[redacted]

#4

NAVY DEPARTMENT

THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

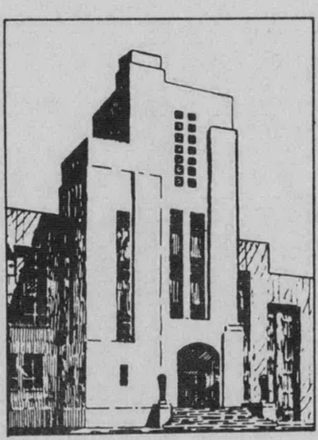
[redacted]

PITCH REDUCTION WITH FIXED BOW FINS ON A MODEL OF THE SERIES 60, 0.60 BLOCK COEFFICIENT

by

[redacted]

Ulysses A. Pournaras



RESEARCH AND DEVELOPMENT REPORT

October 1956

Report 1061

PITCH REDUCTION WITH FIXED BOW FINS ON A MODEL OF THE SERIES 60, 0.60 BLOCK COEFFICIENT

by

Ulysses A. Pournaras

October 1956

Report 1061

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

NOTATION

A, a	Inertia coefficient	Also with Subscripts
B, b	Damping coefficient	
C, c	Restoring coefficient	
F	Exciting force	
F_n	Froude number	
L	Length of model	
h	Wave height, $2r_m$	
r_m	Wave amplitude	
Z	Dimensionless heave, z_m/r_m	
z_m	Heave amplitude	
δ	Phase, heave after pitch	
λ	Wave length	
ψ	Dimensionless pitch, ψ_m/ϑ	
ψ_m	Pitch amplitude	
ϑ	Wave Slope	

ABSTRACT

The paper presents the results of model tests to determine the feasibility of reducing the pitching motion of ships by means of antipitching fins. A 10-ft self-propelled model representing the parent form of Series 60 and block coefficient 0.60 was tested in waves of various lengths and heights. Data are presented nondimensionally for possible prediction of full-scale performance, and, where necessary, at model scale. It is shown that – depending on speed and wave conditions – a pitch reduction of from 10 to 30 percent can be accomplished with bow fins having an area 2.5 percent of the water-plane area of the ship.

INTRODUCTION

Considerable attention has been given in recent years to the general problem of the motion of ships in both regular and irregular seas and to the operating limitations imposed on ships by such motions.[1-5] The importance of reducing the pitching motion has been recognized and some attempts at solution have been initiated.

The problems associated with the reduction of pitch become evident upon inspection of the familiar equation of the uncoupled pitching motion of a ship:

$$A\frac{d^2\psi}{dt^2} + B\frac{d\psi}{dt} + C\psi = Me^{int} \qquad [1]$$

The three reactions of the left-hand side of Equation [1] are the inertia, damping, and restoring reactions. Any one of these three terms can be altered, at least theoretically, to produce desired changes in the motion. The inertia reaction, for example, can be altered by redistributing the mass or sectional areas of the ship. The restoring reaction can also be altered by redistributing the ship displacement vertically or longitudinally. In practice, however, desirable or imposed characteristics impose limitations on the naval architect's freedom to vary a design. The feasibility of reducing pitch thus becomes dependent on the feasibility of increasing the damping coefficient of Equation [1] without introducing unacceptable departures from a desired form or from recognized shipbuilding practices.

It is, indeed, possible to design a hull form having relatively high damping characteristics; however, such form would deviate significantly from what is known as a normal form. On the other hand, it is generally recognized that only radical deviations from normal form are sufficient to bring about a significant decrease in the motion. One possibility remains – that of increasing the damping characteristics of the ship by means other than modifications in the basic ship form, for example by the use of fins, or wing appendages, located at selected points along the hull.

---

[1] References are listed on page 8.

Some experimental work has been carried out in this direction.[6] A noteworthy full-scale application has been the installation of antipitching fins on the Holland-America Line vessel RYNDAM. The RYNDAM experience has been somewhat unsatisfactory and discouraging. It has been reported that the ship suffered greatly by transverse vibrations attributed to the fins. These were installed at the bow of the ship not far below the static load waterline. After two days operation, they had to be removed before the vessel could continue her journey. Model test results, on the other hand, have given promise of large reductions in pitching amplitudes through the influence of antipitching fins, and further investigations were thought advisable despite the RYNDAM experience.

The Taylor Model Basin has been active for some time in the study of antipitching fins. The present report describes a series of tests in waves with a 10-ft self-propelled model representing the 0.60 block coefficient, Series 60 parent form with and without antipitching fins. It is emphasized that scaling up of the data pertaining to the model with fins may be accompanied by serious errors resulting from possible scale effects which as yet have not been determined.

DESCRIPTION OF MODEL

TMB Model 4607 is a 10-ft plastic model representing the 0.60 block coefficient, Series 60 parent form.[7] A partial list of model characteristics is given in Table 1. The model was equipped with a TMB stock propeller No. 2071 driven by a 1.25-hp, dc motor. The radius of gyration of the model was 25 percent of the waterline length for dynamic similarity with typical ships. The center of gravity was 0.15 ft aft of the midship section, the model being at even keel. A photograph of the model is presented in Figure 1.

TABLE 1

Principal Characteristics of Model 4607

Length, LBP, ft	10.00
Model Displacement, lb	265.70
Draft, ft	0.53
Maximum Beam, ft	1.33
Load Waterplane Area, sq ft	9.41
Load Waterplane Coefficient C_{wp}	0.706
Block Coefficient C_B	0.60

The antipitching fins, designated PSF-1, port and starboard, were essentially flat plates, 1/8 in. thick, shaped at the leading and trailing edges. The leading edge was swept back. The span of each fin was 4 in., and the root and tip chords were 5 and 3.5 in., respectively. The planform area was 34 sq in. or 2.5 percent of the load waterplane area. The leading edge of the root chord was located 1 1/8 in. aft of the forward perpendicular. The fins were fitted with tip fences, 4 in. long and 3/4 in. deep by 1/16 in. thick. It might be noted that the swept-back planform was arrived at from structural rather than hydrodynamic considerations. Reducing the load toward the tips results in a smaller bending moment at the root; this in turn lessens the structural difficulties of attaching the fins to the hull. Tip fences were used to approach two dimensional flow.

The fins were attached to the hull by fitting them to a cylinder 7 1/2 in. long and 1 1/4 in. in diameter. The cylinder was cut and shaped into the hull so that it was tangent to the keel, with the root chords of the port and starboard fins parallel and 1 1/4 in. apart. The nose of the cylinder was faired to the forefoot on the lower side, and its upper side was faired to a spherical surface of a radius equal to that of the cylinder. No attempts were made to fair the attachment with fillets. Schematic plans and photographs of the fins and the installation are shown in Figures 2 and 3.

TEST PROGRAM

The model was self-propelled in waves according to the schedule of Table 2. All tests were conducted in head seas. Wave size and motion data were obtained by means of motion-picture records and also by electronic pickup and recording systems. The model was guided by an arrangement which allowed freedom in heave, pitch, surge, and sway but restricted the model in roll and yaw.

