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UNIVERSITY OF ICELAND
DEPARTMENT OF ENGINEERING AND SCIENCE

COMPARATIVE MODEL TESTS OF THE ICEBREAKER PERFORMANCE OF TWO CANADIAN COAST GUARD ICEBREAKERS

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SUMMARY

Icebreaking performance model tests described in this paper demonstrated that the hull form, incorporating a modern bow design, for a new design Canadian Coast Guard medium icebreaker exhibits icebreaking performance superior to that of the CCGS NORMAN MCLEOD ROGERS. Furthermore the model icebreaking performance data for this new design hull correlates well with existing model and full scale data for icebreakers with similar gross dimensions.

The icebreaking performance of the newly designed hull form (referred to as the "R" Class hull) was compared with that of CCGS NORMAN MCLEOD ROGERS in uniform plate ice and in mush ice, a compacted aggregate of finely broken ice typical of heavily trafficked canals, rivers and harbors. The measure of performance employed during these tests was the *appendaged hull resistance* as measured in a *constant speed towing test*.

1/36th scale models of the two icebreakers were towed at various constant speeds, side by side in model fields of uniformly thick "plate" ice. The "R" Class was tested at two drafts at zero trim. The ROGERS was tested at shallow draft at zero trim and at deep draft with sufficient trim to keep the plumb portion of her stem from encountering the ice cover. In the design draft condition, at speeds in excess of three knots, the resistance of the "R" Class was zero to twelve percent lower than that of the ROGERS for all ice thicknesses for which tests were conducted.

The resistance of the "R" Class in the deep draft condition was found to be between ten and sixteen percent lower than that of "R" Class at design draft.

It was also determined that the resistance of the "R" Class in the deep draft condition was as much as thirty percent lower than that of the ROGERS for reasonable speeds and ice thicknesses. *The tests indicate that the "R" Class*

icebreaker in deep draft condition with her propulsion plant producing 15,000 SHP, is capable of maintaining a speed of advance of approximately three knots in three feet of uniformly thick lake ice.

The models of the "R" Class and ROGERS Class icebreakers were separately towed through fields of finely broken, compacted ice at various constant speeds. A comparison of the towing resistance for the two ships indicated that the resistance offered to the motion of the hull of the ROGERS at a speed of three knots is approximately twelve percent greater than that of the "R" Class in mush ice depths greater than 3 feet.

INTRODUCTION

In 1969 the Canadian Coast Guard took delivery of a new medium size icebreaker named CCGS NORMAN MCLEOD ROGERS.

The ship was designed to serve a number of functions and within certain hull size restraints. Consequently its hull was not designed solely for icebreaking performance, the result being somewhat of a compromise typical of most of the icebreaking fleet.

Nevertheless the vessel has acquired a reputation as being an efficient icebreaker, partly owing to her power ratio, which is high amongst Canadian vessels of this size and class.

Because of operational requirements, and restriction on draft and length, this vessel has a full hull form, having a block coefficient of 0.68 and relatively shallow draft.

In 1972 the Canadian Ministry of Transport made the decision to design and build one or more new icebreakers for the Great Lakes, River St. Lawrence and Gulf regions to bolster the existing fleet which was becoming hard pressed to serve the increasing traffic requirements of these areas.

It was decided for a number of reasons that the new design should be a ship of approximately the same power and physical dimensions as the NORMAN MCLEOD ROGERS and subject to the same restraint on maximum Lakes draft (20 feet). However, the new vessel was also to differ in many ways from her predecessor, amongst which was the requirement that she should be capable of operation in Arctic waters as a Class 3 ship under the new Canadian Government Arctic Pollution Prevention Regulations.

The many differences in requirements, principally that of Arctic service, coupled with restrictions on draft and length, resulted in a hull form rather fuller and beamier than at first hoped, with the concurrent concern that her icebreaking performance might suffer. To offset possible loss of icebreaking performance it was decided at the outset to adopt a modern bow form having a low bow rake angle, in this case approximately 18 degrees, curving to a steeper angle lower down, and with wide dihedral angle in the sections at the stem, referred to as small bow angle complements.

The merit of this type of bow had been shown only in model tests and theoretical treatment up to that time, with the only full scale application being that of the S.S. MANHATTAN. The results, though convincing, were not proven to be better for all service situations than a well designed form of more common type. In particular, the effectiveness of the new bow form was not certain in frazil ice conditions and slush ice, both of which are common problems in Great Lakes and St. Lawrence River winter navigation. The effectiveness in deep snow cover was not proven, although there was little doubt that improved performance could be expected in solid ice cover with or without a limited snow cover.

Since a good portion of the new vessels' working life is expected to be in conditions where slush ice is a factor, and in view of the general absence of comparative data for the performance of this type of hull form in ice, a series of model tests was designed to compare the performance of the new icebreaker (designated an "R" Class Icebreaker) with the NORMAN MCLEOD ROGERS in both hard cover conditions and slush ice. Since the hull forms of the two vessels do not differ greatly excepting for the bow form, the results are of interest, the outcome of the test program being a confirmation of the superiority of the new form over the original in almost all conditions tested.

TEST DESCRIPTION

Model Description

Scale models of the CCGS NORMAN MCLEOD ROGERS (Hull 289) and the new "R" Class design were constructed of wood. The models were coated with special paints which are resistant to ice abrasion. Resistance tests were conducted at two levels of hull-ice friction coefficient. The desired hull-ice friction coefficient was obtained by wet sanding the hull surface in a direction parallel to the station lines. The models were ballasted and their radius of gyration adjusted using standard procedures.

Test Basin

The models were tested in the ARCTEC ICE MODEL Basin. This facility consists of a refrigerated model towing basin 60 feet long, 8 feet wide and four feet deep in which saline ice is rapidly grown with a patented cryogenic spray system. A constant speed towing carriage towed the ship models through the model ice fields. The models were towed side by side in the basin. Single model test runs were conducted to confirm the fact that there was no detectable effect of interaction between the two models during the tandem towing tests.

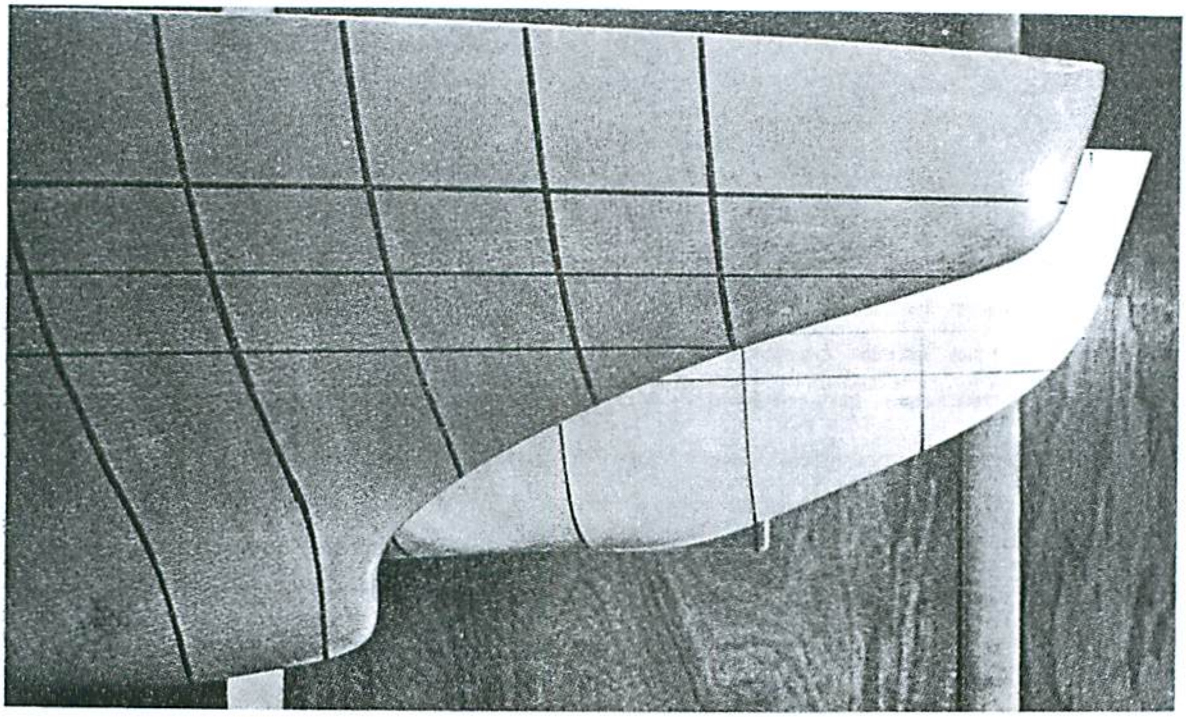


Figure 1a. Side View of the Forebodies of "R" Class and NORMAN MCLEOD ROGERS ("R" Class is in foreground)

