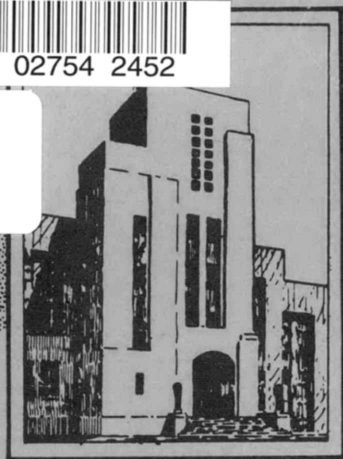

NAVY DEPARTMENT

DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

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APPLIED MATHEMATICS

SPEED REDUCTION IN WAVES

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by

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Margaret D. Bledsoe

HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

April 1958

Report 1083

SPEED REDUCTION IN WAVES

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Page

LIST OF TABLES

NOTATION

B	Beam
C_b	Block coefficient
F	Froude number
F_0	Still water Froude number
H	Draft
h	Wave height, trough to crest
L	Length between perpendiculars
V	Speed
V_d	Design speed in still water
V_0	Still water speed
Δ	Displacement
λ	Wave length
λ_c	Critical wave length

ABSTRACT

This report presents the results of an experimental study to determine the effect of various parameters governing speed reduction in a seaway. Models of three typical ships (block coefficients varying from 0.50 to 0.75) were tested in head seas in regular waves, ranging in length from approximately one-half to twice ship length, for several wave heights and still water thrusts. The speed loss due to the added resistance in waves was determined for each condition. The results are presented in the form of graphs showing the critical wave length (wave length for maximum speed loss) as a function of wave height and still water speed. Also included are plots showing the percentage speed loss for constant wave lengths as a function of the above parameters; and contours of constant speed loss in waves of various lengths and heights. Finally, graphs are presented comparing the performance of the three vessels.

INTRODUCTION

At the present time no criteria are available from which the limiting acceptable sea conditions for conducting speed trials can be determined. Consequently, it has been the general practice to wait for almost perfect weather conditions so that reliable results could be assured. It was the original purpose of this project to establish the threshold conditions under which a ship's speed is affected by the seaway. These threshold conditions could then serve as a general guide in evaluating full-scale trials. Thus, the study should have been restricted only to mild sea conditions. However, the testing accuracy is relatively poor in these conditions and since the present tendency is to go to higher sustained speeds at sea, the original purpose of the study was extended to include some general information on factors governing speed reduction in a seaway. Accordingly, the tests were carried out under more serious sea conditions than those required for establishing the threshold conditions, the latter then being obtained by interpolation to the condition of small sea. The results of the present study, while containing information pertinent for evaluating standardization trials, may also provide general information on speed loss at sea.

DESCRIPTION OF TESTS

Models of three typical ships were tested in the 140-ft basin. In this facility a gravity-type dynamometer is used as the towing mechanism and waves are produced by a pneumatic-type generator. Wave heights are measured by a capacitance-type gage where the unbalance of the bridge is a function of the immersion of the element.[1] The bridge output is recorded by a Sanborn-type recorder.

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[1]References are listed on page 28.

The models tested were a 6.42-ft model of a destroyer escort, a 5-ft model of the Series 60 parent form of 0.60 block coefficient,[2] and a 5-ft model of the cargo ship M/S SAN FRANCISCO. The ship lines are shown in Figures 1 through 3 and the form characteristics are listed in Table 1.

TABLE 1

Characteristics of Ship Forms

Characteristics	Destroyer Escort	Series 60	M/S SAN FRANCISCO
Model Number	4369	4509	3572-5A
Length L_{BP}, ft	308	400	429
Beam B, ft	36.7	53.33	59
Full Load Draft Amidships, H, ft	11.5	21.33	24.37
Corresponding Displacement Δ, tons	1802	7807	13,264.4
Block Coefficient, C_b	0.50	0.60	0.75
Design Speed, knots	25	17	14

The lines of the ships selected for the work represent a considerable range in ship form. The destroyer escort has fine lines and a low block coefficient (C_b = 0.50), the SAN FRANCISCO has full lines with a block coefficient of 0.75, and the Series 60 is between the above two extremes with a block coefficient of 0.60.

The models were ballasted for displacement and draft conditions corresponding to that listed in Table 1 for the ships. The radius of gyration determined by the bifilar method was 25 percent of the length for each of the models. The dimensionless natural periods associated with these radii of gyration are listed in Table 2.

TABLE 2

Dimensionless Natural Periods $\tau = \frac{T}{\sqrt{\frac{L}{g}}}$

Ship	Natural Pitching Period	Natural Heaving Period
Destroyer Escort	1.39	1.34
Series 60	1.77	1.77
M/S SAN FRANCISCO	1.93	1.88

Each model was first tested in still water and the tow force was determined at several speeds. Tests were then conducted for three still-water thrusts corresponding approximately to 33, 67, and 100 percent design speed in head seas in regular waves whose length ranged from approximately 0.5 to 1.5 ship lengths. The tests were made at wave heights of 1, 2, and 3 in. model scale corresponding approximately to values of ship length to wave height of 60, 30, and 20. Because of the severity of some of the above specified conditions the speed reduction was found to be so serious that the forward speed of the models could not be determined with any certainty. These regions of uncertainity are indicated in the graphs by the dotted lines.

The range of test conditions was somewhat limited by the capacity of the facility used. To the extent that this range did not include possible sea conditions, the results are incomplete.

DISCUSSION OF RESULTS

In order to establish reference conditions for the wave tests, tow forces were found for a series of speeds in still water. These forces were then corrected for the tare in the towing system and the resistances so obtained are plotted in Figures 4a, 4b, and 4c. Wave tests were performed for thrusts corresponding to approximately one-third, two-thirds, and design speed for each of the ships. The experimentally obtained speeds for the various test conditions are listed in the Appendix.

Faired curves of speed versus wave height for constant wave lengths are plotted in Figures 5, 6, and 7. The dashed portions of the curves indicate regions where the data have either been extrapolated since the test conditions were beyond the limit of the test facility used or the speed was somewhat uncertain because of the models' unsteady motion in the more severe conditions.

Figures 8, 9, and 10 obtained from Figures 6 through 7 show speed loss in waves for constant wave heights. From these figures it can be seen that the region for maximum loss in speed shifts toward the shorter wave lengths with increasing wave height for a constant tow force. Furthermore, as the tow force is increased, the critical region shifts toward the longer wave lengths for any wave height. This can be seen more clearly in Figures 11, 12, and 13 where the critical wave length has been plotted as a function of still water speed for various wave heights. A comparison of these three figures shows that for the same still water Froude number, the destroyer escort experiences maximum speed loss at lower values of λ/L than the other vessels. For example, considering the case of a tow force which could produce a speed in still water corresponding to a Froude number of 0.2, the λ/L for maximum speed reduction for the destroyer escort was 0.9 while that for the Series 60 and SAN FRANCISCO was 1.0 and 1.13, respectively, when running in waves of $h/L = 0.017$. The destroyer escort (Figure 11) does not experience maximum speed reduction in waves of λ/L of 1.0 and larger, and minimum h/L of 0.017 until a still water Froude number of approximately 0.3 is obtained.

From the speed reduction curves (Figures 8, 9, and 10) the percentage speed losses were evaluated and are shown in Figures 14 through 20. Here the percentage speed loss is shown as a function of wave height (ship scale) for various wave lengths. Figures 14 through 16 compare the three types of ships where the thrust used for each would produce design speed in calm water, Figures 17 through 19 show the same comparison for a thrust corresponding to approximately two-thirds design speed and finally, Figure 20 shows the percentage speed loss for the destroyer escort with thrust for one-third design speed in still water. Tests were not made at this thrust for the Series 60 and the SAN FRANCISCO. The speed in waves of these models at this thrust was so low that the accuracy and reliability of the results obtained in the facility used were in question. The difficulty of measuring low speeds arises from the fact that the motion of the model produces waves which disturb the prescribed wave pattern which in turn results in unsteady model motion.

A more useful presentation of the information contained in these figures is given in Figures 21 through 26. These figures show the combination of wave heights and wave lengths which result in 1, 5, 10, and 20 percent speed loss for each ship. Figures 21 and 22 are appropriate for the destroyer escort with thrust for design and two-thirds design still water speed. Figures 23 and 24 pertain to the Series 60 and Figures 25 and 26 to the SAN FRANCISCO for the above thrust conditions. Figures 21 through 26 may prove useful when determining the limiting sea condition in which standardization trials may be conducted. The acceptability of the sea condition depends on the type of ship and applied thrust as well as on the wave dimensions. If a maximum speed loss of 1 percent is permissible, Figure 21 shows that standardization trials for the destroyer escort (with thrust for design speed in still water) can be conducted effectively in waves whose length is 75 percent of the ship length if the wave height is no greater than 3 ft. In longer waves the trial results will still be useful if the wave heights are smaller; at the critical wave length (λ = 1.141), the maximum acceptable wave height is 2 ft. At the lower thrust (Figure 22) the 1-percent speed loss is obtained for λ/L = 0.75 when the wave height is approximately 1 ft. Figures 23 and 25 show that acceptable sea conditions for trial purposes at design speed are more limited for the cargo and merchant ships. For the ships which these represent, trials should not be run in waves higher than approximately 2.5 ft if the wave length is as large as 0.75L, and at the critical wave lengths the wave height should not be greater than 0.5 ft. A comparison of Figures 23 and 24, and 25 and 26, show the more limited extent of acceptable sea conditions for conducting the trials when the thrust is reduced.

Figures 27 through 31 compare the performance of the three ships in waves of constant height. Figures 27 and 28 show the speed reduction for thrust for design and two-thirds design speed in still water, respectively, in waves of h/L = 0.017. Figures 29 and 30 show the same comparison in waves of h/L = 0.033. The dashed line represents the estimated speed for the SAN FRANCISCO obtained by extrapolation from the original data. Figure 31 compares the speed reduction for the three models in waves of h/L = 0.017 for a thrust which would produce 14 knots (ship scale) in still water. In Figures 27 through 30 the speeds have been nondimensionalized by dividing by the still water speed V_0; namely, design and two-thirds design speed for the respective ships. Consequently, these figures do not compare the relative performances at identical values of the still water Froude number F_0. Therefore, proper interpretation of these figures requires that one consider not only that the ships represent different degrees of fullness, but also that the still water speeds for the three ships differ. In each of these figures it is seen that the critical region for speed loss in waves of constant height occurs at approximately the same λ/L value for the three models. For example, in Figure 27 for $h/L = 0.017$ and $V_0 = V_d$, the design speed in still water, the maximum speed loss occurs around $\lambda/L = 1.15$. For the higher wave height $h/L = 0.033$ and the lower thrust $V_0 = 2/3\ V_d$, the critical region, while the same for the three models, shifts toward the shorter wave lengths. These figures show also that the destroyer escort loses considerably less speed than either the cargo or merchant ship, there being little difference between the latter two with the exception of the case of $h/L = 0.033$ and thrust for two-thirds design speed. While the variation in block coefficient is greater between the Series 60 and the SAN FRANCISCO than between the destroyer escort and Series 60, it must be remembered that the design speeds of the Series 60 and the SAN FRANCISCO are much lower (17 and 14 knots, respectively) than that of the destroyer escort (25 knots). It is well-known that slow ships lose more speed in a seaway than a fast ship, under identical conditions.