RESULTS AND DISCUSSION

Prior to testing in waves, the natural periods of heave and pitch had been obtained for Model 4607 with and without fins. These are shown in Table 3 along with the computed critical speeds at which the amplitudes of the motions are maxima.

PITCH

The pitch amplitudes of the model heading into waves of various height h and with lengths λ from 0.75 to 1.50 times the length of the model L, are presented in Figures 4 and 5; these graphs show the pitch amplitude vs. Froude number and speed for the model with and without fins. The experimental points indicated have been corrected linearly for wave height e.g., by multiplying the experimental values by the ratio of the nominal to the actual wave height. The variations of the measured wave heights were less than 7.5 percent.

Pertinent points to be observed are the shifting of the critical speed, i.e., the speed of maximum motion, and the magnitude of the resulting amplitude reductions as a function of speed, wave length, and wave height. The shift in the critical speed to lower values in the case of the model with fins can be explained by the increase of the natural period in pitch caused by the fins with the consequence that a lower speed of advance is required for

TABLE 2

Model 4607 – Schedule of Tests in Waves

λ ft	λ/L	h in.	λ/h	Speed Range	
				Without Fins knots	With Fins knots
7.5	0.75	2.5	36	0 to 3.2	0 to 3.2
10.0	1.00	2.5 4.0	48 30	0 to 3.2 0 to 2.7	0 to 3.2 0 to 2.7
12.5	1.25	2.5 5.0	60 39	0 to 3.2 0 to 3.7	0 to 3.2 0 to 2.7
15.0	1.50	2.5 6.0	72 30	0 to 3.2 0 to 2.7	0 to 3.2 0 to 2.7

TABLE 3

Natural Periods in Pitch and Heave and Computed Critical Speeds

		Natural Periods sec	Critical Speeds, knots			
			λ=7.5 ft	λ=10.0 ft	λ=12.5 ft	λ=15.0 ft
Heave	Without Fins With Fins	1.045 1.065	0.59 0.50	1.42 1.33	2.35 2.22	3.32 3.16
Pitch	Without Fins With Fins	1.010 1.180	0.73 0.09	1.64 0.78	2.59 1.53	3.61 2.35

synchronism. The effects of the forward speed, wave height, and wave length will be considered simultaneously in the explanation of the effect of the fins in reducing the amplitude of the motion.

Damping generally depends on the vertical component of the velocity, which, in turn, is dependent on the frequency and amplitude of the oscillation. Other things being equal, an increase in the vertical velocity results in greater damping. The same argument holds for the case of increasing wave lengths at a given speed since longer waves imply lower frequencies and, therefore, lower damping. Past the critical speed, also, the amplitude of the motion decreases and so must the damping. It will be observed that at speeds above the critical, the model with fins experiences a milder decrease of amplitude than the model without fins. The trend is for equal amplitudes at some higher speed outside the range of the tests when the amplitudes are small and the effect of added damping is only minor.

The preceding remarks must be viewed as general. Considerations as to the effects of phase relationship between heaving and pitching, which govern the amplitude of the vertical motion of the fins and possibly their contribution to damping, have been omitted.

HEAVE

In Figures 6 and 7, the heave amplitude is presented in the same fashion and for the same conditions as in the case of pitch. Again, the experimental points indicated have been corrected linearly for the wave height. The shift of the critical speed to a lower value for the model with fins is again present but is not so obvious. The damping of the fins, as reflected by the increase of the natural period, results in a shift of the critical speed. This shift alone, however, cannot explain the reductions effected in the amplitude of the motion since the change in natural period is hardly significant. One must also consider the effect of the frequency of encounter, the amplitude of the motion, and above all, the two most important factors: coupling effects and the phase between the motions in heave and pitch.

The importance of coupling effects is generally recognized but little is known concerning their magnitude. The magnitude is assumed to be proportional to the amplitude of the motion. The phase angles evidently assume some importance also and, therefore, any discussion that follows must remain within a general and qualitative nature. The equation of the heaving motion, for example, including pitch coupling terms is

$$A_1 \frac{d^2 z}{dt^2} + B_1 \frac{dz}{dt} + C_1 z + a_2 \frac{d^2 \psi}{dt^2} + b_2 \frac{d\psi}{dt} + c\psi = Fe^{iwt} \qquad [2]$$

We observe from Equation [2] that the effect of pitch on heave depends on the angle of pitch. Pitch angle, in turn, depends partly on the coupling of heave and pitch and, therefore, on the displacement in heave. It is noted that for all practical purposes, the natural periods in heave and pitch are identical for the model without fins. Consequently, the critical speeds in heave and pitch are also identical. The effect of the fins is to increase the natural period in pitch much more than the natural period in heave. The natural periods are thus separated as are the critical speeds. With fins, the critical speed for pitch is reached first. Upon reaching the critical speed in heave, the amplitude of pitch has already declined, and the coupling effects are apt to be smaller for the model with fins. The algebraic sign of the coupling effect will be determined by the phase relationship between heave and pitch. The significance of the phase relationship between the two motions thus becomes apparent.

PHASE RELATIONSHIPS

The phase relationship between heave and pitch are presented in Figures 8 and 9. The experimental values are plotted directly without any correction for wave height variations and must, therefore, be treated with the proper caution.

LOCATION AND VERTICAL MOTION OF APPARENT PITCHING AXIS

The location of the apparent pitching axis[8] and the amplitude of its vertical motion are presented in Figures 10 through 13. By definition, the apparent pitching axis is the point of minimum vertical motion along the ship. The longitudinal location of the apparent pitching axis and the amplitude of its vertical motion can be used together to assess further effects of the antipitching fins. As the curves of Figures 10 through 13 have been computed on the basis of phase angles, they should be viewed only as indicative of a trend.

GENERAL OBSERVATIONS

It was found that the model without fins shipped quantities of green water over the bow, especially in the longer and steeper waves. The shipping of green water was less severe in the 10-ft waves ($\lambda/L = 1.00$) of 30:1 length-height ratio, and increased in severity with speed. The most severe condition was at speeds approaching 2 knots ($F_n \cong 0.20$) in the 15-ft waves ($\lambda/L = 1.50$) of 30:1 length-height ratio. Large quantities shipped over the bow and flowed over the deck to near amidships. Forefoot and forebody emergence were frequently observed to occur in the 30:1 waves, particularly in the upper half of the speed range.

The use of fins delayed the shipping of green water in terms of speed and wave length. When shipping of green water did occur, less water was shipped by the model with fins at the same speeds and wave conditions. In no case did the forefoot or the forebody of the model with fins emerge. During the tests in the 15-ft by 6-in. waves ($\lambda/L = 1.50$, $\lambda/h = 30$) and for the full speed range, the fins were observed to come near the surface of the water but never to break clean and skim. The fins also approached the surface in the 10-ft by 4-in. waves ($\lambda/L = 1.00$, $\lambda/h = 30$) at zero speed and at very low speeds of advance.

