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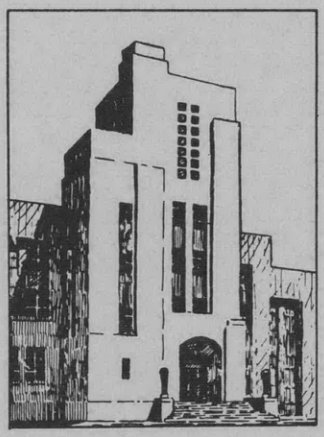
BEHAVIOR OF THE SERIES 60, 0.60 BLOCK COEFFICIENT MODEL IN WAVES

by

V.G. Szebehely, Dr. Eng. and S.E. Lee



RESEARCH AND DEVELOPMENT REPORT

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NOTATION

C_t	Total model resistance coefficient referred to the nominal wave height (h)
$(C_t)_S$	Total model resistance coefficient in still water
h	Nominal wave height (= 1.25 in.), trough to crest
h_m	Measured wave height, trough to crest
R_a	Added model resistance in waves of height h
R_S	Total model resistance in still water
R_t	Total model resistance referred to the nominal wave height (h)
$(R_t)_m$	Measured total model resistance in waves of height h_m
S	Nominal wetted surface of model (= 4.26 square feet)
V	Model speed
z_o	Amplitude of heave referred to the nominal wave height (h)
$(z_o)_m$	Measured amplitude of heave in waves of height h_m
δ_m	Measured heave lag referred to pitch in waves of height h_m
ζ_o	Dimensionless amplitude of heave
ϑ	Maximum wave slope referred to the nominal wave height (h)
ϑ_m	Maximum wave slope computed from the measured wave height (h_m)
λ	Wave length
ρ	Density of water in tank $\left(= 1.936 \frac{\text{slugs}}{\text{cu ft}}\right)$
Ψ_o	Dimensionless amplitude of pitch
ψ_o	Amplitude of pitch referred to the nominal wave height (h)
$(\psi_o)_m$	Measured amplitude of pitch in waves of height h_m

ABSTRACT

Results of seaworthiness tests carried out as part of the activities of the Series 60 Task Group of the Seaworthiness Panel of the Society of Naval Architects and Marine Engineers are presented in the form of tables and graphs. A 5-ft model of the Series 60, parent form of 0.60 block coefficient was tested in still water and in waves 3.75, 5, 6.25, and 7.50 ft long having a nominal wave height of 1.25 in. Resistance, amplitudes of pitch and heave, speeds and phase lags were measured in the range of 0 to 4 fps.

INTRODUCTION

The tests described in this report were performed during the summer of 1955 as part of the activities of the Series 60 Task Group of the Seaworthiness Panel of the Society of Naval Architects and Marine Engineers. The objective of the Task Group is to correlate testing techniques and experimental results of various towing tanks. The present report contains the findings of the Taylor Model Basin staff based on tests carried out in the 140-ft basin using a gravity-type towing arrangement and a pneumatic wavemaker.

DESCRIPTION OF TESTS

The 5-ft model of the Series 60 parent form of 0.60 block coefficient used in these tests is the property of the Experimental Towing Tank, Stevens Institute of Technology. This model was used by all towing tanks in order to eliminate differences in shape, surface, and dynamic characteristics from the result. It was made of wood with a varnished surface. No turbulence stimulation was used. The weight of the model equipped with towing bracket was 33.27 lb. Its radius of gyration, measured by the customary bifilar method, was 25.9 percent of the length. The length between perpendiculars is 5 ft.

The model was first tested in still water and its resistance was determined at various speeds. The testing was then continued in waves 3.75, 5, 6.25, and 7.5 ft long and with a nominal height of 1.25 in. The motion was photographed with a 35-mm movie camera; the waves were measured with a capacitance-type wave-height recorder.

ANALYSIS OF TEST RESULTS

RESISTANCE

1. Still-Water Resistance

The tow forces obtained from the tests were corrected for the internal friction (tare) of the towing equipment. The resistance values so obtained are denoted by R_S. The total model resistance coefficient, defined by

$$(C_t)_S = \frac{R_S}{\frac{\rho}{2} V^2 S} \qquad [1]$$

was also computed, with S = 4.26 sq ft and ρ = 1.936 slugs/cu ft. The variation in water temperature was insufficient to alter the value for the density. Both R_S and $(C_t)_S$ are plotted in Figure 1.

