 5×10^4) and the model data in the form of percent difference and the actual magnitude in pounds. These absolute and relative differences are presented as a function of the model speed non-dimensionalized by the design speed value.

Values of appendage resistance as a percentage of bare hull resistance for the fourteen selected models are presented versus speed-length ratio in Figures 4a, 4b, and 4c.

DISCUSSION OF CORRELATION

In order to discuss the correlation of the results obtained from the mathematical model to the model data, the speed range will be broken down into two components. The first speed range will be defined to be below design speed and the second will be above design speed. The design speed for hull forms 1 and 2 is approximately equal to a speed-length ratio of .8 and for hull form 3 the design speed-length ratio is about 1.2. It is assumed that the appendage drag below design speed is for the most part dependent on Reynolds number and that the contribution of the Froude dependent resistance becomes a factor slightly below and about design speed.

Figure 4 indicates that the agreement between the mathematical model and the model data below design speed is very good. For example, the average magnitude of this difference at 80 percent design speed is less than 0.2 pounds. We may, therefore, deduce that the mathematical model is valid in this speed range. The deviation from the mean may be caused by a misalignment of such appendages as struts, stabilizer fins, bilge keels, etc., to the flow and will be discussed later in the text. For now, it will be called an induced drag (R_i) that is, in nature, independent of Reynolds number.

The case for the differences between the results from the mathematical model and the model data is similar for the higher speed range. However,

the magnitude is larger, which would tend to confirm the second part of our assumption, i.e., that the Froude number dependent resistance has an effect at the higher speed-values. The shape of the curve through the data is still more evidence indicating the Froude number dependence of this component of the appendage drag.

INTERACTION BETWEEN APPENDAGES AND HULL

If it is assumed that part of the difference between the calculated values and those data deduced from the model resistance tests is due to the previously mentioned induced resistance caused by misalignment to the flow, then the question arises as to what causes the rest of the difference? This may be answered by using some deductive reasoning.

It is a well known phenomenon that an appended model will not necessarily have the same trim characteristics as a bare hull model. It is also known that the trim of a model has an effect on its wave making resistance. Now, it will be recalled that the model data used for the verification of the mathematical model were obtained by subtracting the bare hull model resistance from the appended hull model resistance. Furthermore, since we were able to predict all but 0.2 pounds of the appendage drag up to 80 percent of design speed (this being almost totally dependent on Reynolds number) there is no reason to believe that we do not have the same relative accuracy for predicting Reynolds number dependent drag above the design speed. It appears to be reasonable, therefore, to deduce that the remainder of the difference between the values obtained from the calculation procedure and the model data is caused by the interaction of the appendages on the hull form and that this interaction is a resistance that is Froude number dependent and wave making in nature.

CONCLUSIONS

Summarizing what has been accomplished in the preceding chapters, the following conclusions may be drawn.

1. A mathematical model has been developed for the prediction of the viscous components for appendage drag.
2. The predictions obtained from the mathematical model have been correlated with model appendage resistance data obtained from the results of fourteen ship-model resistance tests and the mathematical model was found to be an effective means of predicting appendage drag.

The differences between the results from the mathematical model and the model data appear to be due to two basic resistance components, i.e., induced drag due to misalignment of an appendage to the flow and a Froude number dependent drag due to the interaction between the appendages and the hull form. These effects will be considered at greater length as this study progresses.

3. A Fortran IV computer program, refer to Appendix I, to be used on the Center's CDC 6700 computer has been developed using the mathematical expressions presented herein. The computer program as presented herein utilizes excessive core space and is presently being modified. The modified version will be available by 1 March 1972. The program also contains an error in the base drag formulation; however, this error is being corrected in the modified version. The present form will provide correct drag values as long as base drag terms are not needed.

RECOMMENDATIONS

A procedure for calculating the vector lift and drag components of the appendages could be developed, and their effect on the change in trim angle correlated to the added appendage drag due to change in underway trim. This could be done by assuming that the forces acting on the appendages are located at the centroid of the appendages; then by taking the sum of the moments about the center of flotation, the change in trim due to the addition of appendages could be calculated. These developments would be very helpful to the designer.

An experimental study should be conducted on a set of carefully selected geosims to verify the scaling technique. This study should also indicate if a correlation allowance for appendages is necessary. Since it may be difficult to conduct some phases of such an experimental program in a towing tank due to the size of some of the larger geosim appendages, the use of a subsonic wind tunnel may be considered as complementing the work done in a towing tank.

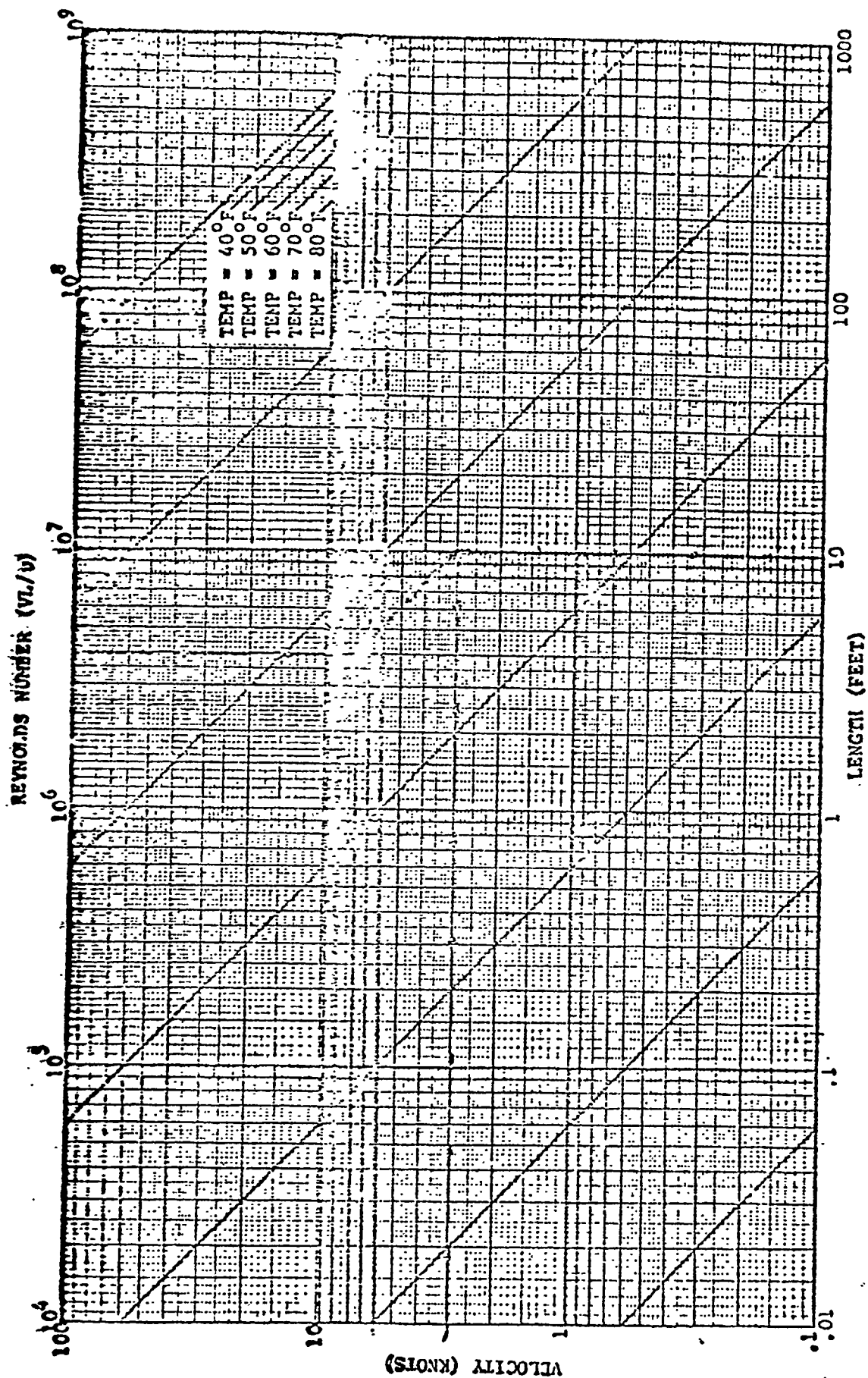


FIGURE 1 - Graphical Representation of the Reynolds Number Formula as a Function of Velocity, Length and Temperature

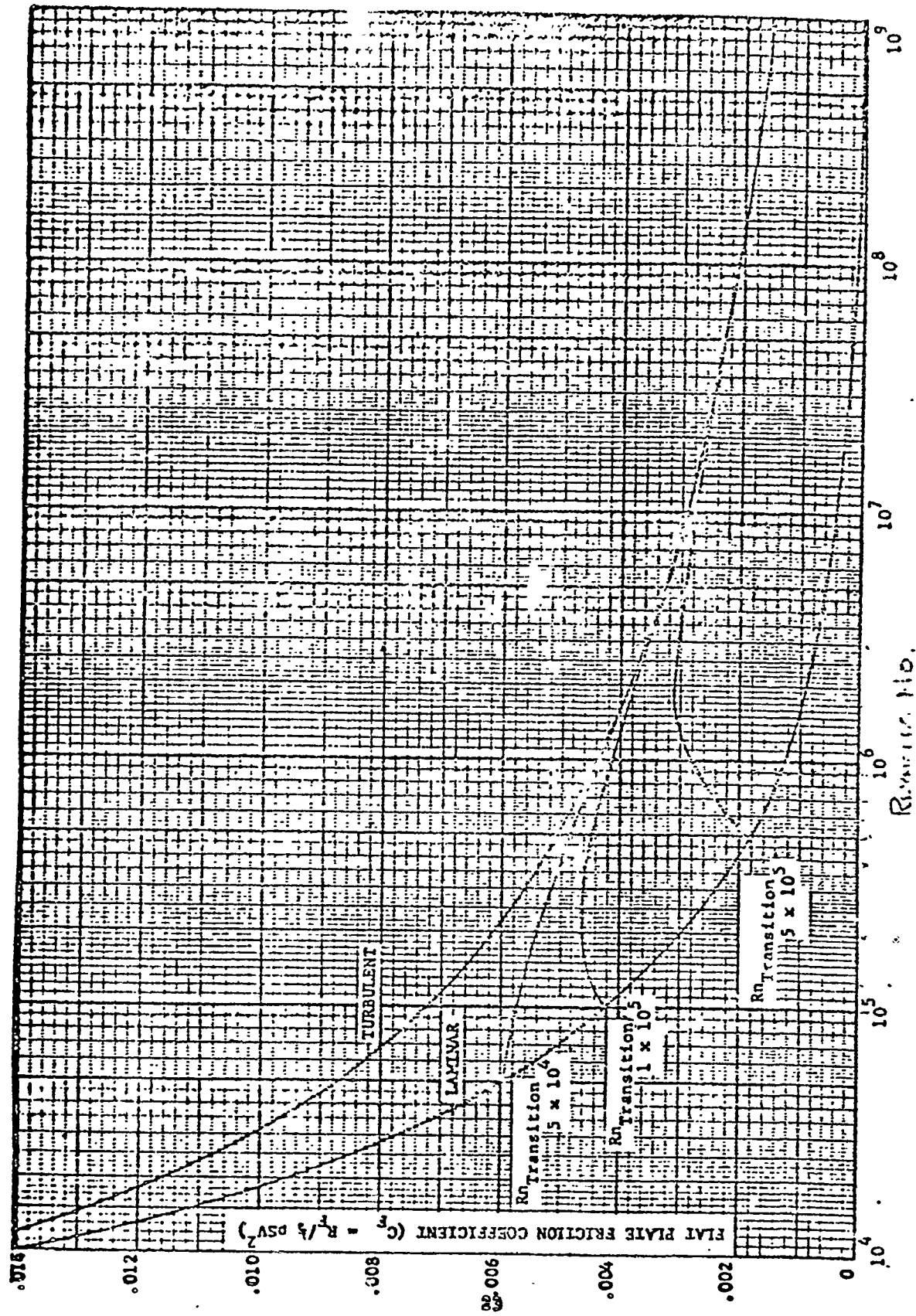


Figure 2 - Curves of Laminar, Transition and Turbulent Flat Plate Friction Coefficient as a Function of Reynolds Number