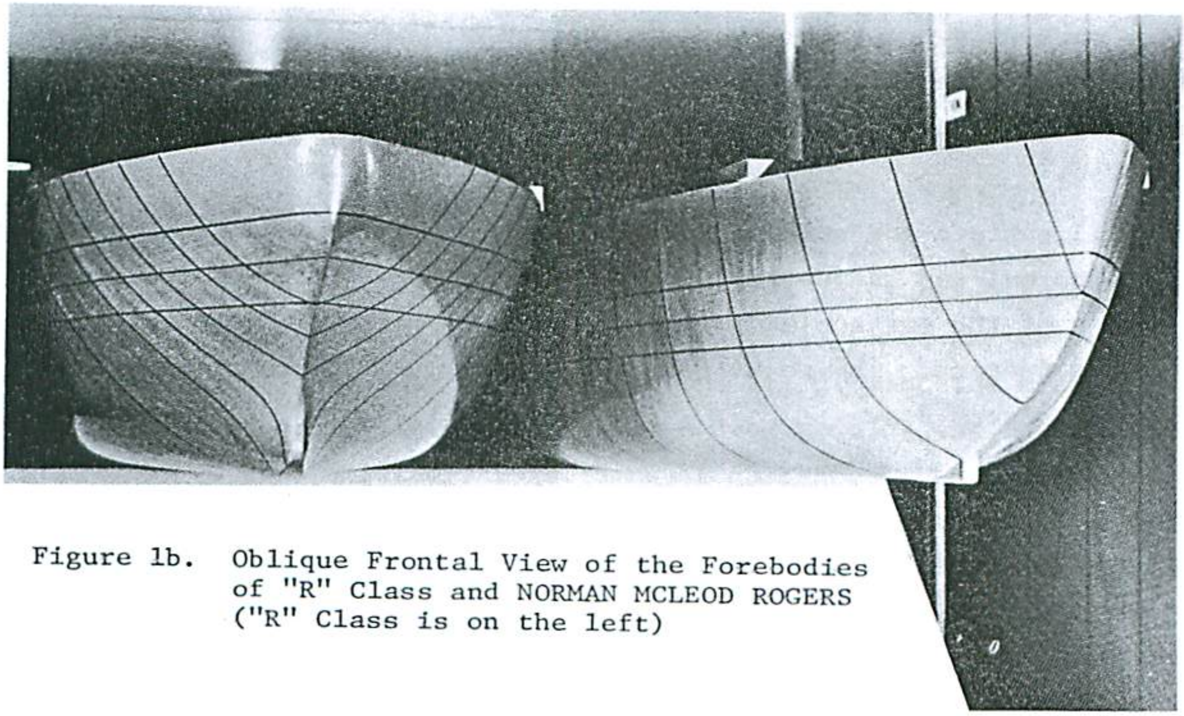


Figure 1b. Oblique Frontal View of the Forebodies of "R" Class and NORMAN MCLEOD ROGERS ("R" Class is on the left)

Test Measurements

The following variables were measured for each test in uniform ice:

Horizontal Resistance	-	R
Ice Flexural Strength	-	σ_f
Ice Thickness	-	h
Hull Surface - Ice Surface Coefficient of Friction	-	μ
Ship Speed	-	v

The horizontal resistance was measured using hollow strain gauged blocks to sense the shear between the model and the towing carriage. The models were attached to the force blocks in a manner which allowed pitching, rolling and heaving motions but which restrained yawing and swaying.

The ice flexural strength was measured by cutting in-situ cantilevers in the ice sheet and then loading their free end until failure occurred. The forces required for failure, along with the lengths, widths, and thicknesses of the broken cantilevers, were measured. The flexural strength was then determined from the well-known standard formula

$$\sigma_f = \frac{6 P_f \ell}{B h^2} \tag{1}$$

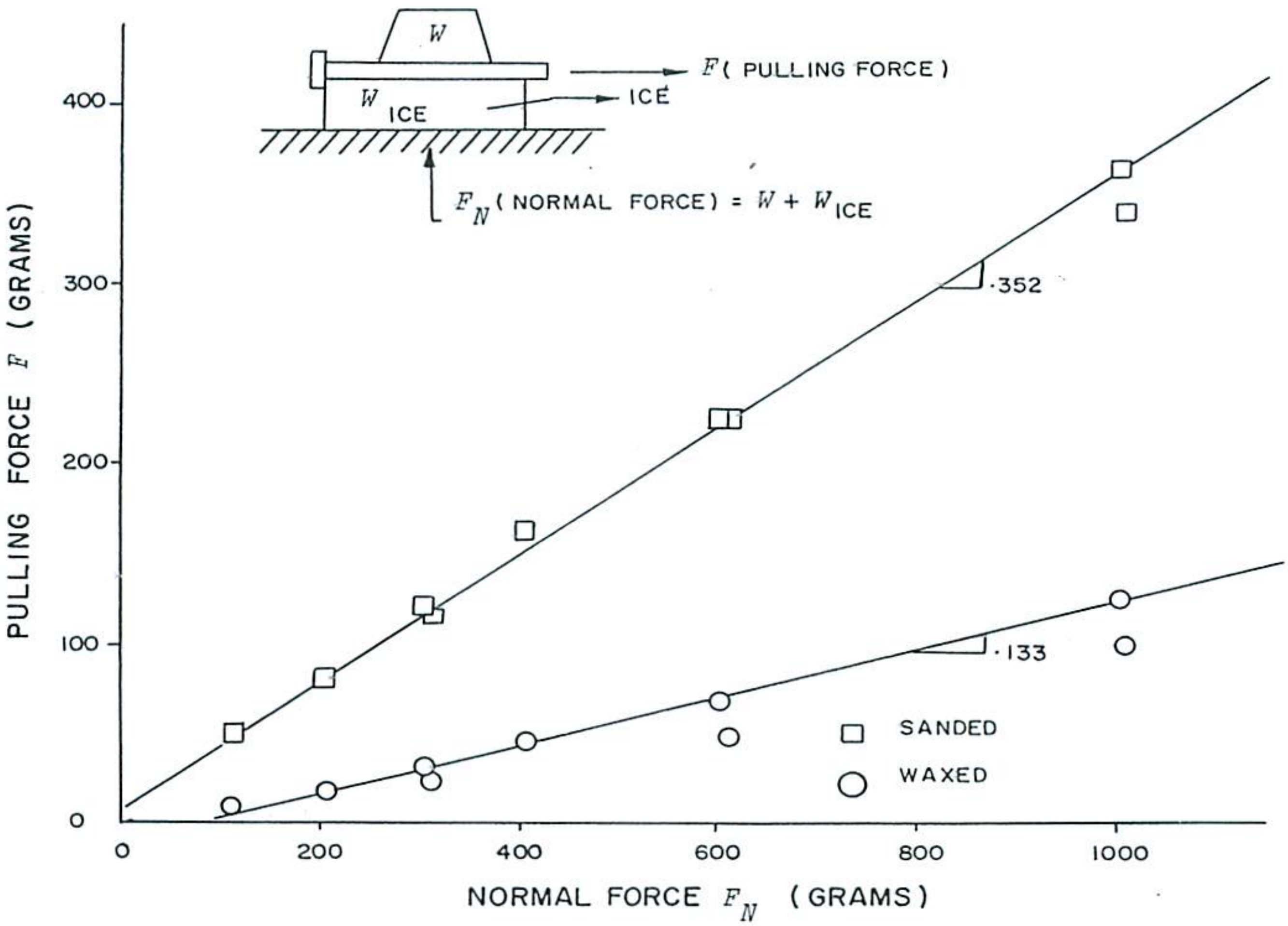
for cantilever beams. These values of flexural strength were then averaged to produce the value reported. This test was conducted at set intervals along the length of the basin.

After each run, ice thickness was measured on both sides of the broken ship channels at intervals of two feet. Measurement was made with vernier calipers, insuring that any refrozen surface water had been scraped from the sample measured.

The hull surface-ice surface friction factor was obtained from measurements of the normal and tangential forces during steady motion of ice samples over portions of the surface of the model hulls. The models were tested at two friction factors. The results of the friction coefficient measurements are shown in figure 2.

The model speed and position were measured simultaneously by recording the passing of one revolution of a spoke in the carriage drive system on the oscillograph. This pulse on the oscillograph indicates a carriage movement of a fixed distance. By recording the distance travelled on a time based recorder, the velocity over any range was calculated. The carriage position in relation to the ice sheet was determined by noting the starting position of the model, then counting the pulses.

Figure 2 Friction Test Results



<u>Test Procedure</u>

A typical test day started with the growing of an ice sheet of the proper thickness. The sheet was grown with both models in place and connected to the drive carriage. At the completion of the ice growth, the carriage and models were freed of any ice and snow and a zero reading was taken on the force block. Four distinct runs were made in each ice sheet. Each run was made at a different speed in accordance with the proposed schedule. The length of each run was in the order of 1.5 to 2 ship lengths. Figure 3 shows the models just before a test run. At the end of the test, the models were withdrawn from the ice sheet and a confirmation of the force block zero was made. After this was completed, the ice strengths and thicknesses along the broken channels were measured. This process is shown in figure 4. The two broken channels formed by the models with the undisturbed ice in the center are clearly visible.