In Figure 31 a comparison of the speed loss for the three models is made for waves of $h/L = 0.017$ and $V_0 = 14$ knots (ship scale). When compared at the same still water speed, the Series 60 and SAN FRANCISCO showed the same maximum speed loss while the destroyer escort's loss in speed was 7 percent less. It can also be seen in the figure that the critical wave length to ship length ratio shifts toward the higher values for the models of fuller form.

CONCLUSIONS

This study shows that if a 1 percent error is acceptable, standardization trials can be effectively conducted for the destroyer escort with thrust for design speed (25 knots) in waves whose length is as large as 0.75 ship length if the wave height does not exceed 3 ft. At lower thrusts the acceptable sea conditions are correspondingly reduced. The acceptable sea conditions for standardization trials on slower and fuller ships of the Series 60 and SAN FRANCISCO type are more limited.

A comparison of the speed loss experienced by the three models with thrust for the same still water speed shows equivalent speed loss for the merchant and cargo ships with the speed loss for the destroyer escort being less by 7 percent.

The critical wave length (wave length for maximum speed loss) for constant thrust was found to shift toward the shorter wave lengths with increasing wave height. For any wave height, the critical region shifted to the longer wave lengths as the tow force was increased. This trend was observed for each of the models tested.

APPENDIX

EXPERIMENTAL SPEEDS OBTAINED FOR VARIOUS TEST CONDITIONS

TABLE 3

Experimental Data for Wave Tests on Destroyer Escort Model

Thrust for design speed (V_0 = 6.06 fps).

Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in	Speed V fps
3	0.84	6.02	5	1.03	5.93	7.5	3.10	4.17
	0.94	6.02		0.93	6.04		3.11	4.02
	1.02	5.99		1.11	5.92	8	0.96	5.90
	1.37	5.94		2.03	5.82		1.87	5.48
	1.51	5.94		2.44	5.80		1.92	5.38
	1.57	5.90		2.67	5.73		3.06	4.41
	1.58	5.92		2.69	5.71	9	1.00	5.90
	1.82	5.88		3.18	5.64		2.03	5.53
	1.89	5.87	6	1.00	5.98		3.08	4.98
	2.24	5.88		2.01	5.63		3.14	4.93
4	1.01	5.98		2.96	4.98			
	1.45	5.95		3.05	4.88			
	1.98	5.96	7	0.99	5.88			
	1.98	5.90		1.84	5.42			
	2.12	5.87		2.10	5.20			
	2.75	5.86		2.81	4.21			
	2.85	5.84		3.01	3.95			
				3.03	3.97			
				3.09	3.91			

Thrust for 67 percent design speed (V_0 = 4.00 fps).

Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in.	Speed V fps
3	0.77	3.92	6	1.11	3.53
	0.88	3.91		1.96	2.72
	1.18	3.84		3.00	1.85
	1.63	3.74		3.04	1.83
	1.74	3.73	7	1.00	3.61
	1.79	3.68		1.08	3.56
	2.02	3.70		2.11	2.79
	2.12	3.68		3.10	1.99
4	1.04	3.89	8	0.90	3.75
	1.92	3.63		2.02	3.18
	2.06	3.56		3.09	2.39
	2.75	3.36	9	1.01	3.82
	2.89	3.33		2.04	3.41
5	1.02	3.73		3.14	2.80
	1.98	2.91			
	2.71	2.02			
	2.81	1.92			
	3.01	1.78			
	3.09	1.86			

Thrust for 33 percent design speed ($V_0 = 2.26$ fps).

Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ	Wave Height h in.	Speed V fps
3	0.87	2.11	7	0.99	1.90
	0.92	2.10		2.14	1.38
	1.27	1.96		2.24	1.36
	1.31	1.99			
	1.41	1.84	8	1.16	1.94
	1.58	1.84		2.00	1.52
				2.06	1.61
4	0.90	2.04			
	1.45	1.78	9	1.16	2.01
	1.87	1.40			
	2.08	1.35			
	2.08	1.43			
5	1.08	1.78			
	1.97	1.21			
	2.01	1.19			
6	1.14	1.78			
	1.05	1.77			
	1.06	1.81			
	1.93	1.20			
	2.02	1.21			

TABLE 4

Experimental Data for Wave Tests on Series 60, 0.60 Block Coefficient

Thrust for design speed (V_0 = 3.32 fps).

Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in.	Speed V fps
2	0.44	3.29	6	1.04	2.66
	0.98	3.24		1.97	1.85
				2.88	1.19
3	0.59	3.27		2.96	1.22
	1.05	3.23		3.04	1.17
	1.85	2.99		3.22	1.16
	2.45	2.88			
			7	0.97	2.99
4	0.61	3.26		1.96	2.43
	1.02	3.15		3.06	1.83
	2.04	2.04			
	2.09	2.13	8	0.86	3.20
	2.17	2.21		1.91	2.84
	2.20	2.08		2.85	2.39
5	1.04	2.69	9	1.04	3.24
	2.01	1.43		2.09	3.05
	2.11	1.38		3.04	2.72
	2.13	1.43			

Thrust for 67 percent design speed (V_0 = 2.23 fps).

Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in.	Speed V fps
2	0.37	2.19	8	0.89	2.11
	0.44	2.20		1.97	1.78
	0.95	2.15			
3	0.59	2.14	9	1.08	2.11
	1.16	2.04		2.14	1.93
	1.87	1.65			
4	1.00	1.67			
	1.89	0.76			
	2.01	0.78			
5	1.04	1.50			
	2.00	0.81			
	2.08	0.83			
6	1.00	1.76			
	2.05	1.19			
	2.09	1.20			
7	1.01	1.96			
	1.97	1.48			

TABLE 5

Experimental Data for Wave Tests on M/S SAN FRANCISCO Model

Thrust for design speed ($V_0 = 2.56$ fps).

Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in.	Speed V fps
2	0.52	2.52	5	0.92	2.06	7	3.10	1.37
	0.56	2.52		1.00	2.05		3.16	1.43
3	0.59	2.53		1.98	1.17	8	0.86	2.41
	0.60	2.52		1.98	1.15		0.88	2.44
	1.08	2.41		2.00	1.18		1.84	2.11
	1.54	2.22	6	0.93	2.00		1.84	2.13
	1.60	2.26		0.95	1.99		2.92	1.72
4	0.50	2.48		2.03	1.23	9	0.97	2.48
	0.61	2.42		2.04	1.23		0.98	2.50
	0.99	2.32		2.05	1.21		2.02	2.24
	1.00	2.33	7	1.00	2.27		2.04	2.27
	1.40	1.97		1.03	2.27		3.12	1.95
	1.61	1.87		1.93	1.81		3.17	2.02
	1.62	1.82		1.93	1.81			
				1.98	1.79			
				3.04	1.46			

Thrust for 67 percent design speed ($V_0 = 1.72$ fps).

Wave Length λ ft	Wave Height h in.	Speed V fps	Wave Length λ ft	Wave Height h in.	Speed V fps
2	0.44	1.65	6	0.99	1.21
	0.49	1.62		1.03	1.21
3	0.60	1.60		1.03	1.23
	0.60	1.60	7	0.94	1.49
	1.13	1.34		1.00	1.48
	1.13	1.34		1.90	1.00
4	0.62	1.46	8	0.81	1.58
	1.06	1.11		0.92	1.60
	1.13	1.06		1.74	1.24
	1.46	0.74	9	1.11	1.44
5	0.87	1.19		1.11	1.47
	1.01	1.19			
	1.03	1.17			
	1.04	1.20			