○ DATA DEDUCED FROM MODEL RESISTANCE TESTS

--- ANALYTICAL PREDICTION USING FORCED TURBULENCE

— ANALYTICAL PREDICTION USING $R_{Transition}$ OF 5×10^4

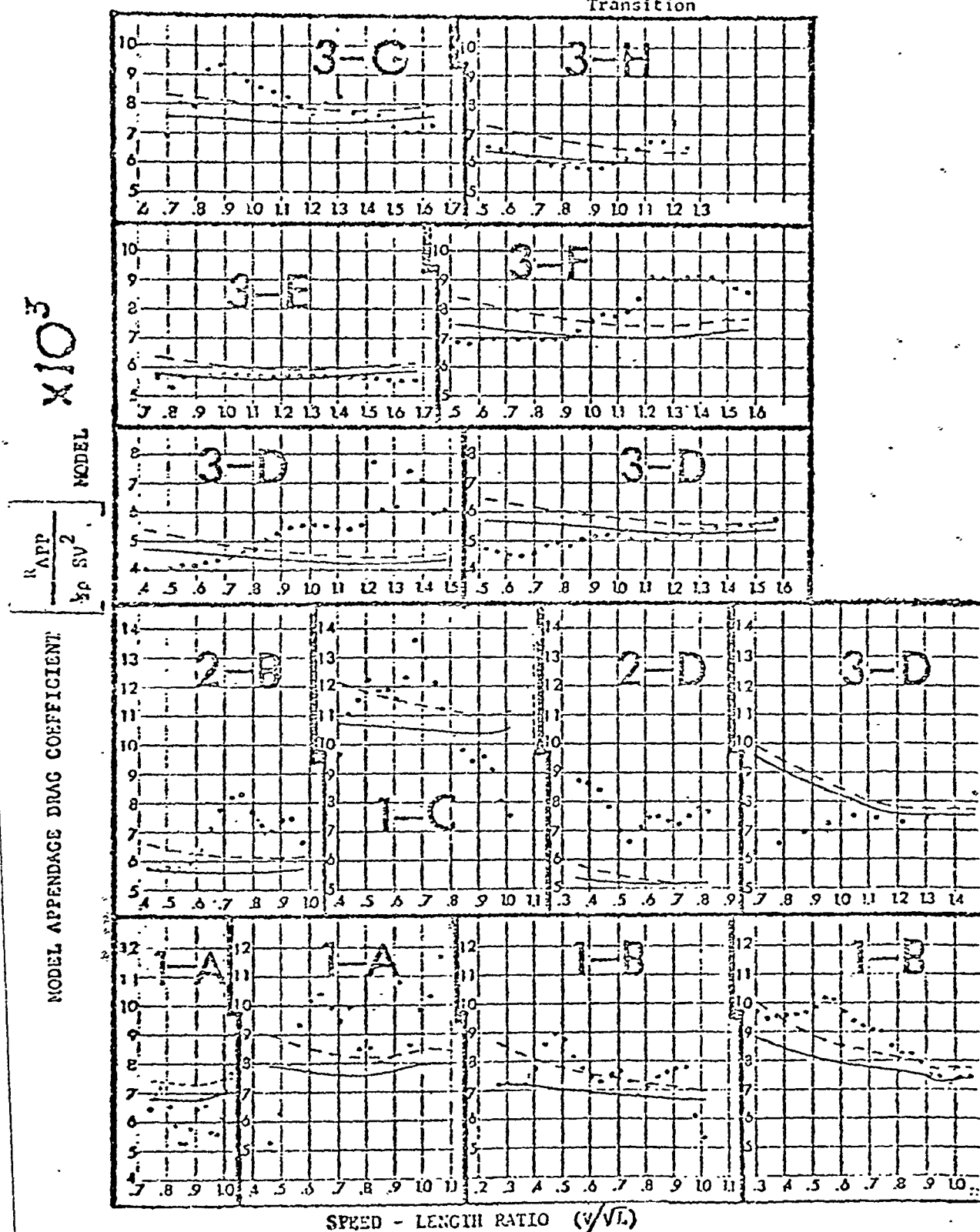


Figure 3 - Comparison of Values of Appendage Drag Obtained from the Mathematical Model with those Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

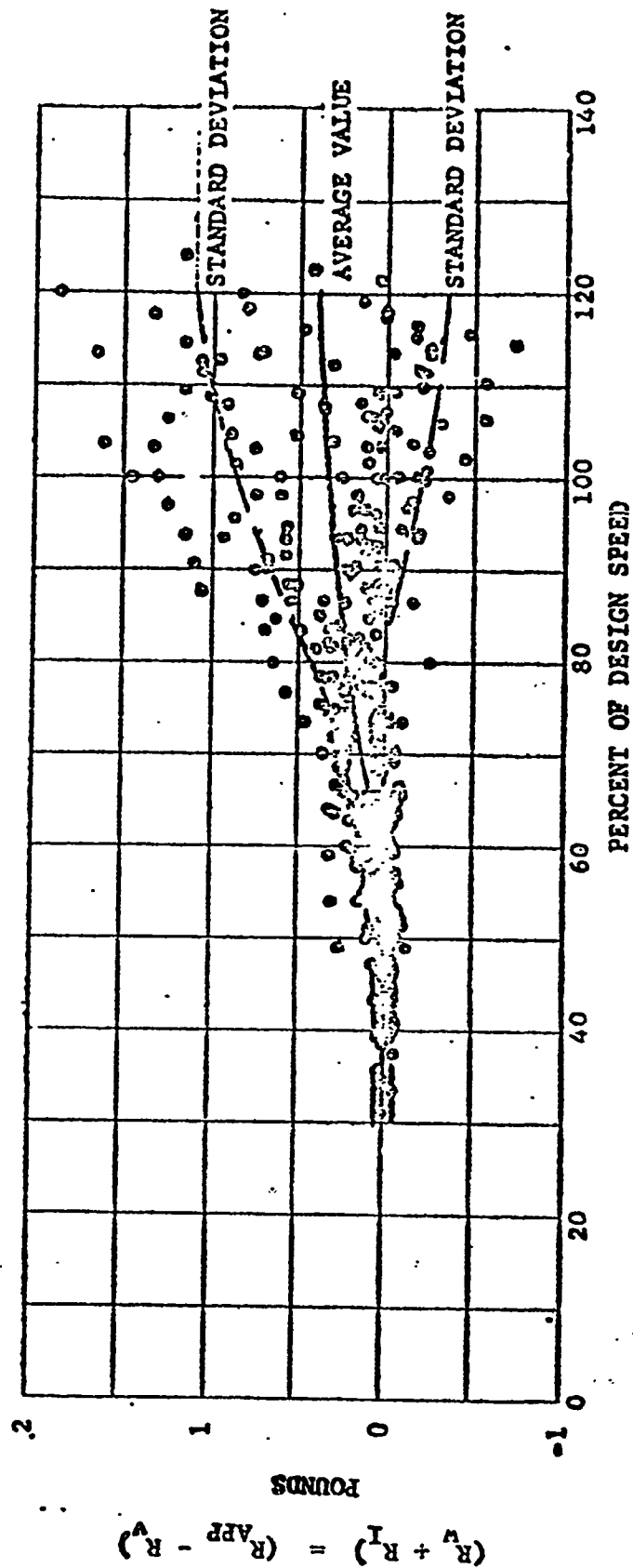
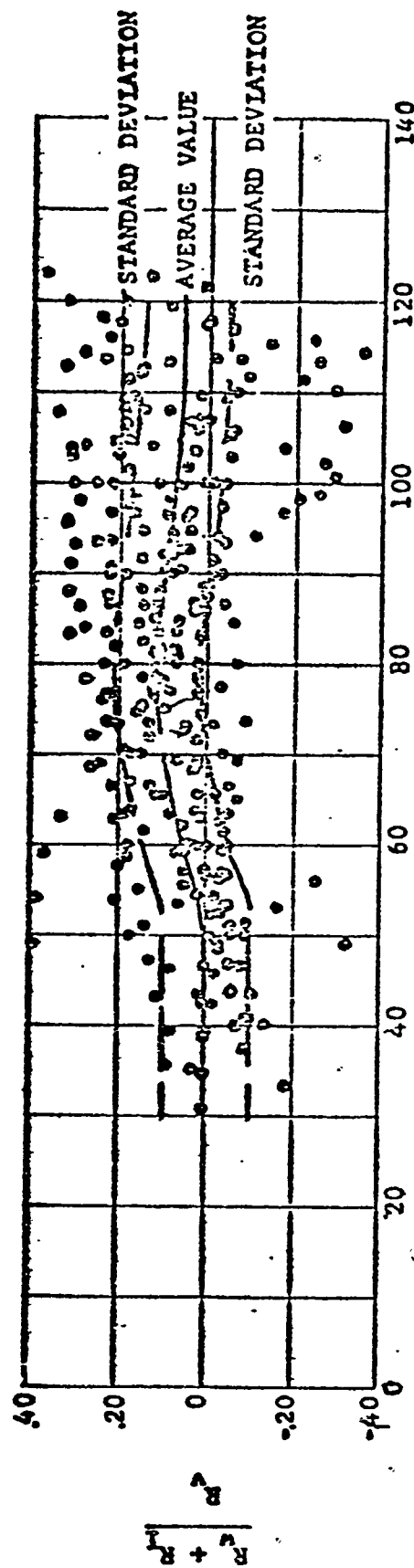


Figure 4 - Model Scale Differences Between Center Tests and the Mathematical Model.

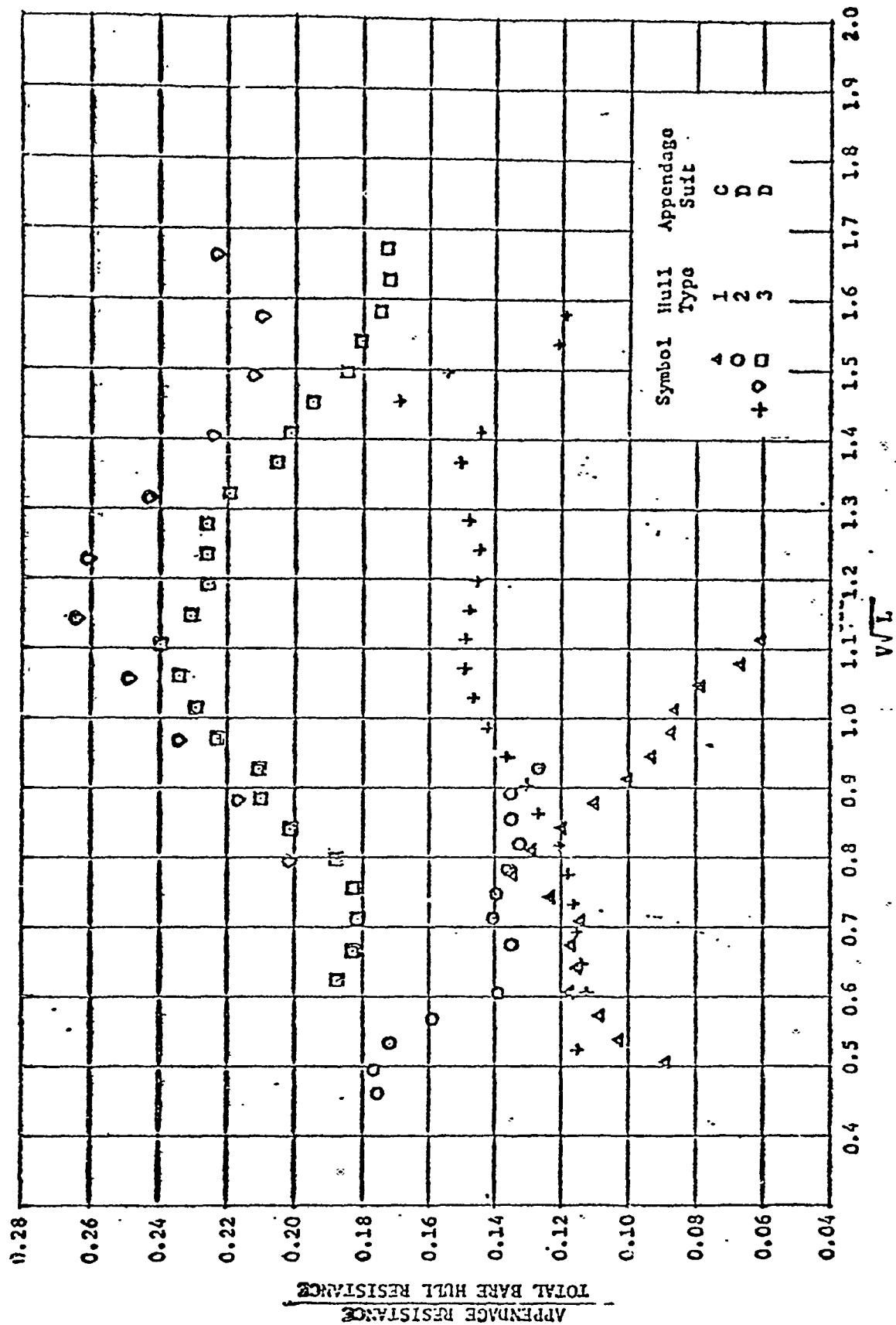


Figure 4a - Comparison of Values of Appendage Drag as a Percentage of Bare Hull Drag
Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

