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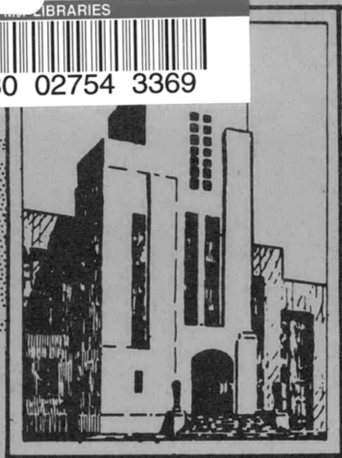

DEPARTMENT OF THE NAVY

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MODEL EXPERIMENTS ON THE EFFECT OF A BULBOUS BOW ON SHIP SLAMMING

by

Kazuo Ochi, Dr. Eng.

[redacted]

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NOTATION

A_o	Sectional area at midship
B	Breadth
C_b	Block coefficient
D	Depth of ship
F	Froude number ($V / \sqrt{gL}$)
H	Draft of ship
h	Wave height
L	Length of ship
V	Ship speed
Z	Amplitude of heave
Z_T	Double amplitude of heave
Z_T/h	Dimensionless heave
λ	Wave length
ϕ	Amplitude of pitch
ϕ_T	Double amplitude of pitch
ϕ_W	Wave slope
$\phi_T/2\phi_W$	Dimensionless pitch

ABSTRACT

This report presents the results of model experiments to determine the effect of a bulbous bow on ship slamming. The experiments were conducted on two 5.5-ft models; one, the MARINER, had a bulb whose area was 4 percent of the midship area; the other, the modified MARINER, had the same principal dimensions as the MARINER but had no bulb.

Based on the experimental results, a comparative evaluation is made of the effect of the bulb on slamming. It is found that the differences between the MARINER and the modified MARINER are not as large as had been expected.

The MARINER appears to be superior to the modified MARINER at speeds less than 1.5 knots (14.7 knots full scale) and inferior to the modified MARINER at speeds above 2.0 knots (19.6 knots full scale).

INTRODUCTION

Bulbous bows have not generally been adopted from seaworthiness considerations; instead, they have been used largely because they produce better propulsion characteristics and lower resistance in calm water. However, some discussion of the effect of a bulbous bow on the seaworthiness of ships appears in the literature. Dillon and Lewis [1] made an experimental study using a series of models with bulb sizes varying from 0 to 13 percent of the midship area. They concluded that a wide variation of bulb size had only a small effect on power or speed and on pitching motion in head seas. They mentioned also that no evidence of slamming appeared in any of the regular wave tests. It is regrettable, however, that their tests were not made under conditions severe enough to produce slamming. Bledsoe and Stefun [2] conducted experimental and theoretical studies on Series 60, block coefficient 0.60 models, with and without bulb. They found that in general the bulb had no effect on the amplitude of pitching and heaving; however, some exceptions were noted.

Information concerning the effect of a bulbous bow on ship slamming is, to date, almost nonexistent. It is well known that the shape of a ship's forward sections, such as U- and/or V-shape, is an important factor in slamming. Likewise, the addition of a bulbous bow might also be an important factor in slamming, depending on the size and shape of the bulb; since it can easily emerge from the water under slamming conditions.

In an attempt to evaluate the effect of the bulb on slamming, model experiments were made using the MARINER, with a 4-percent bulb, and a modification of the MARINER effected by removing the bulb. Most of the tests were made at light draft because at that condition the ship bow is more likely to come out of the water and thus slamming is more likely to occur.

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[1] References are listed on page 10.

Pitching and heaving motions, bow accelerations, bottom pressures, and speed loss were measured in various wave conditions and at a series of speeds.

This report describes the experimental procedure and presents the results of the tests.

EXPERIMENTAL PROCEDURE

MODEL PARTICULARS

Two 5.5-ft models of the MARINER were employed in these experiments. One model had the original lines of the MARINER with a 4-percent bulb at the bow; the other had principal dimensions identical with those of the MARINER but had no bulbous bow. The lines of the models are shown in Figure 1. The lines of the modified MARINER (without bulb) were obtained by extending the MARINER lines below the design waterline so as to be as "sisterly" as possible with the original form except for the bulb. The modification was made for those lines between the forward perpendicular and Station 3; therefore, the sectional area curves of the two models show a slight difference in this region. (See Figure 2.) However, this difference should not alter the hull form coefficients. The characteristics of the models and the MARINER are given in Table 1.

TABLE 1

Characteristics of the MARINER

Item	Model	Prototype
Length, LOA, feet	5.86	563.64
Length, LBP, feet	5.50	528.00
Breadth, B, feet	0.79	76.00
Depth, D, feet	0.37	35.50
Draft, max, H_{max}, feet	0.31	29.75
Block coefficient, C_b	0.624	0.624
Prismatic coefficient, C_p	0.635	0.635
Midship coefficient, $C_{\blacksquare}$	0.983	0.983
Water-plane coefficient, C_w	0.745	0.745
Displacement, max, ∇_{max}	51.5 (lb)	21,093 (ton)
Displacement, light draft	32.7 (lb)	
Radius of gyration	0.24 L	0.24 L
Bulbous bow (percent of midship area)	4	4
for modified MARINER	0	
Scale ratio	1	96.00

TEST METHOD AND PROCEDURE

The experiments were performed in the 140-ft tank of the David Taylor Model Basin. All tests were made in head seas composed of regular waves. The waves were generated by a pneumatic type wavemaker, and their dimensions were measured at one fixed point in the tank by a capacitance-type recorder. The models were towed under constant thrust by a gravity-type dynamometer.

The experimental conditions for which tests were made are shown in Table 2. For this slamming study, a series of tests was made at light draft; however, tests at maximum draft were also carried out in waves whose length was equal to the model length. A wave-height to wave-length ratio h/λ of 1/20 was used in the tests for the effect of wave length and draft. Tests to determine the effect of wave height were also made on the modified MARINER in waves whose length was equal to the model length. In this case, the range of h/λ varied from 1/40 to 1/18.

Resistance, pitching and heaving motions, bow acceleration, and slamming pressures were measured in the experiments. The pitching motion was measured by a Honeywell gyroscope, and the heaving motion was determined by a $\pm 2\ g$ Statham linear accelerometer located at the center of gravity. Sinusoidal motion was assumed; therefore the heaving acceleration was converted to motion by dividing by the square of the encounter frequency. A $\pm 15\ g$ Statham linear accelerometer was also located near the forward perpendicular for recording the bow acceleration. Slamming pressures were measured at nine points on the bottom by 50-psi Dynisco-type pressure gages. The locations of the pressure gages are listed in Table 3.

TABLE 2

Outline of Experimental Conditions

Item	Wave Length, λ feet	λ/L	Wave Height, h inches	h/λ	Draft, H inches	Trim by Stern inches	Model Speed knots
Influence of wave length	9.64	1.75	5.80	1/20	2.50	0.90	from 0 to 2.8
	6.88	1.25	4.13	↓	↓	↓	from 0 to 2.3
	5.50	1.00	3.30				from 0 to 2.3
	4.13	0.75	2.48				from 0 to 1.8
Influence of draft	5.50	1.00	3.30	1/20	3.72	0	from 0 to 2.25
Influence of wave height (MARINER with no bulb)	5.50	1.00	3.66	1/18	2.50	0.90	about 1.46
	↓	↓	3.30	1/20	↓	↓	↓
			2.64	1/25			
			2.20	1/30			
			1.88	1/35			
			1.65	1/40			

TABLE 3

Location of Pressure Gages

Pressure Gage	Location		
	Longitudinal	Transverse	Vertical
No. 1	0.100 L aft of FP	Centerline	Base line
No. 2	0.125 L	Centerline	Base line
No. 3	0.150 L	Centerline	Base line
No. 4	0.175 L	1 1/8 in. outboard	1/4 in. above B.L.
No. 5	0.175 L	1 5/8 in. outboard	3/4 in. above B.L.
No. 6	0.200 L	Centerline	Base line
No. 7	0.225 L	1 1/2 in. outboard	1/4 in. above B.L.
No. 8	0.250 L	Centerline	Base line
No. 9	0.300 L	Centerline	Base line

EXPERIMENTAL RESULTS

RESISTANCE AND SPEED LOSS

Tow forces were determined for a series of speeds in still water and in waves. These forces were then corrected for the tare in the towing system and converted into resistance. The resistances so obtained are plotted as a function of speed for various waves at light draft condition in Figures 3 and 4 for the MARINER and modified MARINER, respectively. The resistances for maximum draft in still water and in waves whose length equals the model length are also shown in the figures. These figures show that MARINER always has less resistance than the modified MARINER both in still water and in waves.

Figure 5, obtained from Figures 3 and 4, shows the speed loss at light draft in waves of varying length for constant thrust. In the figure, the 7-lb thrust is that necessary to produce speeds of 2.58 knots and 2.35 knots at the full-load condition (25.3 and 23.0 knots full scale) in still water for the MARINER and the modified MARINER, respectively. The thrusts of 4.54 lb for the MARINER and 3.74 lb for the modified MARINER are those necessary to produce the design speed (20 knots) in still water at maximum draft.

It can be seen that the region for maximum speed loss corresponds to wave length of 0.8 to 1.2 times the ship length. This result agrees well with the experimental results found for three models by Bledsoe[3] and for a Liberty Ship model by Szebehely and Lum.[4] For convenience, the percentage of speed loss for both models is plotted in Figure 6. This figure shows that the percentage of speed loss for the thrust corresponding to design speed in still water is greater than that for the thrust corresponding to a higher speed in still water. Figure 6 also shows that the speed loss for the MARINER seems to be slightly less than that for the modified MARINER in waves whose lengths are greater than ship length.

MOTIONS IN WAVES

Figures 7 through 10 show the pitching and heaving motions versus ship speed in various wave lengths. It is seen from these figures that the pitching and heaving motions of the MARINER are generally larger than those of the modified MARINER at light draft in all wave lengths, whereas at the maximum draft condition, in waves equal to ship length, the pitching and heaving motions of the MARINER and modified MARINER are approximately equivalent.

It should not be concluded, however, that the larger pitching and/or heaving motion of the MARINER than that of the modified MARINER always results in more violent slamming for the MARINER, since slamming depends not only on the magnitude of the motions, but also on the phase lag between pitch and heave and the phase lag between bow motion and wave. Therefore, a comparison of the amplitude of slamming acceleration, to be discussed later, will be more meaningful for a comparative evaluation of slamming for the two models. However, since an investigation of the relation between pitching, heaving, and waves might be profitable for further analysis of slamming phenomena, Figures 11 through 13 were prepared.

Figure 11 shows the dimensionless pitching and heaving versus wave length for the thrust of 7 lb. This thrust corresponds to that which would produce speeds of 2.58 and 2.35 knots for the MARINER and the modified MARINER models, respectively, in calm water. It is clear in the figure that both the dimensionless pitching and heaving amplitudes increase with increasing wave length up to $\lambda/L = 1.50$. For longer waves the response is almost independent of wave length. Pitch and-heave double amplitudes versus wave height obtained for the modified MARINER are shown in Figures 12 and 13. The experiments were made at various wave heights, for constant wave length ($\lambda/L = 1.00$) and model speed (1.46 knots), (14.3 knots full scale). As shown in the figures, the double amplitude of pitching and heaving increases linearly with increasing wave height up to a height of $h/\lambda = 1/25$. For higher waves, the rate of increase becomes less. In other words, the dimensionless pitching and heaving amplitudes show a constant value up to a wave height of $h/\lambda = 1/25$, and then decrease slightly for higher waves. This trend agrees with experimental results obtained on other merchant ship models.[5]

Figures 14 and 15 show the double amplitude of acceleration as measured at the bow, neglecting impact, for the MARINER and modified MARINER respectively. Figure 16 shows a comparison of the bow acceleration for the two models in waves of $\lambda/L = 1$. From these figures it can be seen that the bow acceleration for the MARINER is less than that for the modified MARINER in all wave lengths. Inasmuch as the pitching and heaving motions of the MARINER are a little larger than those of the modified MARINER, the above results may seem surprising. However, it should be noted that the bow acceleration is a combination of the acceleration due to pitching and heaving with consideration of the phase lag between them. The phase lag between pitching and heaving is especially important for bow acceleration. For instance, the same results mentioned above were derived in the author's previous experiments on the effect of ship forms upon slamming.[5] There, the bow acceleration of the U-form model was larger than that of the V-form model, even though the motions of the U-form were less. However, the phase lag between pitching and heaving showed a considerable difference. The phase lag for the U-form was more unfavorable than that for the V-form model.

Slamming accelerations, which take the form of sudden sharp peaks superimposed on the acceleration due to wave and ship motion, are plotted against ship speed for various wave lengths in Figures 17 and 18. The striking features of these figures are that slamming acceleration appears at a certain ship speed and also that this minimum speed, above which slamming occurs, shifts to higher speeds with increasing wave length. Another feature is that the magnitude of slamming acceleration does not increase linearly with increasing wave length, and no slamming acceleration appears for a comparatively short waves such as $\lambda/L = 0.75$. It is interesting to note that the magnitudes of slamming acceleration for both models are for the most part equal, although the magnitude of the bow acceleration due to motion in waves for the MARINER is less than that for the modified MARINER.

A comparison of the slamming accelerations for the two models for a particular wave length shows an interesting result. For instance, Figure 19 shows a comparison of slamming acceleration in waves of length equal to ship length. Here it is seen that the slamming acceleration for the MARINER is a little less than that for the modified MARINER at comparatively low speeds whereas the MARINER becomes a little larger than the modified MARINER at speeds over 1.5 knots (14.7 knots full scale). This trend agrees with the general trend for impact pressures, as is discussed later.