A flow phenomenon was observed which may be serious and which should be further investigated. On their downward stroke, the fins forced water from the lower to the upper side around the leading and trailing edges. The flow appeared in two distinct sheets. The leading edge sheet, probably under the influence of the forward speed, closed in over the upper surface of the fin faster than did the trailing edge sheet. The two met near the surface of the water and produced a whirl. As the fins came near the surface in the more severe conditions, the two sheets partially escaped into the air and produced an audible slap at the sides of the bow. Removal of the tip fences during spot check runs did not influence the amplitudes of the motion but produced a third sheet of water around the tip. This sheet appeared stronger than the other two and slapped the sides of the bow with greater intensity. It is believed that such flow will result in large unsteady forces on the hull in the vicinity of the fins. Scale effects will probably be introduced because the atmospheric pressure is the same for the model as for the ship.

CONCLUSIONS

The test results indicate that reduction of the pitching motion of ships can be effected by means of fixed antipitching fins. Further theoretical and experimental investigations are considered necessary before the useful range and limitations of antipitching fins can be adequately established. The pitch reduction attributable to the fins considerably improves dryness of the model in head seas. The practical speed range, as restricted by motions of undesirable magnitude, is also extended. Forefoot and forebody emergence occurring during the tests without the fins were not observed when the fins were installed.

ACKNOWLEDGMENTS

The author is greatly indebted to Dr. V.G. Szebehely for his valuable suggestions and encouragement during the course of this study. The cooperation of the members of the Ship Dynamics Branch in obtaining and analyzing the data is gratefully acknowledged. The author is particularly indebted to Mr. G.P. Stefun who analyzed the motion records.

REFERENCES

1. Weinblum, G. and St. Denis, M., "On the Motion of Ships at Sea," Transactions Society of Naval Architects and Marine Engineers, Vol. 58 (1950).

2. St. Denis, M. and Pierson, W.J., Jr., "On the Motion of Ships in Confused Seas," Transactions Society of Naval Architects and Marine Engineers, Vol. 61 (1953).

3. St. Denis., M., "On Sustained Sea Speed," Transactions Society of Naval Architects and Marine Engineers, Vol. 59 (1951).

4. Lewis, E.V., "Ship Speeds in Irregular Seas," Transactions Society of Naval Architects and Marine Engineers, Vol. 63 (1955).

5. Szebehely, V.G. and Todd, M.A., "Ship Slamming in Head Seas," David Taylor Model Basin Report 913 (Feb 1955).

6. Edstam, U.B. and Vytlacil, N., Jr., "Hydrodynamic Effect of a Bow Hydrofoil on Three Vessel Types," Master of Science Thesis, Massachusetts Institute of Technology (1955).

7. Todd, F.H., "Some Further Experiments of Single-Screw Merchant Ship Forms -Series 60," Transactions Society of Naval Architects and Marine Engineers, Vol. 61 (1953).