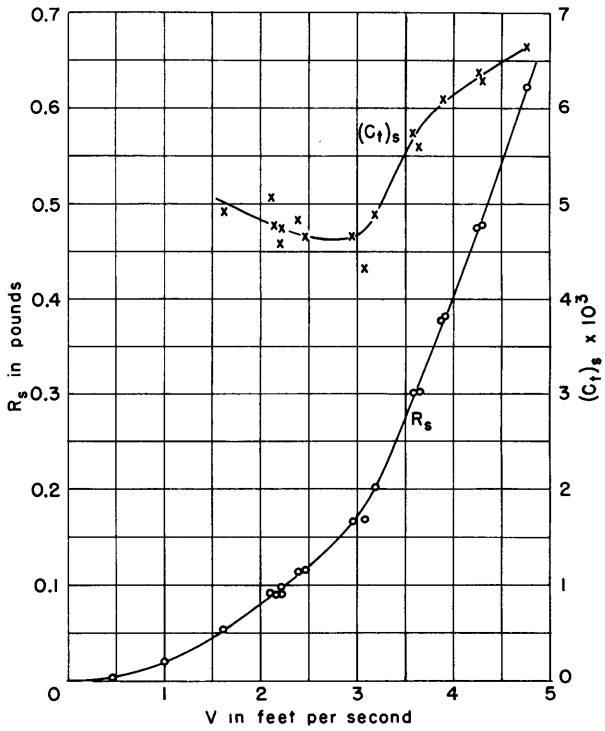

Figure 1 - Still-Water Resistance of Series 60, 0.60 Block Coefficient Model, SNAME Tests

2. Resistance in Waves

The resistance in waves was assumed to be of the form

$$R_t = R_S + R_a \qquad [2]$$

where R_t is the total resistance in waves at a given speed,

R_S is the still-water resistance at the same speed, and

R_a is the added resistance resulting from wave action.

The tow forces measured in the wave tests were first corrected for tare, and then the total resistance $(R_t)_m$ was recorded for each run. Since the same blower rpm and valve frequency of the wavemaker do not always result in consistent wave heights, the measured resistances were corrected to a nominal wave height of 1.25 in. by the formula

$$R_a = [(R_t)_m - R_S]\left(\frac{h}{h_m}\right)^2 \qquad [3]$$

where R_a is the added resistance corresponding to a nominal wave height h = 1.25 in.,

$(R_t)_m$ is the total resistance measured in waves of height h_m, and

R_S is the still-water resistance corresponding to the speed at which the wave test was performed.

Using the $(R_t)_m$ values from the tests and the corresponding still-water resistances (R_S) from Figure 1, the added resistances (R_a) were computed from Equation [3]. Finally, using Equation [2], the total resistances (R_t) were obtained. The total model resistance coefficient in waves was computed by

$$C_t = \frac{R_t}{\frac{\rho}{2} V^2 S} \qquad [4]$$

or, after substitution, by

$$C_t = \frac{R_S (h_m^2 - h^2) + (R_t)_m h^2}{\frac{\rho}{2} V^2 S h_m^2} \qquad [5]$$

MOTIONS

The experimentally obtained heave and pitch amplitudes, $(z_o)_m$ and (ψ_o) formed the basis of the motion analysis. The dimensionless heave and pitch amplitudes were computed by the following equations:

$$\text{dimensionless heave amplitude: } \zeta_o = \frac{2(z_o)_m}{h_m} \qquad [6]$$

$$\text{dimensionless pitch amplitude: } \Psi_o = \frac{(\psi_o)_m}{\vartheta_m} \qquad [7]$$

where $\vartheta_m = \frac{\pi h_m}{\lambda}$ is the maximum wave slope corresponding to h_m and λ.

The heave and pitch amplitudes corresponding to the nominal wave height (h) were computed from

$$z_o = \frac{h}{2} \zeta_o \qquad [8]$$

and

$$\psi_o = \vartheta \Psi_o \qquad [9]$$

where $\vartheta = \frac{\pi h}{\lambda}$ is the maximum wave slope corresponding to h.

The heave and pitch amplitudes referred to the nominal wave height can be also computed from

$$z_o = (z_o)_m \frac{h}{h_m} \qquad [10]$$

and

$$\psi_o = (\psi_o)_m \frac{h}{h_m} \qquad [11]$$

The lag of heave referred to pitch (δ_m) was also obtained from the experiments. No wave-height correction was applied to the measured δ_m values because of the experimental difficulty in determining phase lags in general and because of the uncertainty of the theory involved.