SLAMMING PRESSURE

The maximum impact pressures due to slamming are given as a function of speed for constant wavelengths in Figures 20 through 25. These pressures were recorded at points along the keel line within the range from 0.1 L to 0.3 L aft of the forward perpendicular. It can be seen in Figures 24 and 25 that for the short wave length ($\lambda/L = 0.75$) impact pressures occur only at the foremost stations and that they are too small to be considered as slamming pressures. A comparison of Figures 20 through 25 shows that for a particular location the speed at which the slamming pressures are largest shifts toward higher speeds with increasing wave length. For instance, pressure gage P-2 which is located 0.125 L aft of the forward perpendicular on the MARINER, shows maximum pressure at a speed of 1.2 knots for the wave of $\lambda/L = 0.75$, and at a speed of 1.45 knots for $\lambda/L = 1.00$, 1.95 knots for $\lambda/L = 1.25$, and about 3.0 knots for $\lambda/L = 1.75$.

It might be of interest to mention the relation between synchronous speed for pitch and the speed where severe slamming occurs. The synchronous speed for pitch for the MARINER at light draft is 1.19 knots (11.7 knots full scale) in waves whose length equals the ship length, and the pitching motion does become severe at this speed, as shown in Figure 7. On the other hand, severe slamming occurs at a speed of about 1.45 knots (14.2 knots full scale), as is evidenced by the increased bow acceleration in Figure 14 and by the high slamming pressure in Figure 20. Therefore, it appears that severe slamming occurs at a somewhat higher speed (about 20 percent higher) than the speed for synchronism with pitch. This result is in close agreement with results obtained in the experiments on the U-and V-form models (block coefficient 0.74).[5]

One example of the effect of increasing ship draft on the magnitude of slamming pressures can be seen in Figures 20 and 21. These figures show that the slamming pressures become small at the maximum draft, and also that the speed range within which slamming occurs becomes small.

A comparison of the slamming pressures between the MARINER and the modified MARINER may be obtained from these figures. However, Figure 26 is prepared in order to provide a more comprehensive picture of the general trend. Figure 26 shows a comparison of the slamming pressures on both models at the station 0.15 L aft of the forward perpendicular, where pressure gage P-3 is located. This location was chosen for comparison since the largest pressures were measured here on both models for all wave lengths.

An interesting and an important trend can be derived from Figure 26; namely, that the maximum slamming pressures on the MARINER are nearly equal to or a little less than those on the modified MARINER at speeds lower than the speed for severest slamming for all wave lengths, whereas the slamming pressures on the MARINER are greater than those on the modified MARINER at speeds *above* the speed for severest slamming. In other words, so far as slamming is concerned, it appears that the difference between the MARINER and the modified MARINER is small below the speed critical for slamming, whereas the modified MARINER is superior to the MARINER at speeds above this critical speed. The speed for severest slamming at a specific location on the ship is, of course, a function of the wave length. For instance, the speeds for severest slamming at the station 0.15 L aft of the forward perpendicular are about 1.5 knots (14.7 knots full scale) for the wave of $\lambda/L = 1.00$, 1.8 knots (17.6 knots full scale) for the wave of $\lambda/L = 1.25$, and is estimated to be about 3.0 knots (29.0 knots full scale) for the wave of $\lambda/L = 1.75$.

The above statement may be more easily understood from the plots in Figures 27 and 28. These figures show a comparison of the slamming pressures on the two models at stations 0.10 L and 0.15 L aft of the forward perpendicular, as a function of wave length. The hatched zone in the figures indicates that the MARINER is superior to the modified MARINER. It appears from these figures that the MARINER is superior to the modified MARINER at speeds below 1.0 knots (9.8 knots full scale), but the MARINER is inferior to the modified MARINER at the higher speeds of 2.0 knots and 2.5 knots (19.6 knots and 24.5 knots full scale).

Figure 29 shows the effect of wave height on the magnitude of slamming pressure for the modified MARINER. Tests were made at the speed for which slamming had been found to be violent. Although the slamming pressure increases with increasing wave height, other conditions being equal, the rate of increase depends upon the longitudinal location along the ship bottom. The most interesting feature in Figure 29 is the minimum wave height which produces slamming. The minimum wave height which causes slamming in the forward portion of the model is 1/51 of the wave length at the speed for severest slamming. This result agrees well with experimental results obtained on other merchant ship models.[6]

The distribution of slamming pressure along the keel line obtained in waves of length equal to ship length is shown in Figure 30 for speeds of 1.0 knots and 1.5 knots (9.8 knots and 14.7 knots full scale).

It should be mentioned that the values of the slamming pressures plotted in the figures are not the instantaneous pressures but are the peak values measured at each location during slamming. As shown in Figure 31, there exists a difference in time between the pressure peaks recorded by each of the gages. This time difference is not always uniform but is a function of wave length and ship speed. For design purposes, however, the peak or maximum pressure at each location is important. Therefore, the peak value of the pressure measured at each location is plotted in Figure 30.

Now Figure 30 indicates that the position of maximum pressure on the keel line shifts toward midship with increasing ship speed; that is, the location is about $0.14\,L$ aft of the forward perpendicular for the 1.0-knot speed and is about $0.17\,L$ aft of the forward perpendicular for the 1.5-knot speed.

Pressure distribution curves were also prepared for waves of different lengths at the 1.5-knot speed; these are shown in Figure 32. It is clear in this figure that the pressure magnitudes for the long wave such as $\lambda/L = 1.75$ or for the short wave of $\lambda/L = 0.75$ are very small at this speed, and also that the magnitudes of pressure for the modified MARINER are greater than those for the MARINER in waves of lengths equal to or a little longer than ship length. The location between $0.15\,L$ and $0.17\,L$ would appear to be the dangerous zone for slamming at this speed.

Figure 33 shows an example of the distribution of slamming pressure around the girth at the station $0.175\,L$ aft of the forward perpendicular. This was obtained at speeds for both moderate and severe slamming in waves whose length equals the ship length and whose height is 1/20 of their length.

It should be noted that the distribution curve presents the envelope of the peak pressure at each point during a slam, since the maximum pressure occurs at the keel at the instant it contacts the water surface and the pressure moves rapidly from keel to bilge. No pressure gage was located at this station on the keel line; however, the magnitudes of the pressure on the keel line can be easily interpolated from Figures 20 and 21. These magnitudes then are plotted as the pressures on the keel line at this station.

It may be seen from this figure that the pressure distribution curves for the two models show almost similar trends, and that the maximum pressure occurs at the keel line for both models. This trend agrees with the experimental results obtained from other merchant ship model tests.[6]

CONCLUSIONS

From the results of these experimental studies on the effect of a bulbous bow on ship slamming, using models of the MARINER (with bulb) and the modified MARINER (without bulb), the following conclusions can be drawn:

1. The MARINER has less resistance than the modified MARINER both in still water and in waves, and the waves critical for maximum speed loss are the waves whose lengths are nearly ship length.

2. Bow acceleration for the MARINER is less than that for the modified MARINER; however, the pitching and heaving motions for the MARINER are larger than those for the modified MARINER.

3. Slamming acceleration does not increase linearly with increasing wave length, and no slamming acceleration appears for either model for a short wave such as $\lambda/L = 0.75$.

4. Slamming acceleration for the MARINER is a little less than that for the modified MARINER at comparatively low speed but becomes larger than the latter at high speed.

5. The peak slamming pressures on the MARINER are nearly equal to or a little less than those on the modified MARINER at speeds *below* the speed for severest slamming in all wave lengths, but are higher than those of the modified MARINER at high speeds *above* the speed for severest slamming.

6. At the speed most critical for slamming, the minimum wave height which causes slamming on the forward position of the modified MARINER is about 1/50 of the wave length.

7. The location where the pressure distribution along the keel line shows the maximum value shifts toward midship with increasing ship speed, and the region between 0.15 L and 0.17 L appears to be the dangerous zone for slamming at a speed of 1.5 knots (14.7 knots full scale) for both models.

8. The pressure distribution over a particular section of both the MARINER and the modified MARINER show almost similar trends, and the maximum pressure occurs at the keel line.

9. From a consideration of the above results, it is apparent that the difference between the MARINER and the modified MARINER is not as great as might have been expected. However, the MARINER appears to be superior to the modified MARINER at speeds less than 1.5 knots (14.7 knots full scale), but inferior to the modified MARINER at high speeds such as 2.0 knots (19.6 knots full scale).

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REFERENCES

1. Dillon, E.S. and Lewis, E.V., "Ships with Bulbous Bows in Smooth Water and in Waves," Transactions, Society of Naval Architects and Marine Engineers, Vol. 63 (1955).

2. Bledsoe, M.D. and Stefun, G.P., "A Study of the Effects of a Bulb on the Series 60, 0.60 Block Coefficient Model," David Taylor Model Basin Hydromechanics Laboratory Technical Note No. 1 (1955).

3. Bledsoe, M.D., "Speed Reduction in Waves," David Taylor Model Basin Report 1083 (Apr 1958).

4. Szebehely, V.G. and Lum, S.M.Y., "Model Experiments on Slamming of a Liberty Ship in Head Seas," David Taylor Model Basin Report 914 (Feb 1955).

5. Ochi, K. and Akita, Y., "Ship Behavior and Slamming in Regular Waves," Proceedings, Symposium on the Behavior of Ships in a Seaway, Wageningen (1957).

6. Ochi, Kazuo, "Model Experiments on Ship Strength and Slamming in Regular Waves," Transactions, Society of Naval Architects and Marine Engineers, Vol. 66 (1958).