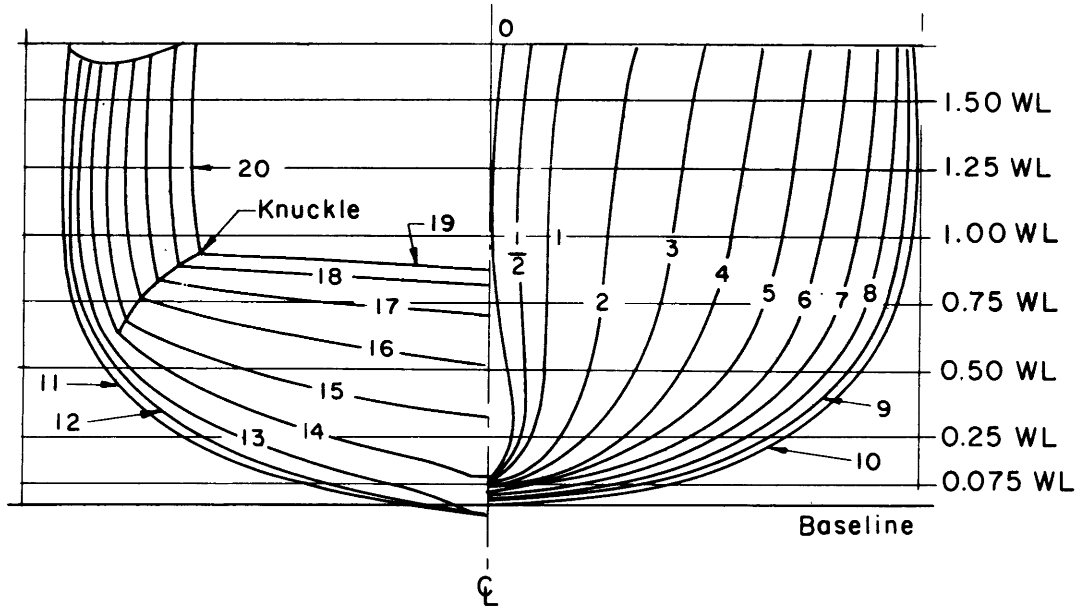

Figure 1 - Body Plan for Destroyer Escort

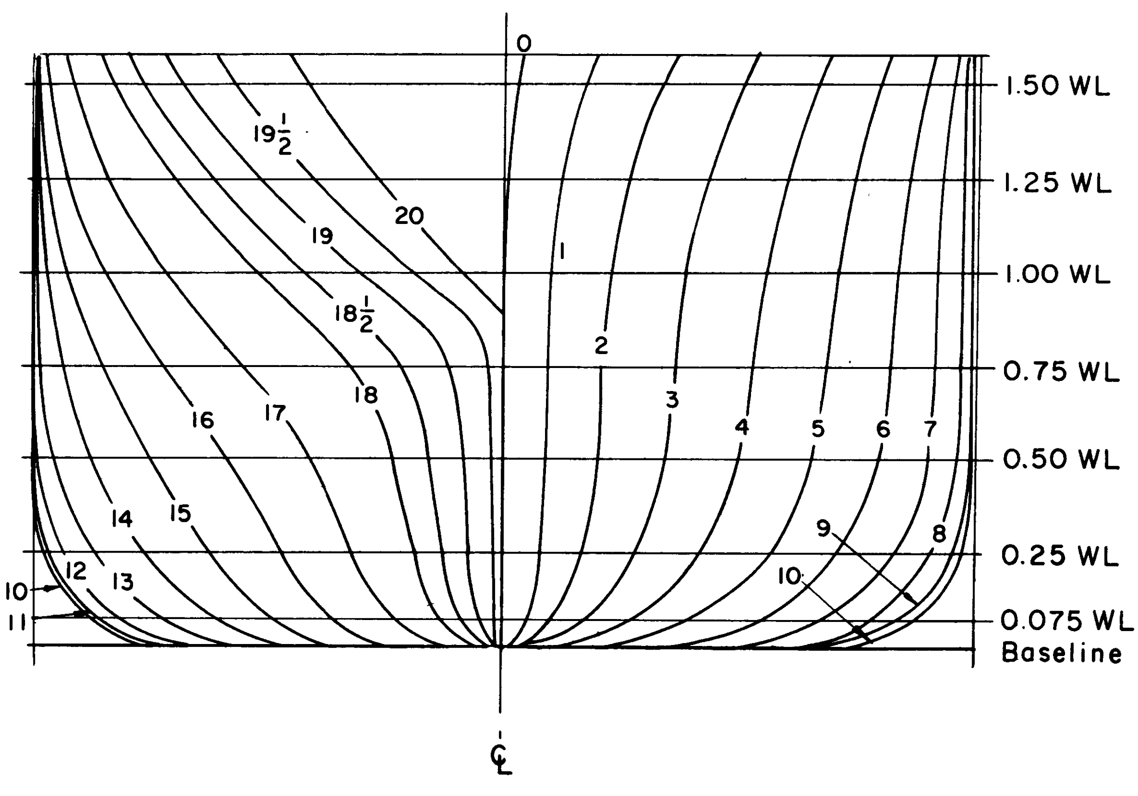

Figure 2 - Body Plan for Series 60, 0.60 Block Coefficient

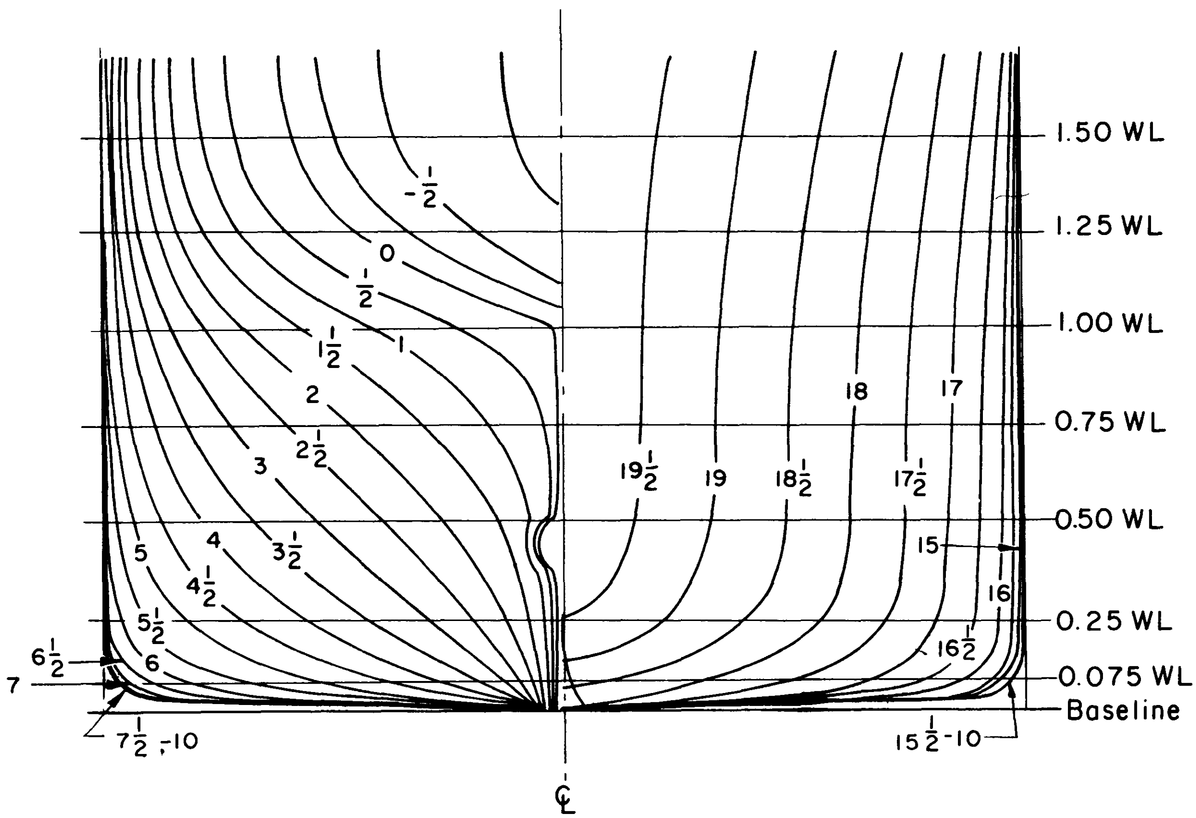

Figure 3 - Body Plan for M/S SAN FRANCISCO

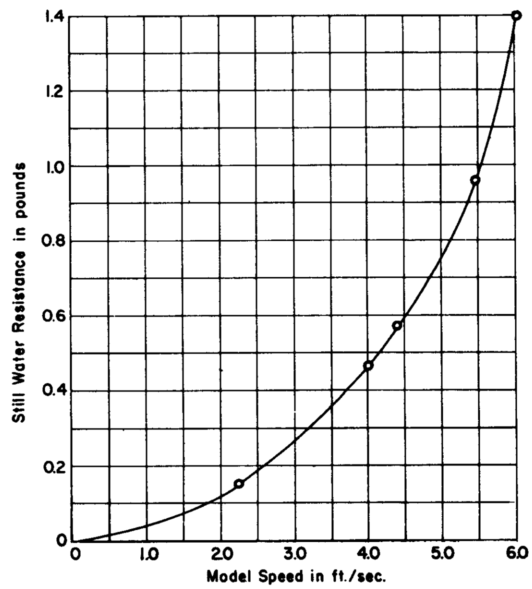

Figure 4a - Destroyer Escort

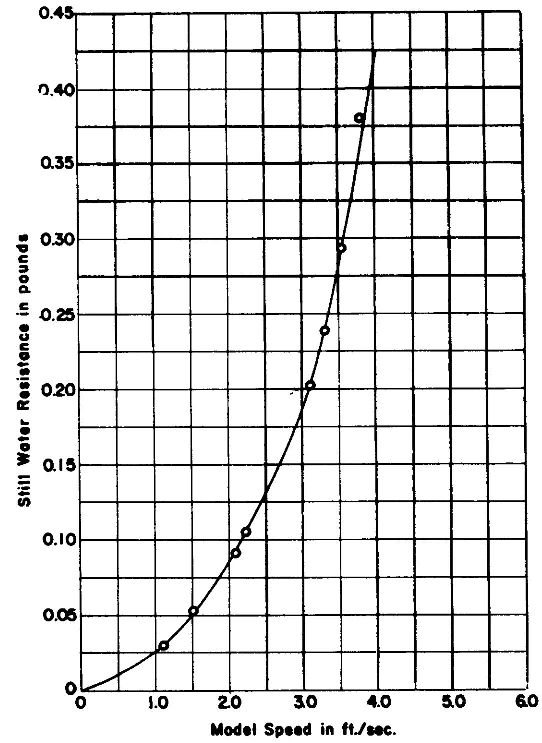

Figure 4b - Series 60, 0.60 Block