Figure 3 DISPOSITION OF MODELS PRIOR TO TEST RUN

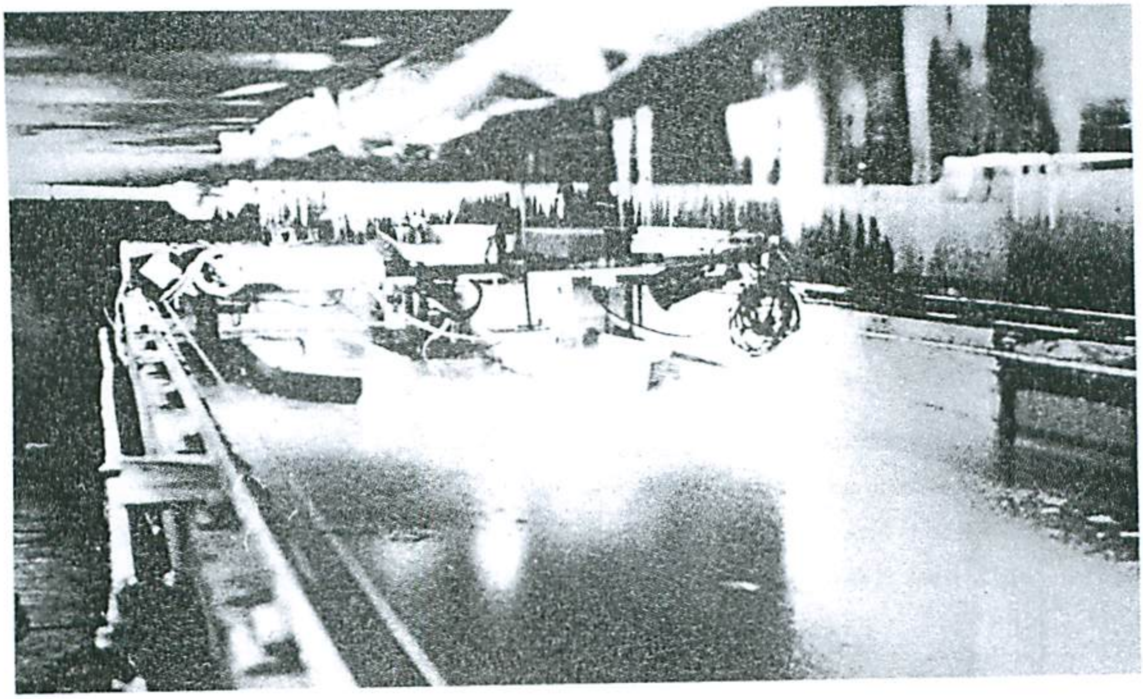
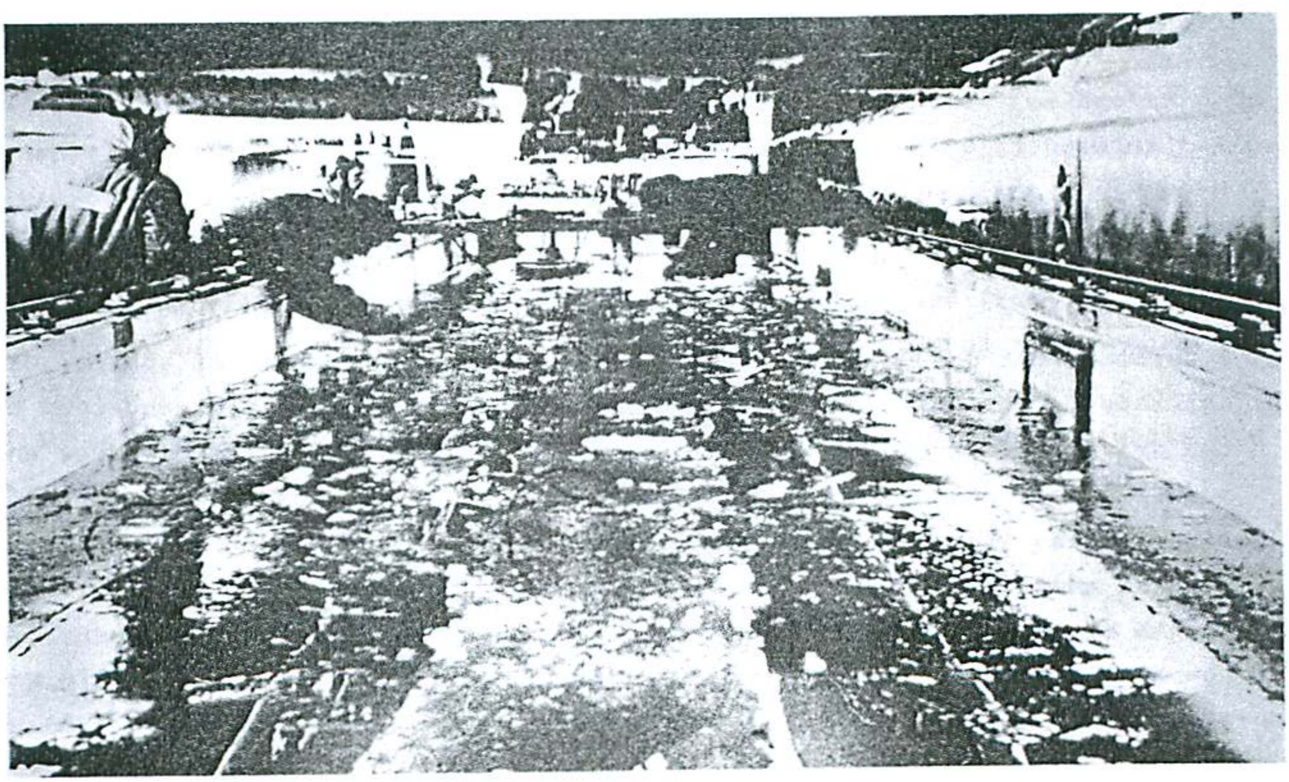


Figure 4 ICE THICKNESS AND ICE PROPERTIES MEASUREMENT



In addition to testing in uniform ice, tests were conducted in mush ice. For these tests, uniform ice sheets of approximately 1.5cm thickness were grown and then broken up into very small pieces. These small pieces of ice were then uniformly distributed to the desired mush thickness. For tests in which the mush thickness was greater than 1.5cm additional ice sheets were grown until the desired mush thickness was obtained.

RESULTS

Resistance of Motion in Uniformly Thick Ice

Acquisition of Data - The models of the "R" Class and the NORMAN MCLEOD ROGERS were towed at constant speed through eight model ice fields, the thickness of which was varied between 1.0 and 3.0 centimeters. This range corresponds to a full scale ice thickness range of approximately fourteen to forty-three inches. The flexural strength of the model ice fields varied between .240 and .375 kg/cm^2 which corresponds to a full scale range of 8.6 to 13.4 kg/cm^2. In each of the six sheets, four distinct carriage speeds were used. The model speeds ranged from 3.0 centimeters per second to 144 centimeters per second corresponding to a full scale range of 0.4 to 17 knots.

Two levels of hull ice friction factors were employed during the test program, 0.35 and 0.133 which correspond to the same full scale values. High speed films of the models operating together in the ice were acquired for a majority of the test runs.

The "R" Class hull form was tested at two drafts at zero trim. The deep draft condition corresponded to a full scale draft of 24 feet, the design draft to 20 feet. The ROGERS was tested at a model draft corresponding to a full scale draft of 20 feet. The deep model draft for the ROGERS corresponded to a full scale draft of 24 feet with four feet of trim by the stern. This was necessary because, at a draft of 24 feet on an even keel, the ROGERS presents a virtually plumb stem to the ice cover. In Figure 1a the forebodies of the two models were shown. The top waterline corresponds to the 24 foot waterline. The lines are separated by four feet. Note the stem angle of the ROGERS at the deep draft. The particulars for these two hulls are tabulated in Table 1.

Sixty distinct data points were acquired during uniform ice resistance tests. They are tabulated in Table 2.

TABLE 1

	"R" CLASS Full Scale	"R" CLASS Model (λ=36)	NORMAN MCLEOD ROGERS Full Scale	NORMAN MCLEOD ROGERS Model (λ=36)
Length (ft)	315.00	8.75	266.00	7.39
Breadth (ft) at waterline	63.00	1.72	62.5	1.73
Draft Design (ft)	20.00	0.555	20.00	0.555
Deep (ft)	24.00	0.666	24.00	0.666
Hull Coefficients Design η_2	2.45	2.45	2.41	2.41
μ_0	1.53	1.53	2.44	2.44
Deep Draft η_2	2.66	2.66		
μ_0	1.53	1.54		
Minimum Plate Ice Thickness (in)	14.00	0.39 (1 cm)		
Maximum Plate Ice Thickness (in)	42.00	1.20 (3 cm)		
Minimum Mush Ice Depth (in)	36.00	1.0 (2.5 cm)		
Maximum Mush Ice Depth (in)	144.00	4.0 (10 cm)		
Block Coefficient (C_b) at 20' draft	0.625		0.68	

Analysis of Data - Based upon the results of previous work by Edwards and Lewis [1], [2], it was assumed that the resistance to motion in plate ice could be expressed in the following dimensionless manner:

$$\frac{R}{\rho_\omega g\, Bh^2} = f\left[\left(\frac{v}{\sqrt{gh}}\right)\quad\left(\frac{\sigma_f}{\rho_\omega g\, h}\right)\quad \mu\right] \qquad (2)$$

The dimensional data tabulated in the first four columns of Table 2 were converted to the dimensionless numbers in equation (2). These numbers are also tabulated in Table 2. The dimensionless resistance ($R/\rho_\omega g\, Bh^2$) was plotted against Froude number ($v/\sqrt{gh}$) for each model, draft and friction factor. A typical result is shown in Figure 5A for the "R" Class at deep draft and friction coefficient of 0.35. Dimensionless strength is treated as a parameter.

