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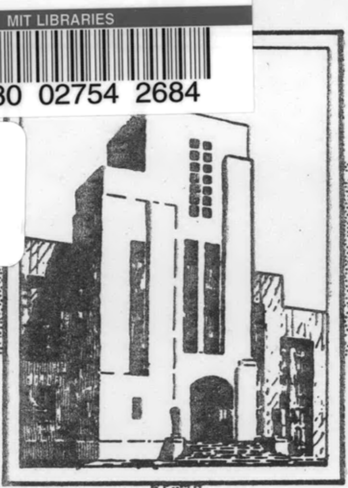

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SCALE EFFECT ON THE DRAG OF A TYPICAL SET OF PLANING BOAT APPENDAGES

by

Eugene P. Clement

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ABSTRACT

Geometrically similar models of a set of planing boat appendages were manufactured in four different sizes, and tested to determine the scale effect error involved in predicting appendage drag. Data from the test of the smallest appendage set when mounted on a hull model were fairly consistent with data from the three larger appendage sets when mounted on a friction plane. The results indicate that use of an extrapolator which is appreciably steeper than Schoenherr's line at Reynolds numbers below about 10^6 would give more nearly correct predictions of full scale appendage resistance.

INTRODUCTION

Models of planing boats and other small craft are towed in model basins in order to predict the performance of the corresponding full scale boats. On occasion these models are fitted with appendages for the purpose of predicting the resistance of the appended craft. Some uncertainty has existed as to the appropriate method of scaling up the model appendage resistance, or the resistance of the complete appended model, in order to arrive at an accurate estimate of the resistance of the appended full scale craft. (The main reason for the uncertainty was the low local Reynolds numbers at which these relatively small model appendages operate.) In order to shed some light on this question, a set of representative planing boat appendages was manufactured in four different sizes and tested in the model basin for resistance. Results of these tests are presented in this report.

THE MODELS TESTED

A 1/10-scale model of a high speed planing boat, DTMB Model 4129, had previously been tested both in the bare hull condition and with dummy appendages. For the appended test the model of this 4-screw craft was fitted with four essentially identical sets of appendages - each set consisting of a dummy propeller shaft, hub, a short and long strut, and a rudder. A drawing of one of these appendage sets is shown in Figure 1.

For the purpose of the appendage scale effect test a pair of additional sets of 1/10-scale appendages was manufactured. In addition, geometrically similar appendage sets were manufactured, in pairs, to the scale ratios, 1/5, 1/3 and

1/2. All four pairs of appendage sets are shown in Figure 2. Also manufactured, to carry the pairs of appendage sets during the tests was a wood friction plane (see Figures 2 and 3). Each equal-sized pair of appendage sets was mounted on the friction plane for testing, with one set on each side of the plane. By testing the appendage sets in pairs, in this fashion, accuracy of the results was improved, because twisting moments on the plane were eliminated, and because the magnitude of the significant drag forces was doubled.

TEST PROCEDURE AND RESULTS

The friction plane was rigidly attached to the floating girder of Carriage 2, at the draft indicated in Figure 3. The floating girder is connected by linkages to a resistance dynamometer. First the resistance of the bare plane was measured at 1 knot intervals up to 18 knots. The four pairs of appendage sets were then mounted, successively, on the plane, and the drag of the plane plus appendages measured. The speed range in each case was the same as for the bare plane. A dry-dock at one end of the towing basin was utilized for changing the appendage sets. Accordingly, it was possible to keep the plane fixed to the towing carriage during the entire course of the tests, thereby avoiding the possibility of a change in the alignment of the plane with respect to the direction of motion.

The values of speed and drag measured during the tests are given in Table 1. It was estimated that the accuracy of the drag measurements was ±.05 lb. All data have been omitted from the report for which the drag accuracy value of 0.05 lb equals as much as 5% of the measured appendage drag. The drag of the appendages alone was obtained from the test data by the following procedure. From the measured values of V and R the ratio R/V^2 was calculated. Next, at the same nominal values of speed the ratio of R/V^2 for the plane alone was subtracted from the ratio of R/V^2 for the plane with appendages. This was considered to give an accurate value of R/V^2 for the appendages alone, for the test speeds of the plane with appendages. The values of R/V^2 for the appendages alone were then divided by the ratio $\frac{1}{2}\rho S(1.689)^2$, to obtain values of the resistance coefficient C_t, for the appendages. The value used for S in each case was the total wetted surface of the particular pair of appendage sets-excluding, however, the flat area of the strut palms, since these mask an equivalent area on the friction plane. The wetted surface value for two sets of 1/2-scale appendages was 8.92 ft^2.