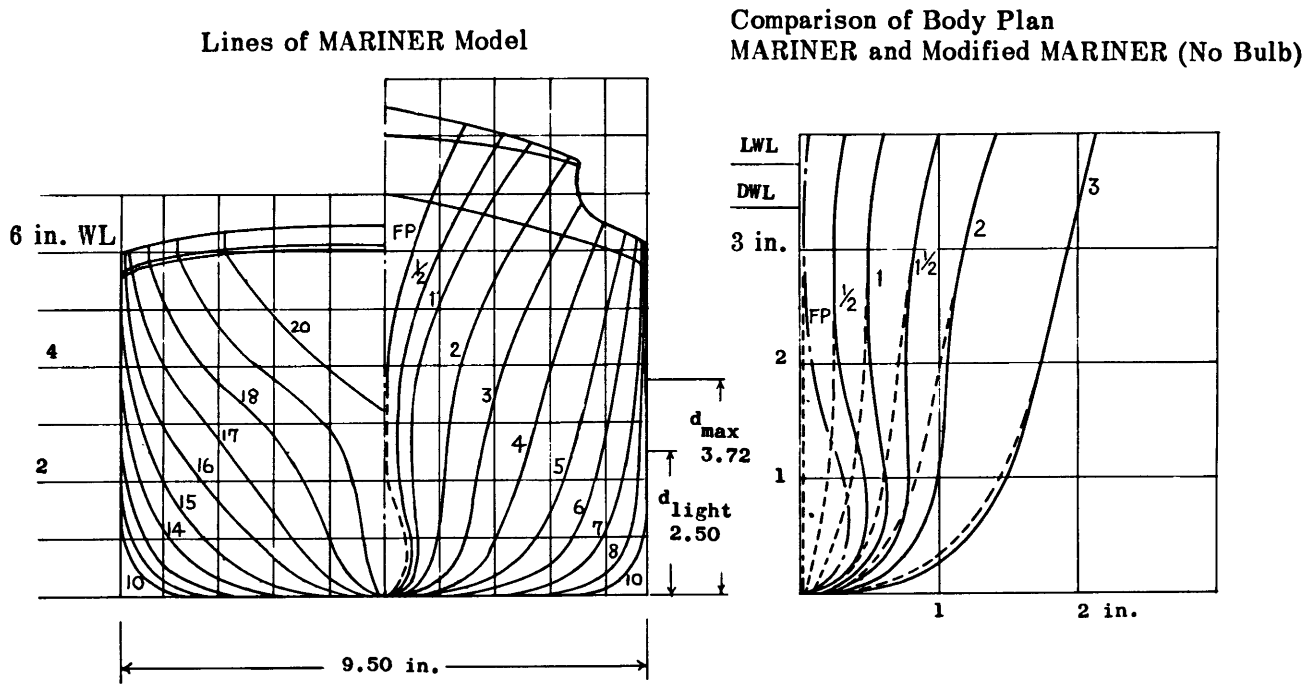

Figure 1 – Lines of MARINER and Modified MARINER Models

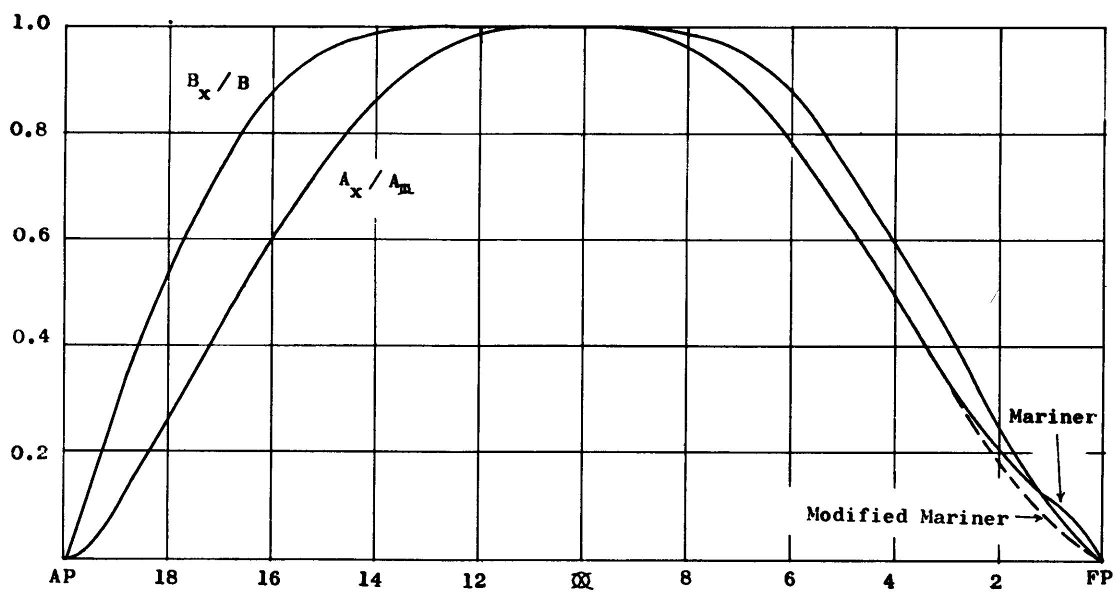

Figure 2 – Sectional Area Curve of MARINER and Modified MARINER Models

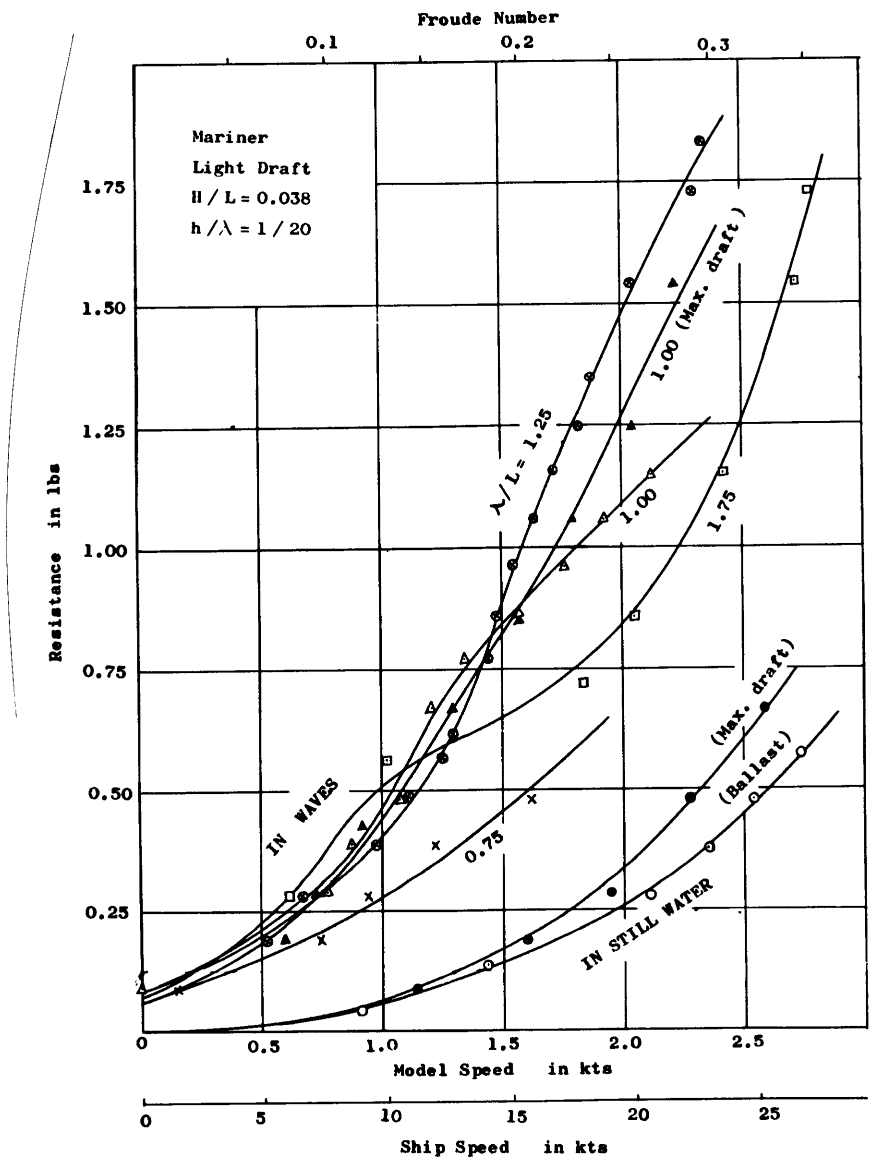

Figure 3 – Resistance of MARINER in Waves versus Ship Speed

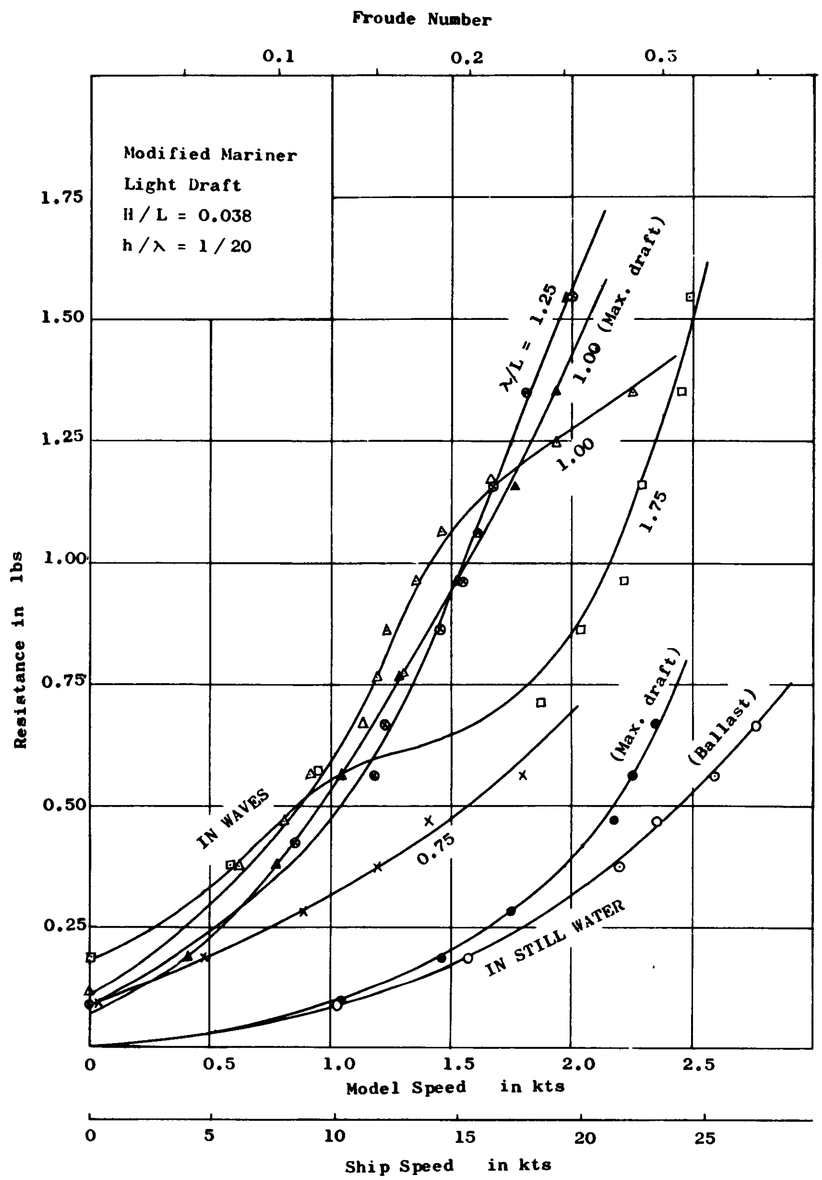

Figure 4 – Resistance of Modified MARINER in Waves versus Ship Speed

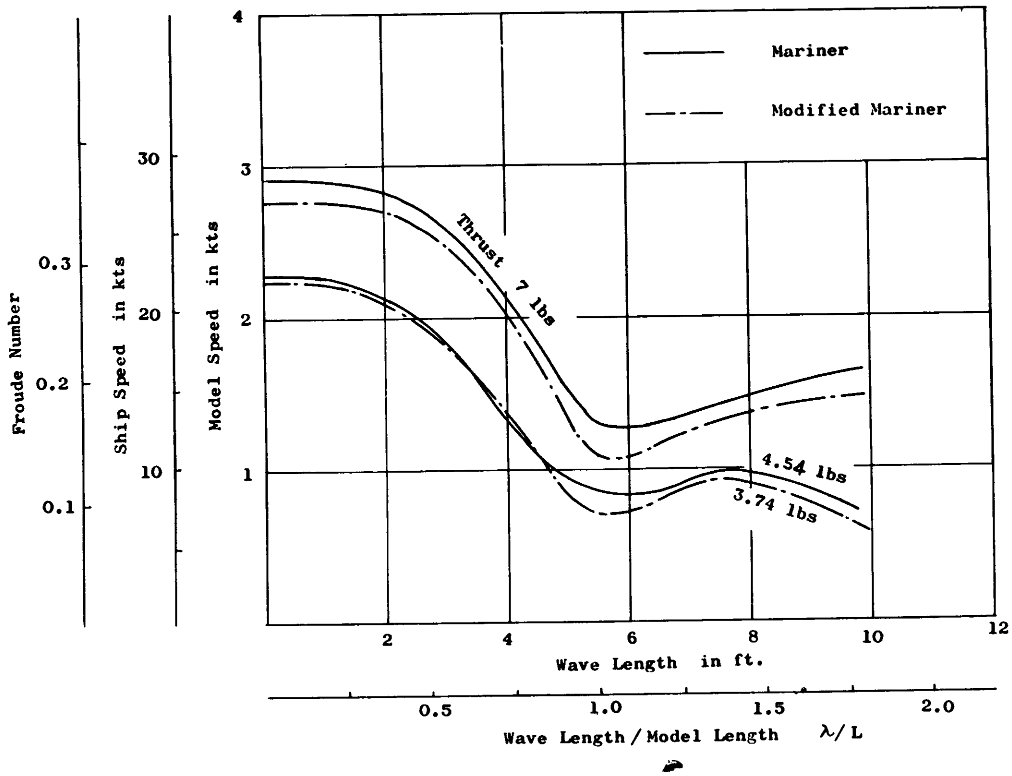

Figure 5 – Speed Reduction Curves for MARINER and Modified MARINER (Light Draft)

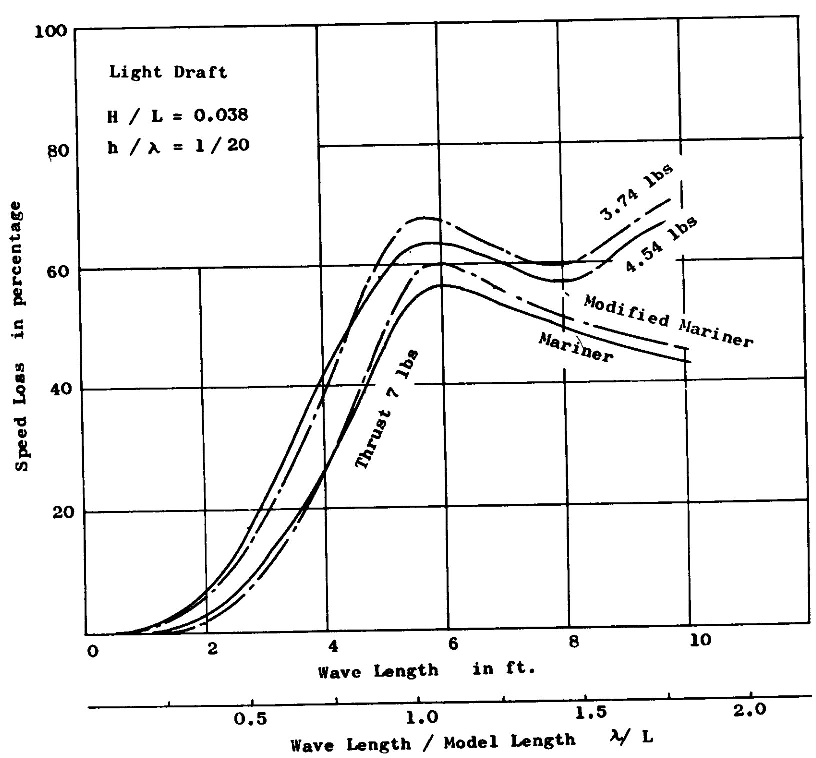

Figure 6 – Percentage of Speed Loss versus Wave Length for MARINER and Modified MARINER (Light Draft)