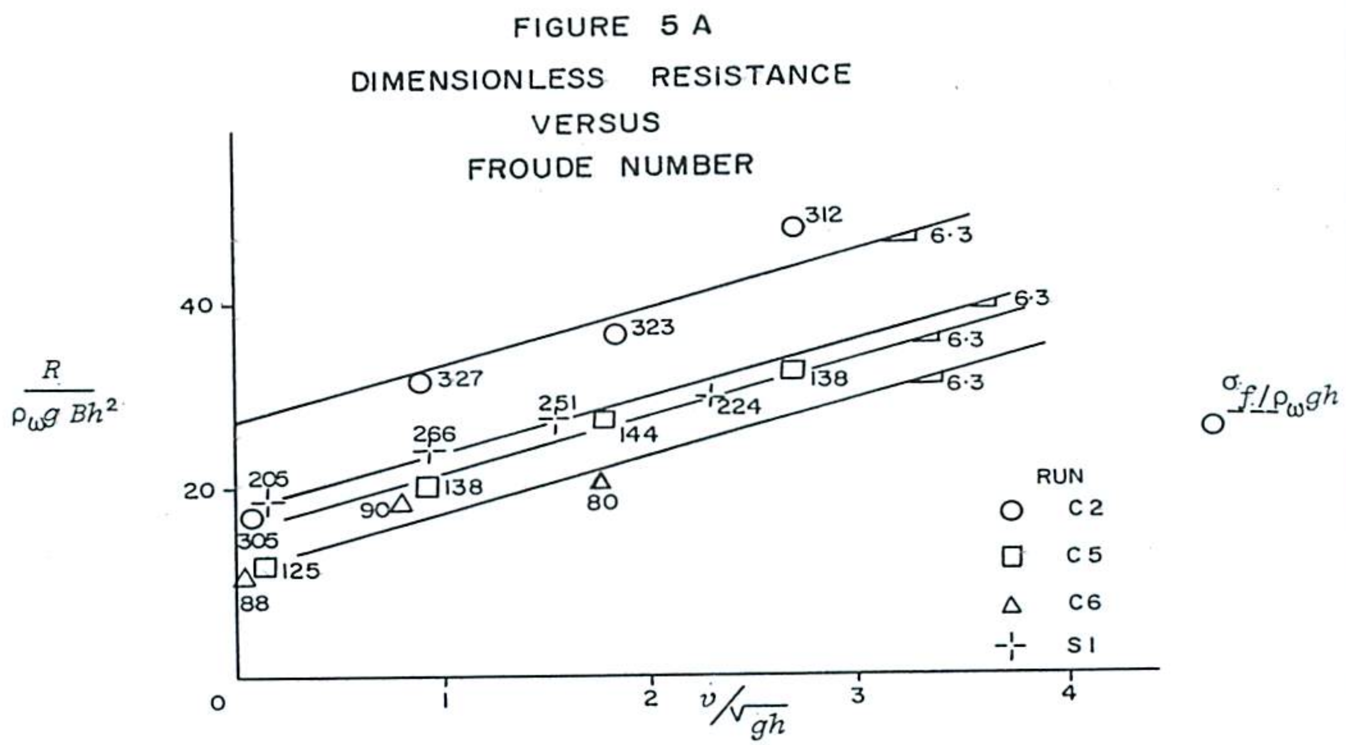
The dimensionless resistance appears to be a linear function of Froude number in this plot. The slopes of the lines appear to be independent of dimensionless strength. Figure 5B is a plot of the dimensionless resistance at zero Froude number versus dimensionless strength.

TABLE 2

RESULTS OF CONTINUOUS ICE TESTING

Date 1973	Run	Model	Draft	R (kg)	h (cm)	v (cm/sec)	σ_f (kg/cm²)	$\frac{v}{\sqrt{gh}}$	$\frac{R}{\rho_\omega g B h^2}$	$\frac{\sigma_f}{\rho_\omega g h}$	μ
2-21	C1a	289	Design	2.64	1.30	28.7	.265	0.80	28.5	275.0	0.35
	a			1.94	1.28	28.7		0.81	21.8	280.0	0.35
	b	289		3.13	1.10	59.4		1.81	48.4	325.0	0.35
	b	R		2.57	1.09	59.4		1.82	39.9	328.0	0.35
	c	289		4.65	1.14	89.0		2.67	66.9	314.0	0.35
	c	R		3.32	1.11	89.0		2.70	49.7	322.0	0.35
	d	289		2.31	1.40	2.94		0.079	21.8	256.0	0.35
	d	R		1.21	1.26	2.94		0.084	13.9	284.0	0.35
	C2a	289	Deep	3.07	1.16	28.8	.347	0.86	42.6	294.0	0.35
	a	R		1.83	1.04	28.8		0.90	31.1	327.0	0.35
	b	289		3.63	1.05	59.4		1.85	61.0	324.0	0.35
	b	R		2.20	1.05	59.4		1.85	36.6	324.0	0.35
	c	289		4.32	1.10	89.3		2.72	66.6	310.0	0.35
	c	R		3.08	1.09	89.3		2.73	47.9	313.0	0.35
	d	289		1.45	1.18	2.90		0.085	19.5	290.0	0.35
	d	R		1.14	1.12	2.90		0.088	16.9	305.0	0.35
2-22	C3a	289	Design	10.09	2.73	44.5	.262	0.86	25.1	94.1	0.35
	a	R		9.81	2.76	44.5		0.86	23.7	93.2	0.35
	b	289		10.98	2.52	99.36		1.99	32.1	102.0	0.35
	b	R		11.09	2.60	99.36		1.97	30.1	98.7	0.35
	c	289		19.0	2.81	144.2		2.75	44.5	91.4	0.35
	c	R		14.03	2.71	144.2		2.80	53.1	94.8	0.35
	d	289		5.44	2.98	4.42		0.082	11.4	86.2	0.35
	d	R		6.82	2.74	4.42		0.085	16.6	93.6	0.35
2-26	C4a	289	Design	3.79	1.62	37.9	.303	0.95	27.7	183.0	0.35
	a	R		3.67	1.67	37.9		0.94	22.7	178.0	0.35
	b	289		5.34	1.57	71.3		1.82	40.1	189.0	0.35
	b	R		4.77	1.62	71.3		1.79	33.4	183.0	0.35
	c	289		7.91	1.80	111.6		2.63	45.3	165.0	0.35
	c	R		6.27	1.73	111.0		2.68	38.3	171.0	0.35
	d	289		3.56	1.93	6.77		0.155	17.7	154.0	0.35
	d	R		5.08	1.95	6.77		0.155	24.7	153.0	0.35
2-27	C5a	R	Deep	3.21	1.71	38.1	.240	0.932	20.2	134.0	0.35
	a	289		4.96	1.76	38.1		0.920	29.8	138.0	0.35
	b	R		3.93	1.63	71.8		1.79	27.1	129.0	0.35
	b	289		6.06	1.82	71.8		1.70	33.8	144.0	0.35
	c	R		5.22	1.71	111.0		2.70	32.9	124.0	0.35
	c	289		8.09	1.90	111.0		2.56	41.7	138.0	0.35
	d	R		2.28	1.88	6.66		0.155	11.8	129.0	0.35
	d	289		4.37	1.83	6.66		0.157	24.2	125.0	
2-28	C6a	R	Deep	8.92	2.99	44.4	.275	0.819	18.3	88.0	0.35
	a	289		10.8	3.07	44.4		0.809	21.2	90.2	0.35
	b	R		8.52	2.88	70.4		1.32	18.9	88.6	0.35
	b	289		11.7	3.04	70.4		1.29	23.4	93.6	0.35
	c	R		10.6	3.07	98.0		1.79	20.8	81.9	0.35
	c	289		17.3	3.30	98.0		1.73	29.5	87.9	0.35
	d	R		5.6	3.06	2.46		0.045	11.0	84.3	0.35
	d	269		7.03	3.20	2.46		0.044	12.7	88.1	0.35
3-08	S1a*	R	Deep	4.64	1.87	40.0	.509	0.934	24.4	266.0	0.35
	b		Deep	5.91	1.99	69.2		1.57	27.4	251.0	0.35
	c			8.05	2.23	107.6		2.30	29.8	224.0	0.35
	d			5.80	2.43	7.3		0.149	18.1	205.0	0.35
3-08	S2a**	R	Deep	3.08	1.92	39.2	.511	0.922	15.4	261.0	0.13
	b		Deep	4.31	1.89	70.7		1.61	22.2	265.0	
	c			6.94	1.89	106.0		2.50	35.7	265.0	
	d			2.74	2.05	7.08		0.163	12.0	243.0	
3-14	S3a**	R	Deep	4.45	3.27	17.3	.343	.305	7.71	103.0	0.13
	b		Deep	6.93	2.75	116.0		2.23	17.0	122.0	
	c			5.54	2.63	87.0		1.71	14.8	128.0	
	d			5.14	3.05	40.0		0.73	10.2	110.0	