PRESENTATION OF RESULTS

The resistance of the model in still water (R_S) and the total model resistance coefficient $(C_t)_S$ are plotted versus model speed (V) in Figure 1. Table 1 gives the corresponding numerical values of V, R_S, and $(C_t)_S$.

The behavior of the model in waves of various lengths is shown in Table 2 and in Figure 2. The table shows measured and computed items. The measured quantities are the speed (V), total model resistance in waves $(R_t)_m$, heave amplitude $(z_o)_m$, pitch amplitude $(\psi_o)_m$ heave lag referred to pitch (δ_m), and wave height (h_m). The computed items are the maximum wave slope (ϑ_m), added and total model resistances (R_a and R_t), total model resistance coefficient (C_t), dimensionless heave and pitch amplitudes (ζ_o and Ψ_o), and heave and pitch amplitudes (z_o and ψ_o).

TABLE 1

Resistance of 5-Foot Model in Still Water

Test No	V fps	R_S lb	$(C_t)_S \times 10^3$	Test No	V fps	R_S lb	$(C_t)_S \times 10^3$
115	0.47	0.003	–	117	2.96	0.168	4.65
111	1.00	.02	–	12	3.08	.169	4.32
11	1.01	.021	–	112	3.18	.202	4.90
122	1.61	.053	4.95	108	3.58	.303	5.75
2	2.11	.093	5.08	13	3.64	.304	5.58
105	2.16	.092	4.80	100	3.88	.379	6.11
17	2.22	.093	4.58	3	3.89	.381	6.12
116	2.22	.097	4.77	110	4.26	.476	6.38
101	2.40	.115	4.85	19	4.30	.478	6.30
1	2.47	0.117	4.66	20	4.76	0.622	6.65