8. Szebehely, V.G., "Apparent Pitching Axis," Forshungsheft für Shifftechnik (Jan 1956).

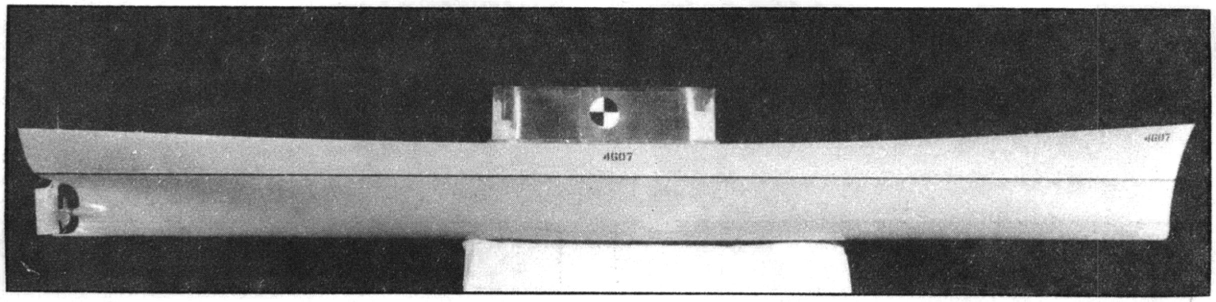


Figure 1 - Model 4607, Series 60, Block Coefficient 0.60

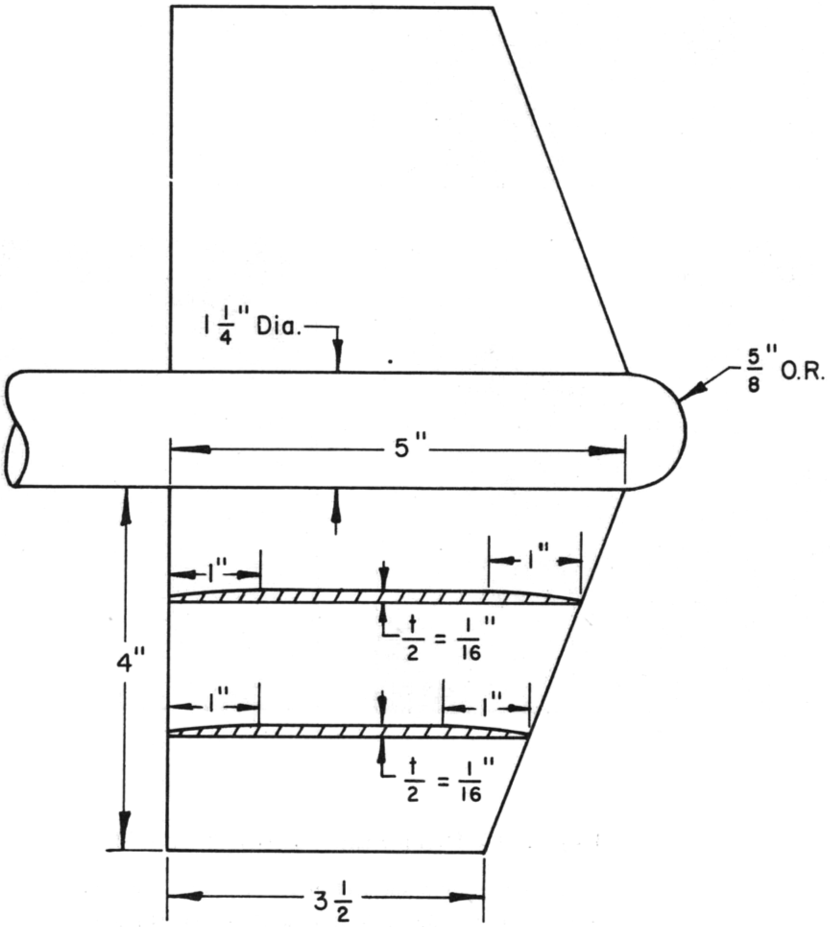
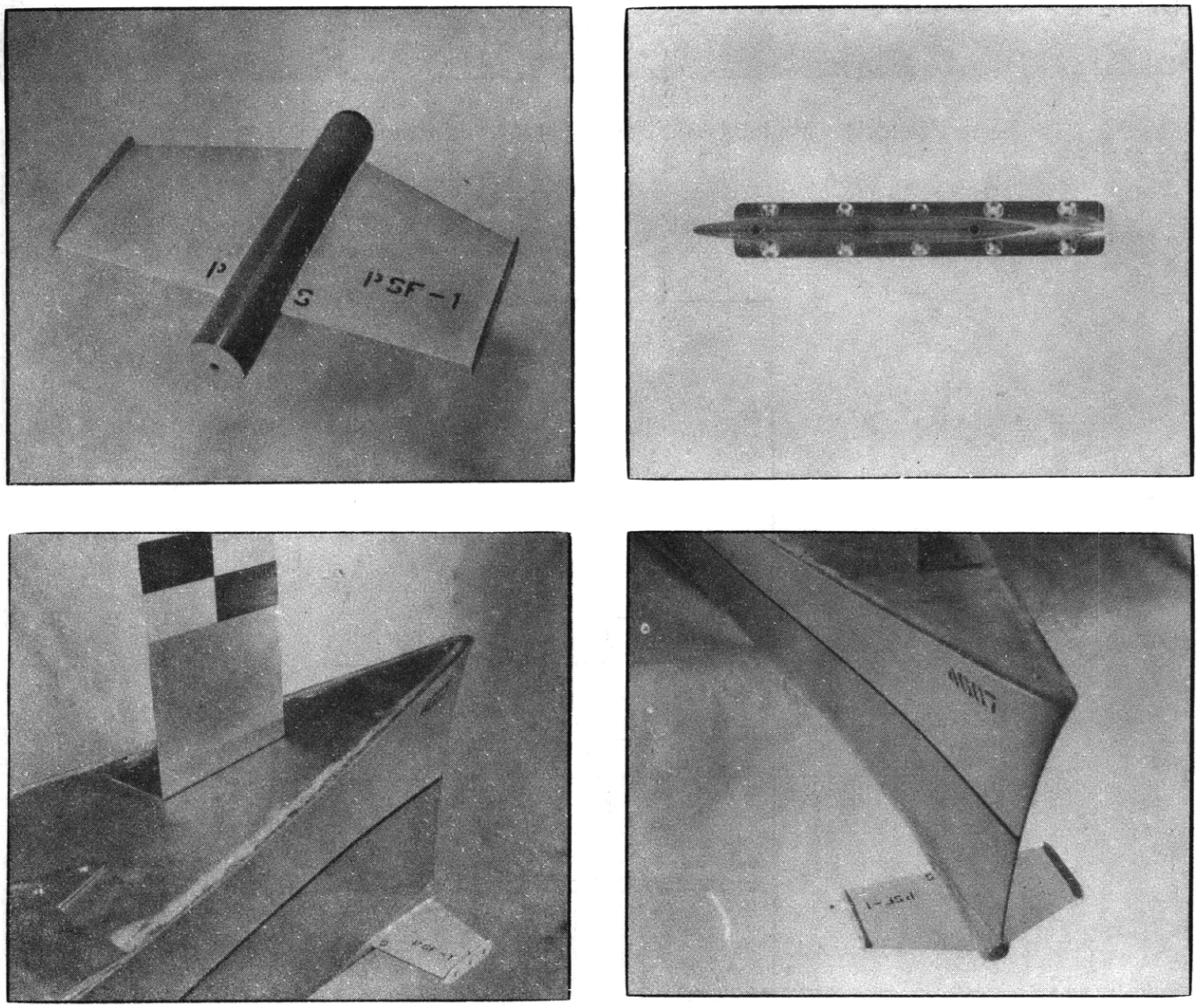


Figure 2 - Planform and Profile Sections of Antipitching Fins



NP21-63384

Figure 3 - Pitch Stabilization Fin PSF-1

The photographs show plan view, profile (fences removed), and the fins as installed aboard Model 4607.

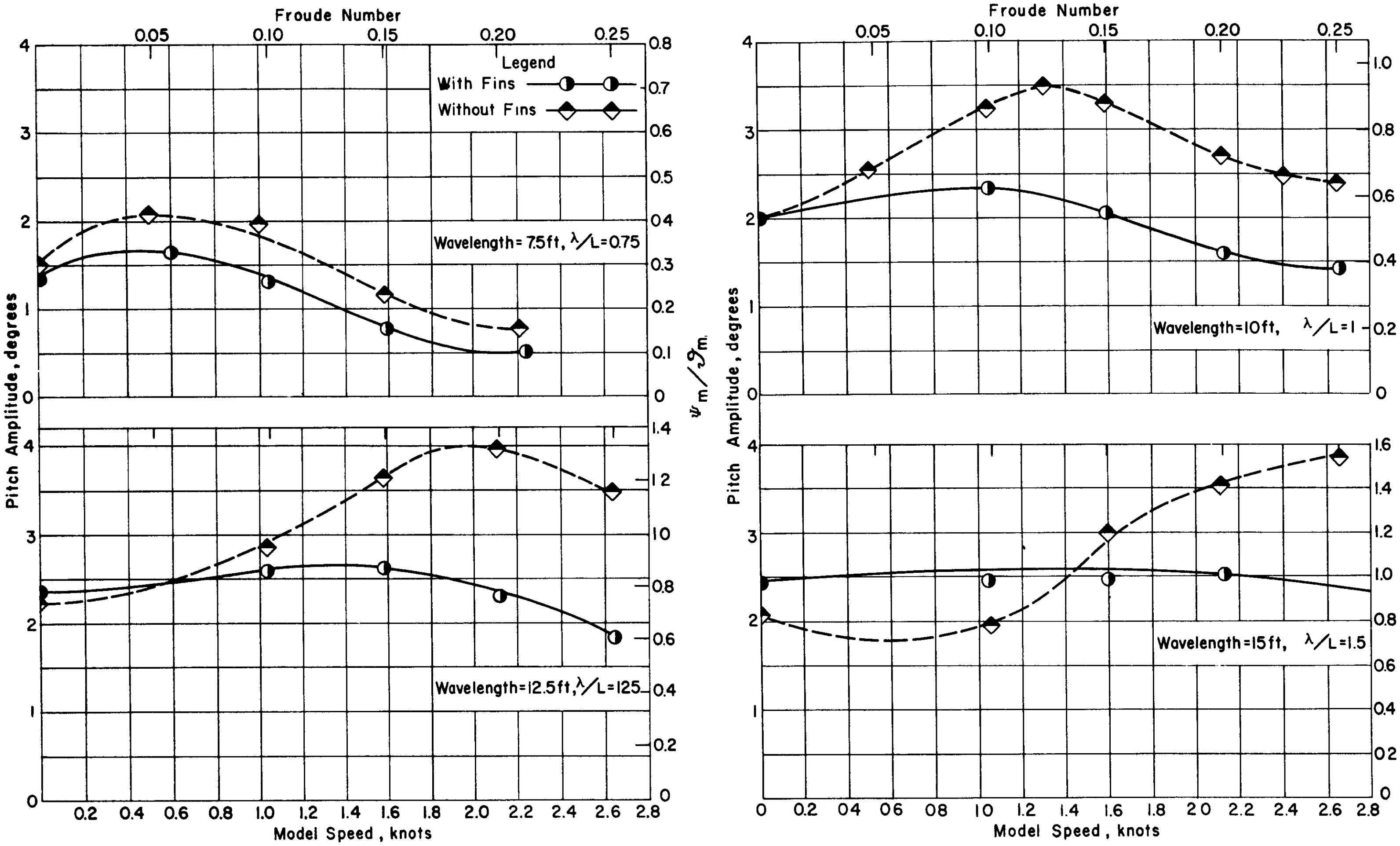


Figure 4 - Experimental Pitch Amplitudes, Waves of Various Lengths and 2.5 Inches High