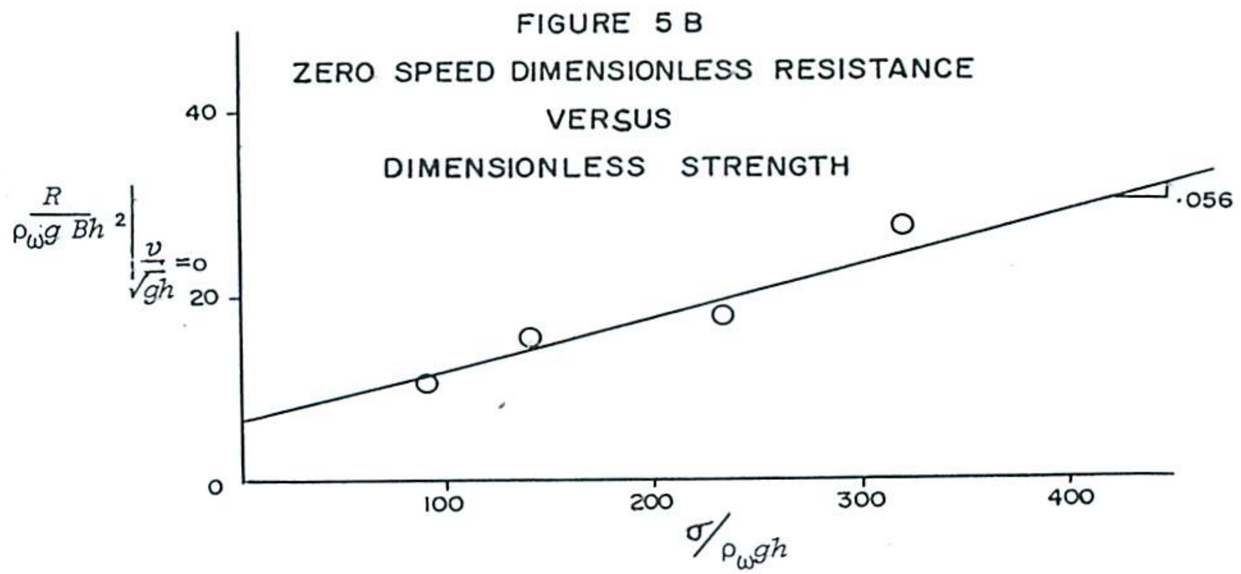
* Single Model - Standard Finish
** Single Model - Waxed



"R" CLASS

DRAFT — 24 FT.

Friction Factor μ = ·35



For a given value of hull surface-ice surface friction factor a predictor equation was obtained from plots such as figures 5A and 5B. The results were of the form .....

$$\frac{R}{\rho_\omega g\, Bh^2} = C_0 + C_1 \frac{\sigma_f}{\rho_\omega g h} + C_2 \frac{v}{\sqrt{gh}} \tag{3}$$

where C_0 is the zero intercept of the curve of dimensionless resistance at a Froude number of zero versus dimensionless strength. C_1 is the slope of that curve. C_2 is the slope of the curve of dimensionless resistance versus Froude number. Table 3 lists the values of these coefficients for the levels of friction factor achieved in the test program.

TABLE 3

FRICTION FACTOR

μ	C_0	C_1	C_2
.352	7	.056	6.3
.133	1	.036	6.3

The coefficient, C_2, apparently does not depend appreciably upon friction coefficient. Within the range of available data, the coefficients C_0 and C_1 were assumed to depend linearly on friction coefficient. Figures 6A and B show this dependence. In the dimensionless equations for both the "R" Class and ROGERS, the coefficients C_0 and C_1 were corrected to a friction factor of 0.145, the value observed during recent full scale trials on the Great Lakes. The equations which follow are a result of the analysis:

"R" Class - Design Draft

$$\frac{R}{\rho_\omega g Bh^2} = 9 + .062 \frac{\sigma_f}{\rho_\omega g h} + 6.9 \frac{v}{\sqrt{gh}} \tag{4}$$

"R" Class - Deep Draft

$$\frac{R}{\rho_\omega g Bh^2} = 7 + .056 \frac{\sigma_f}{\rho_\omega g h} + 6.3 \frac{v}{\sqrt{gh}} \tag{5}$$

ROGERS Design Draft

$$\frac{R}{\rho_\omega g Bh^2} = 8 + .06 \frac{\sigma_f}{\rho_\omega g h} + 11 \frac{v}{\sqrt{gh}} \tag{6}$$

These equations are valid for B/h, $\sigma_f/\rho_\omega g h$, and $v/\sqrt{gh}$ within the ranges of:

$$\begin{aligned} 16.6 &\le B/h \le 51.0 \\ 81.1 &\le \sigma_f/\rho_\omega g h \le 325 \\ 0 &\le v/\sqrt{gh} \le 2.8 \end{aligned} \tag{7}$$