TABLE 2

Behavior of the Model in Waves of Various Length and Nominal Height of 1.25 Inch

	Test No	V fps	$(R_t)_m$ lb	$(z_o)_m$ in.	$(\psi_o)_m$ deg	δ_m deg	h_m in.	ϑ_m deg	R_a lb	R_t lb	$C_t \times 10^3$	ζ_o	Ψ_o	z_o in.	ψ_o deg
3.75-ft Waves	121	0	0.025	0.19	1.59	See page 7 of text.	1.21	4.82	0.027	0.027	∞	0.30	0.33	0.190	–
	77	0.98	.055	.14	2.47		1.13	4.50	.043	.0625	15.9	.25	.55	.155	2.75
	80	0.99	.062	–	2.26		1.17	4.66	.048	.068	16.9	–	.49	–	2.40
	83	1.32	.092	.16	1.43		1.35	5.38	.049	.084	11.7	.24	.26	.150	1.30
	82	1.65	.110	.14	1.12		1.18	4.70	.064	.117	0.3	.24	.24	.150	1.20
	85	2.69	.186	.07	0.56		1.16	4.62	.053	.193	6.5	.12	.12	.075	0.60
	87	3.06	.224	.10	0.32		1.35	5.38	.042	.217	5.6	.15	.06	.094	0.30
	88	3.73	.379	0.05	0.28		1.39	5.53	.040	.370	6.5	0.07	0.05	0.044	0.25
	89	3.95	0.427	–	–		1.33	5.30	0.033	0.423	6.6	–	–	–	–
5-ft Waves	118	0	0.045	0.15	2.30	–	1.31	3.91	0.041	0.041	∞	0.29	0.59	0.180	2.20
	35	1.20	.094	.36	3.55	31	1.29	3.87	.060	.090	15.2	0.56	.93	.350	3.45
	34	1.47	.142	.52	3.18	32	1.28	3.82	.097	.139	15.5	0.81	.83	.505	3.10
	26	1.88	.205	.60	3.27	36	1.27	3.79	.131	.201	13.9	0.94	.86	.585	3.20
	92	1.88	.209	.56	3.18	35	1.27	3.79	.135	.205	14.1	0.88	.84	.550	3.15
	32	2.13	.238	.62	2.94	35	1.21	3.61	.158	.248	13.2	1.02	.82	.635	3.05
	31	2.24	.238	.63	3.05	47.5	1.25	3.73	.138	.238	11.5	1.01	.82	.630	3.05
	28	2.84	.286	.61	2.41	55	1.26	3.76	.135	.285	8.6	0.97	.56	.605	2.40
	29	3.48	.381	.48	1.98	67.8	1.22	3.64	.117	.387	7.8	0.79	.54	.495	2.05
	30	3.90	0.476	0.35	1.70	76.5	1.23	3.67	0.091	0.481	7.7	0.57	0.46	0.356	1.75
6.25-ft Waves	119	0	0.026	0.28	2.14	94	1.49	3.56	0.019	0.019	∞	0.37	0.60	0.230	1.80
	58	0.63	.028	.25	2.73	86	1.26	3.01	0.020	.028	17.1	0.39	0.91	.240	2.70
	53	1.68	.122	.56	3.64	30	1.29	3.08	.061	.118	10.2	0.87	1.18	.545	3.55
	44	1.94	.151	.59	3.82	36	1.24	2.96	.078	.153	9.9	0.95	1.29	.595	3.85
	55	2.25	.207	.67	4.10	40	1.29	3.08	.101	.201	9.7	1.03	1.33	.645	3.95
	46	2.58	.367	0.78	4.22	34	1.22	2.91	.149	.214	10.0	1.28	1.45	.800	4.35
	48	2.90	.334	1.01	4.05	43	1.27	3.03	.174	.329	9.5	1.59	1.33	0.990	4.00
	50	3.17	.382	1.07	3.82	36	1.26	3.01	.184	.379	9.2	1.70	1.27	1.060	3.80
	52	3.31	.423	1.15	3.71	45	1.33	3.18	.176	.401	8.9	1.73	1.17	1.080	3.50
	59	3.52	.478	1.13	3.47	52	1.32	3.15	.181	.458	9.0	1.71	1.10	1.070	3.30
	95	3.56	.477	1.13	3.54	54	1.33	3.18	.165	.455	8.8	1.70	1.11	1.060	3.35
	60	3.96	0.603	1.08	3.16	72	1.30	3.11	0.193	0.586	9.1	1.65	1.02	1.030	3.05
7.5-ft Waves	120	0	0.026	0.38	2.13	87.5	1.26	2.51	0.026	0.026	∞	0.61	0.85	0.38	2.10
	73	1.63	.092	–	2.67	52	1.31	2.61	.034	.088	8.0	–	1.02	–	2.55
	71	2.70	.207	0.64	3.41	37.5	1.30	2.59	.067	.207	6.8	0.98	1.32	0.61	3.30
	72	3.14	.284	.75	3.66	39	1.31	2.61	.083	.279	6.9	1.14	1.40	.71	3.50
	69	3.33	.323	.77	3.72	37	1.21	2.41	.094	.329	1.2	1.27	1.54	.79	3.85
	98	3.53	.380	.90	3.60	41	1.22	2.43	.095	.382	7.4	1.47	1.48	0.92	3.70
	67	3.68	.440	0.95	3.74	43	1.13	2.25	.134	.464	8.3	1.68	1.66	1.05	4.15
	66	4.04	.554	1.12	3.49	51.5	1.22	2.43	.146	.561	8.4	1.84	1.44	1.15	3.60
	63	4.20	.603	1.05	3.42	54	1.21	2.41	.158	.616	8.4	1.74	1.42	1.09	3.55
	64	4.49	.718	1.07	3.03	63	1.22	2.43	.187	.723	8.7	1.75	1.25	1.09	3.15
	65	4.66	0.815	1.10	2.78	62	1.30	2.59	0.208	0.795	8.9	1.69	1.07	1.06	2.65

The table is not complete. Twenty out of 639 values are missing, corresponding to partially unsuccessful experiments.