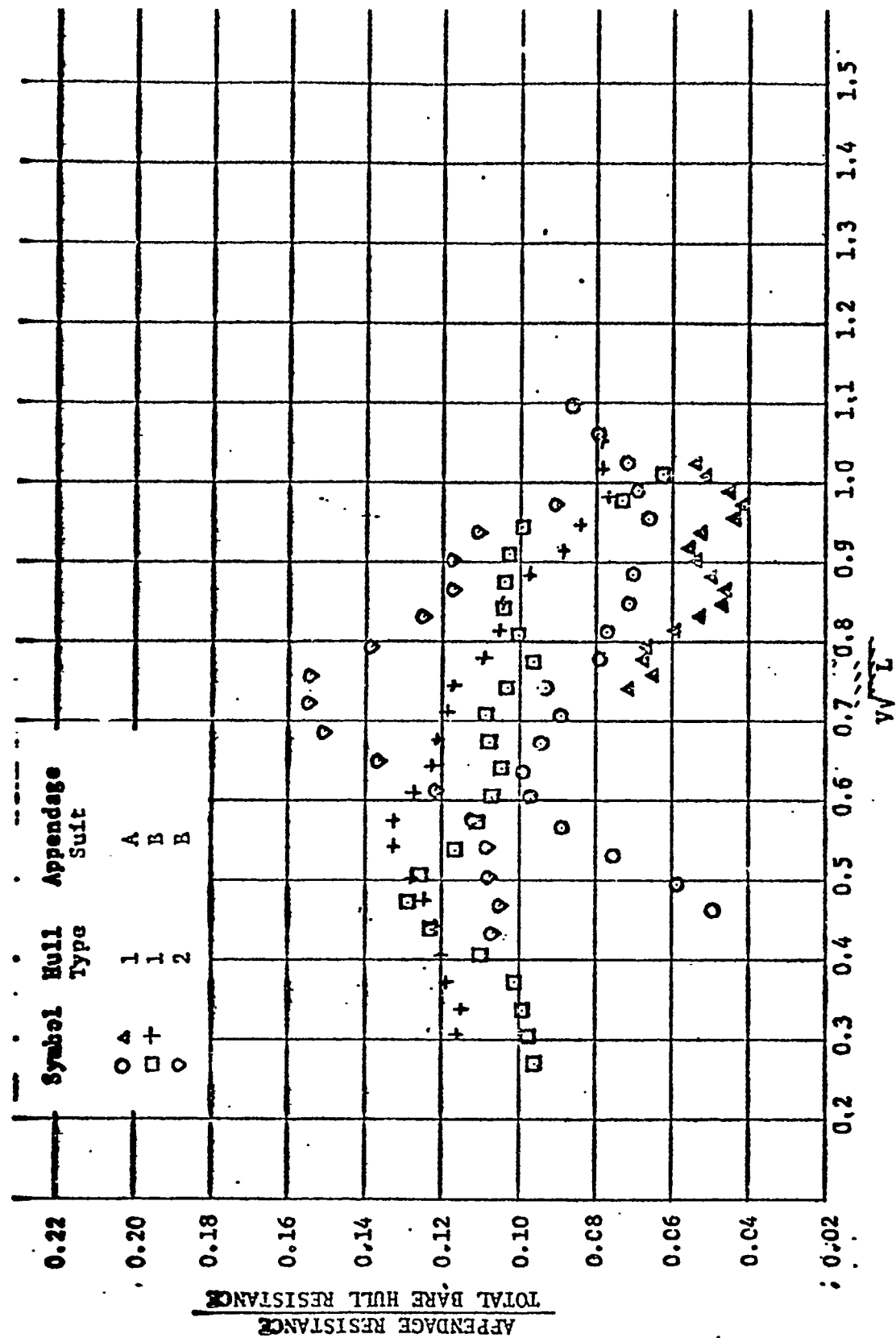


Figure 4b - Comparison of Values of Appendage Drag as a Percentage of Bare Hull Drag
Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

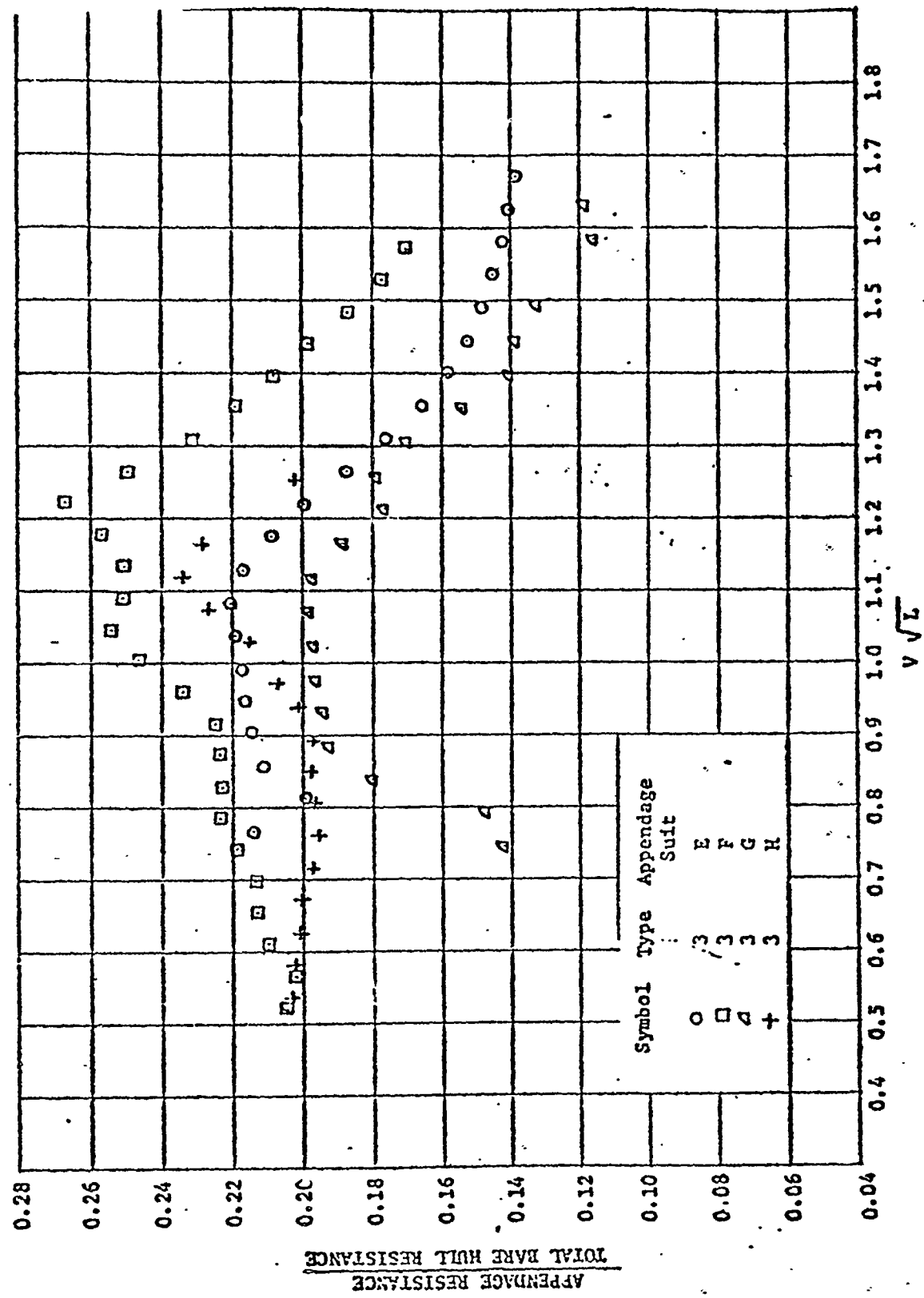


Figure 4c - Comparison of Values of Appendage Drag as a Percentage of Bare Hull Drag
Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