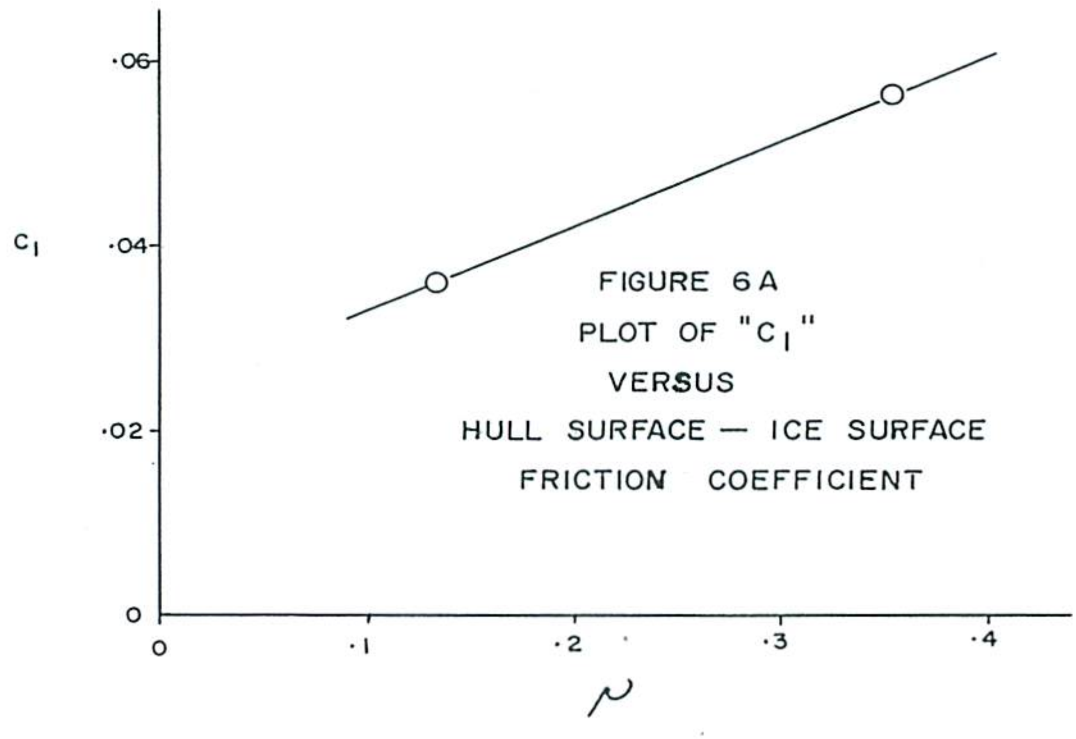


FIGURE 6A
PLOT OF "C1"
VERSUS
HULL SURFACE — ICE SURFACE
FRICTION COEFFICIENT
c1
·06
·04
·02
0
0
·1
·2
·3
·4
μ

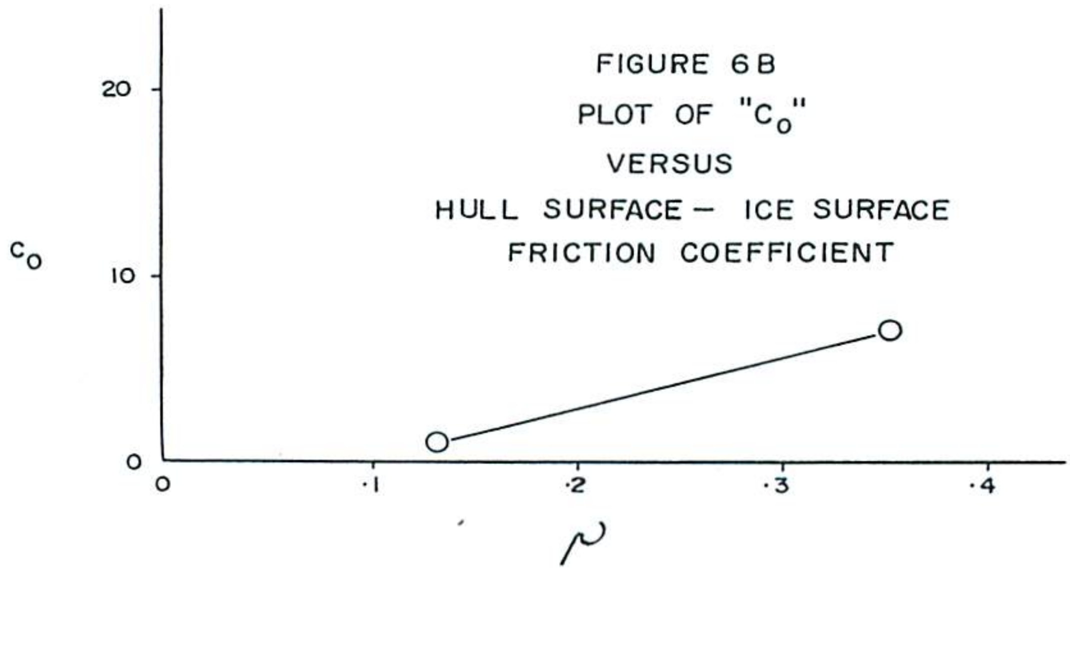
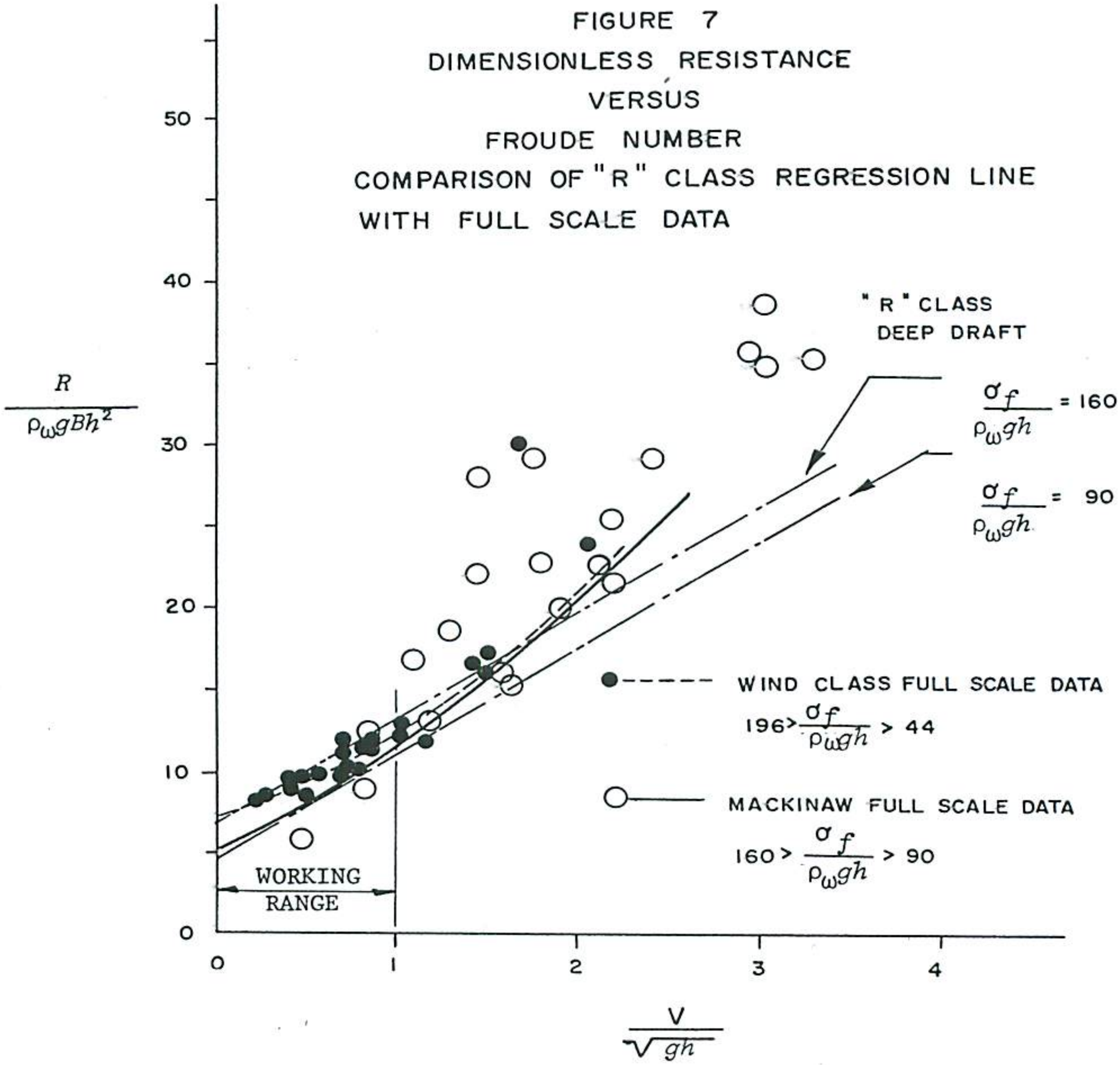


FIGURE 6B
PLOT OF "C0"
VERSUS
HULL SURFACE — ICE SURFACE
FRICTION COEFFICIENT
c0
20
10
0
0
·1
·2
·3
·4
μ

In Figure 7 equation (5) was plotted for the two extreme values of full scale dimensionless strength to show the similarity between the model results and existing full scale data on ships of similar gross dimensions



The dimensionless equations (4) through (6) were converted to their dimensional equivalents with the following results:

$$R = 1.49\ \rho_\omega g B h^2 + .039\ B h \sigma_f + 11\ \rho_\omega g^{\frac{1}{2}} B h^{\frac{3}{2}} v \qquad \text{ROGERS (Design)} \qquad (8)$$

$$R = 1.67\ \rho_\omega g B h^2 + .041\ B h \sigma_f + 6.9\ \rho_\omega g^{\frac{1}{2}} B h^{\frac{3}{2}} v \qquad \text{"R" Class (Design)} \qquad (9)$$

$$R = 1.3\ \rho_\omega g B h^2 + .037\ B h \sigma_f + 6.3\ \rho_\omega g^{\frac{1}{2}} B h^{\frac{3}{2}} v \qquad \text{"R" Class (Deep)} \qquad (10)$$

These equations were used to calculate icebreaking resistance values for the

ROGERS at a draft of 20 feet, and for the "R" Class at drafts of 20 and 24 feet. Figure 8 shows these values plotted as a function of full scale ship speed. An ice flexural strength of 126 lb/in^2, which is typical for lake ice, was used in the computation.

Figure 8 illustrates the fact that the "R" Class hull with the modern bow form will encounter lower resistance to motion in uniformly thick ice than its predecessor, the CCGS NORMAN MCLEOD ROGERS. In addition the performance of the "R" Class in the deep draft condition is superior to that in the shallow draft design conditions.

Resistance to Motion in Mush Ice

The models of the ROGERS and the "R" Class were towed singly through model fields of mush ice. The "R" Class was tested at two drafts corresponding to full scale drafts of 20 and 24 feet. The ROGERS was tested at a draft corresponding to a full scale draft of 20 feet with no trim. Three mush fields were prepared. The depth of the fields were 2.5, 5.0 and 10.0 centimeters respectively. Each model was towed at four speeds for a total of thirty-five data points. The test results are tabulated in Table 4 and plotted in dimensionless form in Figure 9.

No difference in mush ice resistance could be detected for the two different draft conditions for the "R" Class. Consequently only one dimensionless mush ice resistance equation for the "R" Class resulted from the analysis. The dimensionless mush resistance equation for the two ships are as follows:

$$\frac{R}{\rho_\omega g B h^2} = 0.60 + 0.57 \frac{v^2}{gh} \qquad (11)$$

Hull - "R" Class
Draft - 20 and 24 feet
Trim - None

$$\frac{R}{\rho_\omega g B h^2} = 0.68 + 0.83 \frac{v^2}{gh} \qquad (12)$$

Hull - ROGERS
Draft - 20 feet
Trim - None

These equations were converted to dimensional equations by multiplying both sides by $\rho_\omega g B h^2$. The results are:

$$R = 0.60 \; \rho_\omega g B h^2 + 0.57 \; \rho_\omega B h v^2 \qquad (13)$$

$$R = 0.68 \; \rho_\omega g B h^2 + 0.83 \; \rho_\omega B h v^2 \qquad (14)$$

The ratio of equation (15) for the ROGERS to equation (14) for the "R" Class

FIGURE 8 PLOT OF TOWING RESISTANCE IN ICE VERSUS SHIP SPEED (EXTRAPOLATED FROM MODEL TEST RESULTS)