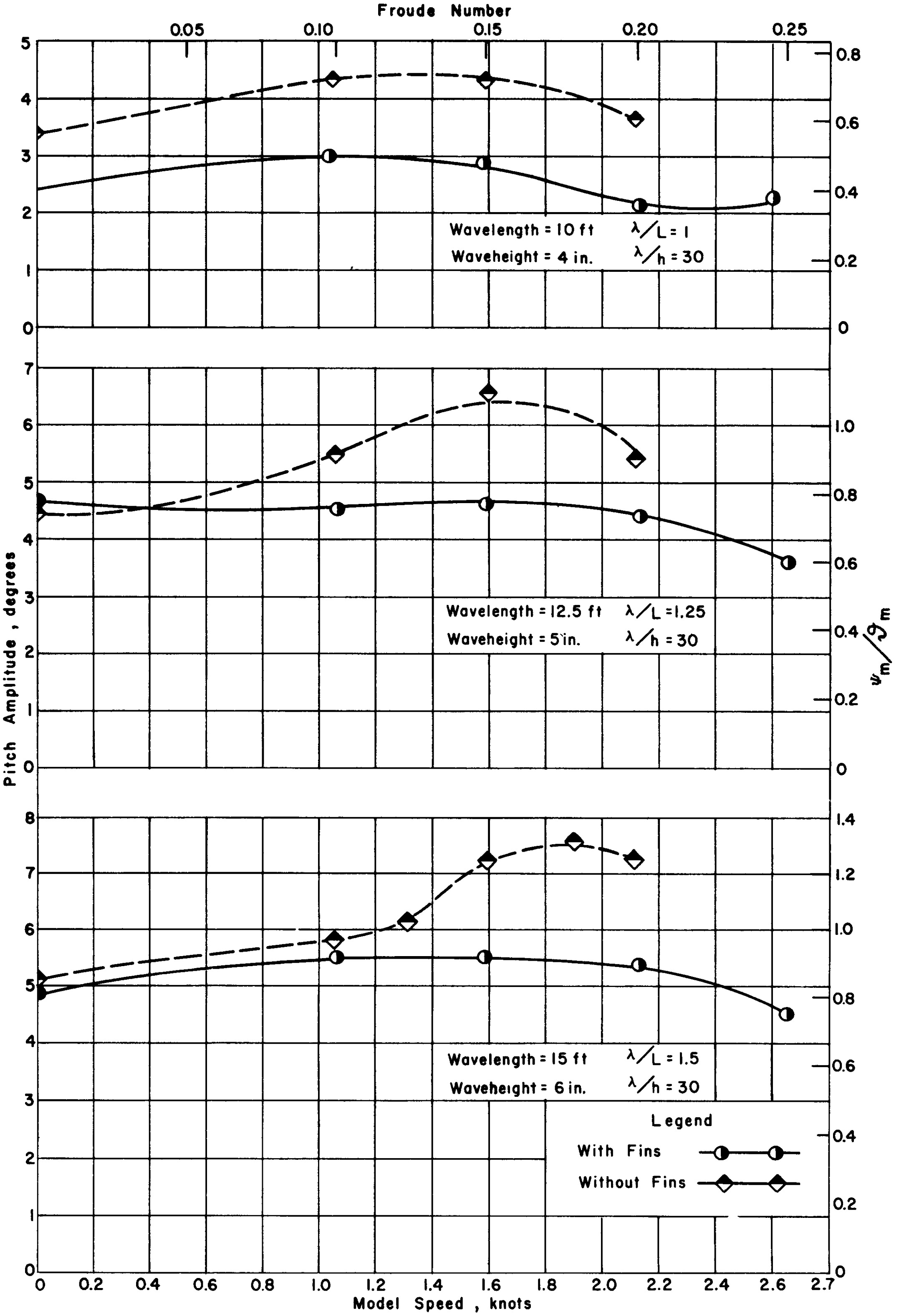


Figure 5 - Experimental Pitch Amplitudes, Wavelength-Height Ratio of 30

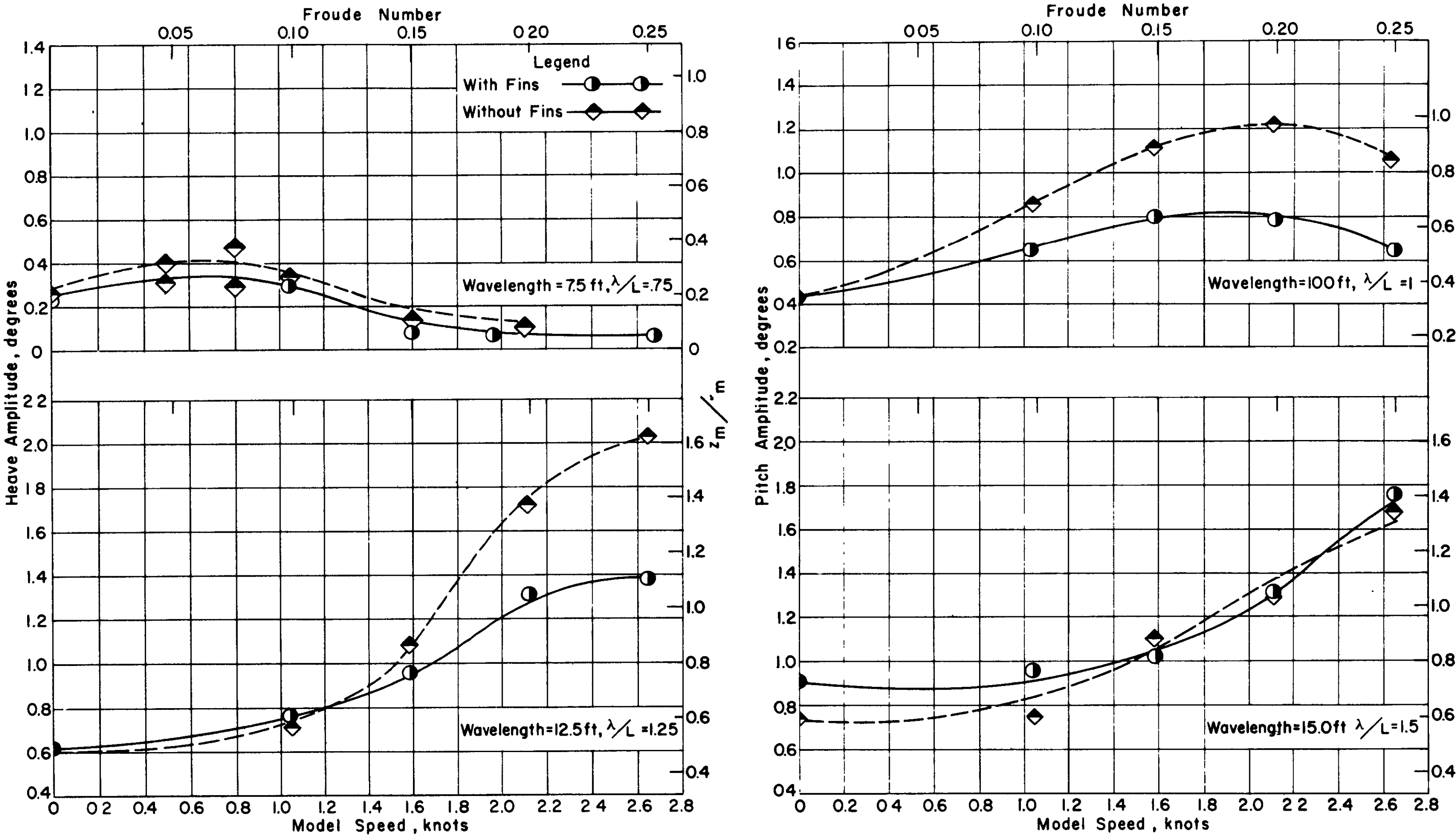


Figure 6 - Experimental Heave Amplitudes, Waves of Various Lengths and 2.5 Inches High