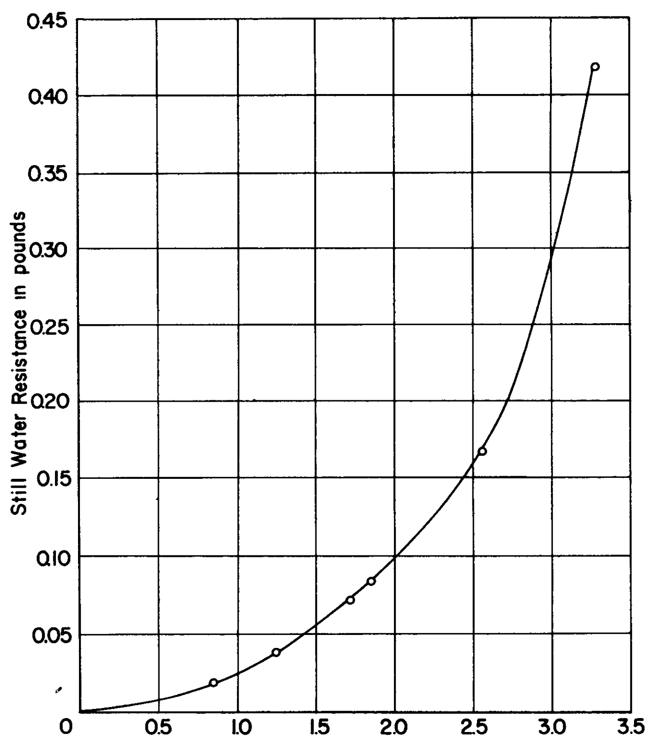

Figure 4c - M/S SAN FRANCISCO

Figure 4 - Still Water Resistance of the Three Models

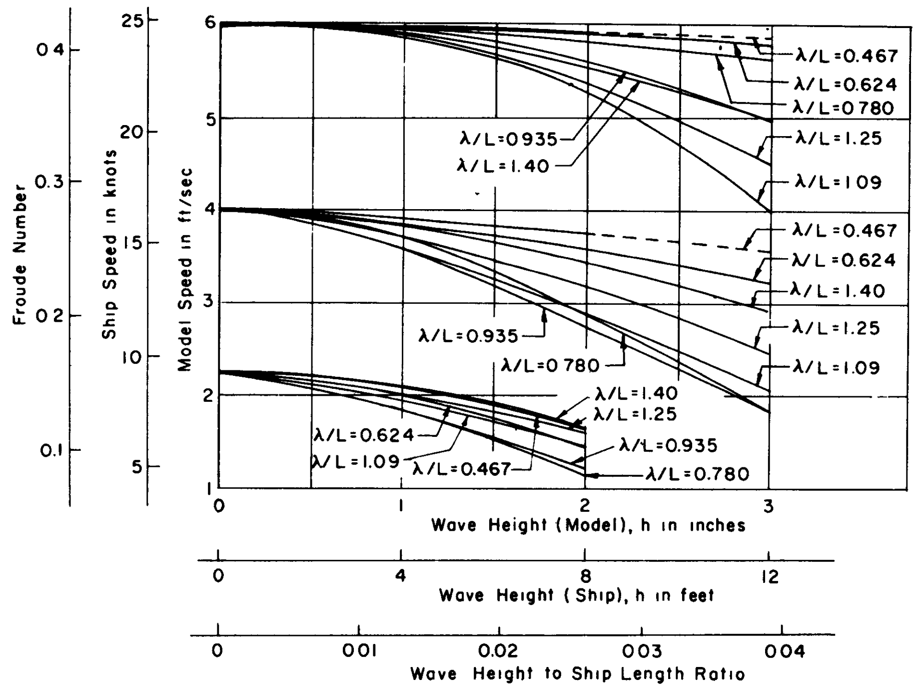

Figure 5 - Speed versus Wave Height for Constant Wave Length, Destroyer Escort

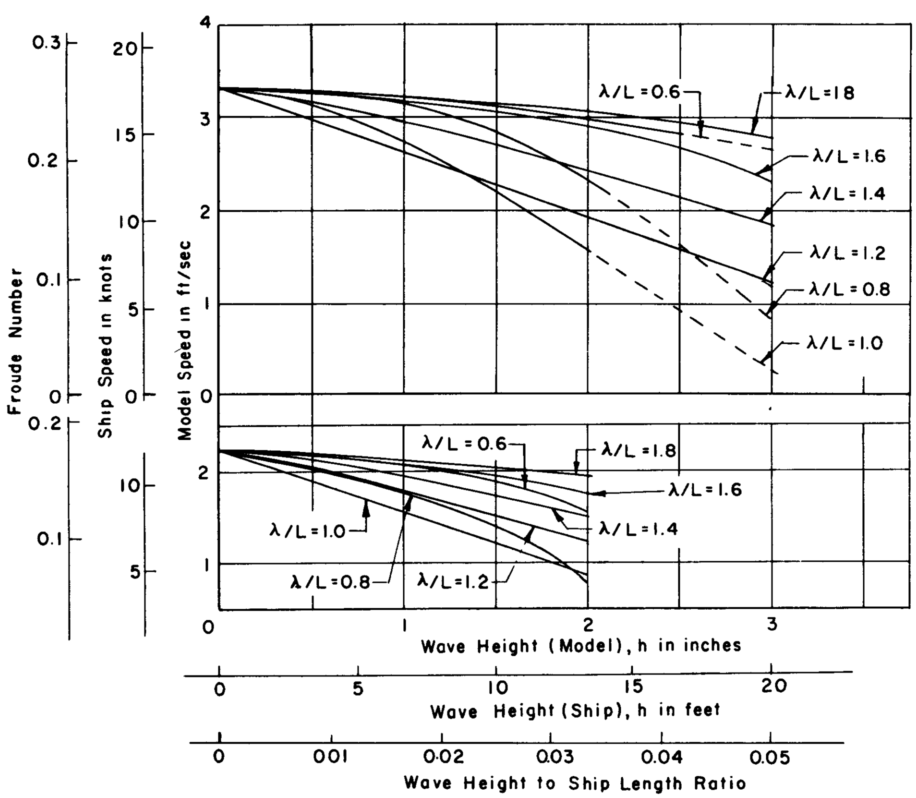

Figure 6 - Speed versus Wave Height for Constant Wave Length, Series 60, 0.60 Block Coefficient