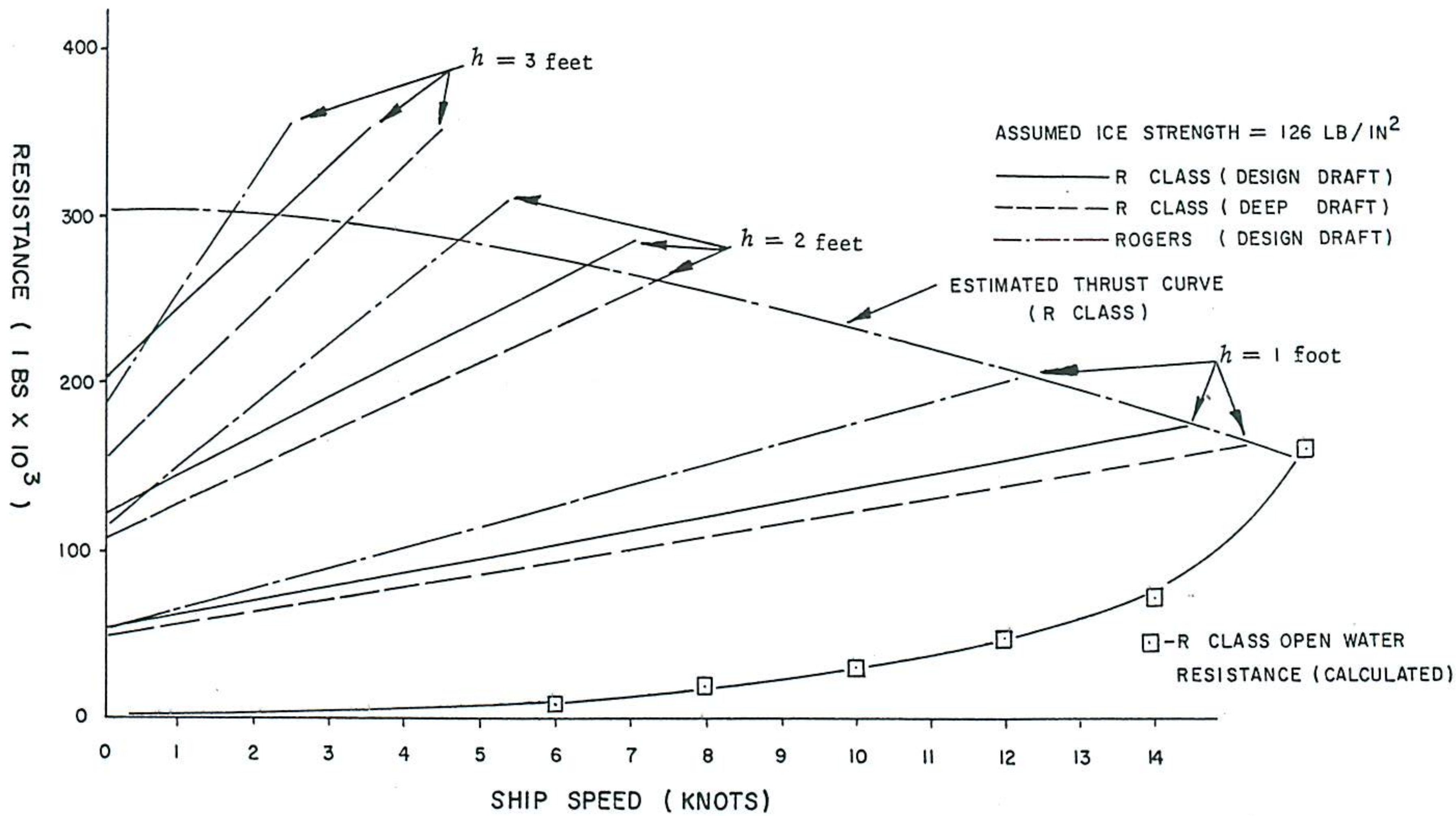
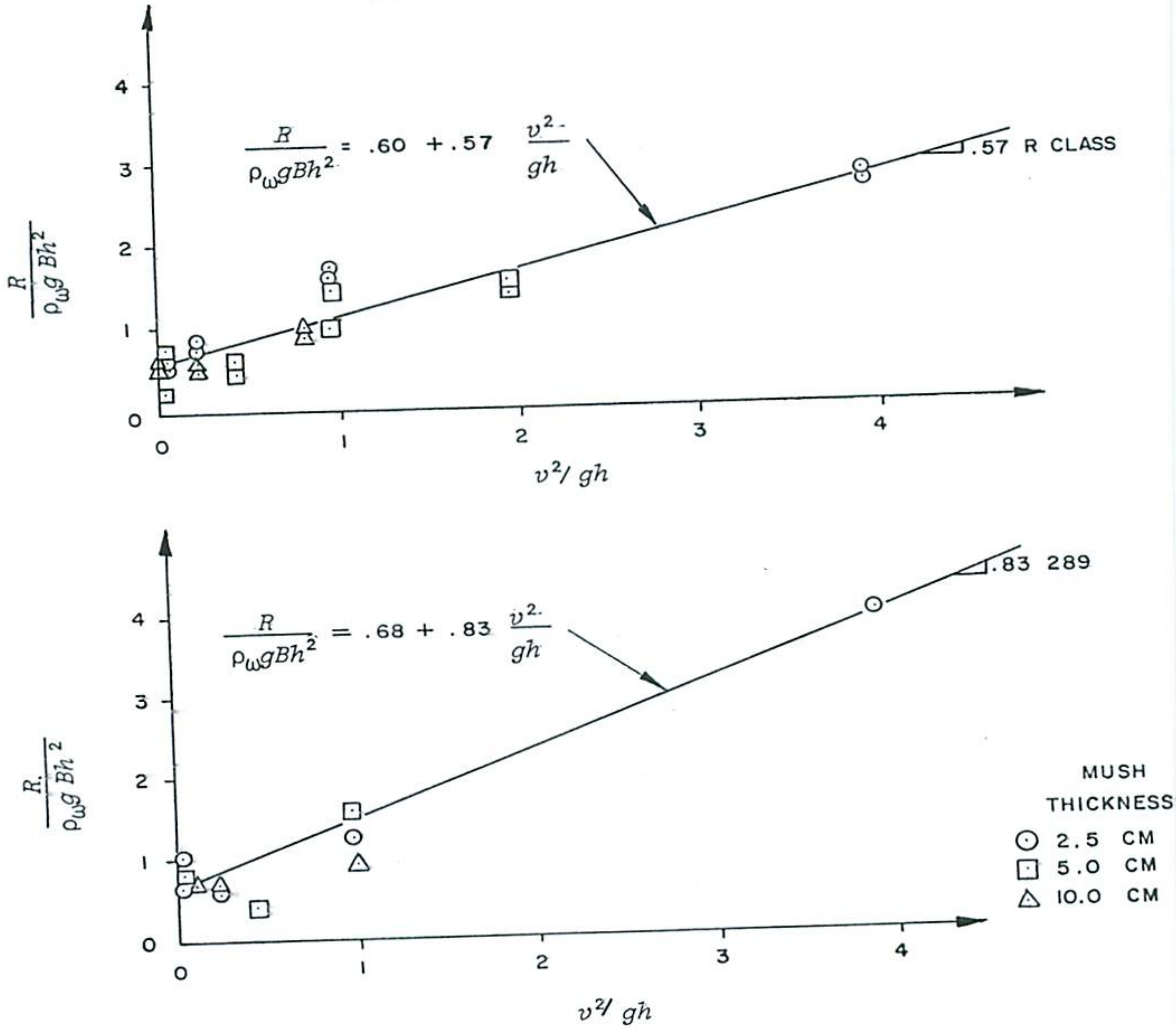


FIGURE 9 DIMENSIONLESS TOWING RESISTANCE VERSUS DIMENSIONLESS VELOCITY SQUARED.



96

TABLE 4

RESULTS OF MUSH ICE TESTS

Date 1973	Run	Model	Draft	R (kg)	h (cm)	v (cm/sec)	$\frac{v}{\sqrt{gh}}$	$\frac{v^2}{gh}$	$\frac{R}{\rho_\omega g B h^2}$
3-1	M2a	289	Design	0.575	5.0	34.4	0.659	0.434	0.422
	b			2.17		69.2	0.991	0.982	1.59
	d			1.12		15.9	0.232	0.0538	0.828
	M3a	R	Design	0.631	5.0	36.3	0.659	0.434	0.464
	b			1.44		70.1	0.991	0.982	1.05
	c			1.92		98.5	1.40	1.96	1.41
	d			1.07		16.1	0.233	0.053	0.787
	M4a	R	Deep	0.85	5.0	34.1	0.659	0.434	0.625
	b			2.05		69.4	0.991	0.982	1.51
	c			2.11		98.5	1.40	1.96	1.55
	d			1.03		16.6	0.232	0.053	0.757
3-2	M5a	R	Deep	2.76	10.0	18.7	0.187	0.0350	0.507
	b			2.98		48.8	0.492	0.242	0.546
	c			5.71		91.1	0.917	0.841	1.05
	d			3.27		10.8	0.109	0.0119	0.602
3-2	M6a	R	Design	3.17	10.0	18.5	0.187	0.035	0.583
	b			3.34		48.8	0.492	0.242	0.616
	c			5.22		90.5	0.917	0.841	0.957
	d			2.91		10.1	0.109	0.0119	0.535
	M7a	289	Design	3.83	10.0	18.5	0.187	0.035	0.704
	b			4.06		48.8	0.492	0.242	0.747
	c			5.40		99.4	1.00	1.0	0.094
	d			4.31		10.6	0.109	0.0119	0.791
3-5	M8a	289	Design	0.217	2.5	23.9	0.484	0.234	0.617
	b			0.45		49.0	0.988	0.976	1.28
	c			1.39		98.6	1.98	3.92	3.97
	d			0.365		10.6	0.212	0.045	1.04
	M9a	R	Design	0.291	2.5	23.9	0.484	0.234	0.83
	b			0.621		49.0	0.988	0.976	1.77
	c			0.986		98.6	1.98	3.92	2.81
	d			0.194		10.4	0.212	0.045	0.552
	M10a	R	Deep	0.274	2.5	24.1	0.484	0.234	0.779
	b			0.599		48.8	0.988	0.976	1.70
	c			0.975		97.8	1.98	3.92	2.78
	d			0.234		10.4	0.212	0.045	0.674

was evaluated at a full scale ship speed of 3 knots. The results are plotted in Figure 10. The plot demonstrates that the mush resistance of the ROGERS Class will always be greater than that of the "R" Class by at least twelve percent.