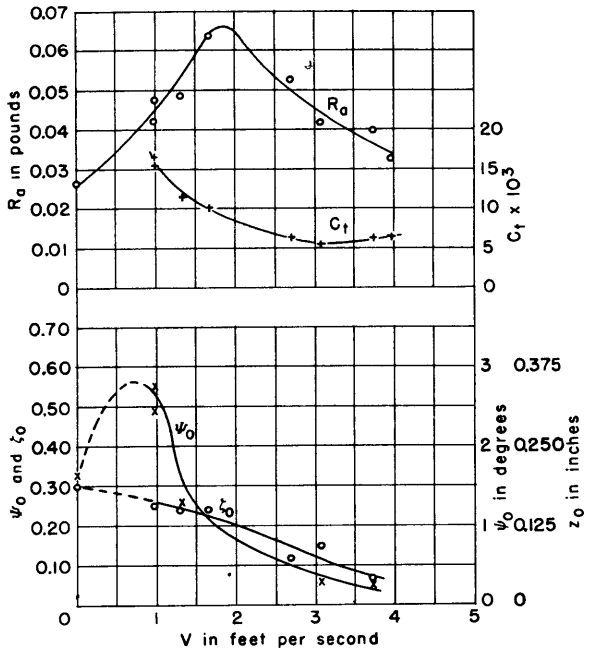

Figure 2a - 3.75-Foot Waves

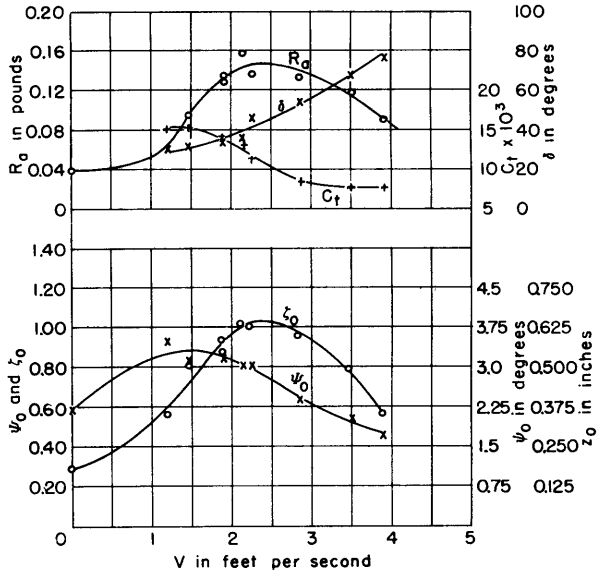

Figure 2b - 5-Foot Waves

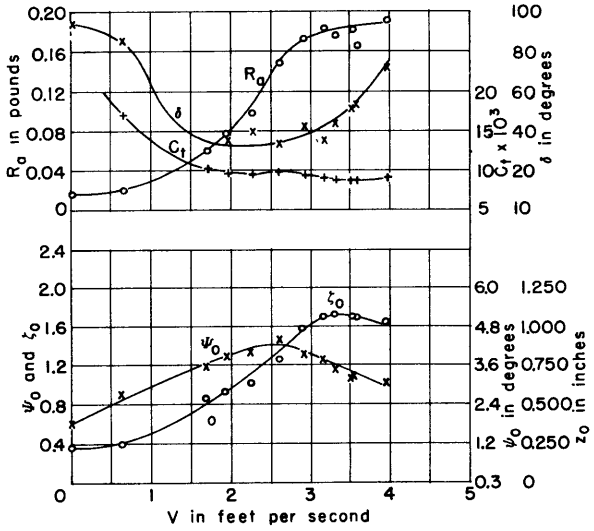

Figure 2c - 6.25-Foot Waves

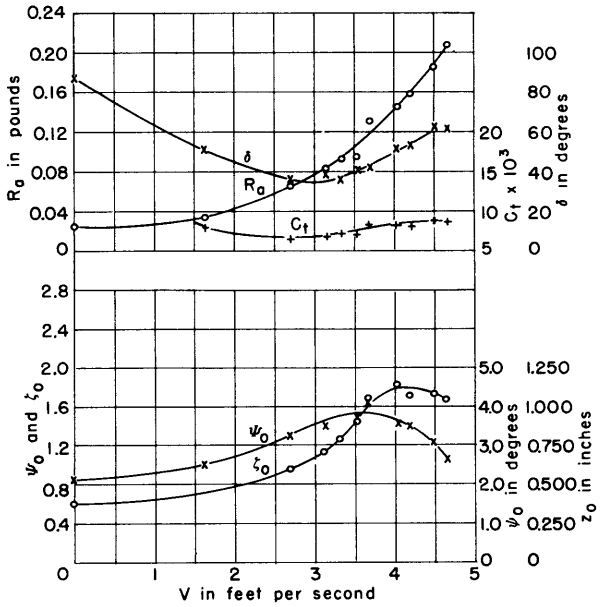

Figure 2d - 7.5-Foot Waves

Figure 2 - Resistance of Series 60, 0.60 Block Coefficient Model, SNAME Tests

Nominal wave height is 1.25 in.