APPENDIX I - LISTING OF COMPUTER PROGRAM

APPEND is a Fortran computer program which may be used to calculate the Reynolds number dependent resistance of the appendages previously mentioned in this text. The program, which has been written for the Center's CDC 6700 computer, will calculate appendage drag for any size appendage, i.e., model-scale or full-scale. APPEND consists of the following subroutines: RUDDER, STRUT, FIN, SHAFT, BOSS, MAIN, BILGE, SKEG, and FRICT, and the function PRESUR. In general, the first eight subroutines are used to calculate the various viscous drag components of the appendage indicated by the title. Subroutine FRICT is used to calculate the friction coefficient (C_f), based on a Reynolds number of transition of 5×10^4 . Function PRESUR is used to calculate the basic pressure coefficient described in equation(11).


```

C C CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF STRUT DRAG
C 315 IF (NSTRUT) 320, 345, 320
C 320 CALL STRUT
C C CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF STABILIZERS FIN DRAG
C 345 IF (NFIN) 350, 375, 350
C 350 CALL FIN
C C CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF SHAFTING DRAG
C 375 IF (NSHAFT) 380, 405, 380
C 380 CALL SHAFT
C C CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF STRUCTURE ROSSINGS
C AND INTERMEDIATE STRUT HARPELS
C 405 IF (NROSS) 410, 435, 410
C 410 CALL ROSS
C C CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF MAIN STRUT HARPEL
C DRAG- THE MAIN STRUT HARPEL INCLUDES THE DUMMY HUB (PROPELLED HUB
C WITHOUT HARPELS) AND THE FAIRWATER.
C 435 IF (NMAIN) 440, 465, 440
C 440 CALL MAIN
C C CALCULATION OF RIGGE KEEL DRAG
C 465 IF (NRIGGE) 470, 495, 470
C 470 CALL RIGGE
C C CALCULATION OF SKEG DRAG
C 495 IF (NSKEG) 500, 525, 500
C 500 CALL SKEG
C 525 DO 530 I=1, 1SPOT
C DAPP(I)=DPRUD(I)*DSTRUT(I)*OFFIN(I)*DROSS(I)*DMAIN(I)*DRIL
C 10F(I)*DSKEG(I)
C DROSS(I)=DROSS(I)*DSTRUTS(I)*OFFINS(I)*DSHAFTS(I)*DROSSS(I)*DMAINS(I)
C 11)*DRIGGES(I)*DSKEGS(I)
C CVISAPP(I)=D.DP(I)/((RHO/2.)*VF(I)*SM)
C CVISAPS(I)=DAPP(I)/((RHO/2.)*VSF(I)*SMS)
C 530 CONTINUE
C PRINT 540
C 540 FORMAT(P7M) CALCULATED REYNOLDS DEPENDENT RESISTANCE COMPONENTS FO
C IN SHIP SCALE APPENDAGES-IN LRS//
C PRINT 545
C 545 FORMAT(11M) THE APPENDAGE DRAG COEFFICIENT=REYNOLDS DRAG
C 1APP(I)/((DENSITY/2.)*(VEL.)*(APPENDAGE WETTED SURFACE))/
C PRINT 550
C 550 FORMAT(10M) VM-KNOTS, 4X, 6M VRL, 5X, 7M RUDDER, 3X, 6M STRUT, 5X, 6M
C IFIN, 5X, 6M SHAFT, 4X, 5M ROSS, 5X, 5M MAIN, 5X, 6M RIGGE, 4X, 5M SKEG, 5X, 6M

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2 TOTAL, 4X, 12M COEFFICIENT//
C DO 570 I=1, 1SPOT
C PRINT 580, VM(I), VRL(I), DRUD(I), DSTRUT(I), OFFIN(I), DROSS(I), DROSSS(I)
C 1)*DMAIN(I), DRIGGE(I), DSKEG(I), DAPP(I), CVISAPP(I)
C 560 FORMAT(1M) 11F10.3, 1P1E15.4)
C 570 CONTINUE
C 580 FORMAT(10M) CALCULATED REYNOLDS DEPENDENT RESISTANCE COMPONENTS FO
C IN SHIP SCALE APPENDAGES-IN LRS//
C PRINT 585
C PRINT 555
C DO 600 I=1, 1SPOT
C PRINT 590, VS(I), VRL(I), DRUDS(I), DSTRUTS(I), OFFINS(I), DSHAFTS(I), DROSS
C 155S(I), DMAINS(I), DRIGGES(I), DSKEGS(I), DAPPS(I), CVISAPS(I)
C 590 FORMAT(1M) 2F7.3, 1P10E12.4)
C 600 CONTINUE
C 595 FORMAT(10M) VM-KNOTS, 5M VRL, 3X, 7M RUDDER, 5X, 6M STRUT, 6X, 4M FIN,
C 1X, 6M SHAFT, 6X, 5M ROSS, 7X, 5M MAIN, 7X, 6M RIGGE, 6X, 5M SKEG, 7X, 6M TOY
C 2AL, 5X, 12M COEFFICIENT//
C DO 610 I=1, 1SPOT
C DAPP(I)=DPRUD(I)*DSTRUT(I)*OFFIN(I)*DROSS(I)*DMAIN(I)*DRIL
C 11)*DSKEG(I)
C DROSS(I)=DROSS(I)*DSTRUTS(I)*OFFINS(I)*DSHAFTS(I)*DROSSS(I)*DMAINS(I)
C 12)*DRIGGES(I)*DSKEGS(I)
C CVISAPP(I)=D.DP(I)/((RHO/2.)*VF(I)*SM)
C CVISAPS(I)=D.DP(I)/((RHO/2.)*VSF(I)*SMS)
C 610 CONTINUE
C PRINT 620
C 620 FORMAT(120M) CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENT
C IFOR MODEL SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-IN LRS//
C PRINT 630
C 630 FORMAT(119M) THE APPENDAGE FLAT PLATE FRICTION COEFFICIENT=FDICT, D
C 1RAG(APP)/((DENSITY/2.)*(VEL.)*(VEL.)*(APPENDAGE WETTED SURFACE))//
C 2)
C PRINT 550
C DO 650 I=1, 1SPOT
C PRINT 560, VM(I), VRL(I), DRUD(I), DSTRUT(I), OFFIN(I), DSHAFTS(I), DROSS
C 105S(I), DMAIN(I), DRIGGE(I), DSKEG(I), DAPP(I), CVISAPP(I)
C 650 CONTINUE
C PRINT 660
C 660 FORMAT(118M) CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENT
C IFOR SHIP SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-IN LRS//
C PRINT 670
C PRINT 555
C DO 680 I=1, 1SPOT
C PRINT 590, VS(I), VRL(I), DRUD(I), DSTRUTS(I), OFFINS(I), DSHAFTS(I), DROSS
C 155S(I), DMAINS(I), DRIGGES(I), DSKEG(I), DAPPS(I), CVISAPS(I)
C 685 CONTINUE
C GO TO 680
C 670 PRINT 675
C 675 FORMAT(10M) 27X, NUMBER OF SPOTS GREATER THAN 25. REDUCE NUMBER OF
C 1SPOTS AND RUNS//
C 680 CONTINUE
C STOP
C END

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SUBROUTINE FIN
COMMON /SPNT,VFL(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
COMMON /TFIN,TFIN(4),TFIN(4),CFIN(4),DFIN(25),OFFIN(25)
DO 3100 J=1,NFIN
PRINT 3100,J
3100 FORMAT(4I1) MODEL AND SHIP SCALE RESISTANCE FOR FIN *12/
PRINT 3110
3110 FORMAT(1D5,7A,4M VRL,9A,9M REYNOLDS,6A,11M FLAT PLATE,4A,8M VFL AU
1G,7A,4M PRESSURE,6A,10M INTERSECT,4A,15M BASE,10A,6H TOTAL//)
DO 3140 I=1,ISPT
3140 CONTINUE
END

CALCULATION OF THICKNESS-CHORD RATIOS AND FULL-SCALE PARAMETERS
TOR=TFIN(1)/CFIN(1)
TOR2=TOR*TOR
TOR4=TOR*TOR*TOR*TOR
CFIN=CFIN(1)*XLAM
TFIN2=TFIN(1)*TFIN(1)
TFIN2=TFIN2*XLAM*XLAM
SFINS=SFIN(1)*XLAM*XLAM
IF (TFIN(1).LE.0.) GO TO 3105
CLOT8=CFIN(1)/TFIN(1)
SFINS=SFIN(1)*XLAM*XLAM
3105 CONTINUE

FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
CALL FRIC(CFIN,REY,VFW(1),CFIN(1),XNU)
CALL FRIC(CFIN,REY,VSFW(1),CFIN(1),XNU)

CONSTANTS TO CONVERT DRAG COEFFICIENTS TO RESISTANCE IN POUNDS
X=MODEL CONSTANT
XS=SHIP CONSTANT

X=5*RMW*SFIN(1)*VFW(1)*VFW(1)
XS=5*RMW*SFINS*VSFW(1)*VSFW(1)

CALCULATION OF DRAG COMPONENTS FOR A SYMMETRICAL FOIL SECTION
CALL FOILSEC(X,XS,CFIN,CFSFIN,TOC,TOC2,TOC4,TFIN(1),
1SFINS,TFIN2,TFINS2,SFIN(1),SFINS,CLOT8,RF,RFS,RFVA,RFVAS,RP,RPS,
2RINT,RINTS,RS,RRS)

TOTAL OF COMPONENT DRAGS
D=RF+RFVA+RP+RINT+RR
DS=RFS+RFVAS+RPS+RRS

SUMMATION OF REYNOLDS INDEPENDENT RESISTANCES TO OBTAIN TOTAL AMOUNT
FOR ALL STRUTS COMBINED PRINTED OUT FROM MAIN PROGRAM
OFFIN(1)=DFIN(1)*D
OFFIN(1)=OFFIN(1)*DS
OFFIN(1)=OFFIN(1)*RF

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OFFIN(1)=OFFIN(1)*RPS
PRINT OUT OF RESISTANCE INFORMATION FOR MODEL AND SHIP OF EACH
FIN WITH ITS REYNOLDS INDEPENDENT RESISTANCE COMPONENTS
PRINT 3120,VFL(1),REY,RF,RFVA,RP,RINT,RO,D
FORMAT(1P,BE15.3,6M MODEL)
PRINT 3130,VFL(1),REYS,RFS,RFVAS,RPS,RINTS,RRS,DS
FORMAT(1P,BE15.3,5M SHIP/)
3120 CONTINUE
3130 CONTINUE
3140 RETURN
END

```



```

SUBROUTINE ROSS
COMMON /POT/VFW(25),VSW(25),VRL(25),RHO,XNU,RHOS,XM,XLAM
COMMON /MS/MSROSS,XLROSS(A),PBROSS(10),ABROSS(8),DBROSS(25),DBROSS(25),M
DO 5140 J=1,NBROSS
PRINT 5100,J
5100 FORMAT(4SH) MODEL AND SHIP SCALE RESISTANCE FOR BOSSING *12/
5110 PRINT 5110
5110 FORMAT(1H0,7X,4H VRL*9X,9H REYNOLDS*6X,9H FRICTION*6X,9H PRESSURE*
16X,6M TOTAL//)
DO 5140 I=1,15POT
CALCULATION OF RATIOS,CONSTANTS AND FULL-SCALE DIMENSIONS
HAB=ABROSS(I)*0.017453
HANSIN=5IN(RAD)
RAD3=RAD3IN*RAD3IN*RAD3IN
XLSROSS=XLROSS(I)*XLAM
RROSS=RBROSS(I)*XLAM
MSROSS=MRROSS(I)*XLAM
FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
CALL FRIC(CFROSS,REV,VFW(I),XLROSS(I),XNU)
CALL FRIC(CFSROSS,REYS,VSW(I),XLSROSS,XNUS)
CONSTANTS TO CONVERT DRAG COEFFICIENT TO RESISTANCE IN POUNDS
XM=MODEL CONSTANT
XS=SHIP CONSTANT
XM=5*RHOS*XLROSS(I)*RBROSS(I)*VFW(I)*VFW(I)
XS=5*RHOS*XLSROSS(I)*RROSS(I)*VSW(I)*VSW(I)
CALCULATION OF THE BASIC PRESSURE DRAG COEFFICIENT
CORASH=PRESSUR(RHO,VFW(I),RBROSS(I),RBROSS(I),XNU)
CORASS=PRESSUR(RHOS,VSW(I),RROSS(I),RROSS(I),XNUS)
CALCULATION OF PRESSURE DRAG CORRECTED FOR CROSSFLOW
RPPRES=XM*CORASH*RAD3
RSPRES=XS*CORASS*RAD3
FRICTIONAL RESISTANCE
RF=XM*0.14159*CFROSS
RFS=XS*0.14159*CFSSROSS
TOTAL OF DRAG COMPONENTS
D=RPRES+RF
DS=RSPRES+RFS
SUMMATION OF REYNOLDS' DEPENDENT RESISTANCE TO OBTAIN TOTAL AMOUNT
FOR ALL STIFFTURE ROSSINGS AND INTERMEDIATE STRUT BARRELS COMBINED

```

CC C

CC C

CCCCC

CCC

CCC

CCC

CCC

CCC

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SURROUTINE MAIN
COMMON /SPOT,VFW(25),VSL(25),VRL(25),VH0,XMU,RH0,XML,XLAM
COMMON /R0,RHAIN,XLAM(4),RHAIN(4),RHAIN(4),RHAIN(4),RHAIN(25),DM
/AIN(25),RHAIN(4),DM(25),DFSHAIN(25),DFSHAIN(25)
DO 6140 J=1,NHAIN
PRINT A100,J
6100 FORMAT(6M) MODEL AND SHIP SCALE RESISTANCE FOR MAINROSS (2/)
PRINT A110
6110 FORMAT(1M0.7X.6M VRL,2X.9M REYNOLDS,6X.9M FRICTION,6X.9M PRESSURE,
16X.5M BASE,10X.6M TOTAL/)
DO 6140 I=1,ISPT
CALCULATION OF RATIOS,CONSTANTS AND FULL-SCALE DIMENSIONS
RAD=RHAIN(J)*0.0174533
RADSI=SI/180
RADSI=SI/180
XLSHAIN=XLAM(J)/XLAM
RSHAIN=RHAIN(J)/RHAIN
RBSHAIN=RHAIN(J)/RHAIN
FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
CALL FRICPLATEMAIN(REF,VFW(I),XLSHAIN(J),XNU)
CALL FRICPLATEMAIN(REF,VFW(I),XLSHAIN(XNU))
CONSTANTS TO CONVERT DRAG COEFFICIENT TO RESISTANCE IN POUNDS
XH=MODEL CONSTANT
XS=SHIP CONSTANT
XW=5.0E-04XLSHAIN(J)*VFW(I)*VFW(I)
XS=5.0E-04XLSHAIN(XNU)*VFW(I)*VFW(I)
CALCULATION OF THE BASIC PRESURE DRAG COEFFICIENT
CDRASH=PRESUR(RH0,VFW(I),RHAIN(J),XNU)
CDRASS=PRESUR(RH0,VFW(I),RSHAIN,XNU)
CALCULATION OF PRESSURE DRAG CORRECTED FOR CROSSFLOW
WPFES=X*CDRASH/RAD3
RSPRES=XS*CDRASS/RAD3
FRICTIONAL RESISTANCE
RF=XW*3.14159*CFMAIN
RFS=XS*3.14159*CFSHAIN
BASE DRAG DUE TO BLUNTNESS OF FAIRWATER TRAILING TIP
R9=(3.14159/4.0)*(XH*RHAIN(J)/XLSHAIN(J)+0.020*((RHAIN(J)/RHAIN(J)
8)*0.1)/12.0*CDRASH/XLSHAIN(J)/RHAIN(J)
R9S=(3.14159/4.0)*(XS*RSHAIN/RSHAIN)+0.020*((RSHAIN/RSHAIN)+0.3)/1
12.0*CDRASH/XLSHAIN/RSHAIN)

```

```

TOTAL OF DRAG COMPONENTS
D=RPRES+RF+R8
US=USPRES+RFS+R8S
SUMMATION OF REYNOLDS DEPENDENT RESISTANCE TO OBTAIN TOTAL AMOUNT
FOR ALL MAIN STOUT RARPLS COMBINED-PRINT OUT FROM MAIN PROGRAM
UMAIN(1)=DM(1)*D
DMAINS(1)=DMAINS(1)+D
DFMAIN(1)=DFMAIN(1)+R8
DFSHAIN(1)=DFSHAIN(1)+RFS
PRINT OUT OF RESISTANCE INFORMATION FOR MODEL AND SHIP OF EACH
MAIN STOUT BARREL WITH ITS REYNOLDS DEPENDENT RESISTANCE COMPONENTS
PRINT A120,VRL(1),REF,R8,R8S
6120 FORMAT(1P6E15.3,6M MODEL)
PRINT A130,VRL(1),REF,RFS,R8S,R8S
6130 FORMAT(1P6E15.3,5M SHIP/)
6140 CONTINUE
RETURN
END