With respect to an appropriate length for calculating Reynolds number for the appendages, it was considered that each appendage set consisted essentially of a shaft, a rudder and one long strut, and that insofar as the calculation of Reynolds number was concerned the flow past each of these appendage items was not significantly affected by the presence of the other appendages or the plane. Accordingly the wetted length for Reynolds number was taken as the average wetted length in the direction of motion of the main three appendages, taken separately. This dimension was estimated to be 1.5 inches for the 1/10-scale appendages. Corresponding values of wetted length were used for calculating the Reynolds numbers of the other, larger sized appendages.

The values of C_t and Reynolds number obtained by the fore-going procedures are plotted in Figure 4, together with Schoenherrs line. It can be seen that the values of total resistance coefficient from the tests of the three larger appendage sets fall essentially along a single line which is nearly parallel to the Schoenherr line. A number of the points from the tests of the smallest (1/10-scale) appendages, however, lie appreciably higher. These high values of resistance coefficient for the smallest appendages can presumably be attributed to laminar separation of the flow.

Additional resistance data for the 1/10-scale appendages were available from another source. These were the data from tests of the hull Model No. 4129, both bare, and equipped with four sets of 1/10-scale appendages. It was clear that it would be of interest to plot these appendage resistance data in a graph like Figure 4. The procedure used was as follows. Model 4129 had been tested at several conditions of displacement and initial trim, both bare hull and with appendages. When the running trim data from the two sets of tests were compared, at the same conditions of displacement and initial trim, it was found that the running trim of the appended model was appreciably different than that of the bare model. Usually the appended model ran at a higher trim than the bare model. Since the resistance of a planing boat varies appreciably with trim angle, particularly at the higher speeds, it was considered necessary to correct for this effect. The bare model had been tested at a sufficient number of conditions so that it was possible by interpolation to obtain for each resistance value for the appended model, the resistance of the bare model at the same condition of displacement, speed and running trim. The differences between these related pairs of resistance readings were taken, and these were considered to give accurate values of resistance for the appendages alone. These differences are plotted in dimensionless form in Figure 5, together with the data for the three larger appendage sets, taken from Figure 4. It can be seen that for Reynolds numbers above about 2 x 10^5 the data for the 1/10-scale appendages obtained in this fashion fall in line quite satisfactorily with the data from the larger sized model appendages. The evident explanation is that when the appendages were on the hull, they were operating in a turbulent wake from the model. Accordingly the phenomenon of laminar separation of the flow from the appendages, with accompanying high drag coefficients, did not occur.

The Schoenherr values of frictional resistance coefficients were subtracted from the values of C_t given in Figure 5, to obtain values of the residual resistance coefficient, C_r. These are plotted against Froude number in Figure 6. The lengths used in the calculation of Froude number were the same as those used in the calculation of Reynolds number. It can be seen from Figure 6 that the values of C_r for each of the appendage sets assume fairly constant values at the high end of the speed range. The values of C_r decrease with increase in appendage size - from about 5 x 10^{-3} for the 1/10 scale appendages, to about 4 x 10^{-3} for the 1/2-scale appendages. The value of C_r for the corresponding full scale dummy appendages would evidently be somewhat below 4 x 10^{-3}. It does not seem possible to be more precise about this value, on the basis of the available data.