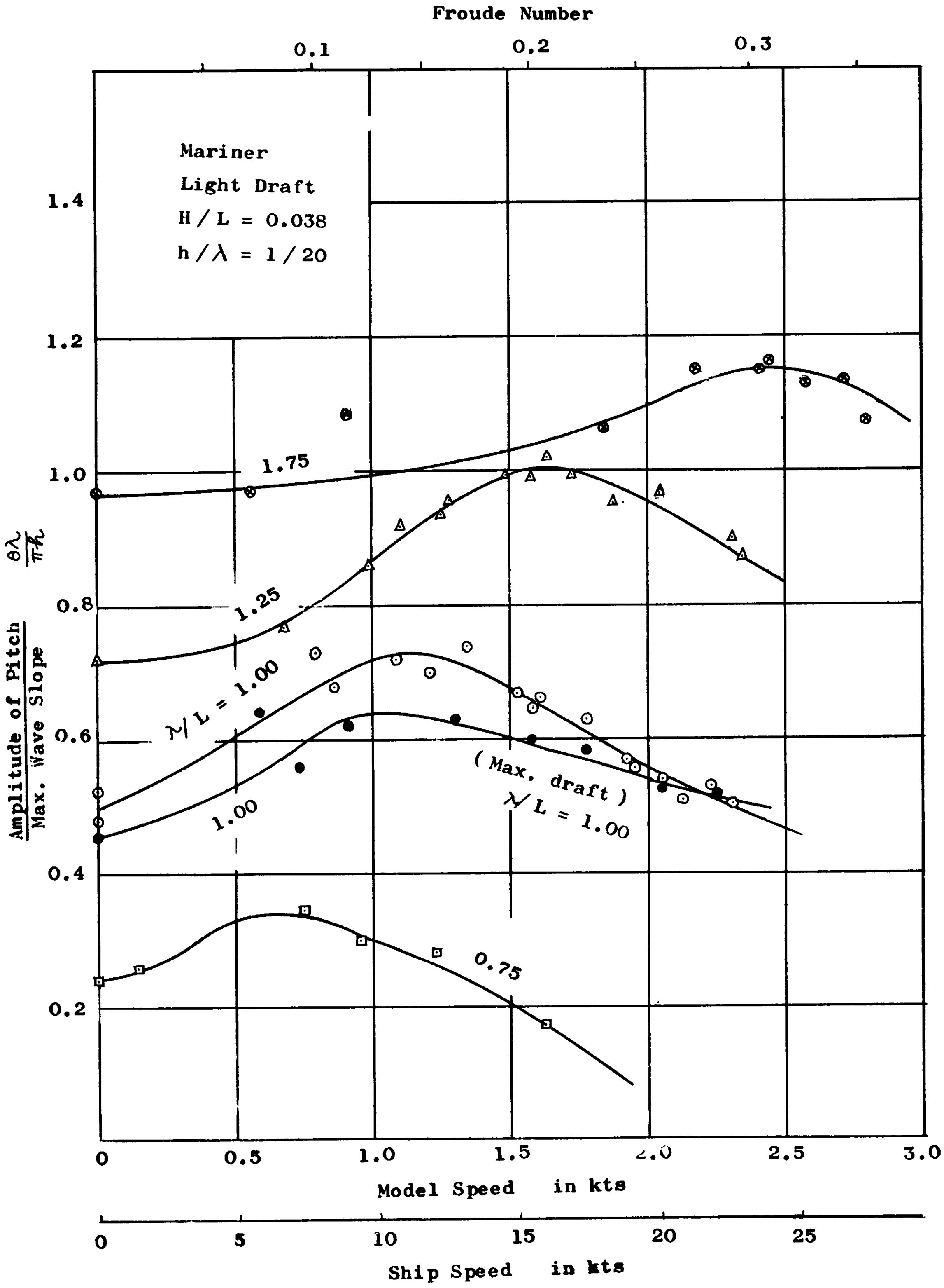

Figure 7 – Pitching Motion versus Ship Speed for MARINER

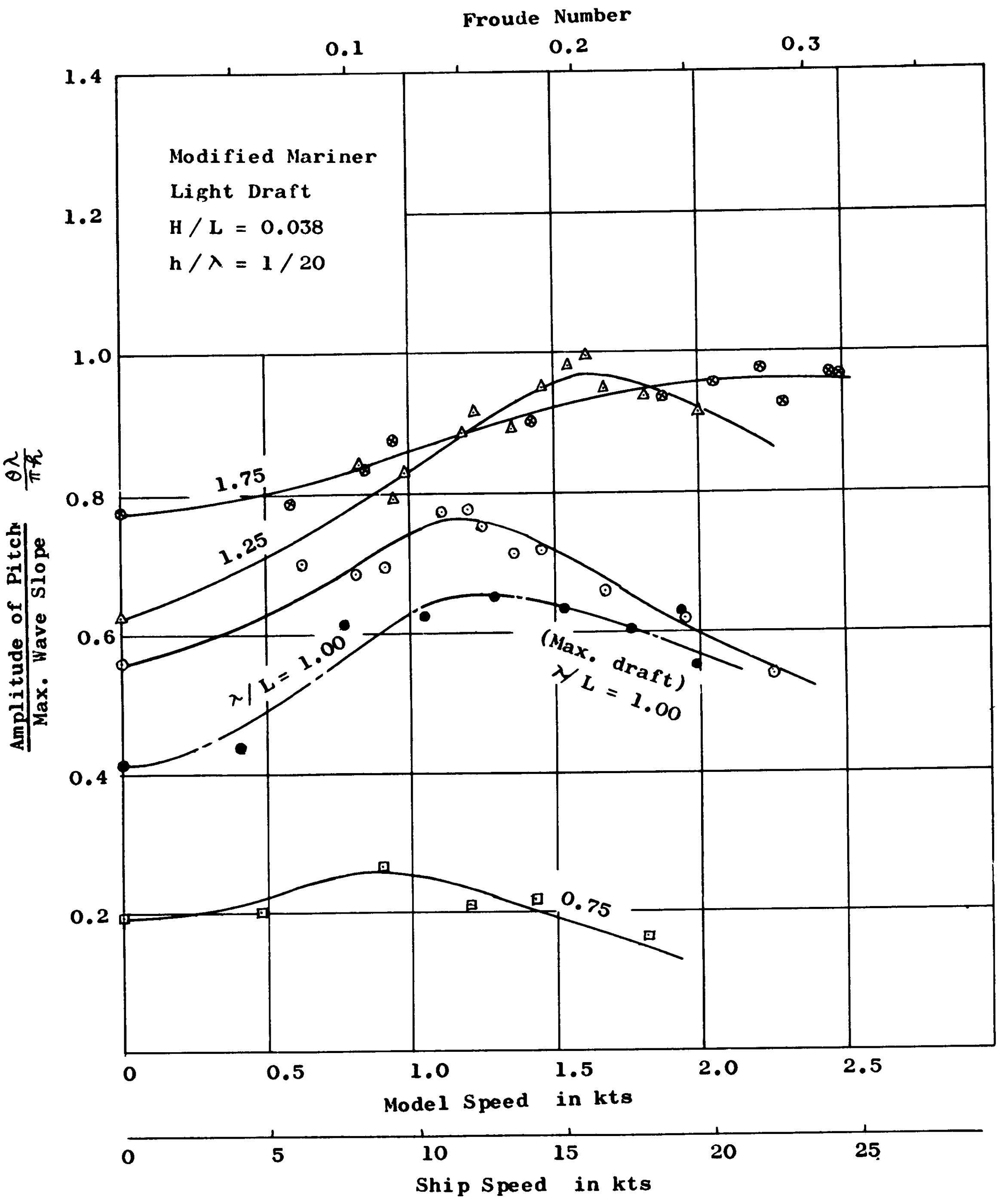

Figure 8 – Pitching Motion versus Ship Speed for Modified MARINER

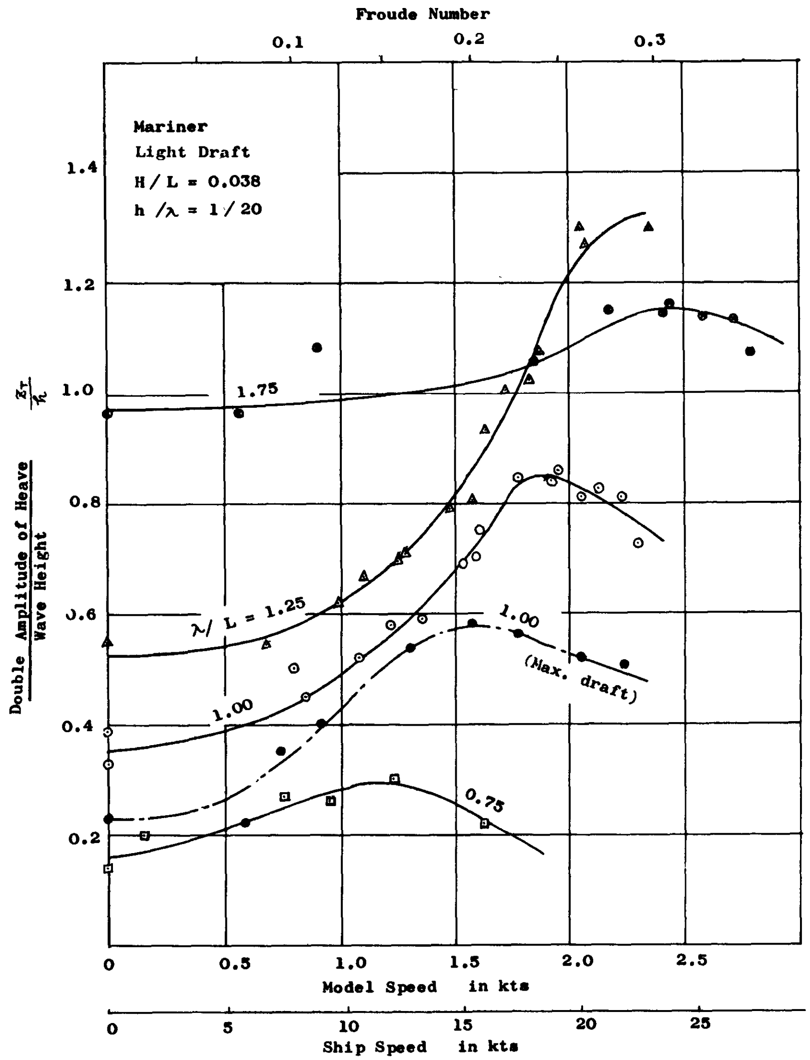

Figure 9 – Heaving Motion versus Ship Speed for MARINER

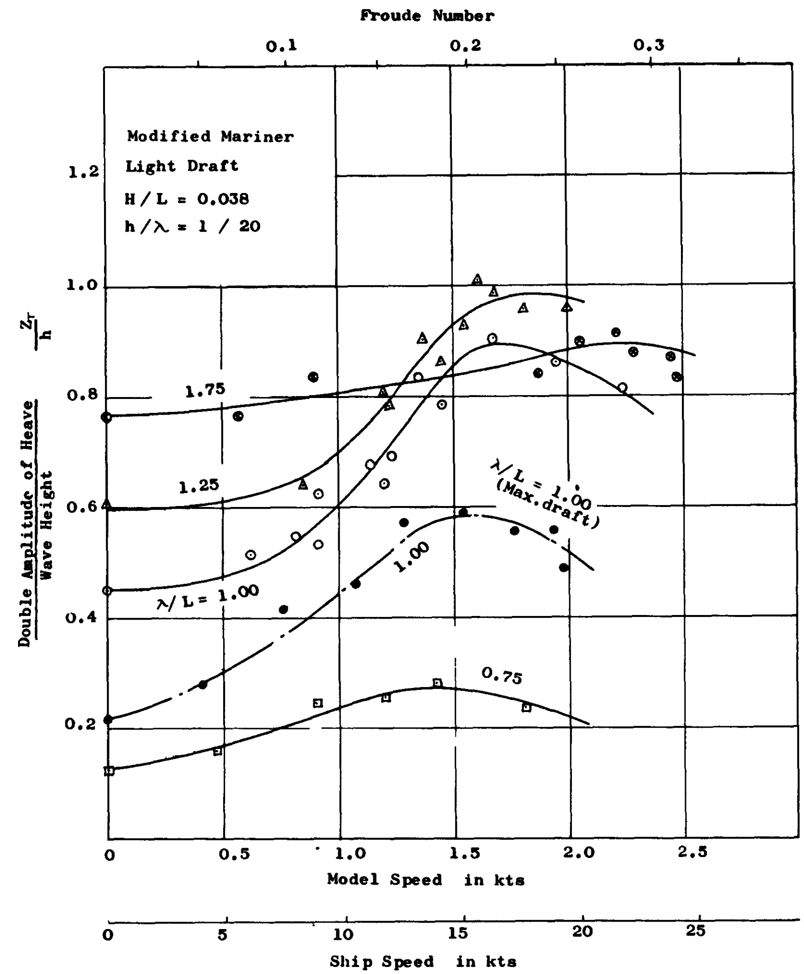

Figure 10 – Heaving Motion versus Ship Speed for Modified MARINER

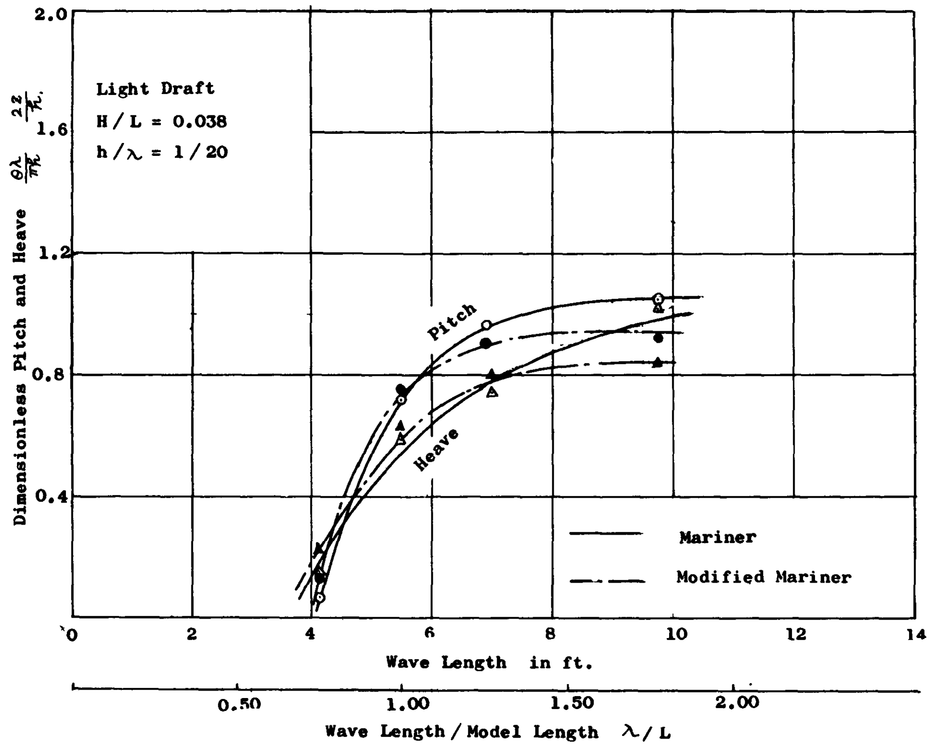

Figure 11 – Dimensionless Pitching and Heaving versus Wave Length for Constant Thrust at High Speed