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```

SUBROUTINE BILGE
COMMON /SPNT/VFV(25),VSPW(25),VRL(25),RHO,XMU,RMOS,XMUS,XLAM
COMMON/MP7/MPILGE,XLRILGE(4),SRILGE(4),DRILGE(25),DRILGES(25),DFRIL
IGE(25),CFSSRILG(25)
DO 7140 J=1,NBILGE
PRINT 7100,J
7100 FORMAT(4H1 MOFL AND SHIP SCALE RESISTANCE FOR BILGE KFEL .12/)
PRINT 7110
DO 7140 I=1,ISPT
XLSHILG=XLRILGE(I)*XLAM
CALL FRIC(CFSSRILGE,REY,VFW(I),XLRILGE(I),XMU)
CALL FRIC(CFSSRILGE,REY,VSPW(I),XLSHILG,XMUS)
DS=.5*RHO*SRILGE(I)*VFW(I)*VFW(I)*CFRILGE
DS=.5*PMOS*SRILGE(I)*XLAM*XLAM*VSPW(I)*VSPW(I)*CFSHILG
DRILGE(I)=DRILGE(I)+D
DRILGES(I)=DRILGES(I)+DS
DFRILGE(I)=DFRILGE(I)+D
DFSHILG(I)=DFSHILG(I)+DS
PRINT 7120,VRL(I),REY,D
7120 FORMAT(1P3E15.3,6H MODEL)
PRINT 7130,VRL(I),REY,DS
7130 FORMAT(1P3E15.3,5H SHIP/)
7140 CONTINUE
RETURN
END

```