DISCUSSION

From these results we can estimate the appendage scale effect error involved in predicting the resistance of the full scale boat from tests of the appended 1/10-scale model. Assume that the correct value of C_r for the full scale appendages is 4.0 x 10^{-3}. The value of appendage C_r predicted from the tests of the 1/10-scale model is 5.1 x 10^{-3} (from Figure 6). The total appendage resistance for the full scale boat (four shafts and four rudders) at a speed of 45 knots is calculated to be 5,900 lb if C_r equals 4.0, and 6,800 lb if C_r equals 5.1. The full scale bare hull resistance at this speed, for a displacement of 185,000 lb and 0° initial trim, is 25,300 lb. Then, the total full scale resistance is 31,200 lb based on the "correct" value of C_r (4.0 x 10^{-3}), and 32,100 lb based on the value of C_r from the tests of the 1/10-scale model (5.1×10^{-3}). Expressed in terms of percentage difference the resistance as predicted from the appended 1/10-scale model will be 2.9% too high because of "scale effect" on the appendage resistance. This end result is caused by the fact that, although the test data in Figure 5 lie nearly along a single line (indicating C_t to be a unique function of Reynolds number), this line is not parallel to the Schoenherr line, which is used as the extrapolator. The 2.9% error would be appreciably reduced if an extrapolator was used which was appreciably steeper than Schoenherr's line at Reynolds numbers below about 10^6. There is in fact an accumulating amount of evidence from the different model basins which indicates that an extrapolator which is steeper than Schoenherr's line at low Reynolds numbers would be more appropriate for extrapolating model resistance to full size.

TABLE I - TEST DATA

Water Temp = 73°F

Bare Plane		Plane with Appendages							
		$\lambda = 10$		$\lambda = 5$		$\lambda = 3$		$\lambda = 2$	
V, Knots	R, lb	V, Knots	R, lb	V, Knots	R, lb	V, Knots	R, lb	V, Knots	R, lb
2.00	1.35	--	--	--	--	--	--	--	--
3.01	3.00	--	--	--	--	--	--	3.00	5.10
4.00	5.15	--	--	--	--	4.00	6.70	4.00	8.65
5.01	7.70	--	--	5.00	8.90	5.01	10.55	5.01	13.70
6.02	10.90	--	--	6.00	12.50	6.00	14.75	6.01	19.05
7.03	14.15	--	--	7.03	16.25	7.01	19.20	7.02	24.75
8.01	17.80	--	--	8.02	20.50	8.02	24.30	8.00	31.05
9.02	21.85	9.00	23.00	8.98	25.00	9.01	29.85	9.00	38.30
9.99	26.50	10.00	27.75	9.99	30.30	9.98	36.25	10.00	46.50
11.00	31.70	11.00	33.05	10.98	36.20	11.00	43.25	10.98	55.20
11.97	37.50	11.96	39.00	11.96	42.80	11.97	51.05	11.97	66.65
13.00	43.45	12.99	45.25	12.99	49.65	12.96	59.55	13.01	77.35
14.00	50.50	13.97	52.85	13.96	57.55	13.96	69.10	13.95	89.00
14.97	57.85	14.97	60.60	14.98	66.15	14.95	79.70	15.00	102.95
15.98	66.05	16.03	69.50	15.96	75.40	15.96	90.95	15.99	117.00
17.00	75.10	16.98	78.40	17.00	85.30	16.97	102.65	17.00	132.35
18.00	84.25	17.98	88.25	18.01	96.30	18.03	115.55	18.02	148.40

λ	DIMENSION A
10	13.17"
5	26.34"
3	43.86"
2	65.85"