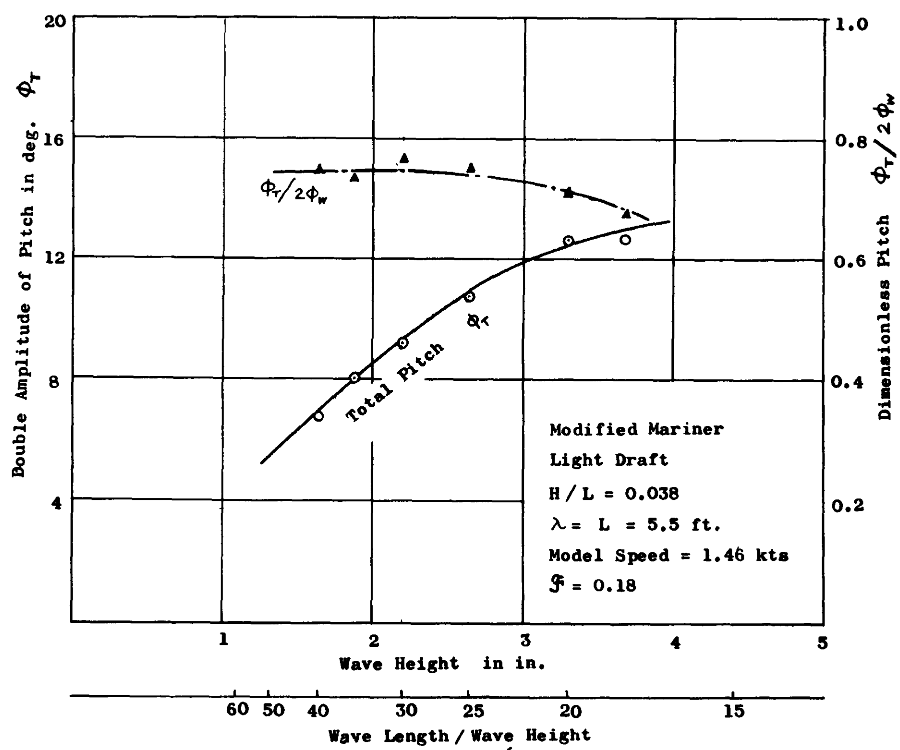

Figure 12 – Pitching Motion versus Wave Height at Model Speed of 1.46 knots

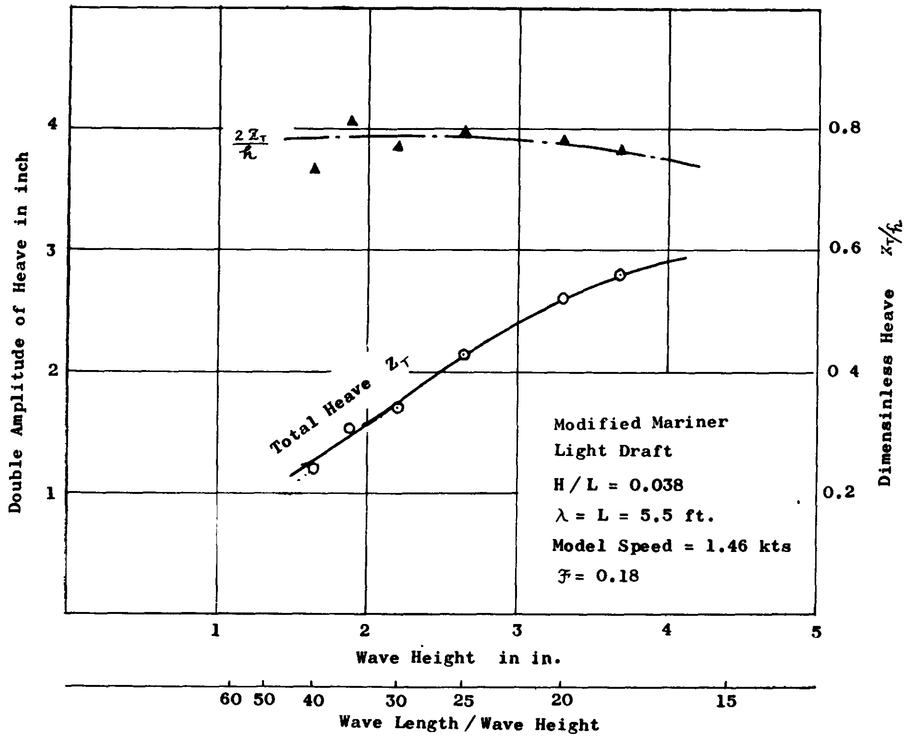

Figure 13 – Heaving Motion versus Wave Height at Model Speed of 1.46 knots

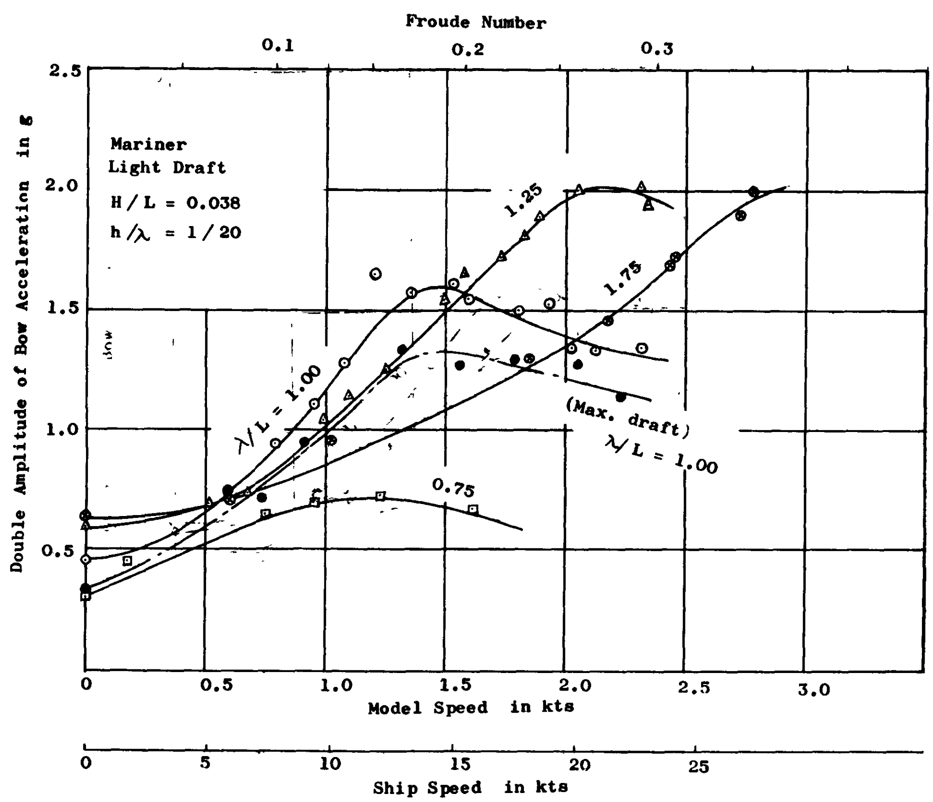

Figure 14 – Double Amplitude of Bow Acceleration versus Ship Speed for MARINER

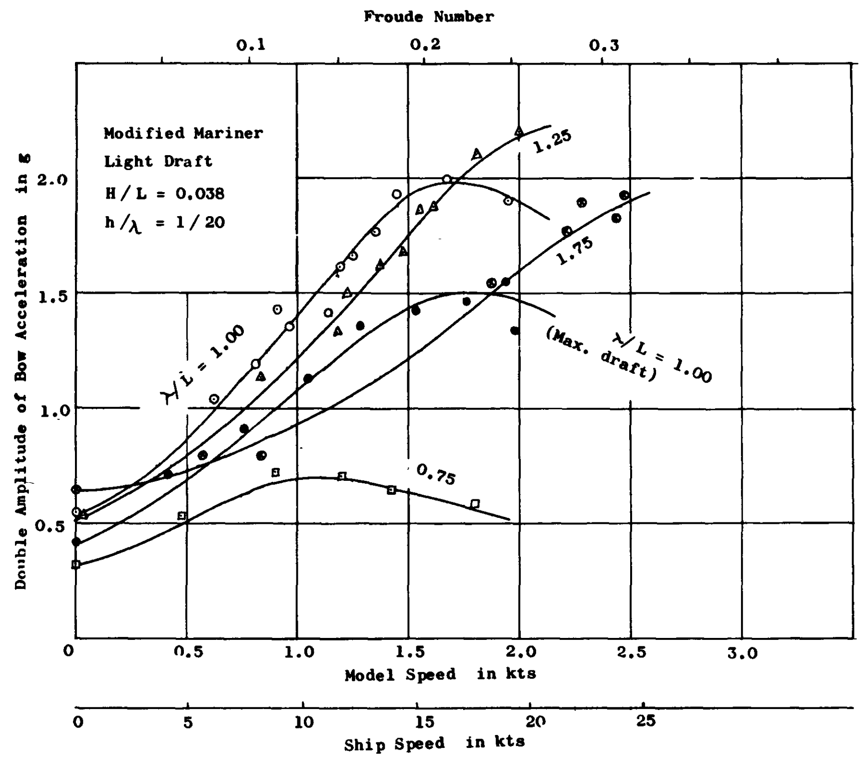

Figure 15 – Double Amplitude of Bow Acceleration versus Ship Speed for Modified MARINER

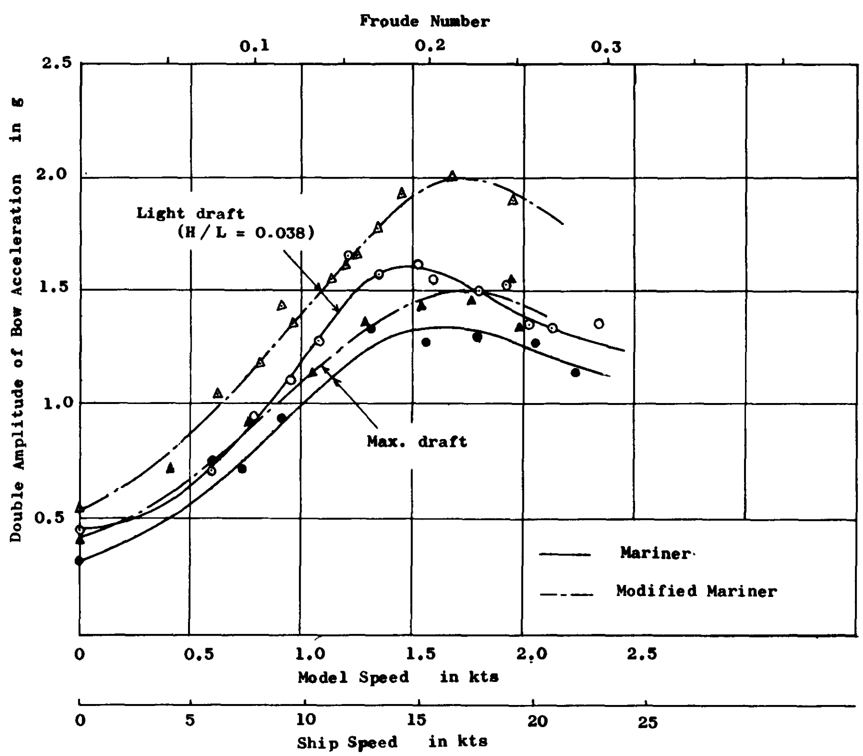

Figure 16 – Comparison of Bow Acceleration for MARINER and Modified MARINER in Waves of $\lambda/L = 1.00$