Figure 2 shows the computed added resistance, the heave lag referred to pitch, the computed total model resistance coefficient, the computed dimensionless heave and pitch amplitudes, and the computed heave and pitch amplitudes all plotted versus model speed. The points shown correspond to the computed values, the curves were faired through them.

No values for δ_m are given for $\lambda = 3.75$ ft. The experimental values were not considered to be sufficiently reliable and so are excluded from the results in Table 2 and Figure 2. Figure 3 shows the total model resistance in still water and in waves plotted against speed. The familiar speed-reduction curves (Figure 4) were obtained from Figure 3 by cross plotting.

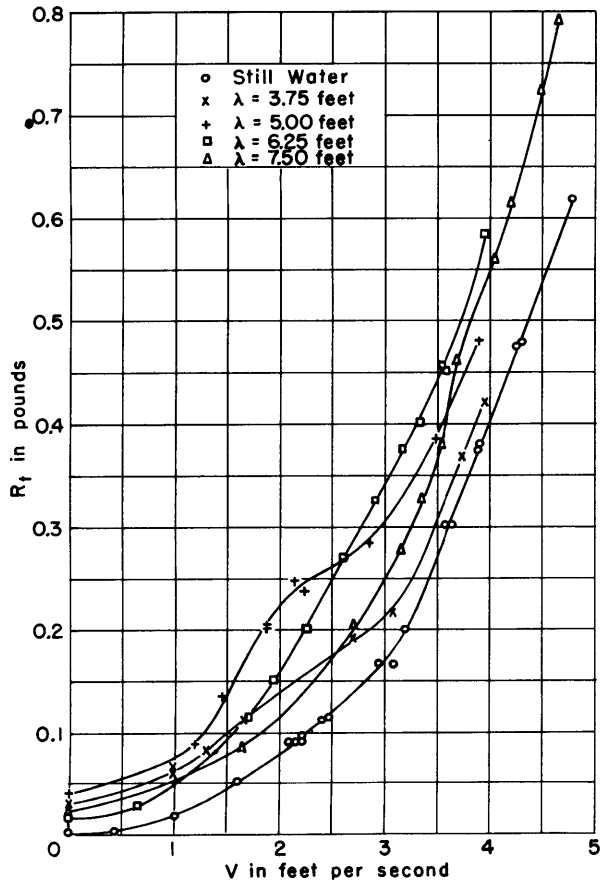

Figure 3 - Total Model Resistance Series 60, 0.60 Block Coefficient Model, SNAME Tests

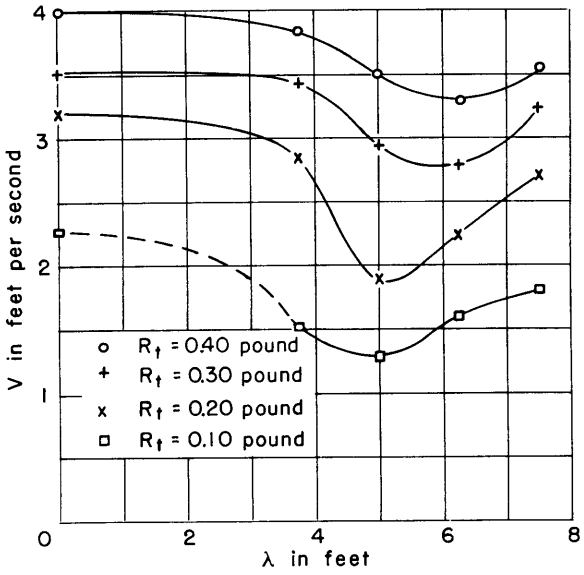

Figure 4 - Speed Reduction Series 60, 0.60 Block Coefficient Model, SNAME Tests

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1 DIR, Swedish State Shipbldg Exper Tank, Goteborg, Sweden

1 DIR, Aero Res Inst of Sweden, Ranhammarsvagen 12, Ulsvunda, Sweden

2 O.N.E.R.A., 25-39 Avenue de la Division Leclerc, Chatillon-Sous-Bagneux (Seine), Paris, France
1 Dr. L. Malavard

2 Superintendent, Ship Div, Natl Physical Lab, Teddington, Middlesex, England

2 DIR, British Shipbldg Res Assn, Curzon St., London, W.1, England
1 Editor, Journal of the British Shipbldg Res Assn

2 Technische Hoge School, Laboratorium voor Scheepsbouwkunde Nieuwe Laan 76, Delft, The Netherlands, Attn. Dr. ir J. Gerritsma

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