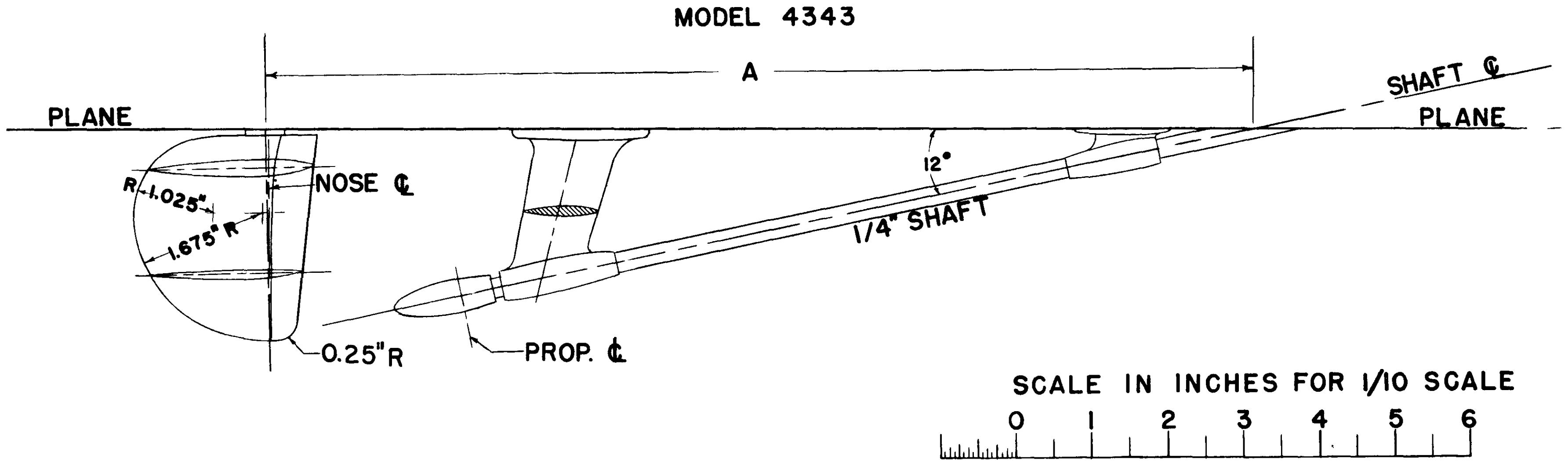

FIGURE 1 - DRAWING OF THE 1/10 - SCALE APPENDAGE SET.