```

SUBROUTINE SKEG
COMMON /SPNT/VFV(25),VSPW(25),VRL(25),RHO,XMU,RMOS,XMUS,XLAM
COMMON/MSKEG,XLSKEG(4),SSKEG(4),DSKEG(25),OSKEG(25),DFSSKEG(25)
DO 8140 J=1,MSKEG
PRINT 8100,J
8100 FORMAT(4H1 MODEL AND SHIP SCALE RESISTANCE FOR SKEG .12/)
PRINT 8110
DO 8140 I=1,ISPT
XLSKEG=XLSKEG(I)*XLAM
CALL FRIC(CFSSKEG,PEY,VFW(I),XLSKEG(I),XMU)
CALL FRIC(CFSSKEG,REY,VSPW(I),XLSKEG,XMUS)
DS=.5*RHO*SSKEG(I)*VFW(I)*VFW(I)*CFSKEG
DS=.5*PMOS*SSKEG(I)*XLAM*XLAM*VSPW(I)*VSPW(I)*CFSKEG
OSKEG(I)=OSKEG(I)+D
DSKEGS(I)=DSKEGS(I)+DS
DFSSKEG(I)=DFSSKEG(I)+D
PRINT 8120,VRL(I),REY,D
8120 FORMAT(1P3E15.3,6H MODEL)
PRINT 8130,VRL(I),REY,DS
8130 FORMAT(1P3E15.3,5H SHIP/)
8140 CONTINUE
RETURN
END

```

SUBROUTINE FOILSECIM,XS,CF,CFS,TOC,T0C2,T0C4,S,SS,TZ,TZ2,QR,SR,C
BLTR,RF,RFS,RFA,NFVAS,RP,RPS,RINT,RINTS,RD,RRS)

FLAT PLATE FRICTION RESISTANCE

RF=XN*2.*CF
RFS=XS*2.*CFS

RESISTANCE DUE TO VELOCITY AUGMENTATION

RFA=XN*4.*CF*TOC
RFVAS=XS*4.*CFS*TOC

RESISTANCE DUE TO PRESSURE OR SEPARATION (VISCIOUS IN NATURE)

RPAXN=120.*CF*TOC4
RPS=XS*120.*CFS*TOC4

ADDED RESISTANCE DUE TO INTERSECTION WITH HULL

RINT=(XN/5)*T2*((1.75*TOC)-(1.0003/TOC2))
RINTS=(XS/5)*TS2*((1.75*TOC)-(1.0003/TOC2))

BASE DRAG DUE TO BLUNTNESS OF TRAILING EDGE

IF (SR.LF.0.) GO TO 9000
RR=(XN/5)*SH*((1.35/((CLOTB*CF)*((1./3.)))
RRS=(XS/5)*SBS*((1.35/((CLOTB*CFS)*((1./3.)))

9000 RB=0.
RBS=0.
RETURN
END

SUBROUTINE FRICTICF,RE,VF,XLEN,XNU)
RE=VF*XLEN*100000./XNU
IF (RE.LT.50000.) GO TO 30
CFTURN=.075/ALOG10(RE/100.)**2
Y=CFTURN
10 CFTURN=.058564/ALOG10(RE*Y)**2
IF (ANS(CFTURN*Y).LE.1.0E-07) GO TO 20
Y=CFTURN*Y/2.
GO TO 10
20 CF=CFTURN*(143.18/RE)
RETURN
30 CF=1.32R/SQRT(RE)
RETURN
END

FUNCTION PRFSUR(RO,V,DTA,M,XN)
RN=V*DTA*100000./XN
SIGMA=(P083+.32.2*RO*H)/(1.5*RO*V*V)
SIGMA2=SIGMA*SIGMA
SIGMA3=SIGMA*SIGMA2
SIGMA4=SIGMA*SIGMA3
SIGMA5=SIGMA*SIGMA4
10 IF (RN-50000.) 10,20,20
IF (RN-2.5) 30,40,40
20 PRFSUR=500425+.498891*SIGMA-.051852*SIGMA2+.0461504*SIGMA3-.06115
30 SIGMA4=.0144903*SIGMA5
GO TO 100
40 PRFSUR=1.17
GO TO 100
50 IF (SIGMA.GT.2.1-AND.SIGMA.LT.2.5) GO TO 50
IF (SIGMA.GE.2.5) GO TO 60
IF (SIGMA.LE.2.1) GO TO 70
50 PRFSUR=4.125-2.25*SIGMA
GO TO 100
60 PRFSUR=0.5
GO TO 100
70 PRFSUR=500089+.499596*SIGMA-.0385078*SIGMA2+.00486754*SIGMA3
100 CONTINUE
RETURN
END

APPENDIX II - INPUT FORMAT FOR COMPUTER PROGRAM APPEND

CARD	ENTRY	FORMAT	FIELD	REMARKS
1	NCASE	I5	1-5	Number of cases to be calculated
2	TITLE	I3A5	1-65	Used to identify the case
3	ISPOT	I5	1-5	Number of speeds to be calculated
	SM	F10.5	6-15	Wetted surface of appendages, ft ²
	RHO	F10.5	16-25	Model water density, slugs/ft ³
	XNU	F10.5	26-35	Model water kinematic viscosity x 10 ⁵ , ft ² /sec
	RHOS	F10.5	36-45	Ship water density, slugs/ft ³
	XNUS	F10.5	46-55	Ship water kinematic viscosity x 10 ⁵ , ft ² /sec
	XLAM	F10.5	56-65	Ship-model linear ratio
	XLSHIP	F10.5	66-75	Ship length, ft
4	NRUD	I5	1-5	Number of rudders - 0 to 4
	NSTRUT	I5	6-10	Number of struts - 0-16
	NSHAFT	I5	11-15	Number of shafts - 0 to 8
	NBOSS	I5	16-20	Number of sterntube bossings and intermediate strut barrels - 0 to 8
	NMAIN	I5	21-25	Number of main strut barrels - 0 to 4
	NBILGE	I5	26-30	Number of bilge keels - 0 to 4
	NSKEG	I5	31-35	Number of skegs - 0 to 4
	NFIN	I5	36-40	Number of stabilizer fins - 0 to 4

THE NEXT
ISPOT CARDS

VS	F10.5	1-10	Ship speed in knots
1-WT	F10.F	11-20	Wake fraction
.	.	.	.
.	.	.	.
.	.	.	.

THE NEXT
NRUD CARDS

SRUD	F10.5	1-10	Rudder planform area for one side, ft ²
TRUD	F10.5	11-20	Rudder maximum thickness, ft

INPUT FORMAT FOR APPEND (CON'T)

CARD	ENTRY	FORMAT	FIELD	REMARKS
	CRUD	F10.5	21-30	Rudder maximum chord, ft
	TBRUD	F10.5	31-40	Thickness of trailing edge of rudder, ft
	SBRUE	F10.5	41-50	Projected area of blunt edge of rudder, ft ²
	.	.	.	.
	.	.	.	.
	.	.	.	.

THE NEXT

NSTRUT CARDS	SSTRUT	F10.5	1-10	Strut planform area for one side, ft ²
	TSTRUT	F10.5	11-20	Strut maximum thickness, ft
	CSTRUT	F10.5	21-30	Strut maximum chord, ft
	TBSTRUT	F10.5	31-40	Thickness of trailing edge of strut, ft
	SBSTRUT	F10.5	41-50	Projected area of blunt edge of strut, ft ²
	.	.	.	.
	.	.	.	.
	.	.	.	.

THE NEXT

NFIN CARDS	SFIN	F10.5	1-10	Fin planform area for one side, ft ²
	TFIN	F10.5	11-20	Fin maximum thickness, ft
	CFIN	F10.5	21-30	Fin maximum chord, ft
	TBFIN	F10.5	31-40	Thickness of trailing edge of fin, ft
	SBFIN	F10.5	41-50	Projected area of blunt edge of strut, ft ²
	.	.	.	.
	.	.	.	.
	.	.	.	.

INPUT FORMAT FOR APPEND (CONT'D)

CARD	ENTRY	FORMAT	FIELD	REMARKS
THE NEXT NSHAFT CARDS	XLSHAFT	F10.5	1-10	Shaft length, ft
	RSHAFT	F10.5	11-20	Shaft diameter, ft
	ASHAFT	F10.5	21-30	Angle of flow, degrees
	HSHAFT	F10.5	31-40	Depth below waterline to shaft, ft
	.	.	.	
	.	.	.	
	.	.	.	
THE NEXT NBOSS CARDS	XLBOSS	F10.5	1-10	Bossing and/or intermediate strut barrel length, ft
	RBOSS	F10.5	11-20	Bossing and/or intermediate strut barrel diameter
	ABOSS	F10.5	21-30	Angle of flow, degrees
	HBOSS	F10.5	31-40	Depth below waterline to bossing and/ or intermediate strut barrel, ft
	.	.	.	
	.	.	.	
	.	.	.	
THE NEXT NMAIN CARDS	XLMAIN	F10.5	1-10	Main strut barrel length, ft
	RMAIN	F10.5	11-20	Main strut barrel diameter, ft
	AMAIN	F10.5	21-30	Angle of flow, degrees
	HMAIN	F10.5	31-40	Depth below water to main strut barrel, ft
	RBMAIN	F10.5	41-50	Diameter of fairwater ending, ft.

INPUT FORMAT FOR APPEND (CONT'D)

CARD	ENTRY	FORMAT	FIELD	REMARKS
THE NEXT				
NBILGE CARDS	LBILGE	F10.5	1-10	Bilge keel length, ft
	SBILGE	F10.5	11-20	Bilge keel wetted surface ft ² (as described in text)
	.	.	.	
	.	.	.	
	.	.	.	
THE NEXT				
NSKEG CARDS	LSKEG	F10.5	1-10	Skeg length, ft
	SSKEG	F10.5	11-20	Skeg wetted surface, ft ² (as described in text)
	.	.	.	
	.	.	.	
	.	.	.	

START THE NEXT CASE BEGINNING WITH CARD #2

APPENDIX III - OUTPUT

The output formats of "Append" have been written so as to give the user detailed information about the drag of his appendages. First, the drag components of each individual appendage are printed out, this includes the speed-length ratio based on the length of the hull and the local Reynolds number. Next, the total calculated frictional resistance components are printed and finally the total calculated viscous resistance is printed. The program will output the above information for both the model and the full-scale appendages.

MODEL AND SHIP SCALE RESISTANCE FOR RUDDER 1

VFL	REYNOLDS	FLAT PLATE	VEL AUG	PRESSURE	INTERSECT	BASE	TOTAL
5.237E-01	1.656E+05	3.877E-02	1.513E-02	3.369E-03	1.517E-02	0.	7.243E-02 MODEL
5.237E-01	1.646E+07	2.908E-02	1.135E-02	2.527E-01	2.331E-02	0.	6.628E-02 SHIP
5.674E-01	1.796E+05	4.520E-02	1.764E-02	3.928E-03	1.784E-02	0.	8.461E-02 MODEL
5.674E-01	1.785E+07	3.377E-02	1.318E-02	2.935E-01	2.743E-02	0.	7.732E-02 SHIP
6.110E-01	1.936E+05	5.209E-02	2.032E-02	4.527E-03	2.074E-02	0.	9.768E-02 MODEL
6.110E-01	1.924E+07	3.880E-02	1.514E-02	3.372E-01	3.184E-02	0.	8.919E-02 SHIP
6.547E-01	2.083E+05	5.977E-02	2.332E-02	5.194E-03	2.400E-02	0.	1.123E-01 MODEL
6.547E-01	2.070E+07	4.440E-02	1.732E-02	3.858E-01	3.689E-02	0.	1.025E-01 SHIP
6.983E-01	2.222E+05	6.748E-02	2.633E-02	5.864E-03	2.730E-02	0.	1.270E-01 MODEL
6.983E-01	2.208E+07	5.002E-02	1.952E-02	4.347E-01	4.197E-02	0.	1.159E-01 SHIP
7.419E-01	2.356E+05	7.531E-02	2.938E-02	6.545E-03	3.070E-02	0.	1.419E-01 MODEL
7.419E-01	2.341E+07	5.374E-02	2.175E-02	4.844E-01	4.720E-02	0.	1.295E-01 SHIP
7.856E-01	2.497E+05	8.397E-02	3.274E-02	7.297E-03	3.449E-02	0.	1.585E-01 MODEL
7.856E-01	2.481E+07	6.207E-02	2.422E-02	5.394E-01	5.302E-02	0.	1.447E-01 SHIP
8.292E-01	2.636E+05	9.290E-02	3.625E-02	8.073E-03	3.843E-02	0.	1.756E-01 MODEL
8.292E-01	2.619E+07	6.860E-02	2.674E-02	5.961E-01	5.907E-02	0.	1.604E-01 SHIP
8.729E-01	2.775E+05	1.022E-01	3.989E-02	8.804E-03	4.254E-02	0.	1.916E-01 MODEL
8.729E-01	2.757E+07	7.542E-02	2.943E-02	6.554E-01	6.545E-02	0.	1.769E-01 SHIP
9.165E-01	2.913E+05	1.120E-01	4.388E-02	9.725E-03	4.694E-02	0.	2.123E-01 MODEL
9.165E-01	2.895E+07	8.255E-02	3.221E-02	7.173E-01	7.216E-02	0.	1.941E-01 SHIP
9.602E-01	3.052E+05	1.221E-01	4.761E-02	1.061E-02	5.152E-02	0.	2.318E-01 MODEL
9.602E-01	3.032E+07	8.997E-02	3.510E-02	7.814E-01	7.920E-02	0.	2.121E-01 SHIP
1.004E+00	3.191E+05	1.326E-01	5.174E-02	1.152E-02	5.631E-02	0.	2.522E-01 MODEL
1.004E+00	3.170E+07	9.768E-02	3.811E-02	8.484E-01	8.654E-02	0.	2.308E-01 SHIP
1.047E+00	3.310E+05	1.435E-01	5.600E-02	1.247E-02	6.131E-02	0.	2.733E-01 MODEL
1.047E+00	3.308E+07	1.057E-01	4.123E-02	9.184E-01	9.424E-02	0.	2.504E-01 SHIP
1.091E+00	3.468E+05	1.548E-01	6.040E-02	1.345E-02	6.653E-02	0.	2.952E-01 MODEL
1.091E+00	3.446E+07	1.140E-01	4.447E-02	9.905E-01	1.023E-01	0.	2.706E-01 SHIP
1.135E+00	3.607E+05	1.665E-01	6.436E-02	1.447E-02	7.195E-02	0.	3.179E-01 MODEL
1.135E+00	3.584E+07	1.226E-01	4.782E-02	1.065E-02	1.106E-01	0.	2.917E-01 SHIP
1.178E+00	3.734E+05	1.776E-01	6.928E-02	1.543E-02	7.717E-02	0.	3.394E-01 MODEL
1.178E+00	3.710E+07	1.307E-01	5.110E-02	1.136E-02	1.184E-01	0.	3.116E-01 SHIP
1.222E+00	3.884E+05	1.916E-01	7.432E-02	1.660E-02	8.344E-02	0.	3.656E-01 MODEL
1.222E+00	3.859E+07	1.406E-01	5.486E-02	1.222E-02	1.243E-01	0.	3.360E-01 SHIP
1.266E+00	4.039E+05	2.052E-01	8.011E-02	1.784E-02	9.024E-02	0.	3.935E-01 MODEL
1.266E+00	4.013E+07	1.512E-01	5.894E-02	1.314E-02	1.387E-01	0.	3.620E-01 SHIP
1.309E+00	4.187E+05	2.194E-01	8.561E-02	1.907E-02	9.694E-02	0.	4.211E-01 MODEL
1.309E+00	4.160E+07	1.616E-01	6.304E-02	1.404E-02	1.691E-01	0.	3.877E-01 SHIP

SHIP AND MODEL SCALE RESISTANCE FOR STRUT 1

VRL	REYNOLDS	FLAT PLATE	VEL AUG	PRESSURE	INTERFECT	RASE	TOTAL
5.237E-01	4.228E+04	4.932E-03	9.429E-04	2.471E-05	1.313E-04	0.	6.033E-03 MODFL
5.237E-01	4.201E+06	3.944E-01	7.541E+00	1.974E-01	2.050E+00	0.	6.023E+01 SHIP