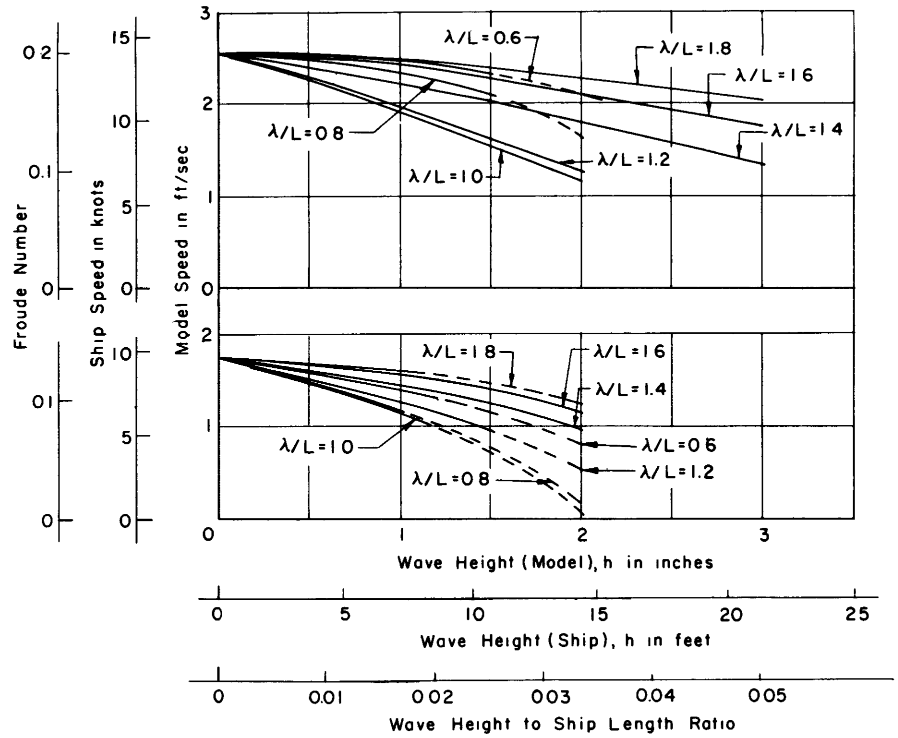

Figure 7 - Speed versus Wave Height for Constant Wave Length, M/S SAN FRANCISCO

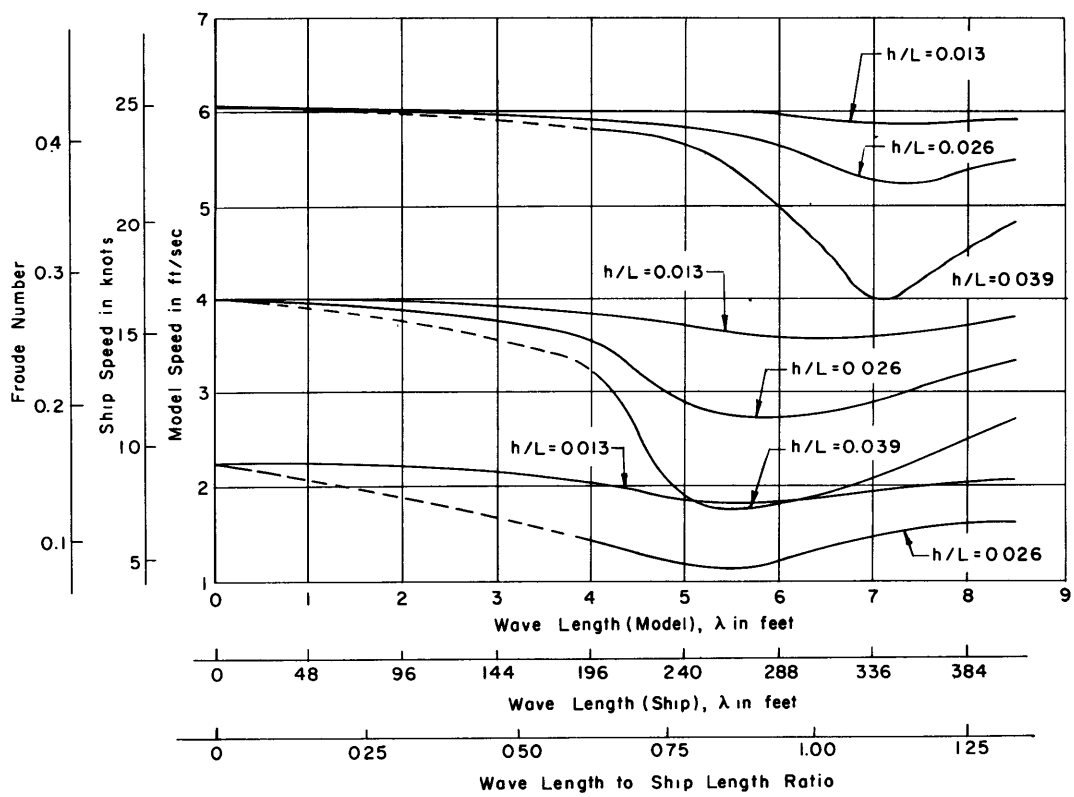

Figure 8 - Speed Reduction Curves for Destroyer Escort

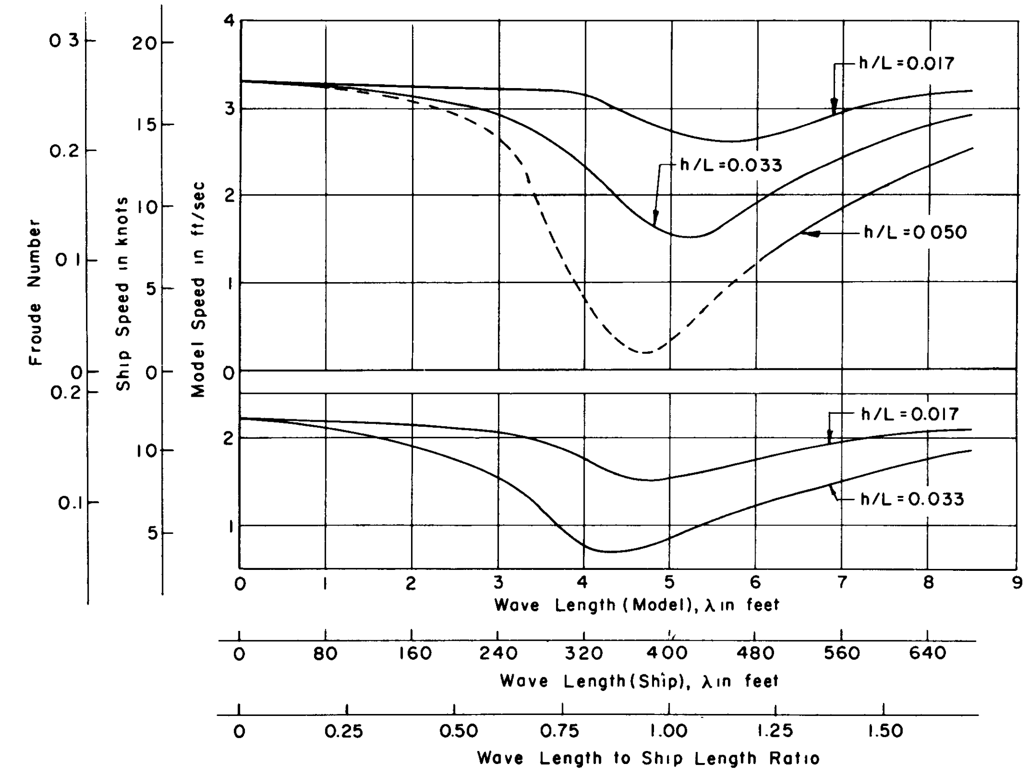

Figure 9 - Speed Reduction Curves for Series 60, 0.60 Block Coefficient

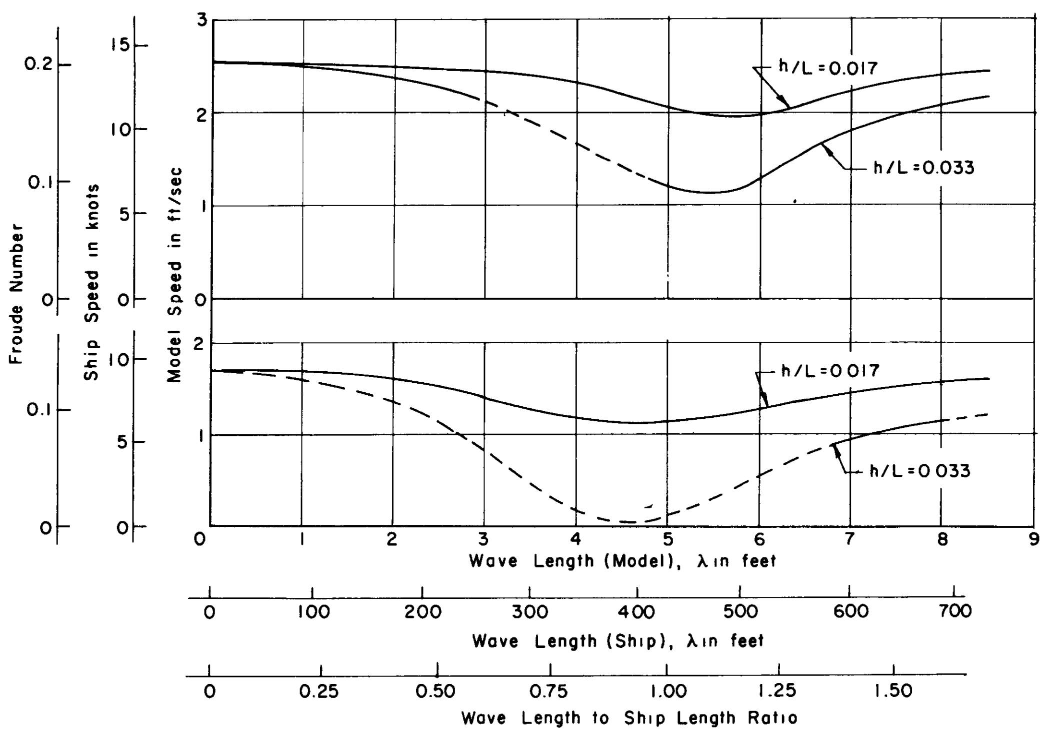

Figure 10 - Speed Reduction Curves for M/S SAN FRANCISCO

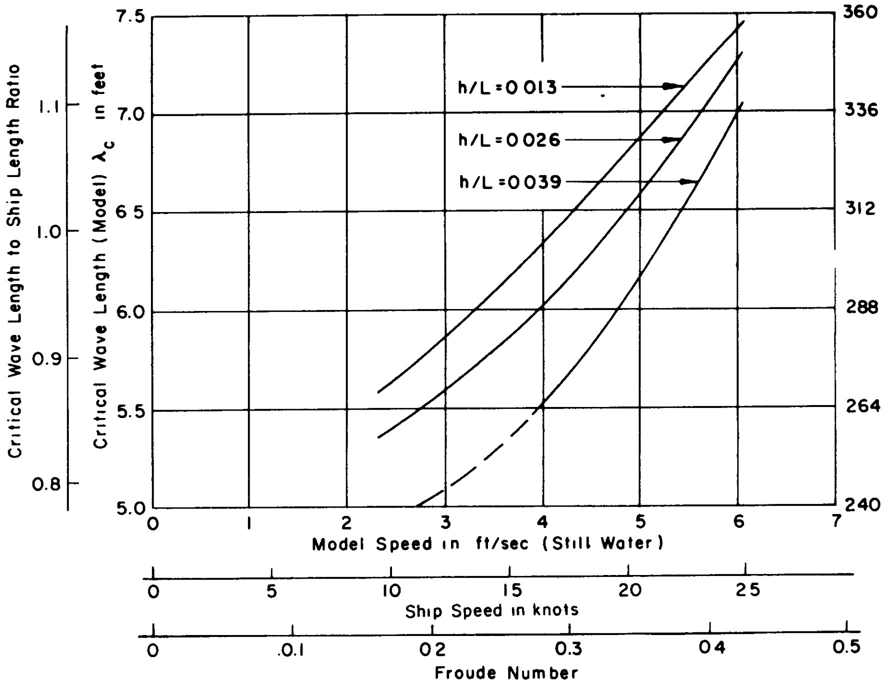

Figure 11 - Critical Wave Length as a Function of Speed and Wave Height, Destroyer Escort

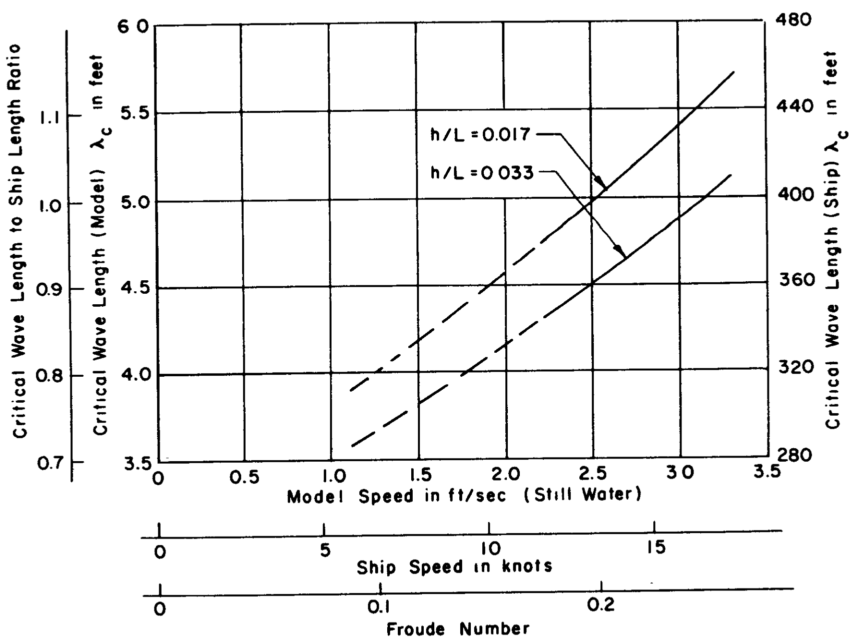

Figure 12 - Critical Wave Length as a Function of Speed and Wave Height, Series 60, 0.60 Block Coefficient

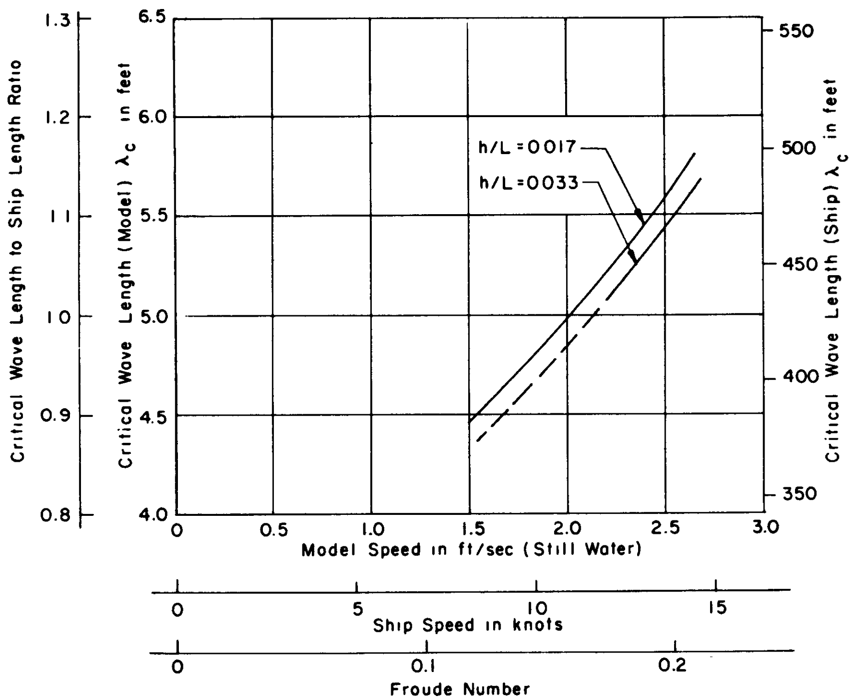

Figure 13 - Critical Wave Length as a Function of Speed and Wave Height, M/S SAN FRANCISCO