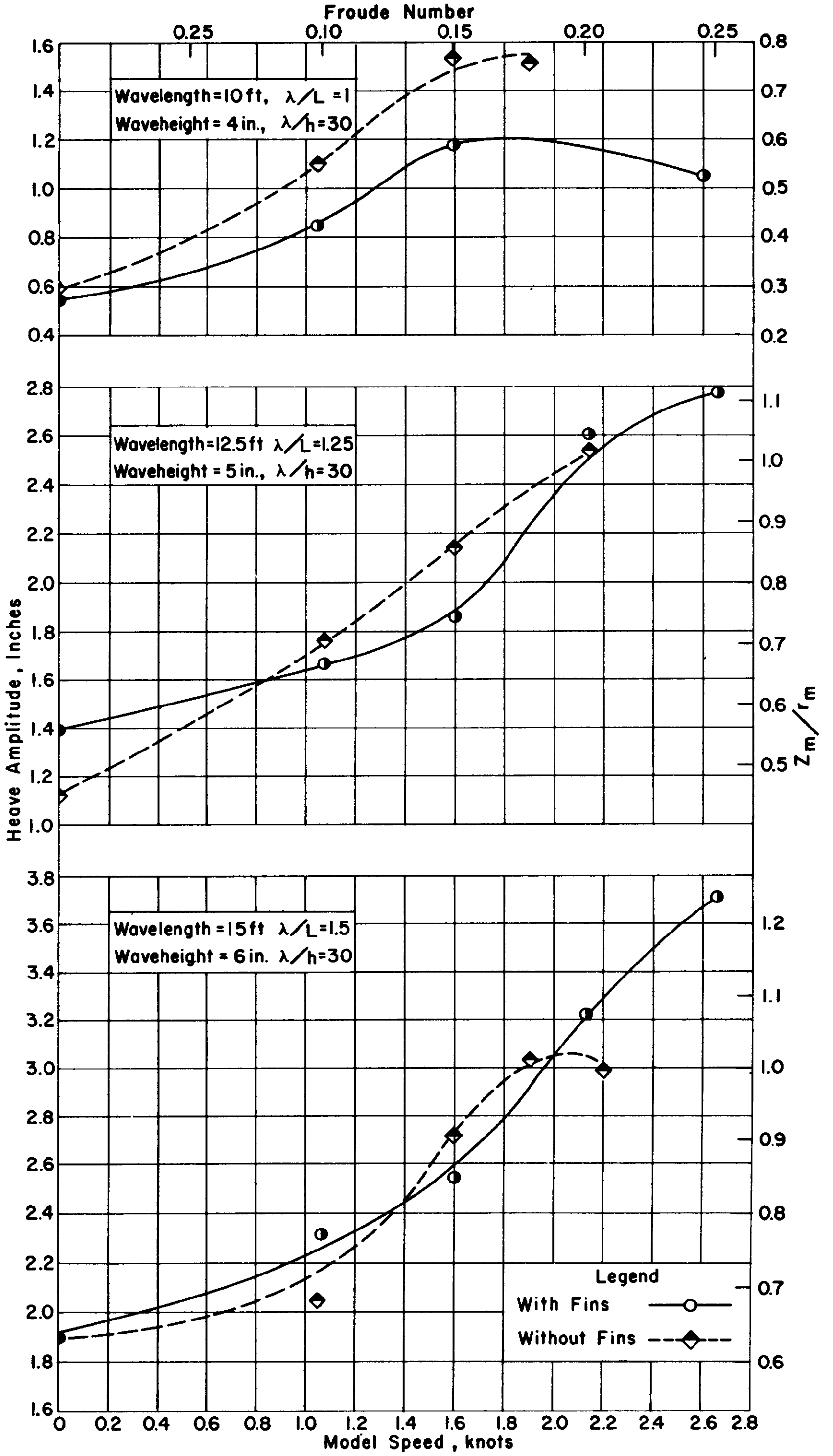


Figure 7 - Experimental Heave Amplitudes, Wavelength-Height Ratio of 30

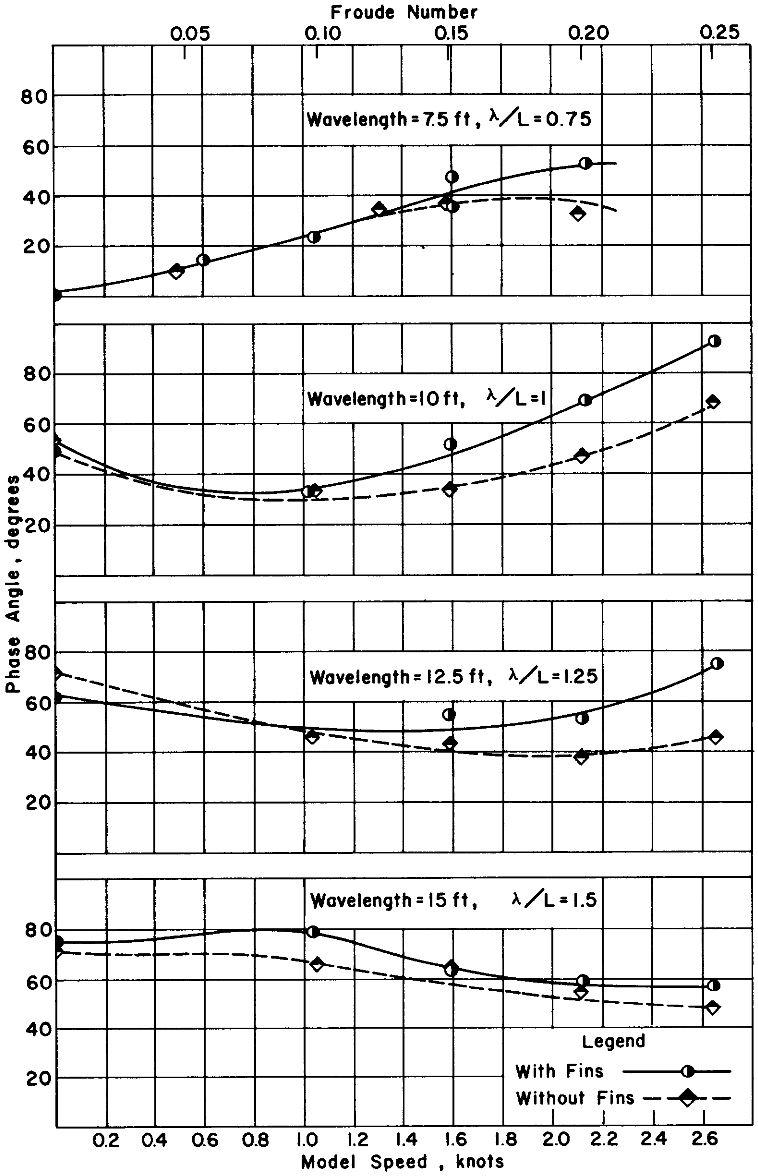


Figure 8 - Experimental Phase Angles of Heave After Pitch, Waves of Various Lengths and 2.5 Inches High