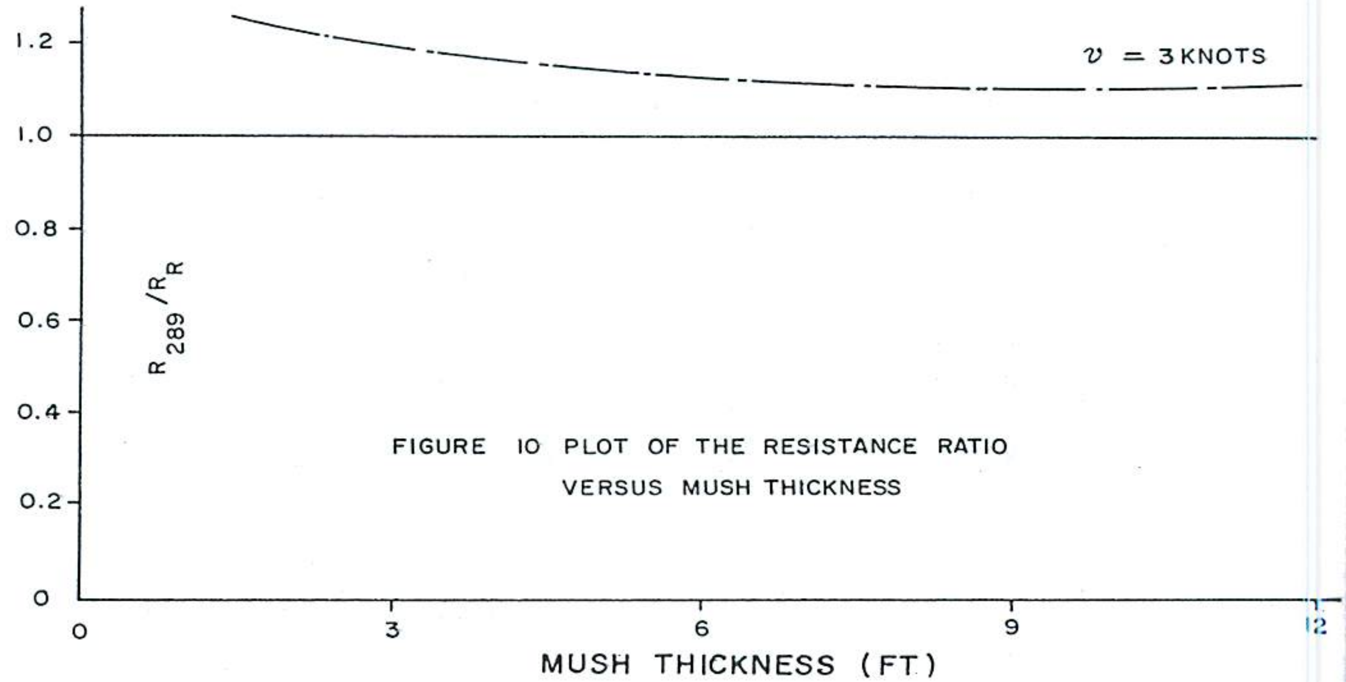
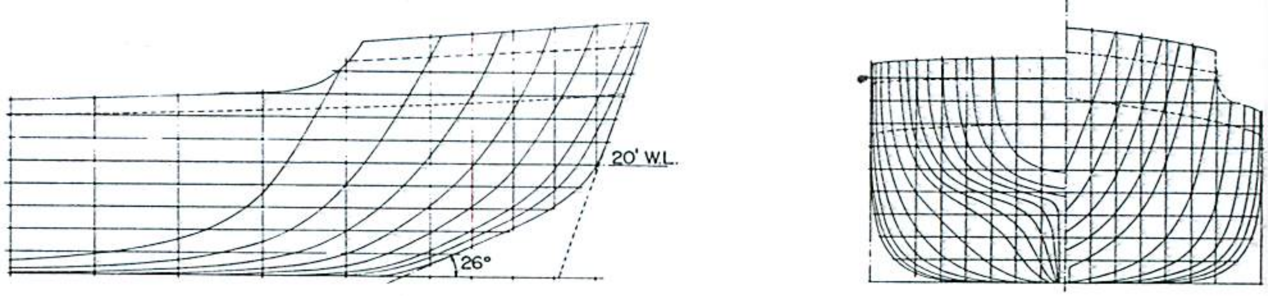
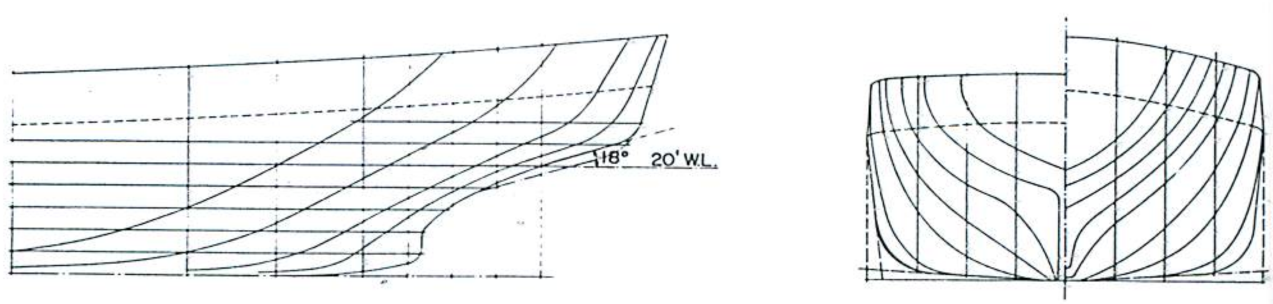


FIGURE 10 PLOT OF THE RESISTANCE RATIO VERSUS MUSH THICKNESS

FIGURE 11 - LINES OF THE ROGERS AND THE "R" CLASS ICEBREAKER



C.C.G.S. NORMAN M^c LEOD ROGERS



"R" CLASS ICEBREAKER

CONCLUSIONS

Based upon the analysis of the results of the model tests described in this paper taken in combination with previously acquired model and full scale data for several classes of icebreakers and icebreaking ships we conclude that:

1. The "R" Class hull form will exhibit icebreaking performance in uniformly thick ice fields which is superior to the performance of the CCGS NORMAN MCLEOD ROGERS in similar ice conditions and that the foregoing is true for operating drafts on both ships between and including twenty and twenty-four feet.

2. The "R" Class hull form will exhibit ice transiting performance in fields of finely broken ice, commonly referred to as mush or shuga, which is superior to the performance of the ROGERS in similar ice conditions and that the foregoing is true for operating drafts of both ships between and including twenty and twenty-four feet.

3. The effect of hull surface/ice surface friction coefficient upon that portion of the continuous icebreaking resistance which is not speed dependent is significant. A 100 percent change in friction factor will cause a corresponding change of 100 percent in non-speed dependent ice resistance within the range of ice conditions and ship which were investigated.

4. The results of these model tests, extrapolated to full scale conditions indicate that the relationship between the continuous icebreaking resistance and the variables, ship speed and ice thickness are consistent with the results of full scale icebreaking trials of ships with similar gross dimensions.

5. The continuous icebreaking performance of the "R" Class icebreaker at its deep draft (24') is superior to its performance at its design draft (20').

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2. Lewis, J.W. and Benze, D.L., "MODEL ICE RESISTANCE TESTS OF THE USCGC MACKINAW IN UNIFORMLY THICK ICE COVER", Technical Progress Report No. 00771-3 Contract No. DOT-CG - 13189-A.

TABLE OF SYMBOLS

Horizontal resistance	–	R
Ice Flexural Strength	–	σ_f
Ice Thickness	–	h
Hull Surface/Ice Surface Coefficient of friction	–	μ
Ship Speed	–	v
Breadth of Ship) Width of cantilever beam)	–	B
Force on cantilever beam	–	P_f
Length of cantilever beam	–	ℓ
Weight	–	W
Mass Density of water	–	ρ_ω
Acceleration of gravity	–	g
Shimansky Icecutting coefficient	–	μ_0
Shimansky Icebreaking coefficient	–	η_2

100