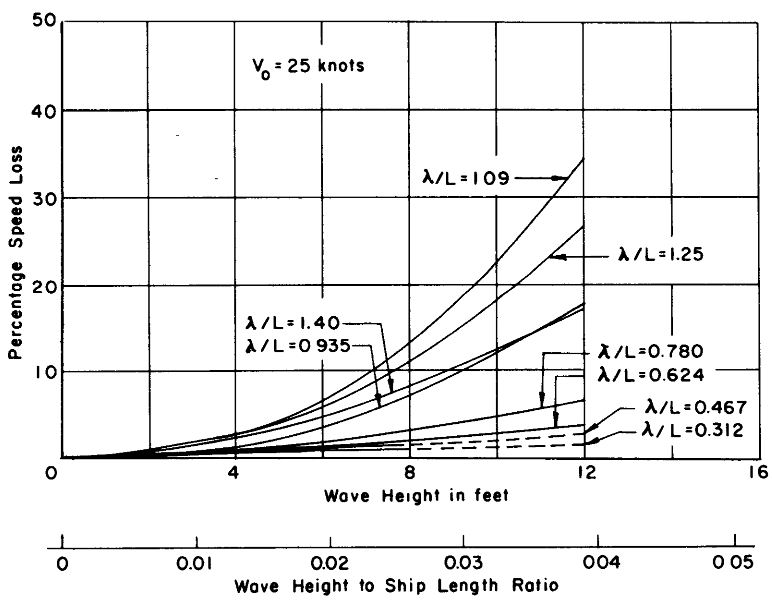

Figure 14 - Speed Loss in Percent for Constant Wave Length with Thrust for Design Speed in Still Water, Destroyer Escort

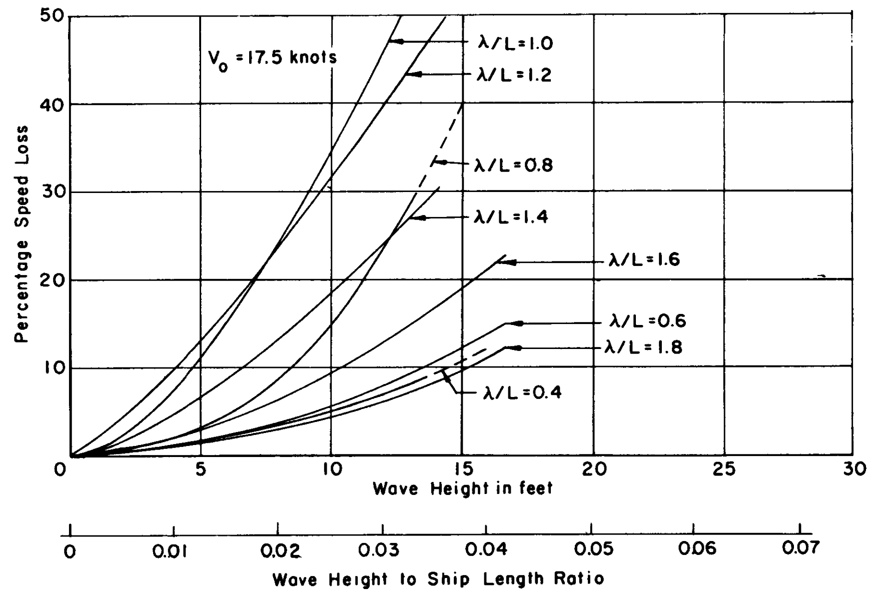

Figure 15 - Speed Loss in Percent for Constant Wave Length with Thrust for Design Speed in Still Water, Series 60, 0.60 Block Coefficient

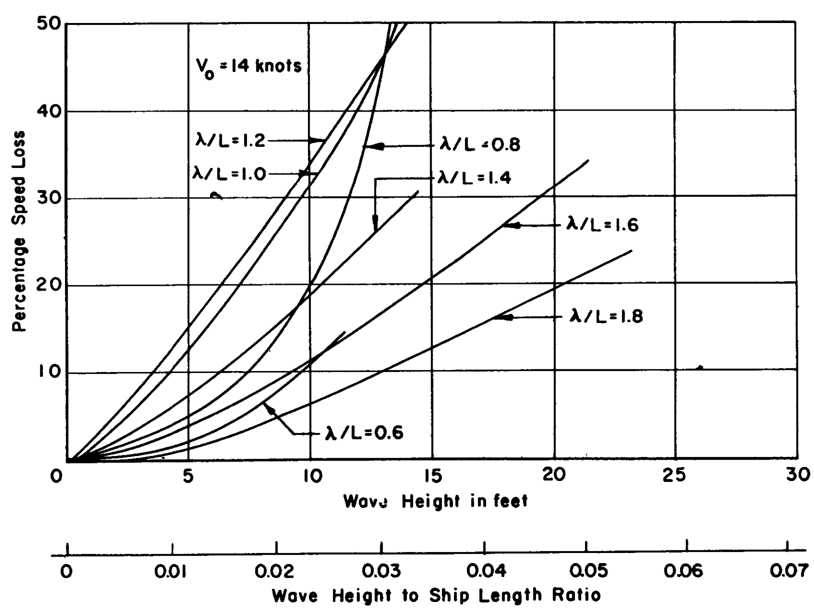

Figure 16 - Speed Loss in Percent for Constant Wave Length with Thrust for Design Speed in Still Water, M/S SAN FRANCISCO

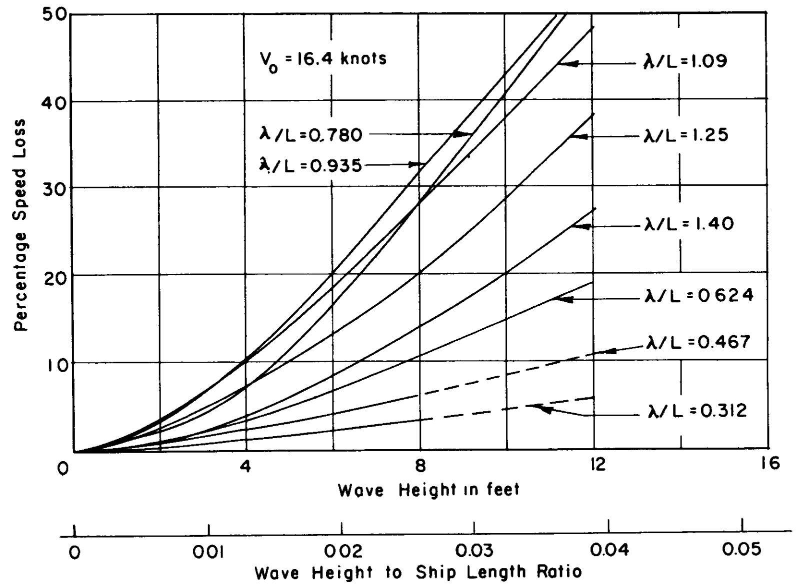

Figure 17 - Speed Loss in Percent for Constant Wave Length with Thrust for Two-Thirds Design Speed in Still Water, Destroyer Escort

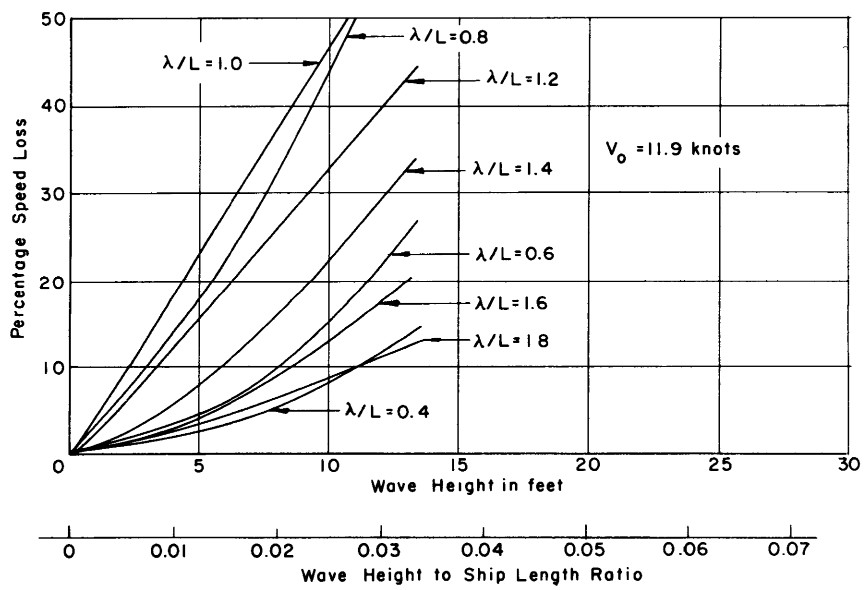

Figure 18 - Speed Loss in Percent for Constant Wave Length with Thrust for Two-Thirds Design Speed in Still Water, Series 60, 0.60 Block Coefficient

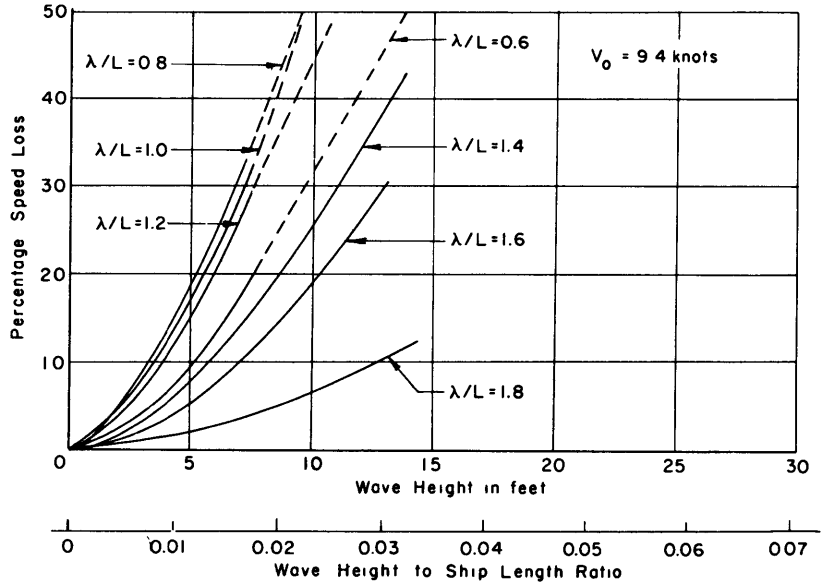

Figure 19 - Speed Loss in Percent for Constant Wave Length with Thrust for Two-Thirds Design Speed in Still Water, M/S SAN FRANCISCO