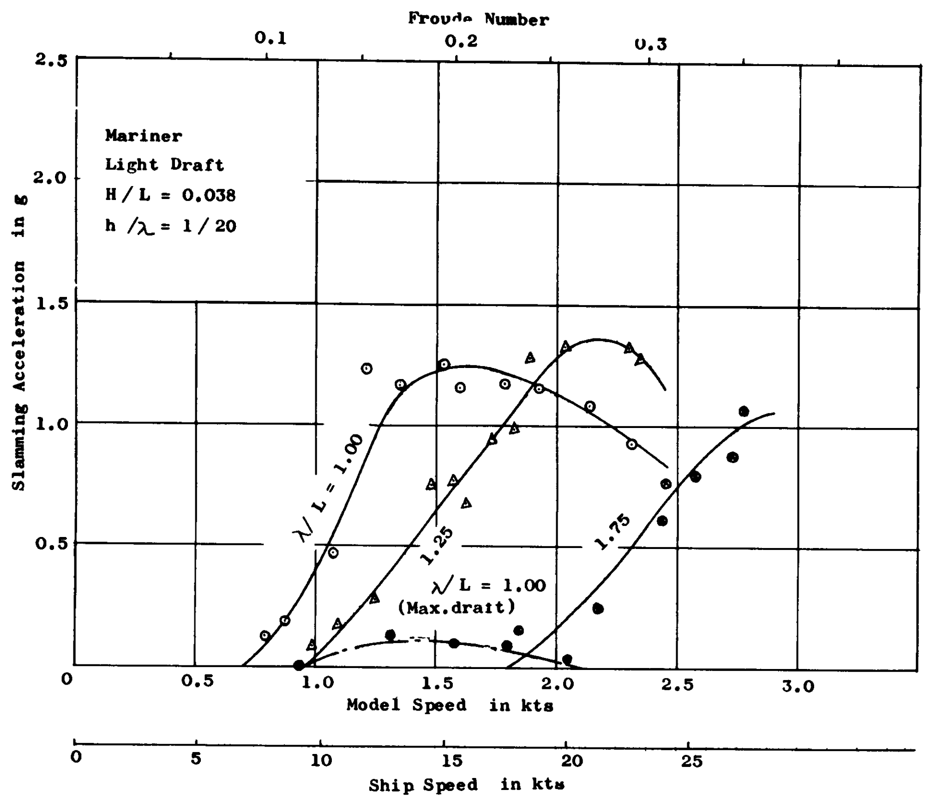

Figure 17 – Slamming Acceleration versus Ship Speed for MARINER

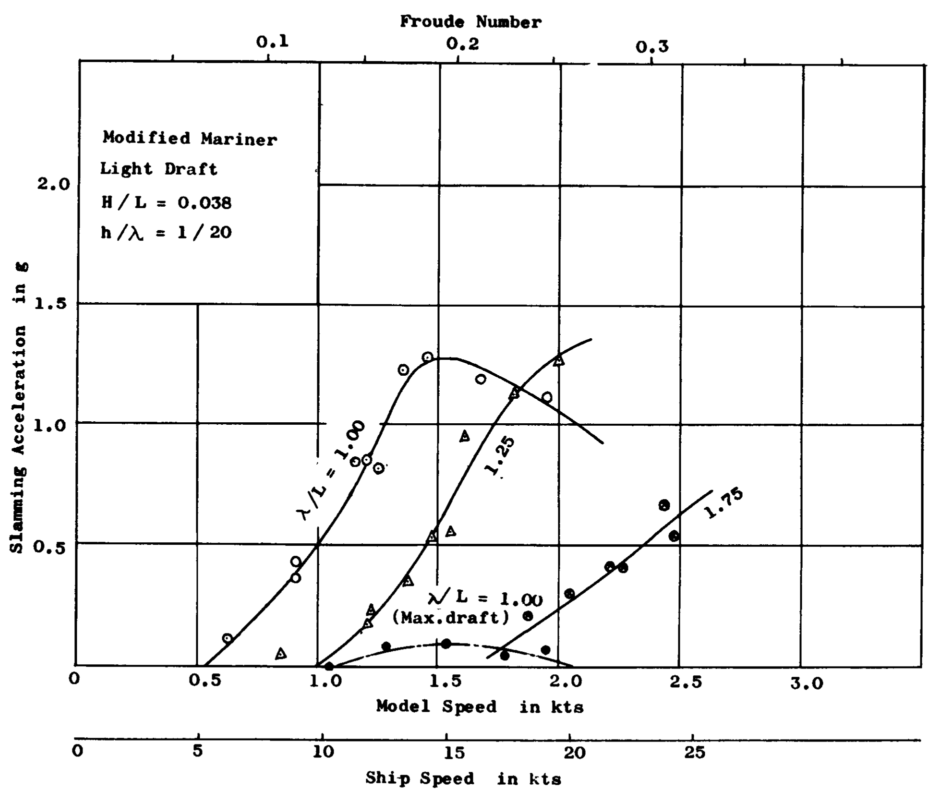

Figure 18 – Slamming Acceleration versus Ship Speed for Modified MARINER

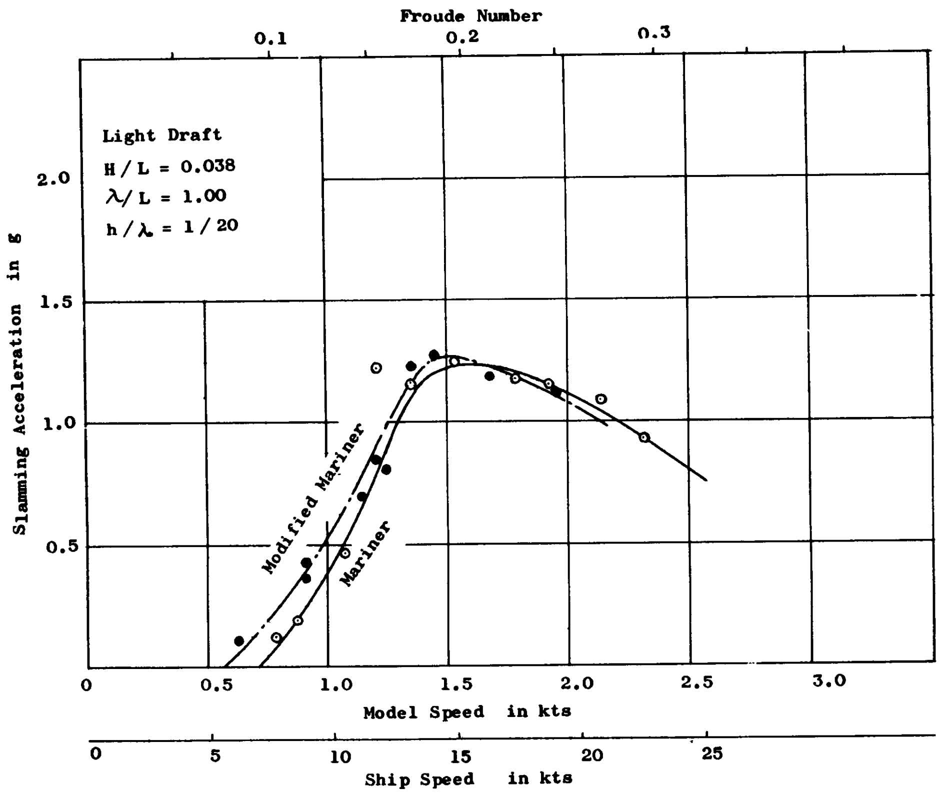

Figure 19 – Comparison of Slamming Acceleration for MARINER and Modified MARINER in Waves of λ/L = 1.00

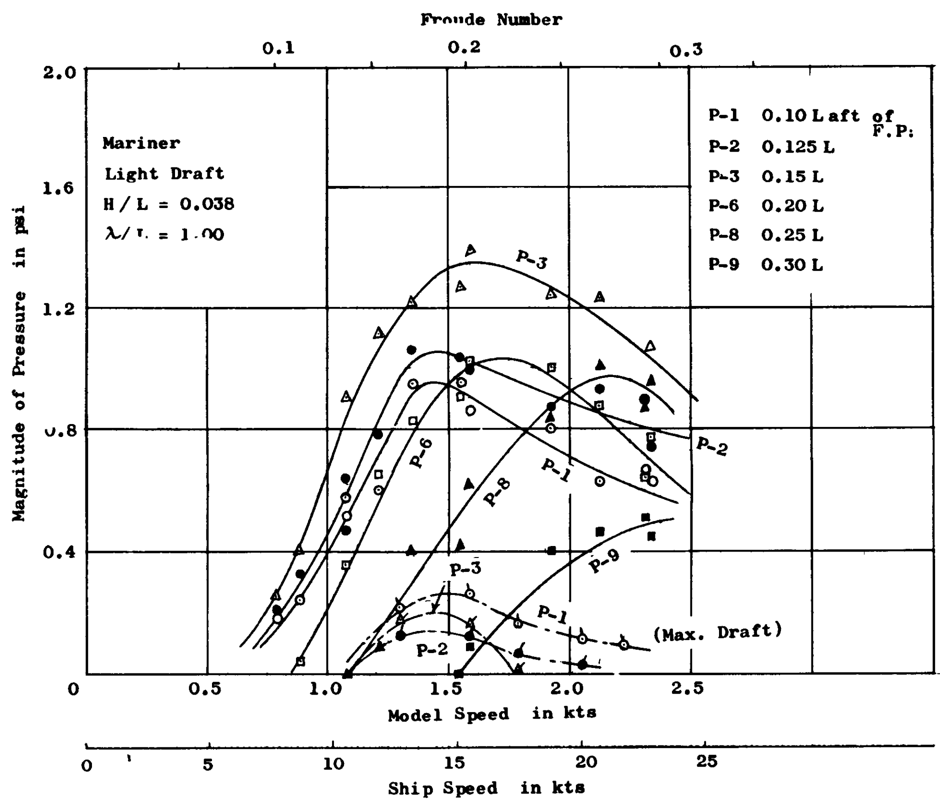

Figure 20 – Slamming Pressure versus Ship Speed for MARINER (λ/L = 1..00)

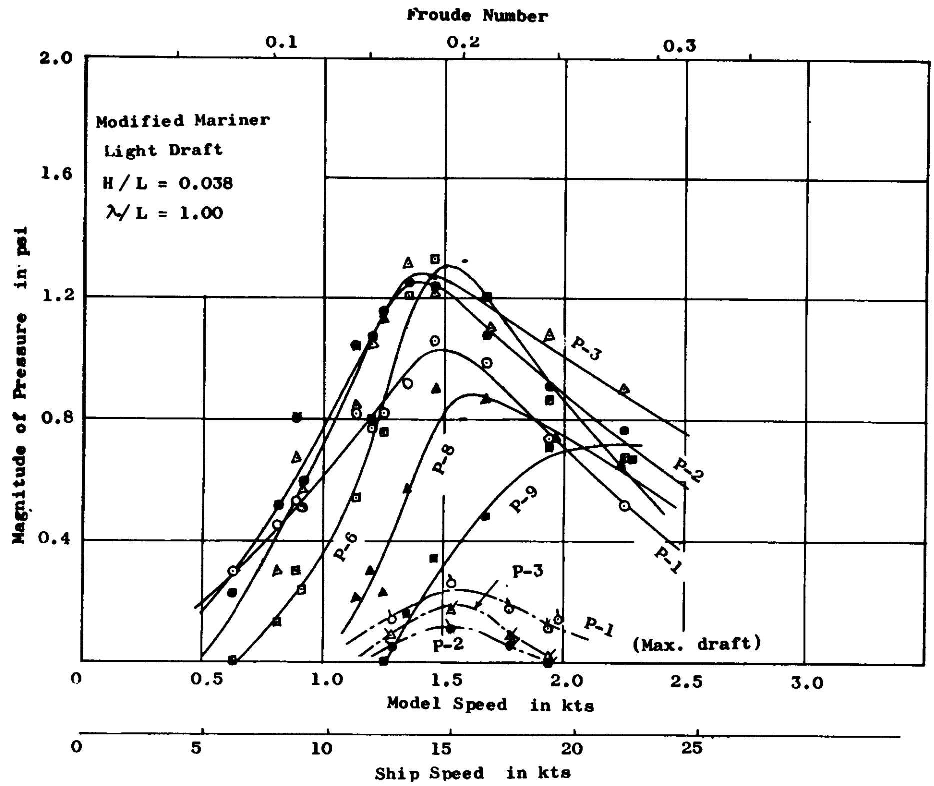

Figure 21 – Slamming Pressure versus Ship Speed for Modified MARINER (λ/L = 1.00)

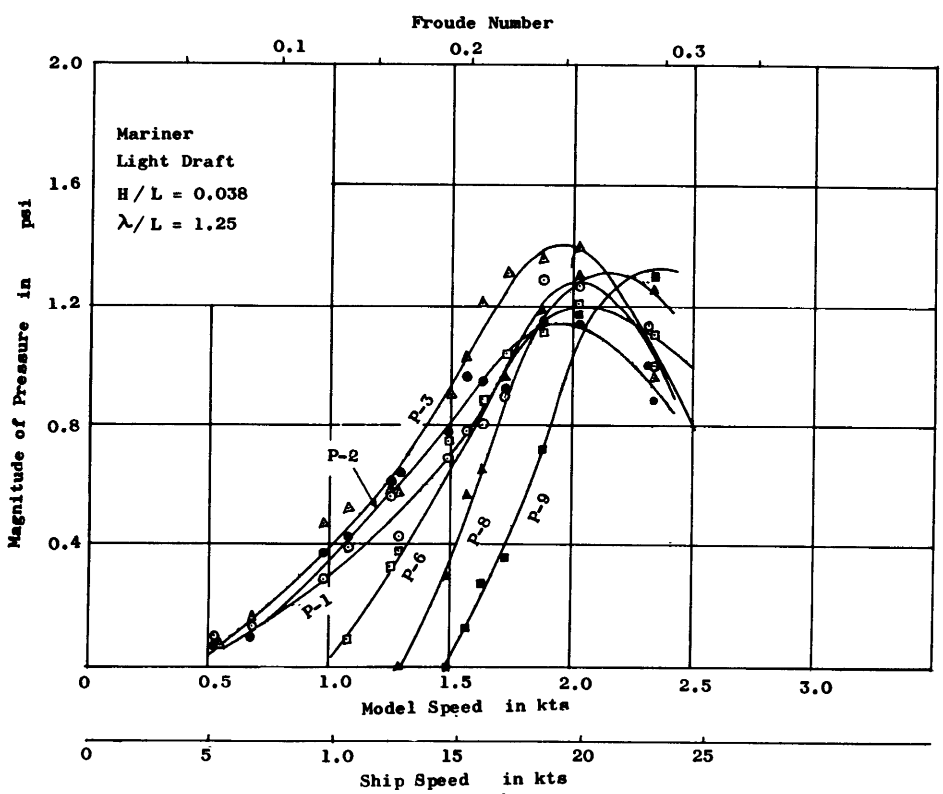

Figure 22 – Slamming Pressure versus Ship Speed for MARINER (λ/L = 1.25)