5.674E-01	4.585E+04	5.569E-03	1.065E-03	2.71E-05	1.568E-04	0.	6.819E-03 MODFL
5.674E-01	4.556E+06	4.577E+01	8.751E+00	2.293E-01	2.411E+00	0.	5.716E+01 SHIP
6.110E-01	4.943E+04	6.234E-03	1.192E-03	3.124E-05	1.872E-04	0.	7.639E-03 MODFL
6.110E-01	4.911E+06	5.254E-01	1.004E-01	2.633E-01	2.801E+00	0.	6.565E+01 SHIP
6.547E-01	5.317E+04	6.838E-03	1.307E-03	3.424E-05	2.104E-04	0.	8.390E-03 MODFL
6.547E-01	5.283E+06	6.008E-01	1.149E-01	3.010E-01	3.242E+00	0.	7.511E+01 SHIP
6.983E-01	5.672E+04	7.830E-03	1.497E-03	3.924E-05	2.399E-04	0.	9.606E-03 MODFL
6.983E-01	5.635E+06	6.764E-01	1.293E-01	3.389E-01	3.688E+00	0.	8.468E+01 SHIP
7.419E-01	6.014E+04	8.845E-03	1.691E-03	4.432E-05	2.698E-04	0.	1.085E-02 MODFL
7.419E-01	5.975E+06	7.533E-01	1.440E-01	3.775E-01	4.147E+00	0.	9.428E+01 SHIP
7.856E-01	6.374E+04	9.972E-03	1.906E-03	4.997E-05	3.031E-04	0.	1.223E-02 MODFL
7.856E-01	6.333E+06	8.383E-01	1.607E-01	4.201E-01	4.658E+00	0.	1.049E+02 SHIP
8.292E-01	6.729E+04	1.114E-02	2.129E-03	5.581E-05	3.377E-04	0.	1.366E-02 MODFL
8.292E-01	6.685E+06	9.259E-01	1.770E-01	4.640E-01	5.191E+00	0.	1.159E+02 SHIP
8.729E-01	7.043E+04	1.236E-02	2.363E-03	6.194E-05	3.741E-04	0.	1.516E-02 MODFL
8.729E-01	7.037E+06	1.017E-02	1.945E-01	5.098E-01	5.752E+00	0.	1.275E+02 SHIP
9.145E-01	7.437E+04	1.364E-02	2.608E-03	6.835E-05	4.125E-04	0.	1.673E-02 MODFL
9.145E-01	7.389E+06	1.113E-02	2.128E-01	5.577E-01	6.341E+00	0.	1.395E+02 SHIP
9.602E-01	7.791E+04	1.498E-02	2.844E-03	7.505E-05	4.527E-04	0.	1.837E-02 MODFL
9.602E-01	7.741E+06	1.212E-02	2.318E-01	6.075E-01	6.960E+00	0.	1.520E+02 SHIP
1.004E+00	8.145E+04	1.637E-02	3.130E-03	9.203E-05	4.948E-04	0.	2.008E-02 MODFL
1.004E+00	8.092E+06	1.316E-02	2.516E-01	6.593E-01	7.607E+00	0.	1.650E+02 SHIP
1.047E+00	8.499E+04	1.782E-02	3.404E-03	8.928E-05	5.388E-04	0.	2.185E-02 MODFL
1.047E+00	8.444E+06	1.423E-02	2.720E-01	7.130E-01	8.282E+00	0.	1.785E+02 SHIP
1.091E+00	8.853E+04	1.932E-02	3.693E-03	9.680E-05	5.046E-04	0.	2.769E-02 MODFL
1.091E+00	8.796E+06	1.534E-02	2.933E-01	7.686E-01	8.987E+00	0.	1.925E+02 SHIP
1.135E+00	9.207E+04	2.087E-02	3.991E-03	1.046E-04	6.323E-04	0.	2.560E-02 MODFL
1.135E+00	9.148E+06	1.649E-02	3.152E-01	8.261E-01	9.720E+00	0.	2.069E+02 SHIP
1.179E+00	9.533E+04	2.235E-02	4.273E-03	1.120E-04	6.778E-04	0.	2.741E-02 MODFL
1.179E+00	9.471E+06	1.758E-02	3.360E-01	8.807E-01	1.042E+01	0.	2.207E+02 SHIP
1.222E+00	9.916E+04	2.415E-02	4.617E-03	1.210E-04	7.331E-04	0.	2.962E-02 MODFL
1.222E+00	9.852E+06	1.890E-02	3.613E-01	9.449E-01	1.177E+01	0.	2.373E+02 SHIP
1.266E+00	1.031E+05	2.607E-02	4.984E-03	1.308E-04	7.930E-04	0.	3.197E-02 MODFL
1.266E+00	1.024E+07	2.031E+02	3.883E+01	1.014E+00	1.219E+01	0.	2.551E+02 SHIP
1.109E+00	1.069E+05	2.796E-02	5.345E-03	1.401E-04	8.520E-04	0.	3.429E-02 MODFL
1.109E+00	1.062E+07	2.170E+02	4.148E+01	1.087E+00	1.310E+01	0.	2.726E+02 SHIP

SHIP AND MODEL SCALE RESISTANCE FOR 1 IN 1

VRL	REYNOLDS	FLAT PLATE	VEL AUG	PRESSURE	INTERSECT	BASE	TOTAL
4.224E-01	2.008E+04	2.432E-03	8.110E-04	1.128E-04	2.620E-04	0.	3.618E-03 MODEL
4.226E-01	1.901E+06	1.425E-01	4.753E+00	6.607E-01	3.753E+00	0.	2.342E+01 SHIP
5.071E-01	2.410E+04	3.197E-03	1.066E-03	1.482E-04	3.773E-04	0.	4.789E-03 MODEL
5.071E-01	2.281E+06	1.991E-01	6.639E+00	9.229E-01	5.405E+00	0.	3.288E+01 SHIP
5.494E-01	2.611E+04	3.605E-03	1.203E-03	1.671E-04	4.428E-04	0.	5.417E-03 MODEL
5.494E-01	2.472E+06	2.306E-01	7.688E+00	1.069E+00	6.343E+00	0.	3.816E+01 SHIP
5.916E-01	2.812E+04	4.029E-03	1.343E-03	1.868E-04	5.135E-04	0.	6.373E-03 MODEL
5.916E-01	2.662E+06	2.641E-01	8.807E+00	1.224E+00	7.357E+00	0.	4.380E+01 SHIP
6.339E-01	3.013E+04	4.468E-03	1.490E-03	2.071E-04	5.895E-04	0.	6.755E-03 MODEL
6.339E-01	2.852E+06	2.997E-01	9.974E+00	1.389E+00	8.445E+00	0.	4.980E+01 SHIP
6.761E-01	3.213E+04	4.923E-03	1.641E-03	2.282E-04	6.707E-04	0.	7.483E-03 MODEL
6.761E-01	3.042E+06	3.374E-01	1.125E+01	1.564E+00	9.609E+00	0.	5.616E+01 SHIP
7.184E-01	3.414E+04	5.391E-03	1.798E-03	2.499E-04	7.571E-04	0.	8.196E-03 MODEL
7.184E-01	3.232E+06	3.771E-01	1.257E+01	1.748E+00	1.085E+01	0.	6.287E+01 SHIP
7.606E-01	3.615E+04	5.874E-03	1.959E-03	2.723E-04	8.488E-04	0.	8.954E-03 MODEL
7.606E-01	3.422E+06	4.187E-01	1.396E+01	1.941E+00	1.216E+01	0.	6.994E+01 SHIP
8.029E-01	3.816E+04	6.370E-03	2.124E-03	2.953E-04	9.458E-04	0.	9.735E-03 MODEL
8.029E-01	3.612E+06	4.624E-01	1.542E+01	2.144E+00	1.355E+01	0.	7.735E+01 SHIP
8.452E-01	4.017E+04	6.880E-03	2.794E-03	3.189E-04	1.048E-03	0.	1.054E-02 MODEL
8.452E-01	3.802E+06	5.080E-01	1.694E+01	2.355E+00	1.501E+01	0.	8.511E+01 SHIP
8.874E-01	4.218E+04	7.402E-03	2.468E-03	3.431E-04	1.155E-03	0.	1.137E-02 MODEL
8.874E-01	3.993E+06	5.556E-01	1.853E+01	2.576E+00	1.655E+01	0.	9.322E+01 SHIP
9.297E-01	4.413E+04	7.937E-03	2.647E-03	3.679E-04	1.268E-03	0.	1.222E-02 MODEL
9.297E-01	4.143E+06	6.051E-01	2.018E+01	2.805E+00	1.817E+01	0.	1.017E+02 SHIP
9.719E-01	4.619E+04	8.464E-03	2.829E-03	3.933E-04	1.304E-03	0.	1.394E-02 MODEL
9.719E-01	4.373E+06	6.564E-01	2.189E+01	3.044E+00	1.966E+01	0.	1.105E+02 SHIP
1.014E+00	4.820E+04	9.044E-03	3.015E-03	4.192E-04	1.509E-03	0.	1.399E-02 MODEL
1.014E+00	4.563E+06	7.099E-01	2.367E+01	3.291E+00	2.162E+01	0.	1.196E+02 SHIP
1.056E+00	5.021E+04	9.121E-03	3.041E-03	4.228E-04	1.637E-03	0.	1.422E-02 MODEL
1.056E+00	4.753E+06	7.652E-01	2.531E+01	3.547E+00	2.346E+01	0.	1.250E+02 SHIP
1.099E+00	5.222E+04	9.914E-03	3.306E-03	4.596E-04	1.771E-03	0.	1.545E-02 MODEL
1.099E+00	4.943E+06	8.223E-01	2.742E+01	3.812E+00	2.537E+01	0.	1.393E+02 SHIP
1.141E+00	5.423E+04	1.074E-02	3.588E-03	4.977E-04	1.910E-03	0.	1.672E-02 MODEL
1.141E+00	5.133E+06	8.814E-01	2.939E+01	4.086E+00	2.736E+01	0.	1.490E+02 SHIP
1.183E+00	5.623E+04	1.159E-02	3.861E-03	5.371E-04	2.054E-03	0.	1.804E-02 MODEL
1.183E+00	5.323E+06	9.423E-01	3.147E+01	4.368E+00	2.943E+01	0.	1.594E+02 SHIP
1.225E+00	5.836E+04	1.252E-02	4.175E-03	5.804E-04	2.212E-03	0.	1.949E-02 MODEL
1.225E+00	5.525E+06	1.009E-02	3.364E+01	4.677E+00	3.170E+01	0.	1.709E+02 SHIP

MODEL AND SHIP SCALE RESISTANCE FOR SHAFT 1

VRL	REYNOLDS	FRICTION	PRESSURE	TOTAL
5.37E-01	5.011E+05	2.547E-02	2.885E-03	2.835E-02 MODEL
5.37E-01	4.978E+07	1.878E+02	1.895E+01	2.067E+02 SHIP
5.674E-01	5.434E+05	2.957E-02	3.393E-03	3.297E-02 MODEL
5.674E-01	5.399E+07	2.182E+02	2.229E+01	2.405E+02 SHIP
6.110E-01	5.858E+05	3.306E-02	3.943E-03	3.790E-02 MODEL
6.110E-01	5.820E+07	2.509E+02	2.590E+01	2.768E+02 SHIP
6.547E-01	6.301E+05	3.885E-02	4.562E-03	4.341E-02 MODEL
6.547E-01	6.261E+07	2.873E+02	2.997E+01	3.172E+02 SHIP
6.983E-01	6.721E+05	4.374E-02	5.191E-03	4.893E-02 MODEL
6.983E-01	6.678E+07	3.238E+02	3.410E+01	3.579E+02 SHIP
7.419E-01	7.127E+05	4.872E-02	5.837E-03	5.454E-02 MODEL
7.419E-01	7.081E+07	3.611E+02	3.835E+01	3.994E+02 SHIP
7.856E-01	7.554E+05	5.422E-02	6.557E-03	6.077E-02 MODEL
7.856E-01	7.505E+07	4.023E+02	4.308E+01	4.454E+02 SHIP
8.292E-01	7.974E+05	5.988E-02	7.305E-03	6.718E-02 MODEL
8.292E-01	7.922E+07	4.448E+02	4.800E+01	4.928E+02 SHIP
8.729E-01	8.393E+05	6.579E-02	8.095E-03	7.388E-02 MODEL
8.729E-01	8.339E+07	4.893E+02	5.318E+01	5.425E+02 SHIP
9.165E-01	8.813E+05	7.196E-02	8.924E-03	8.088E-02 MODEL
9.165E-01	8.756E+07	5.357E+02	6.721E+01	6.029E+02 SHIP
9.602E-01	9.273E+05	7.837E-02	9.795E-03	8.817E-02 MODEL
9.602E-01	9.173E+07	5.841E+02	1.372E+02	7.214E+02 SHIP
1.004E+00	9.652E+05	8.503E-02	1.071E-02	9.574E-02 MODEL
1.004E+00	9.590E+07	6.345E+02	1.994E+02	8.339E+02 SHIP
1.047E+00	1.007E+06	9.104E-02	1.164E-02	1.034E-01 MODEL
1.047E+00	1.001E+08	6.867E+02	2.064E+02	8.931E+02 SHIP
1.091E+00	1.049E+06	9.909E-02	1.265E-02	1.117E-01 MODEL
1.091E+00	1.042E+08	7.409E+02	2.134E+02	9.545E+02 SHIP
1.135E+00	1.091E+06	1.055E-01	1.369E-02	1.202E-01 MODEL
1.135E+00	1.084E+08	7.970E+02	2.211E+02	1.018E+03 SHIP
1.178E+00	1.130E+06	1.135E-01	1.466E-02	1.281E-01 MODEL
1.178E+00	1.122E+08	8.502E+02	2.201E+02	1.078E+03 SHIP
1.222E+00	1.175E+06	1.220E-01	1.587E-02	1.378E-01 MODEL
1.222E+00	1.167E+08	9.149E+02	2.367E+02	1.152E+03 SHIP
1.266E+00	1.222E+06	1.310E-01	1.714E-02	1.482E-01 MODEL
1.266E+00	1.214E+08	9.840E+02	2.459E+02	1.230E+03 SHIP
1.309E+00	1.267E+06	1.400E-01	1.843E-02	1.584E-01 MODEL
1.309E+00	1.258E+08	1.052E+03	2.549E+02	1.307E+03 SHIP

MODEL AND SHIP SCALE RESISTANCE FOR BOSSING 1

VRL	REYNOLDS	FRICTION	PRESSURE	TOTAL
5.237E-01	2.449E+05	2.346E-02	4.463E-03	2.792E-02 MODEL
5.237E-01	2.473E+07	1.734E-02	2.937E-01	2.027E-02 SHIP
5.674E-01	2.699E+05	2.730E-02	5.248E-03	3.254E-02 MODEL
5.674E-01	2.682E+07	2.015E-02	3.448E-01	2.359E-02 SHIP
6.110E-01	2.910E+05	3.140F-02	6.099E-03	3.750E-02 MODEL
6.110E-01	2.891E+07	2.315F-02	4.007E-01	2.716E-02 SHIP
6.547E-01	3.130E+05	3.597E-02	7.056E-03	4.303E-02 MODEL
6.547E-01	3.110E+07	2.650E-02	4.637E-01	3.114E-02 SHIP
6.983E-01	3.339E+05	4.055E-02	8.031E-03	4.848E-02 MODEL
6.983E-01	3.314E+07	2.986E-02	5.276E-01	3.514E-02 SHIP
7.419E-01	3.541E+05	4.521E-02	9.030E-03	5.424E-02 MODEL
7.419E-01	3.518E+07	3.328E-02	5.927E-01	3.922E-02 SHIP
7.856E-01	3.753E+05	5.035F-02	1.014E-02	6.050E-02 MODEL
7.856E-01	3.728E+07	3.707E-02	6.664E-01	4.373E-02 SHIP
8.292E-01	3.961E+05	5.566E-02	1.130E-02	6.696E-02 MODEL
8.292E-01	3.936E+07	4.057E-02	7.425E-01	4.845E-02 SHIP
8.729E-01	4.170E+05	6.120E-02	1.257E-02	7.372E-02 MODEL
8.729E-01	4.143E+07	4.506F-02	8.227E-01	5.328E-02 SHIP
9.165E-01	4.378E+05	6.697F-02	1.381E-02	8.078E-02 MODEL
9.165E-01	4.350E+07	4.932F-02	1.448E-02	6.380E-02 SHIP
9.602E-01	4.587E+05	7.298F-02	1.515E-02	8.813E-02 MODEL
9.602E-01	4.557E+07	5.376E-02	2.531E-02	7.907E-02 SHIP
1.004E+00	4.795E+05	7.922E-02	1.656E-02	9.578E-02 MODEL
1.004E+00	4.764E+07	5.838F-02	3.009E-02	8.847E-02 SHIP
1.047E+00	5.004E+05	8.569E-02	1.803E-02	1.037E-01 MODEL