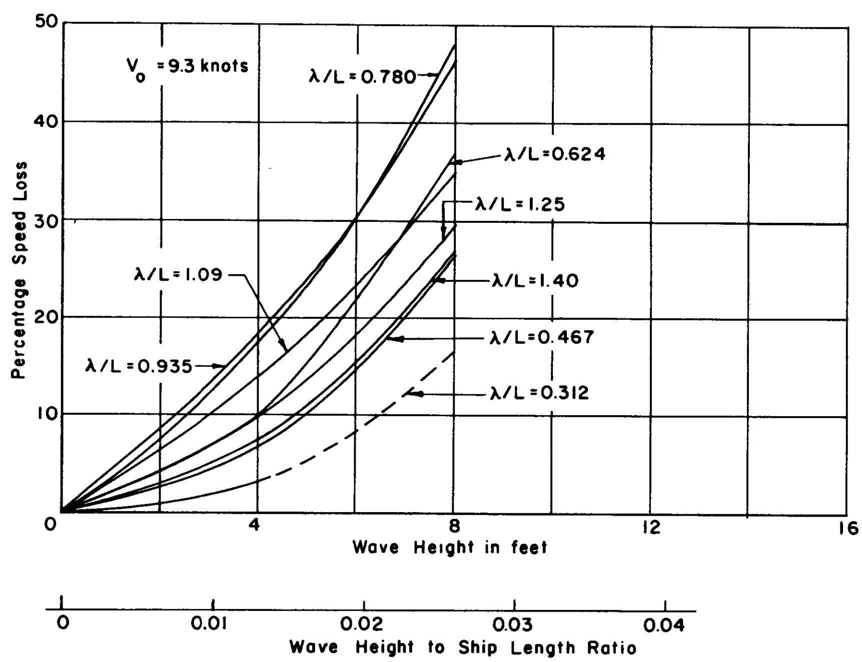

Figure 20 - Speed Loss in Percent for Constant Wave Length with Thrust for One-Third Design Speed in Still Water, Destroyer Escort

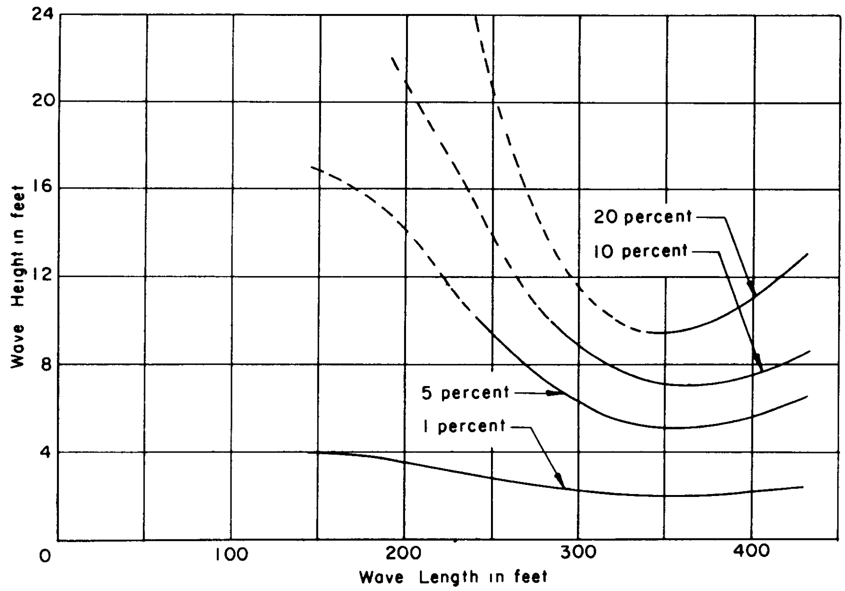

Figure 21 - Contours of Constant Speed Loss with Thrust for Design Speed, Destroyer Escort

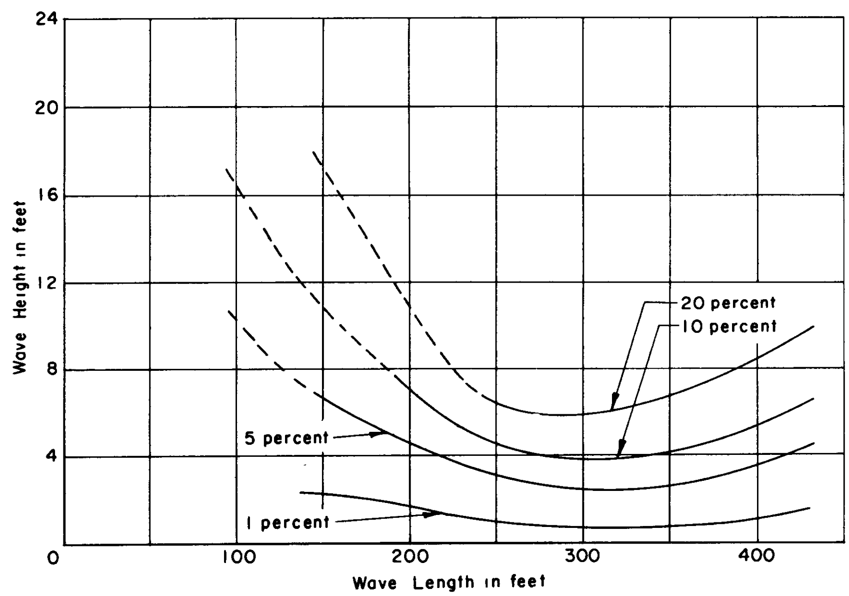

Figure 22 - Contours of Constant Speed Loss with Thrust for Two-Thirds Design Speed, Destroyer Escort

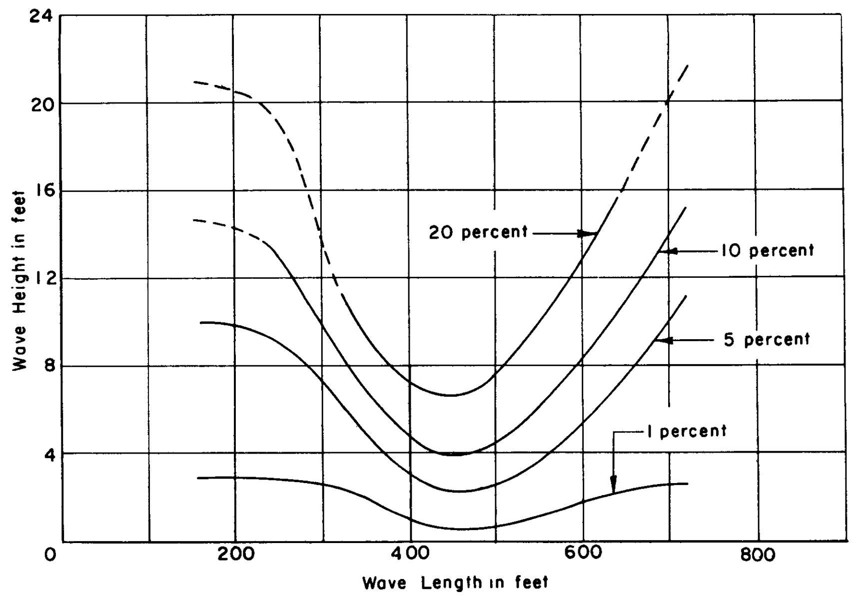

Figure 23 - Contours of Constant Speed Loss with Thrust for Design Speed, Series 60, 0.60 Block Coefficient

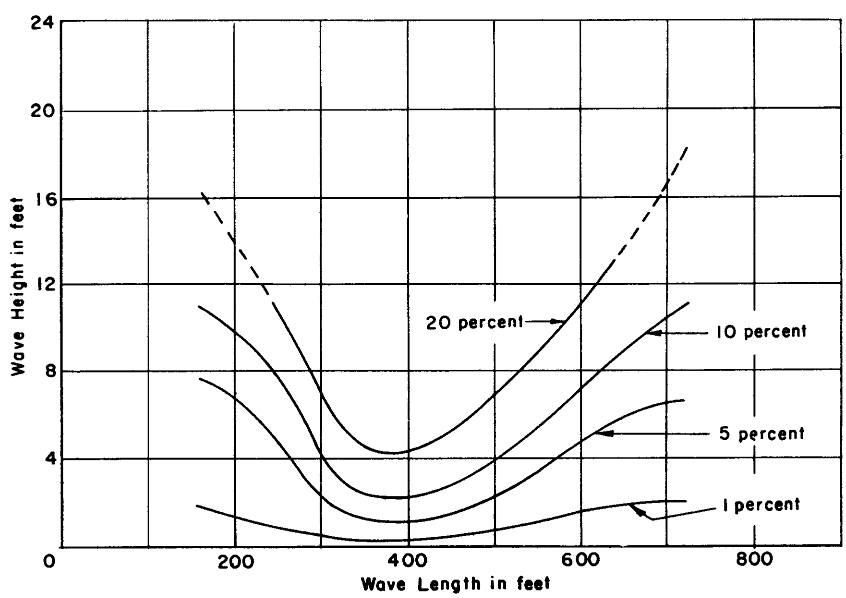

Figure 24 - Contours of Constant Speed Loss with Thrust for Two-Thirds Design Speed, Series 60, 0.60 Block Coefficient

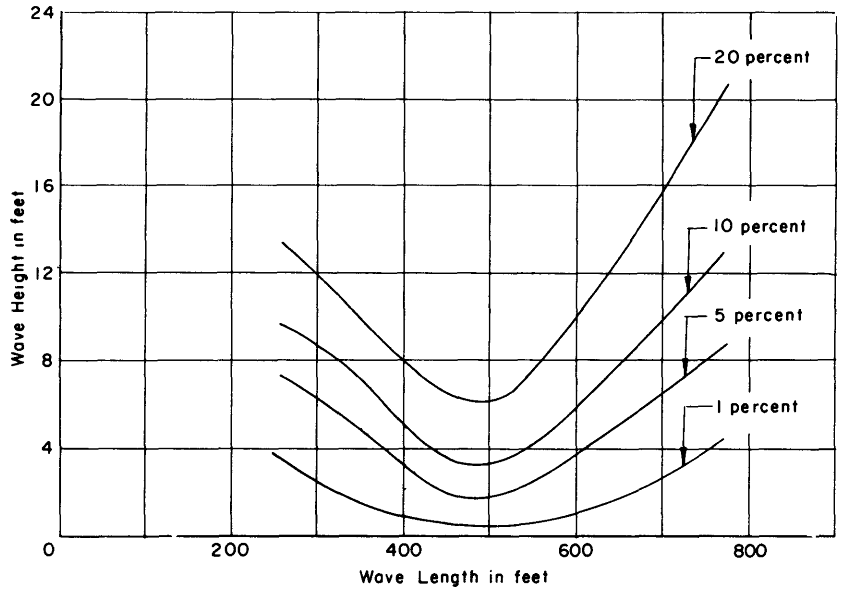

Figure 25 - Contours of Constant Speed Loss with Thrust for Design Speed, M/S SAN FRANCISCO