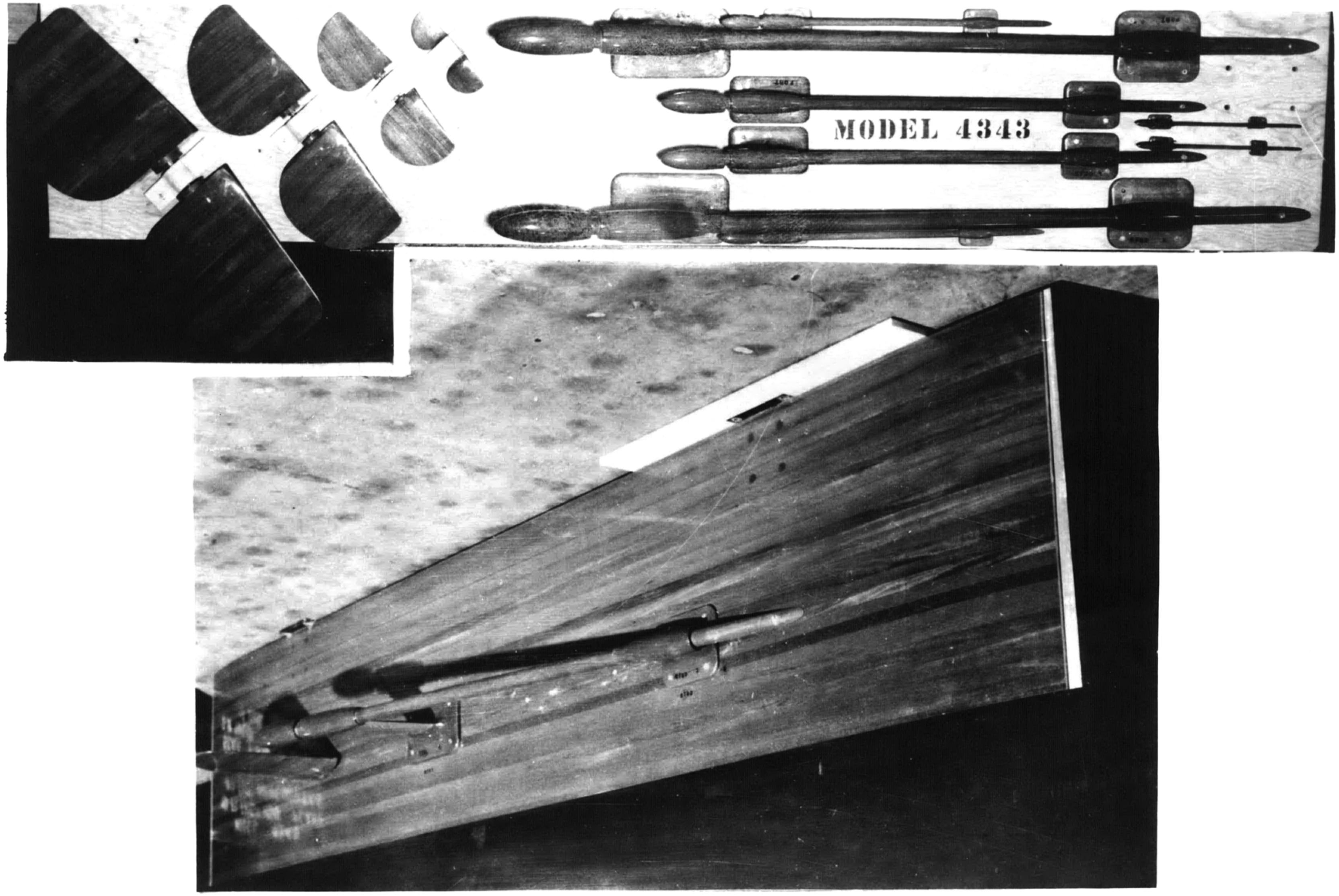

Figure 2 - Appendage Sets Tested, and Starboard Side of the Friction Plane with the 1/2-Scale Appendages in Place.