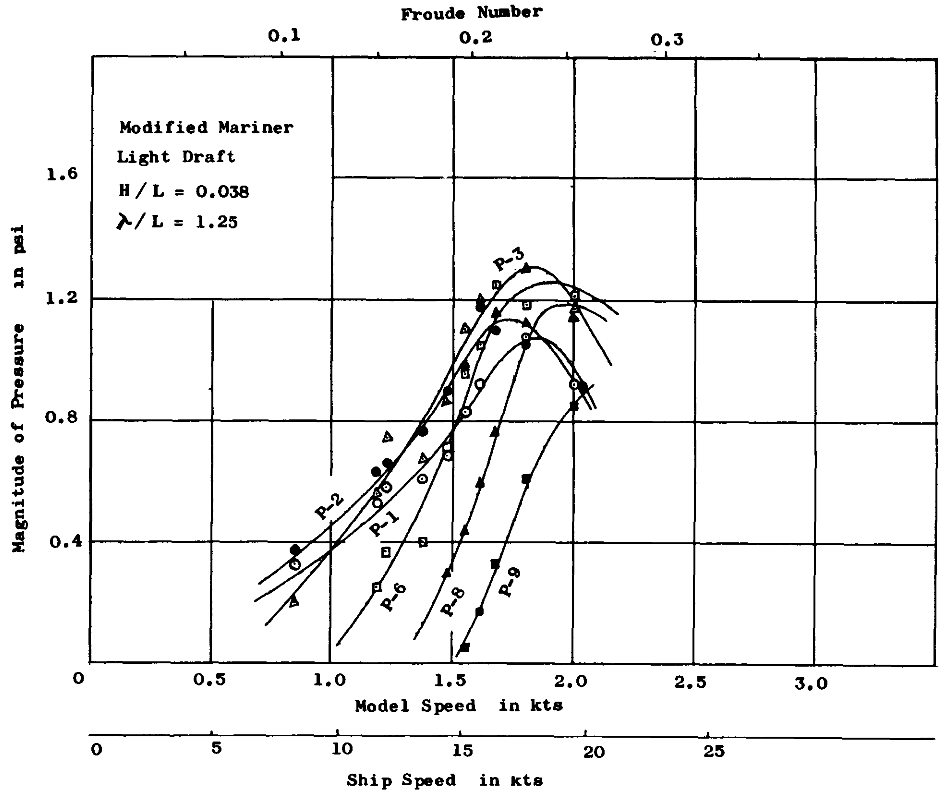

Figure 23 – Slamming Pressure versus Ship Speed for Modified MARINER (λ/L = 1.25)

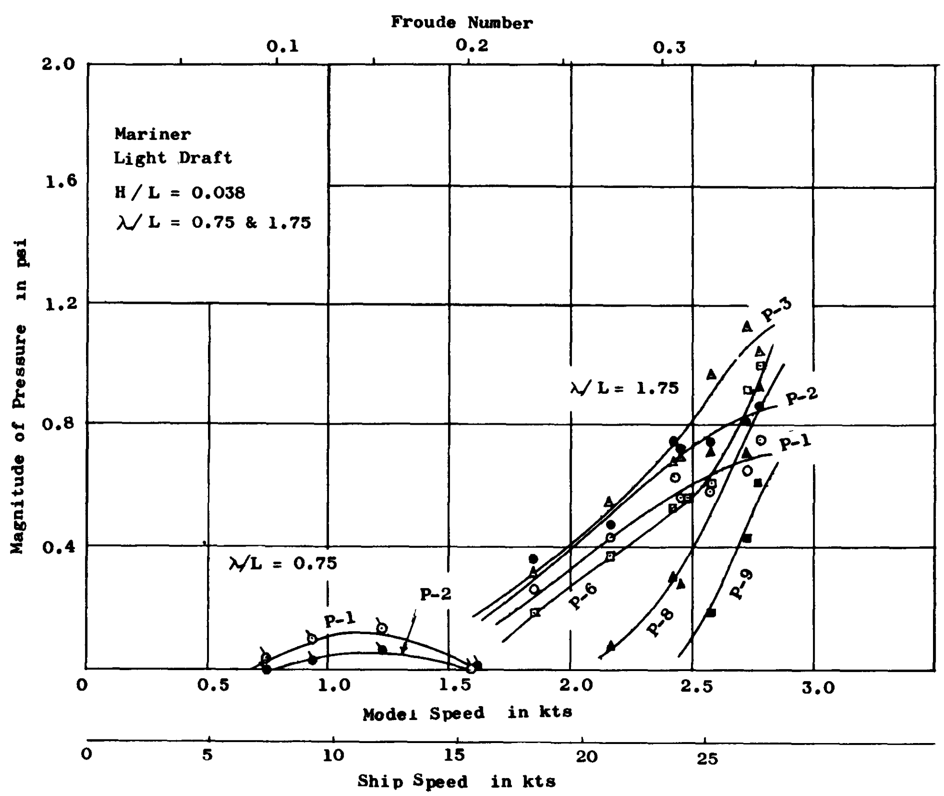

Figure 24 – Slamming Pressure versus Ship Speed for MARINER (λ/L = 0.75 and 1.75)

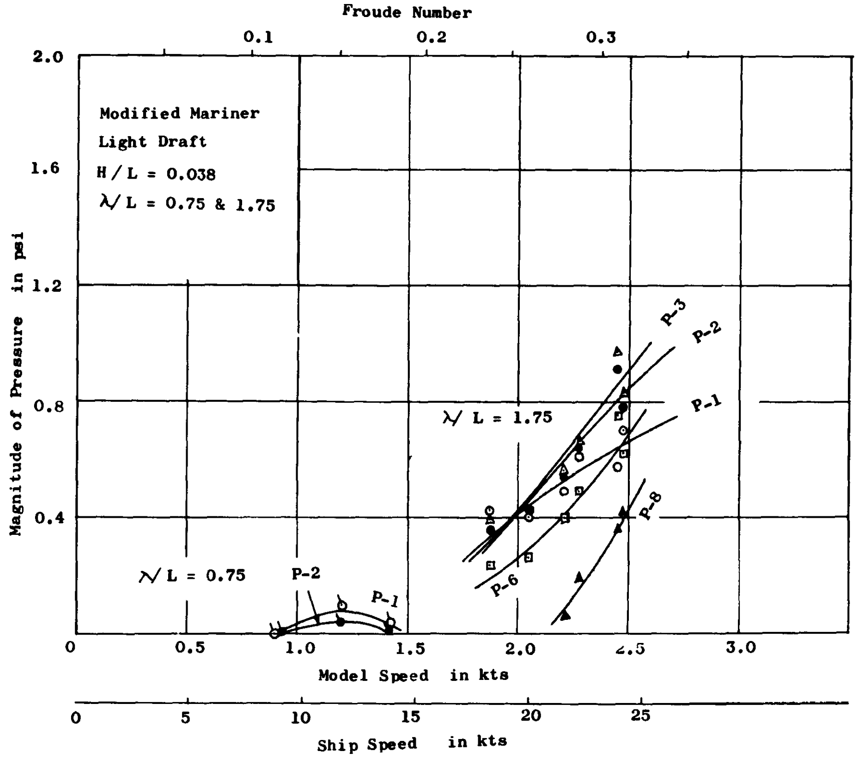

Figure 25 – Slamming Pressure versus Ship Speed for Modified Mariner (λ/L = 0.75 and 1.75)

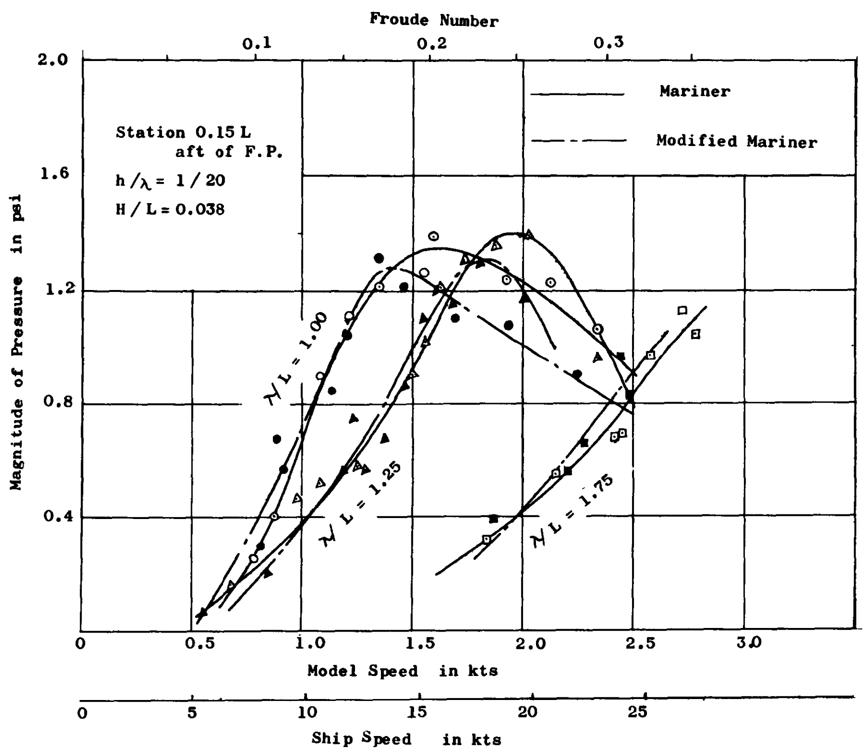

Figure 26 – Comparison of Slamming Pressure on the MARINER and Modified MARINER at Station 0.15 L Aft of Forward Perpendicular for Various Ship Speeds

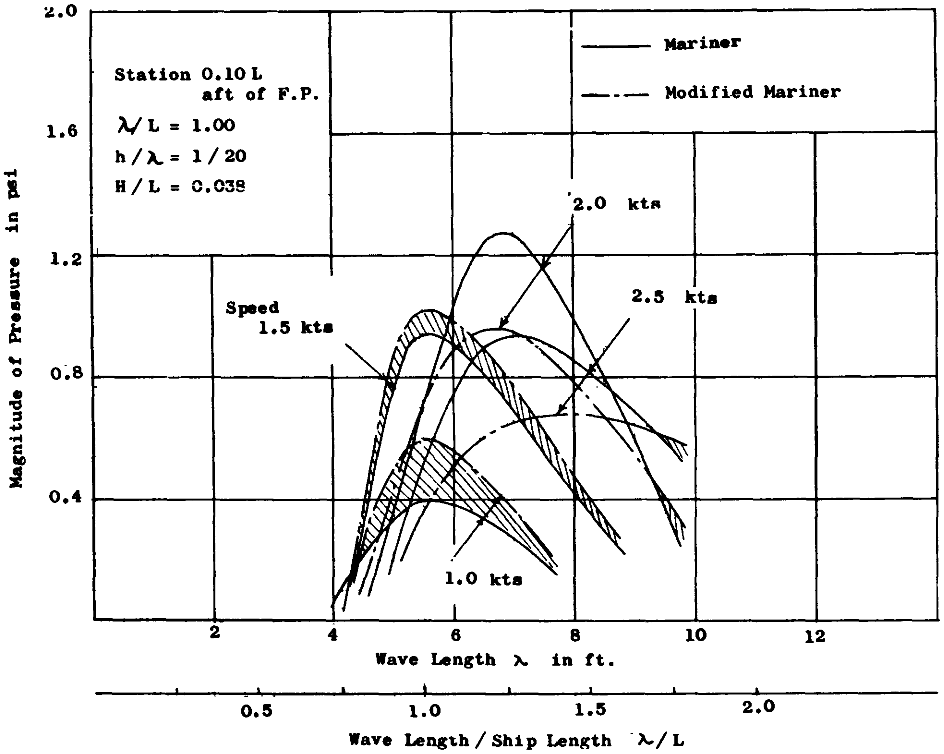

Figure 27 – Comparison of Slamming Pressure on the MARINER and Modified MARINER at Station 0.1 L Aft of Forward Perpendicular for Various Wave Lengths

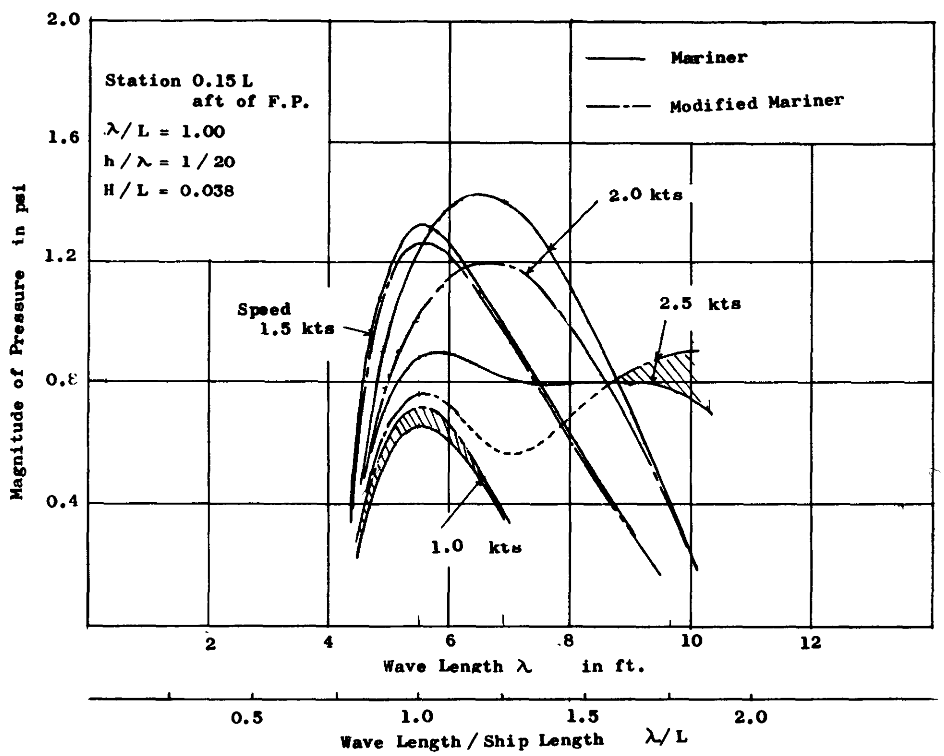

Figure 28 – Comparison of Slamming Pressure on the MARINER and Modified MARINER at Station 0.15 L Aft of Forward Perpendicular for Various Wave Lengths