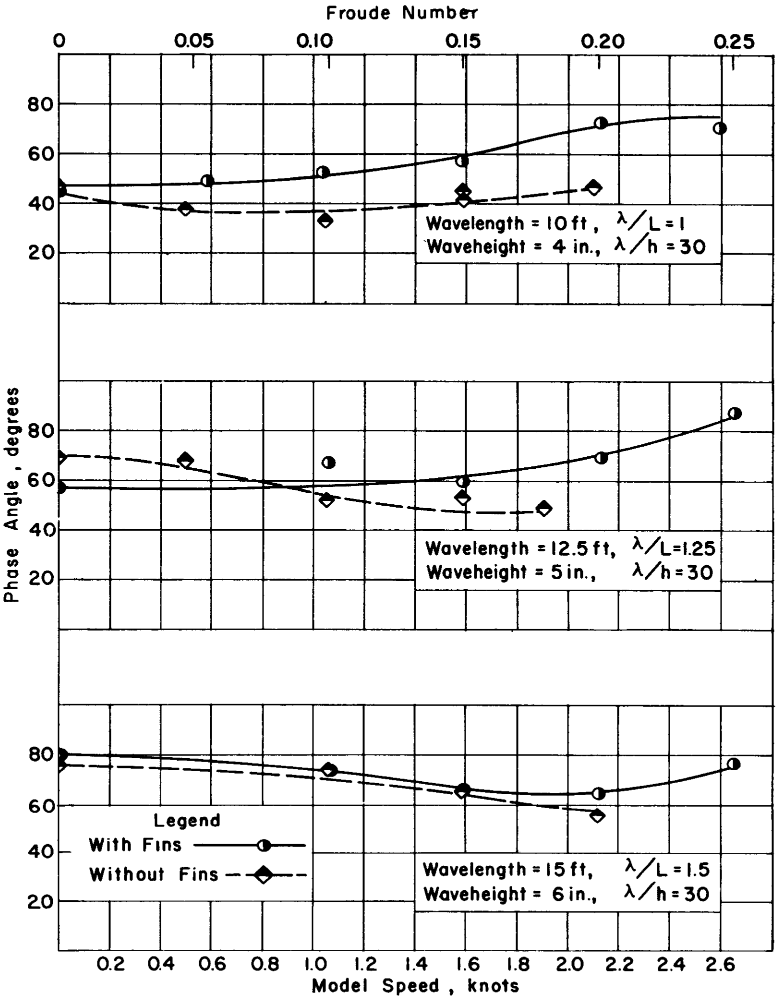


Figure 9 - Experimental Phase Angles of Heave After Pitch, Wavelength-Height Ratio of 30

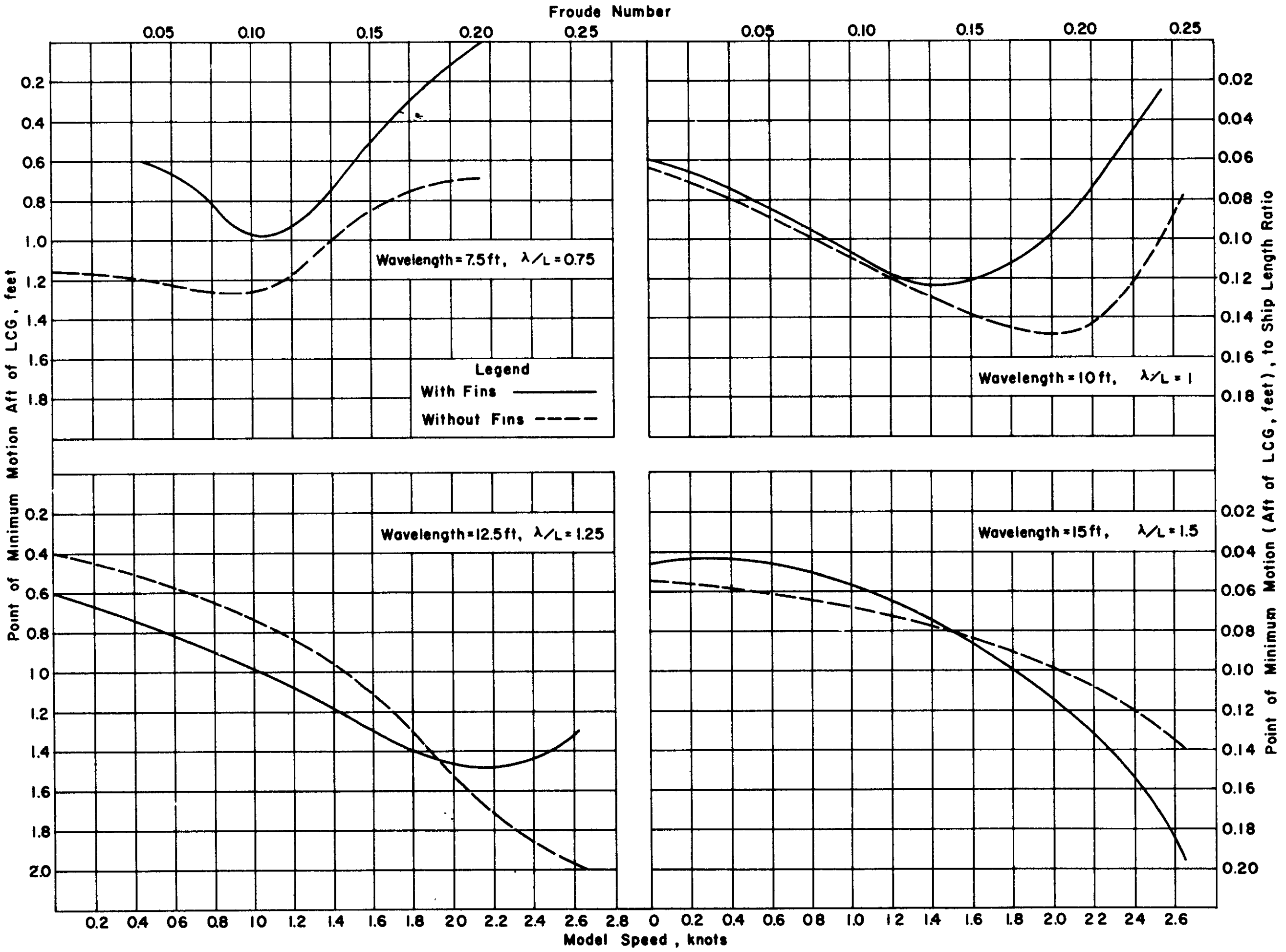


Figure 10 - Computed Location of the Point of Minimum Motion, Waves of Various Lengths and 2.5 Inches High