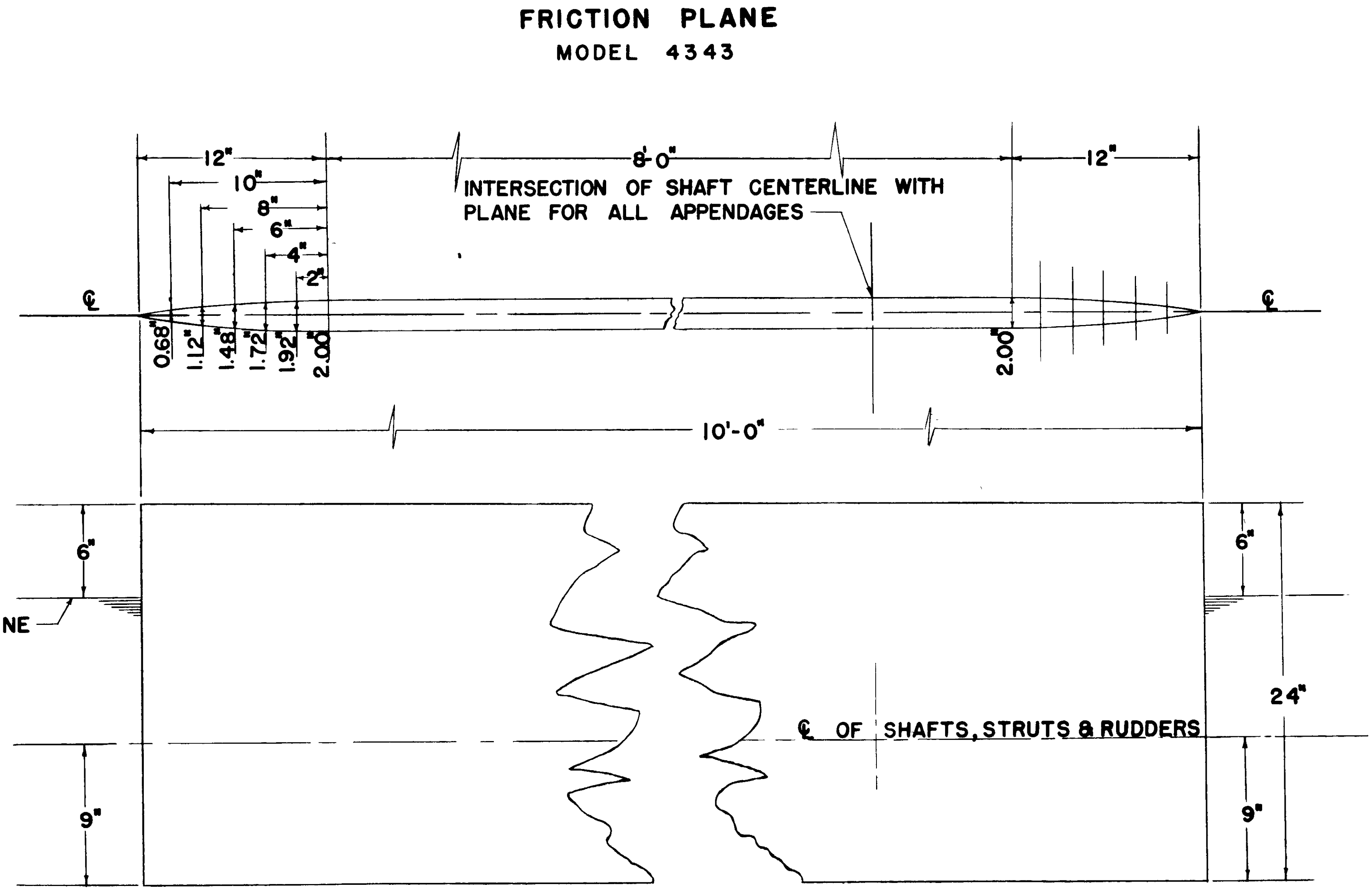

FIGURE 3- FRICTION PLANE ON WHICH THE APPENDAGE SETS WERE MOUNTED FOR TESTING

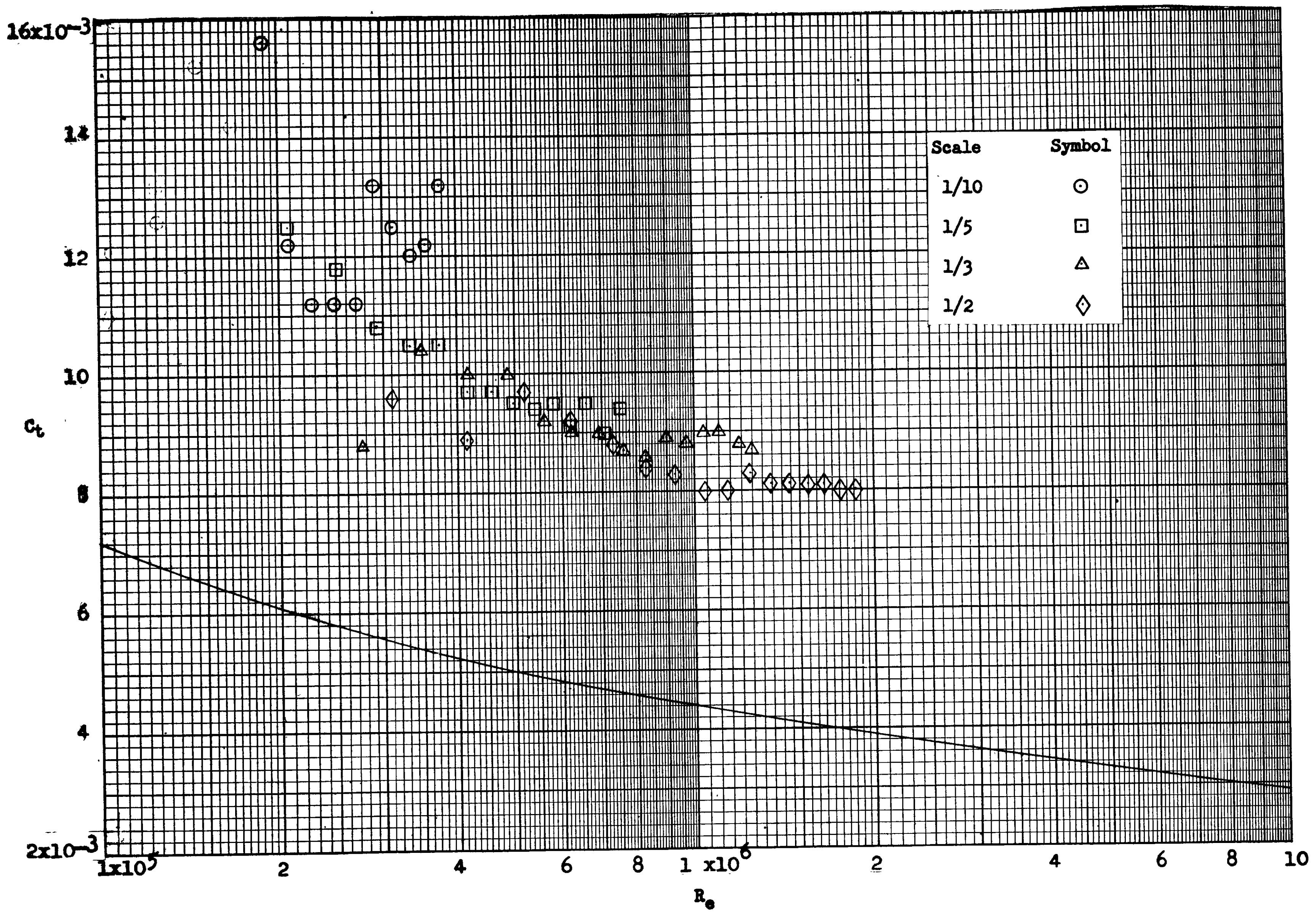

Figure 4 - Resistance Coefficient Versus Reynolds Number for the Four Appendage Sets Tested on the Friction Plane.