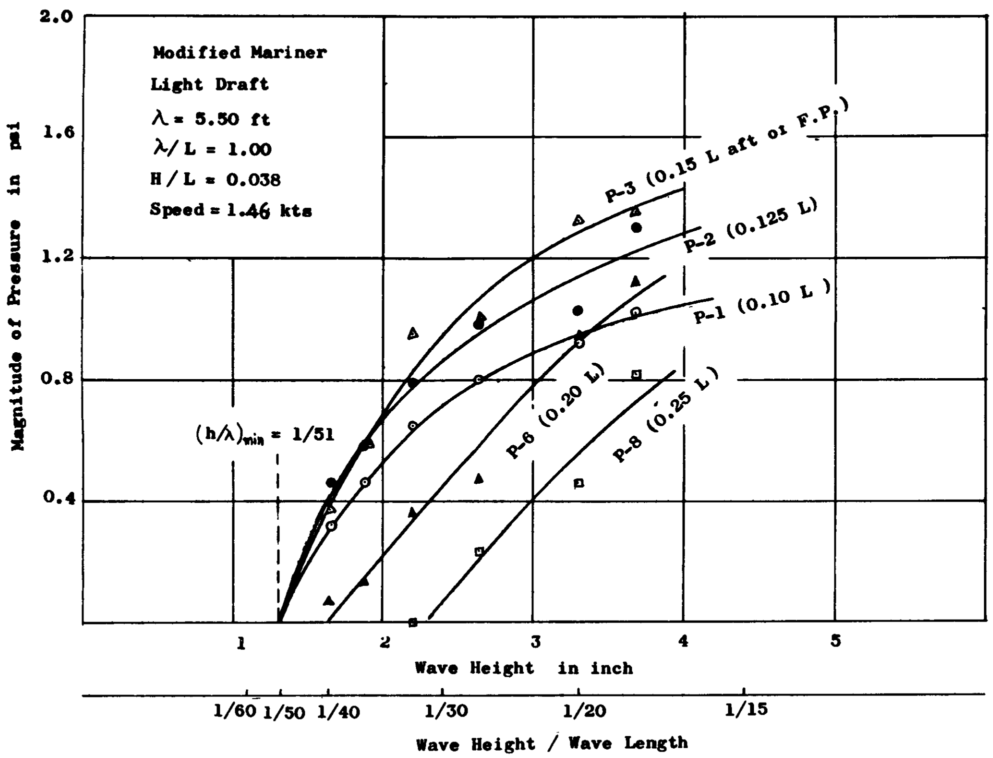

Figure 29 – Effect of Wave Height on Magnitude of Slamming Pressure (Modified MARINER)

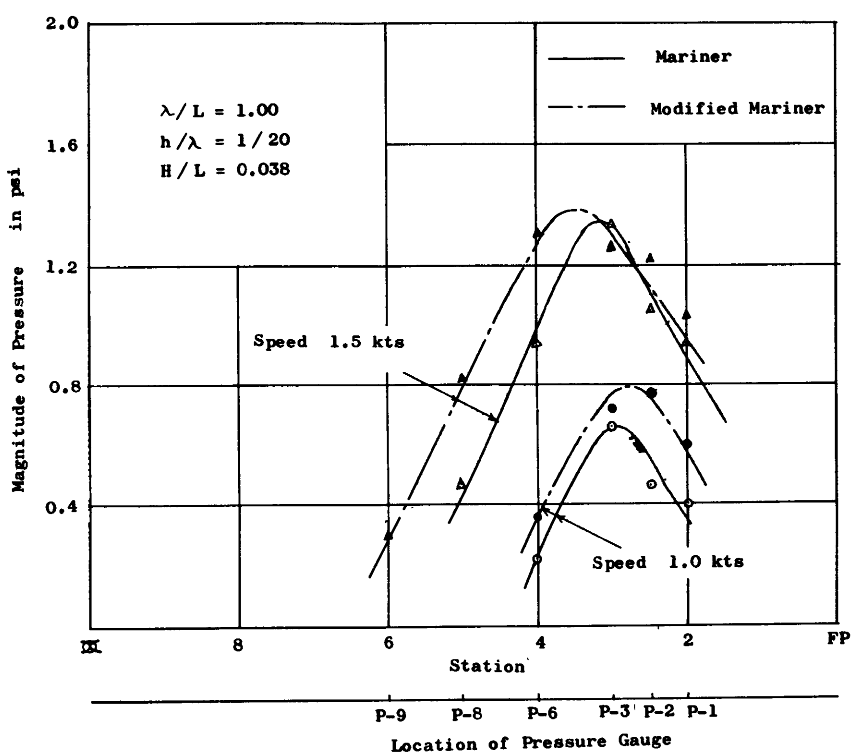

Figure 30 – Distribution of Slamming Pressure along Keel Line in Waves of $\lambda/L = 1.00$

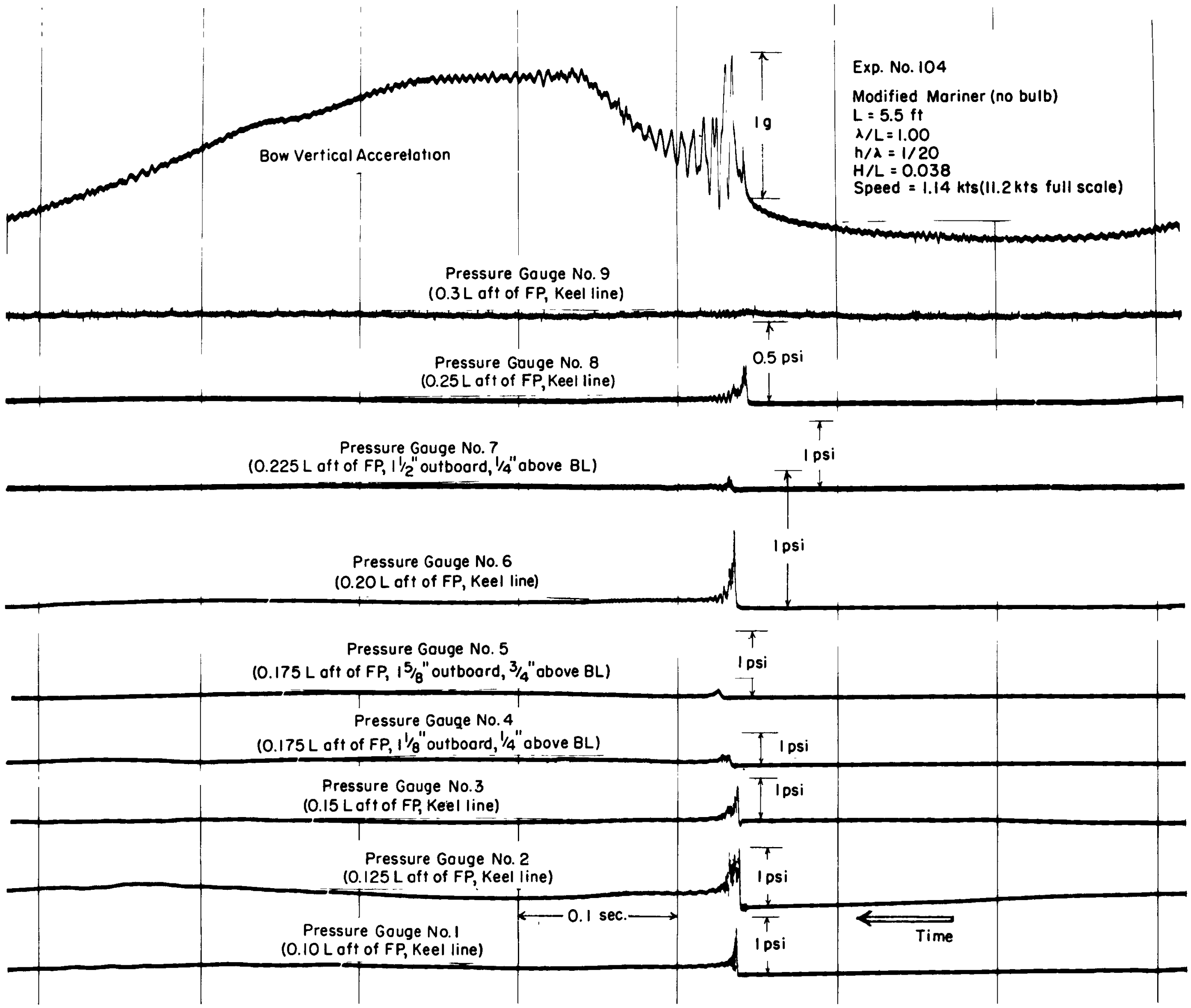

Figure 31 – Sample of Oscillograph Record

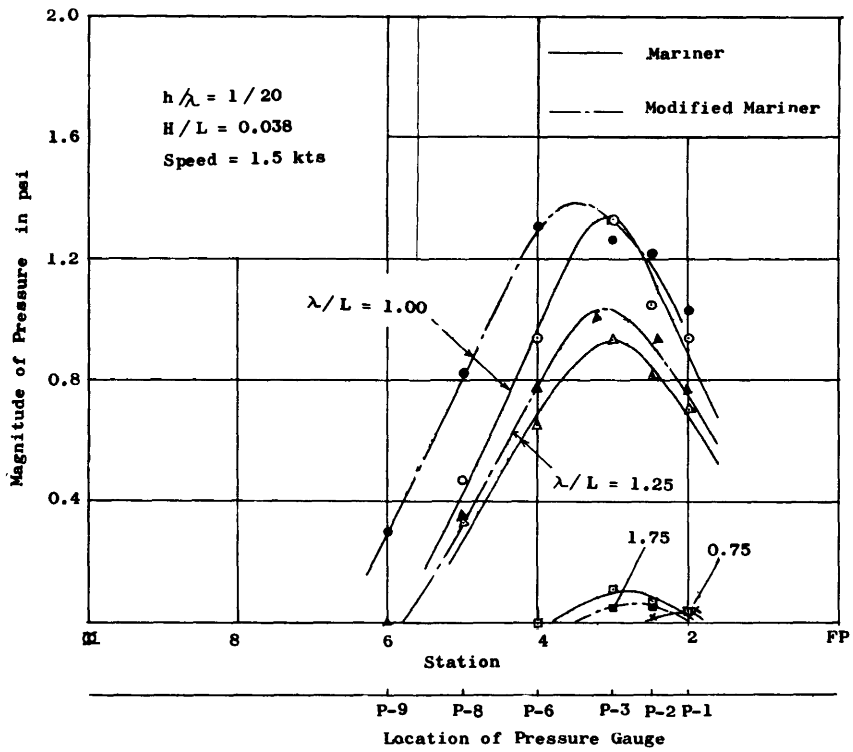

Figure 32 – Distribution of Slamming Pressure along Keel Line in Waves of Various Lengths at a Speed of 1.5 knots

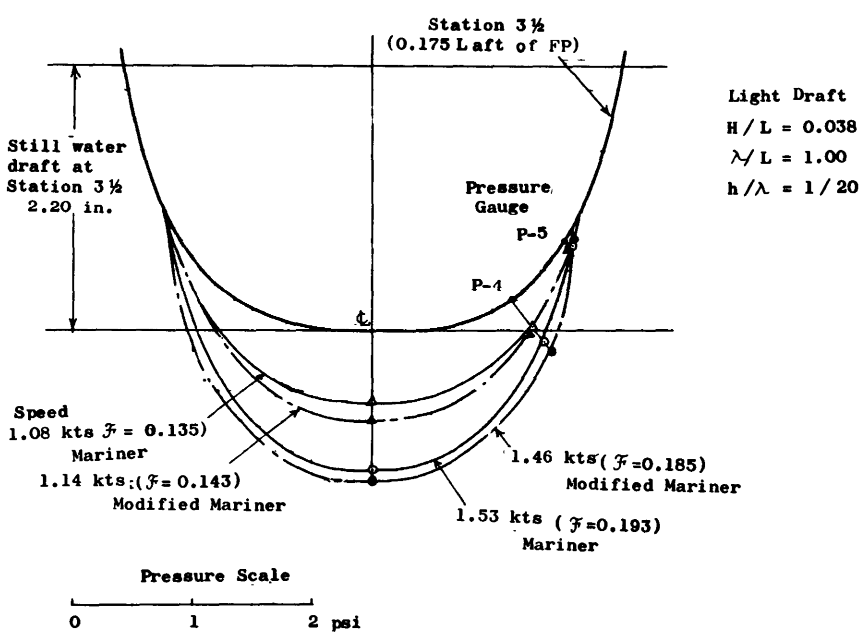

Figure 33 – Distribution of Slamming Pressure around a Section 0.175 L Aft of Forward Perpendicular on MARINER and Modified MARINER

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