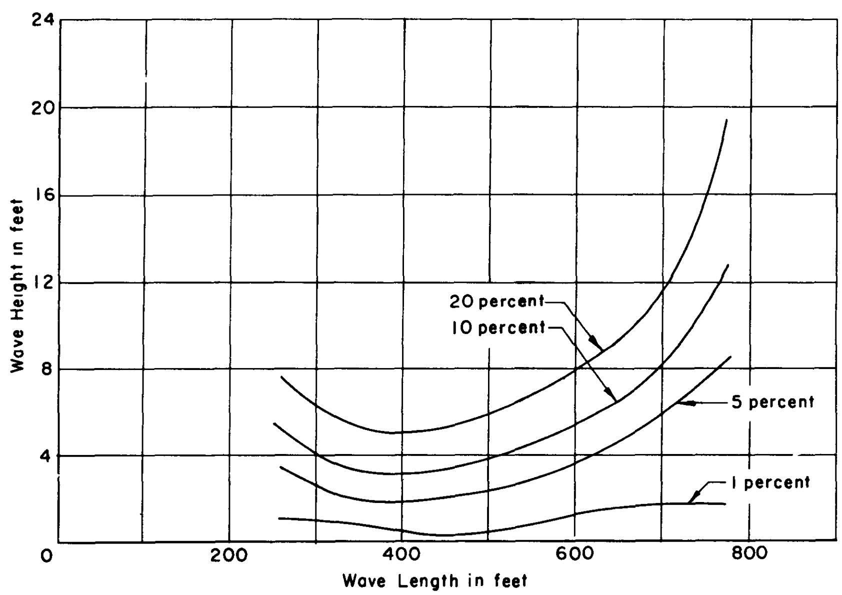

Figure 26 - Contours of Constant Speed Loss with Thrust for Two-Thirds Design Speed, M/S SAN FRANCISCO

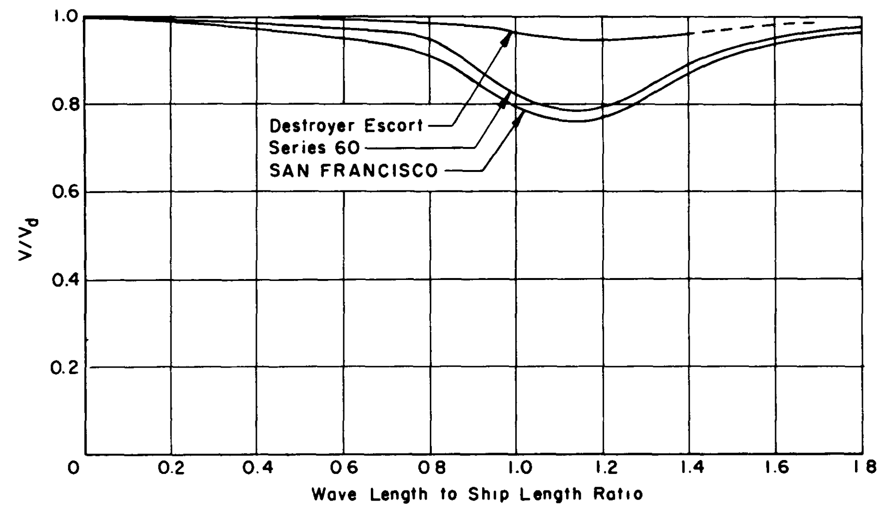

Figure 27 - Comparison of Speed Reduction of the Three Ships for h/L = 0.017 and Thrust for Design Speed in Still Water

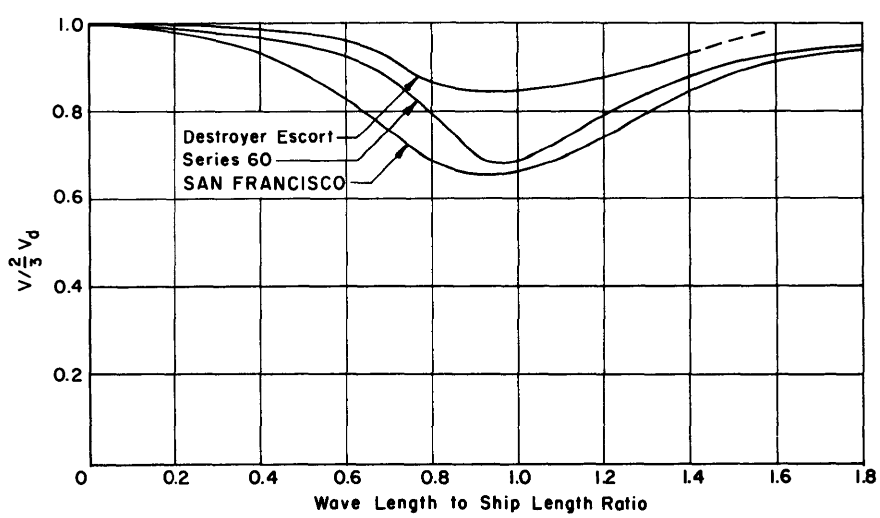

Figure 28 - Comparison of Speed Reduction of the Three Ships for h/L = 0.017 and Thrust for Two-Thirds Design Speed in Still Water

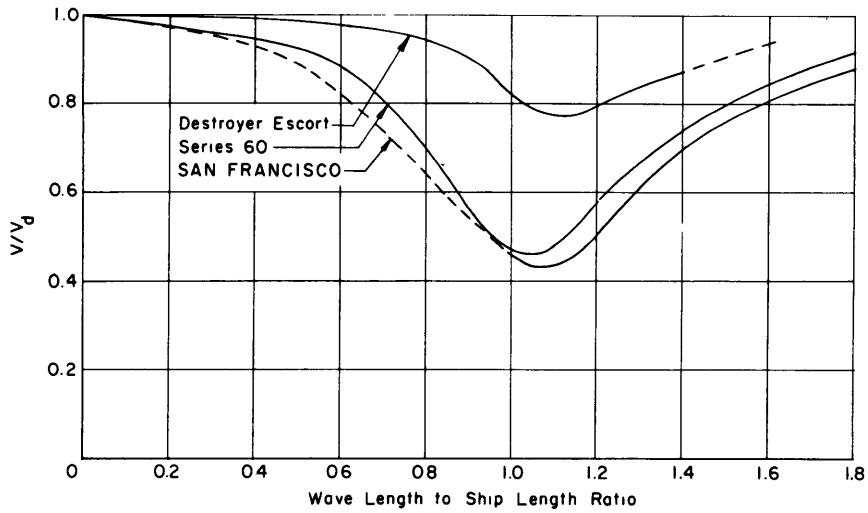

Figure 29 - Comparison of Speed Reduction of the Three Ships for h/L = 0.033 and Thrust for Design Speed in Still Water

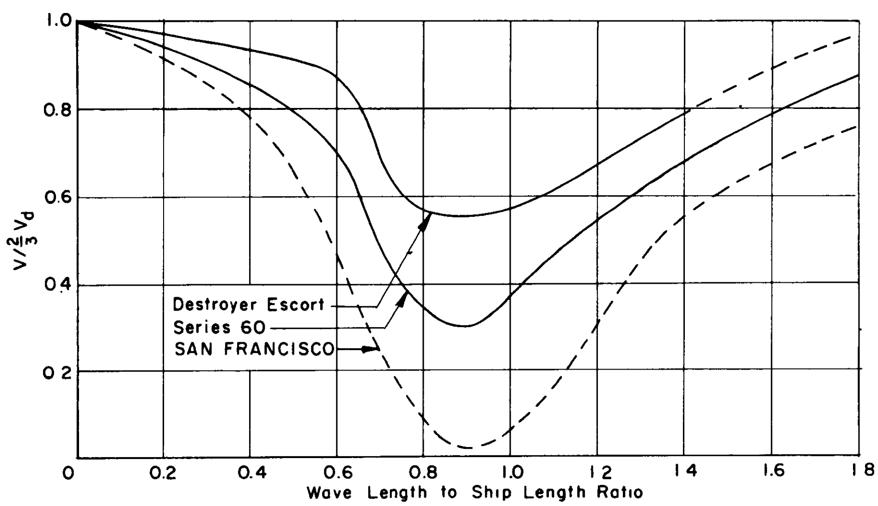

Figure 30 - Comparison of Speed Reduction of the Three Ships for h/L = 0.033 and Thrust for Two-Thirds Design Speed in Still Water

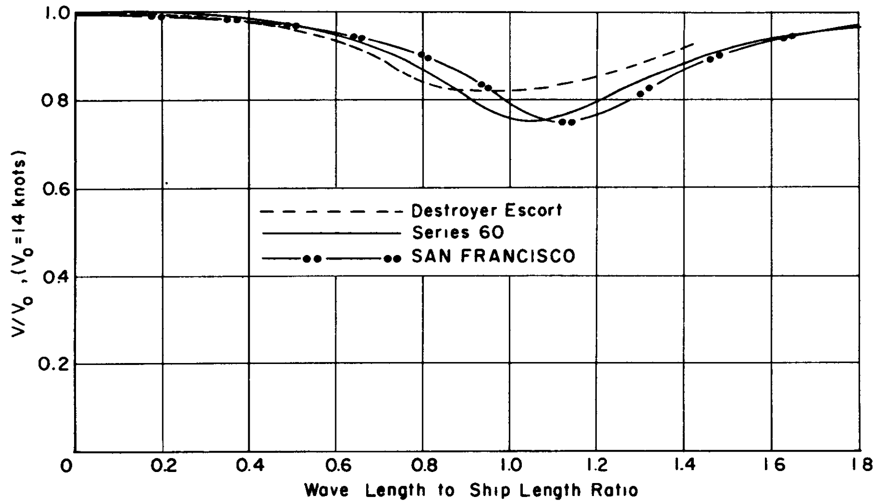

Figure 31 - Comparison of Speed Reduction of the Three Ships for h/L = 0.017 and Thrust for 14 Knots in Still Water

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