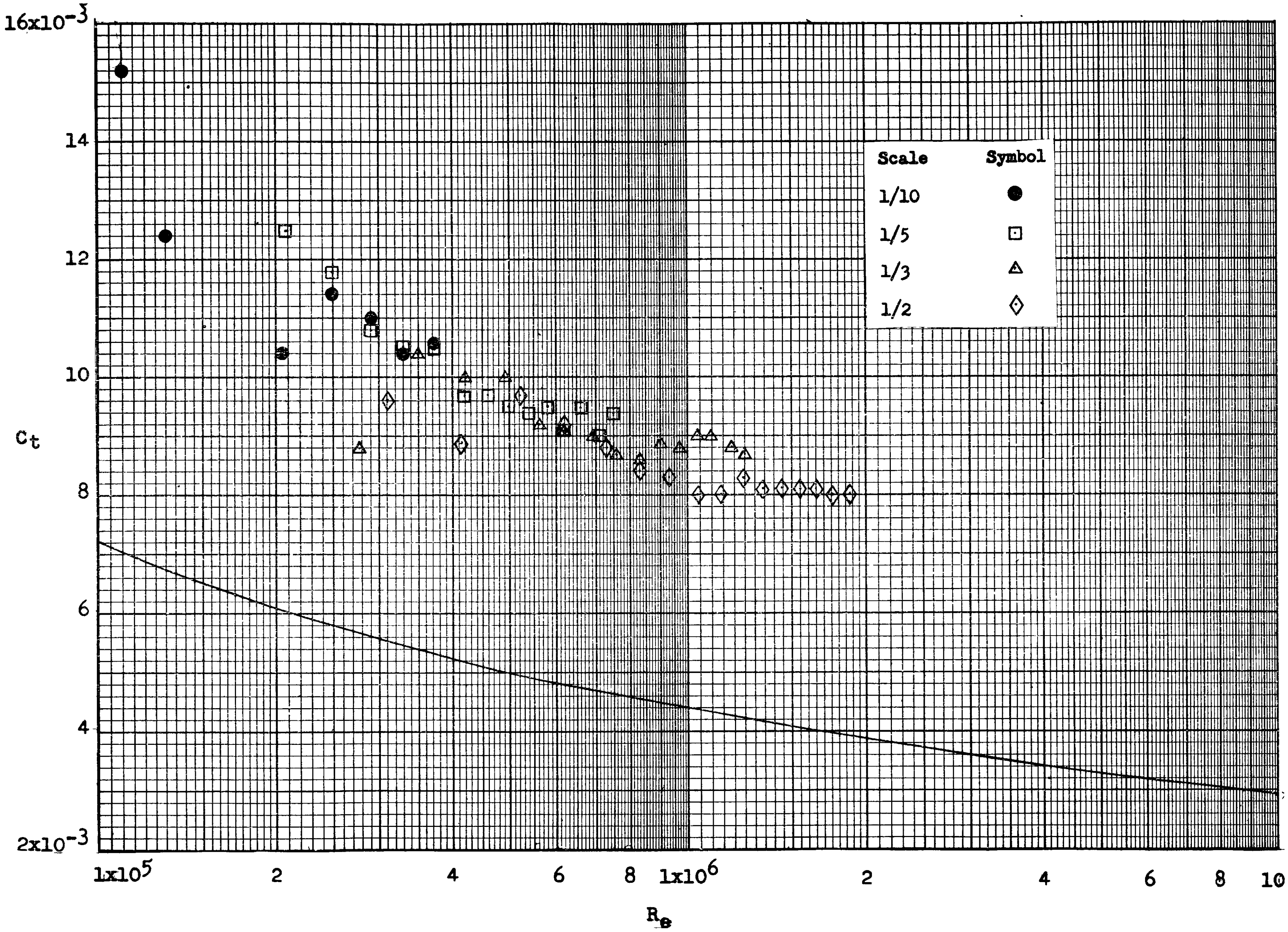

Figure 5 - C_t Versus R_e, Using the Data for the 1/10-Scale Appendages as Measured on the Hull Model.