1.047E+00	4.971E+07	6.318E-02	3.117E-02	9.434E-02 SHIP
1.091E+00	5.212E+05	9.239E-02	1.937E-02	1.120E-01 MODEL
1.091E+00	5.178E+07	6.814F-02	3.228E-02	1.004E-01 SHIP
1.135E+00	5.421E+05	9.932E-02	2.116E-02	1.205E-01 MODEL
1.135E+00	5.396E+07	7.329F-02	3.343E-02	1.047E-01 SHIP
1.178E+00	5.612E+05	1.059F-01	2.269E-02	1.286F-01 MODEL
1.178E+00	5.576E+07	7.816E-02	3.452E-02	1.127E-01 SHIP
1.222E+00	5.878E+05	1.138F-01	2.454E-02	1.364E-01 MODEL
1.222E+00	5.800E+07	8.409E-02	3.585E-02	1.199E-01 SHIP
1.266E+00	6.070E+05	1.223E-01	2.654E-02	1.489E-01 MODEL
1.266E+00	6.031E+07	9.042E-02	3.745E-02	1.277E-01 SHIP
1.309E+00	6.292E+05	1.307F-01	2.852E-02	1.592E-01 MODEL
1.309E+00	6.252E+07	9.465E-02	3.864E-02	1.353E-01 SHIP

MODEL AND SHIP SCALE RESISTANCE FOR MAINROSS I

VRL	REYNOLDS	FRICTION	PRESSURE	BASP	TOTAL
5.237E-01	2.360E+05	2.239E-02	4.231E-03	0.	2.662E-02 MODEL
5.237E-01	2.364E+07	1.612E-02	2.704E-01	0.	1.882E-02 SHIP
5.474E-01	2.559E+05	2.606E-02	4.975E-03	0.	3.103E-02 MODEL
5.474E-01	2.547E+07	1.873E-02	3.179E-01	0.	2.190E-02 SHIP
6.110E-01	2.759E+05	2.998E-02	5.782E-03	0.	3.576E-02 MODEL
6.110E-01	2.741E+07	2.152E-02	3.695E-01	0.	2.521E-02 SHIP
6.547E-01	2.967E+05	3.435E-02	6.691E-03	0.	4.104E-02 MODEL
6.547E-01	2.948E+07	2.463E-02	4.276E-01	0.	2.890E-02 SHIP
6.981E-01	3.165E+05	3.873E-02	7.613E-03	0.	4.615E-02 MODEL
6.981E-01	3.145E+07	2.775E-02	4.855E-01	0.	1.262E-02 SHIP
7.419E-01	3.356E+05	4.319E-02	8.560E-03	0.	5.175E-02 MODEL
7.419E-01	3.335E+07	3.093E-02	5.470E-01	0.	3.648E-02 SHIP
7.856E-01	3.557E+05	4.811E-02	9.616E-03	0.	5.773E-02 MODEL
7.856E-01	3.534E+07	3.445E-02	6.145E-01	0.	4.059E-02 SHIP
8.292E-01	3.755E+05	5.318E-02	1.071E-02	0.	6.389E-02 MODEL
8.292E-01	3.731E+07	3.808E-02	6.846E-01	0.	4.492E-02 SHIP
8.729E-01	3.953E+05	5.848E-02	1.187E-02	0.	7.035E-02 MODEL
8.729E-01	3.927E+07	4.187E-02	7.506E-01	0.	4.944E-02 SHIP
9.165E-01	4.150E+05	6.402E-02	1.309E-02	0.	7.709E-02 MODEL
9.165E-01	4.123E+07	4.583E-02	8.363E-01	0.	5.420E-02 SHIP
9.602E-01	4.348E+05	6.975E-02	1.436E-02	0.	8.411E-02 MODEL
9.602E-01	4.320E+07	4.996E-02	1.314E-02	0.	6.309E-02 SHIP
1.004E+00	4.546E+05	7.572E-02	1.570E-02	0.	9.142E-02 MODEL
1.004E+00	4.516E+07	5.425E-02	2.359E-02	0.	7.784E-02 SHIP
1.047E+00	4.743E+05	8.191E-02	1.710E-02	0.	9.900E-02 MODEL
1.047E+00	4.713E+07	5.870E-02	3.063E-02	0.	8.934E-02 SHIP
1.091E+00	4.941E+05	8.832E-02	1.855E-02	0.	1.069E-01 MODEL
1.091E+00	4.909E+07	6.332E-02	3.167E-02	0.	9.499E-02 SHIP
1.135E+00	5.138E+05	9.494E-02	2.006E-02	0.	1.150E-01 MODEL
1.135E+00	5.105E+07	6.810E-02	3.274E-02	0.	1.008E-01 SHIP
1.178E+00	5.320E+05	1.012E-01	2.151E-02	0.	1.227E-01 MODEL
1.178E+00	5.286E+07	7.263E-02	3.376E-02	0.	1.044E-01 SHIP
1.222E+00	5.534E+05	1.088E-01	2.327E-02	0.	1.321E-01 MODEL
1.222E+00	5.498E+07	7.813E-02	3.499E-02	0.	1.131E-01 SHIP
1.266E+00	5.754E+05	1.170E-01	2.516E-02	0.	1.421E-01 MODEL
1.266E+00	5.717E+07	8.401E-02	3.830E-02	0.	1.203E-01 SHIP
1.309E+00	5.965E+05	1.250E-01	2.703E-02	0.	1.520E-01 MODEL
1.309E+00	5.926E+07	8.900E-02	3.759E-02	0.	1.274E-01 SHIP

MODEL AND SHIP SCALE RESISTANCE FOR RIGOL KEEL Y

VRL	REYNOLDS	TOTAL
5.237E-01	2.047E+06	6.484E-02 MODEL
5.237E-01	2.034E+08	4.946E-02 SHIP
5.674E-01	2.276E+06	7.522E-02 MODEL
5.674E-01	2.205E+08	5.754E-02 SHIP
6.110E-01	2.393E+06	8.633E-02 MODEL
6.110E-01	2.377E+08	6.620E-02 SHIP
6.547E-01	2.574E+06	9.869E-02 MODEL
6.547E-01	2.558E+08	7.587E-02 SHIP
6.983E-01	2.746E+06	1.111E-01 MODEL
6.983E-01	2.728E+08	8.558E-02 SHIP
7.419E-01	2.912E+06	1.277E-01 MODEL
7.419E-01	2.893E+08	9.549E-02 SHIP
7.856E-01	3.086E+06	1.376E-01 MODEL
7.856E-01	3.066E+08	1.065E-01 SHIP
8.292E-01	3.257E+06	1.520E-01 MODEL
8.292E-01	3.236E+08	1.178E-01 SHIP
8.729E-01	3.429E+06	1.670E-01 MODEL
8.729E-01	3.407E+08	1.296E-01 SHIP
9.165E-01	3.600E+06	1.826E-01 MODEL
9.165E-01	3.577E+08	1.420E-01 SHIP
9.602E-01	3.772E+06	1.989E-01 MODEL
9.602E-01	3.747E+08	1.549E-01 SHIP
1.004E+00	3.943E+06	2.158E-01 MODEL
1.004E+00	3.918E+08	1.683E-01 SHIP
1.047E+00	4.115E+06	2.333E-01 MODEL
1.047E+00	4.088E+08	1.823E-01 SHIP
1.091E+00	4.286E+06	2.514E-01 MODEL
1.091E+00	4.258E+08	1.968E-01 SHIP
1.135E+00	4.457E+06	2.702E-01 MODEL
1.135E+00	4.429E+08	2.117E-01 SHIP
1.178E+00	4.615E+06	2.820E-01 MODEL
1.178E+00	4.585E+08	2.260E-01 SHIP
1.222E+00	4.800E+06	3.095E-01 MODEL
1.222E+00	4.769E+08	2.432E-01 SHIP
1.266E+00	4.992E+06	3.326E-01 MODEL
1.266E+00	4.960E+08	2.617E-01 SHIP
1.309E+00	5.174E+06	3.553E-01 MODEL
1.309E+00	5.141E+08	2.799E-01 SHIP

CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENT FOR MODEL SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-IN LRS/
THE APPENDAGE FLAT PLATE FRICTION COEFFICIENT=FRIC. DRAG(APP)/((DENSITY/2.)*VEL.)*(VEL.)*(APPENDAGE WETTED SURFACE))

VM-KNOTS	VRL	RUDDER	STPUY	FIN	SHAFT	ROSS	MAIN	RILGE	SKEG	TOTAL	COEFFICIENT
2.418	.524	.074	.079	0.000	.112	.074	.045	.130	0.000	.517	4.7021E-03
2.419	.537	.090	.092	0.000	.131	.087	.052	.150	0.000	.602	4.6612E-03
2.421	.611	.104	.106	0.000	.150	.100	.060	.173	0.000	.692	4.6229E-03
3.022	.655	.120	.121	0.000	.171	.114	.069	.197	0.000	.793	4.6100E-03
3.224	.698	.135	.138	0.000	.193	.129	.077	.222	0.000	.895	4.5710E-03
3.425	.742	.151	.155	0.000	.215	.164	.086	.247	0.000	.999	4.5222E-03
3.626	.786	.168	.174	0.000	.239	.178	.096	.275	0.000	1.114	4.4976E-03
3.828	.829	.186	.194	0.000	.264	.195	.106	.304	0.000	1.232	4.4659E-03
4.029	.873	.204	.215	0.000	.290	.214	.117	.334	0.000	1.356	4.4355E-03
4.231	.917	.224	.237	0.000	.318	.233	.128	.365	0.000	1.485	4.4063E-03
4.432	.960	.244	.259	0.000	.346	.253	.139	.398	0.000	1.619	4.3783E-03
4.634	1.004	.265	.283	0.000	.375	.274	.151	.432	0.000	1.759	4.3514E-03
4.835	1.047	.287	.307	0.000	.406	.295	.164	.467	0.000	1.904	4.3254E-03
5.037	1.091	.310	.332	0.000	.437	.318	.177	.503	0.000	2.054	4.3005E-03
5.238	1.135	.333	.358	0.000	.470	.349	.190	.540	0.000	2.209	4.2764E-03
5.440	1.178	.355	.383	0.000	.501	.379	.202	.576	0.000	2.356	4.2537E-03
5.641	1.222	.382	.414	0.000	.538	.404	.218	.619	0.000	2.535	4.2308E-03
5.843	1.266	.411	.446	0.000	.578	.432	.234	.665	0.000	2.725	4.2084E-03
6.044	1.309	.439	.478	0.000	.618	.461	.250	.711	0.000	2.913	4.2341E-03
6.246	1.353	.471	.513	0.000	.662	.489	.268	.762	0.000	3.124	4.2537E-03
6.447	1.397	.503	.550	0.000	.707	.512	.286	.813	0.000	3.377	4.2648E-03
6.649	1.440	.537	.588	0.000	.754	.545	.306	.868	0.000	3.565	4.2841E-03
6.850	1.484	.572	.627	0.000	.803	.578	.325	.924	0.000	3.795	4.2941E-03
7.052	1.528	.606	.657	0.000	.851	.614	.345	.980	0.000	4.026	4.3084E-03
7.253	1.571	.644	.710	0.000	.904	.614	.366	1.041	0.000	4.280	4.3210E-03

CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENT FOR SHIP SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-1N LBS
 THE APPENDAGE FLAT PLATE FRICTION COEFFICIENT=FRIC. DRAG(APP)/((DENSITY/2.0)*(VFL.)*(VFL.)*(APPENDAGE WETTED SURFACE))

VS-KNOTS	VRL	RUDDER	STAY	FIN	SHAFT	BOSS	MAIN	DILGE	SKFG	TOTAL	COEFFICI
12.000	.524	5.8163E+02	6.5719E+02	0.	8.3128E+02	5.5481E+02	3.2240E+02	9.8922E+02	0.	3.9367E+03	2.3925E-0
13.000	.567	6.7548E+02	7.6296E+02	0.	9.6622E+02	6.4441E+02	3.7451E+02	1.1507E+03	0.	4.5743E+03	2.3687E-0
14.000	.611	7.7596E+02	8.7591E+02	0.	1.1108E+03	7.4074E+02	4.3032E+02	1.3230E+03	0.	5.2573E+03	2.3474E-0
15.000	.655	8.8792E+02	1.0017E+03	0.	1.2722E+03	8.4731E+02	4.9255E+02	1.5173E+03	0.	6.0191E+03	2.3111E-0
16.000	.698	1.0004E+03	1.1240E+03	0.	1.4342E+03	9.5460E+02	5.5503E+02	1.7117E+03	0.	6.7800E+03	2.2719E-0
17.000	.742	1.1149E+03	1.2544E+03	0.	1.5933E+03	1.0640E+03	6.1863E+02	1.9090E+03	0.	7.5629E+03	2.2402E-0
18.000	.786	1.2414E+03	1.3983E+03	0.	1.7612E+03	1.1840E+03	6.8877E+02	2.1290E+03	0.	8.4244E+03	2.2075E-0
19.000	.829	1.3720E+03	1.5446E+03	0.	1.9703E+03	1.3095E+03	7.6152E+02	2.3554E+03	0.	9.3112E+03	2.1777E-0
20.000	.873	1.5085E+03	1.6975E+03	0.	2.1675E+03	1.4399E+03	8.3742E+02	2.5924E+03	0.	1.0243E+04	2.1410E-0
21.000	.917	1.6509E+03	1.8570E+03	0.	2.3734E+03	1.5760E+03	9.1665E+02	2.8400E+03	0.	1.1204E+04	2.1055E-0
22.000	.960	1.7993E+03	2.0231E+03	0.	2.5879E+03	1.7174E+03	9.9910E+02	3.0922E+03	0.	1.2225E+04	2.0710E-0
23.000	1.004	1.9536E+03	2.1957E+03	0.	2.8111E+03	1.8651E+03	1.0850E+03	3.3660E+03	0.	1.3277E+04	2.0365E-0
24.000	1.047	2.1137E+03	2.3748E+03	0.	3.0420E+03	2.0181E+03	1.1741E+03	3.6454E+03	0.	1.4365E+04	2.0025E-0
25.000	1.091	2.2797E+03	2.5602E+03	0.	3.2821E+03	2.1767E+03	1.2664E+03	3.9351E+03	0.	1.5501E+04	2.0705E-0
26.000	1.135	2.4514E+03	2.7521E+03	0.	3.5318E+03	2.3407E+03	1.3619E+03	4.2348E+03	0.	1.6673E+04	2.1384E-0
27.000	1.178	2.6142E+03	2.9340E+03	0.	3.7676E+03	2.4963E+03	1.4525E+03	4.5191E+03	0.	1.7784E+04	2.1149E-0
28.000	1.222	2.8120E+03	3.1549E+03	0.	4.0544E+03	2.6854E+03	1.5626E+03	4.8644E+03	0.	1.9114E+04	2.1758E-0
29.000	1.266	3.0233E+03	3.3908E+03	0.	4.3607E+03	2.8873E+03	1.6802E+03	5.2343E+03	0.	2.0577E+04	2.1412E-0
30.000	1.309	3.2312E+03	3.6228E+03	0.	4.6623E+03	3.0860E+03	1.7960E+03	5.5982E+03	0.	2.1997E+04	2.1389E-0
31.000	1.353	3.4655E+03	3.8842E+03	0.	5.0023E+03	3.3099E+03	1.9264E+03	6.0006E+03	0.	2.3597E+04	2.1488E-0
32.000	1.397	3.7027E+03	4.1487E+03	0.	5.3466E+03	3.5366E+03	2.0585E+03	6.4242E+03	0.	2.5217E+04	2.1551E-0
33.000	1.440	3.9561E+03	4.4312E+03	0.	5.7145E+03	3.7788E+03	2.1996E+03	6.8688E+03	0.	2.6949E+04	2.1656E-0
34.000	1.484	4.2118E+03	4.7162E+03	0.	6.0800E+03	4.0233E+03	2.3420E+03	7.3174E+03	0.	2.8697E+04	2.1724E-0
35.000	1.528	4.4687E+03	5.0024E+03	0.	6.4593E+03	4.2688E+03	2.4850E+03	7.7605E+03	0.	3.0453E+04	2.1755E-0
36.000	1.571	4.7512E+03	5.3170E+03	0.	6.8698E+03	4.5309E+03	2.6424E+03	8.2648E+03	0.	3.2384E+04	2.1868E-0

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