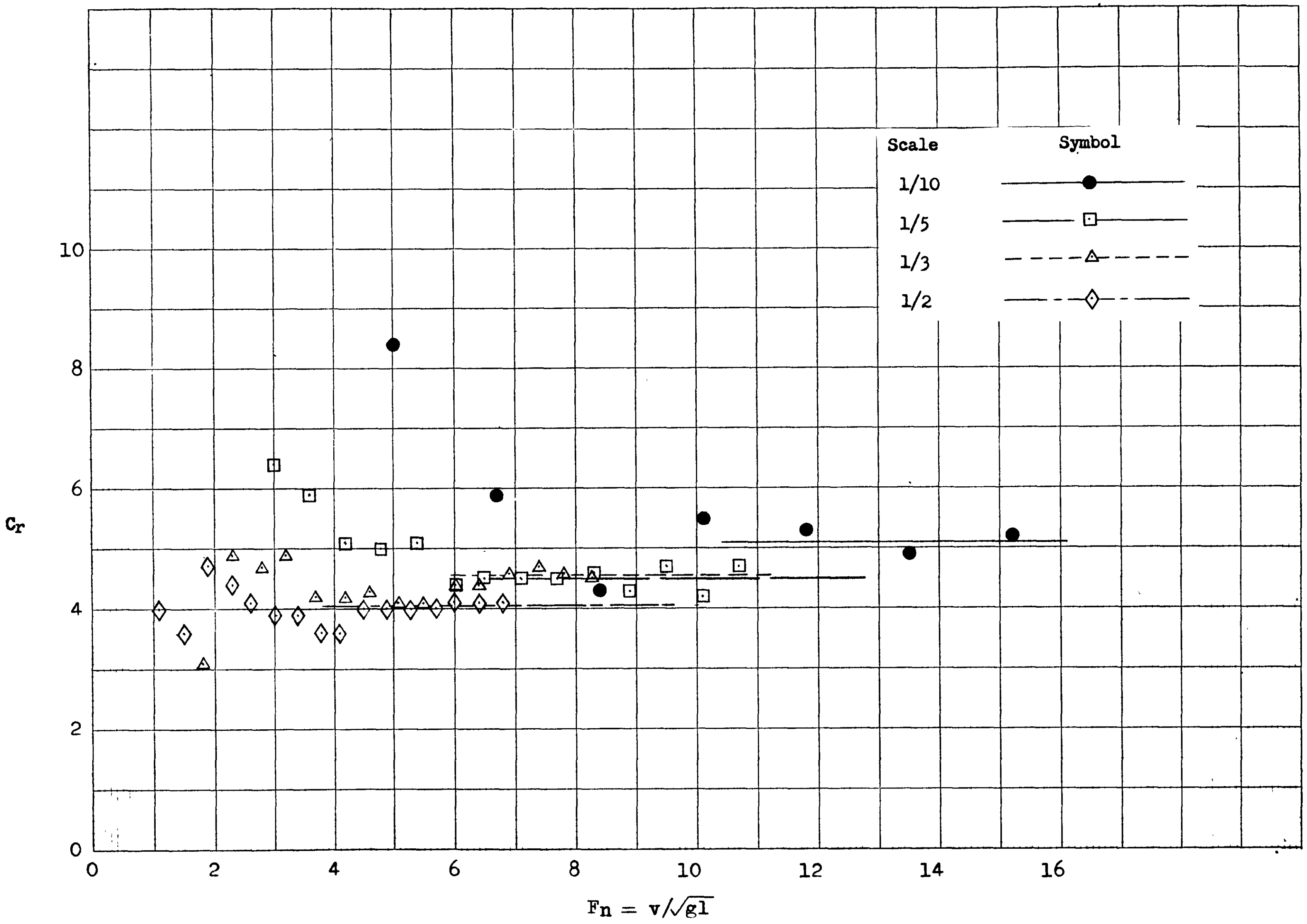

Figure 6 - C_r Versus Froude Number for the Four Appendage Sets.

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3. Planing boats – Drag – Model tests
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