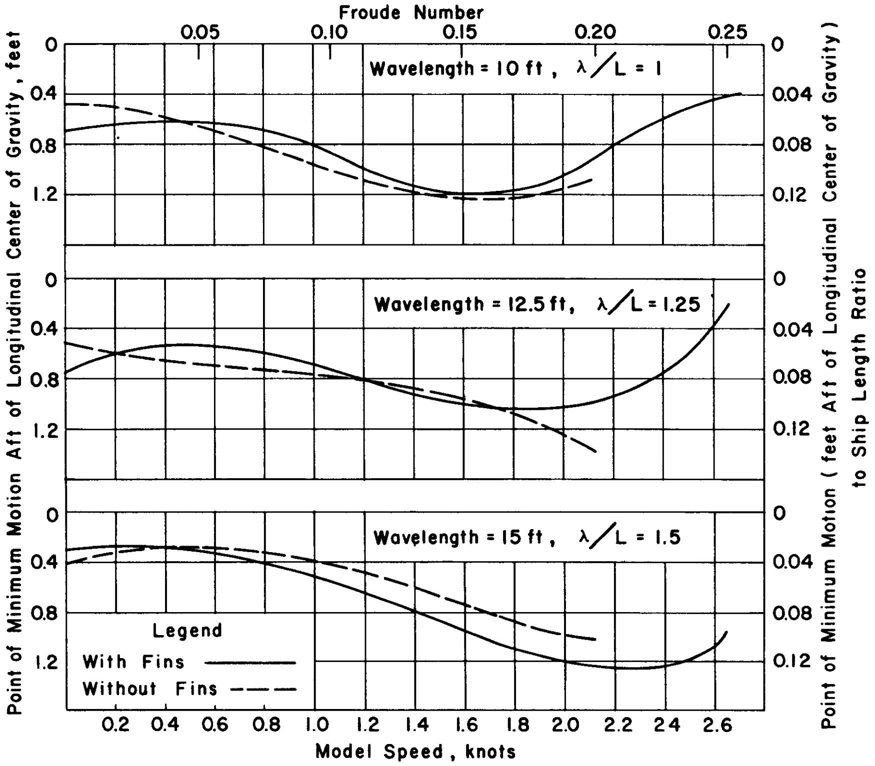


Figure 11 - Computed Location of the Point of Minimum Motion, Wavelength-Height Ratio of 30

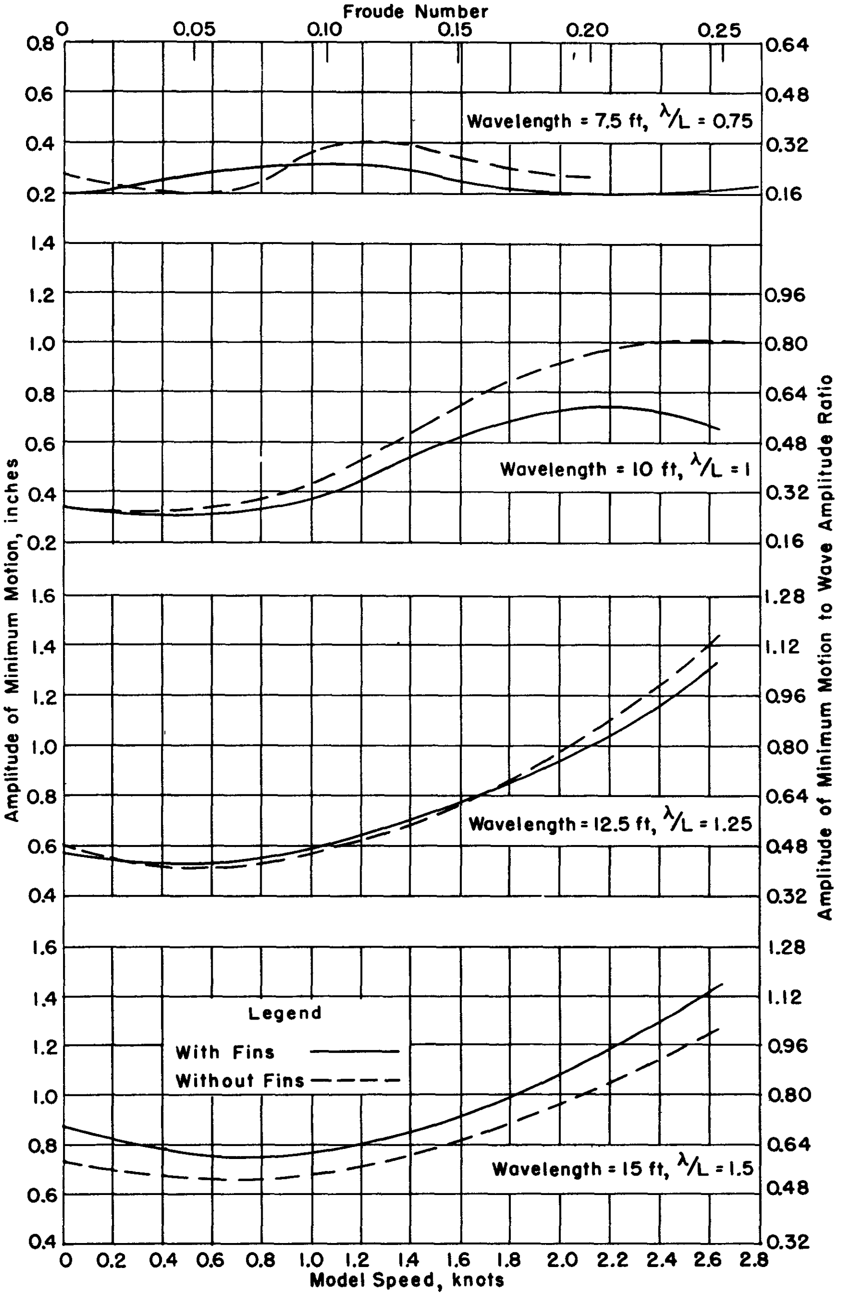


Figure 12 - Computed Vertical Minimum Motion, Four Waves of Various Lengths and 2.5 Inches High

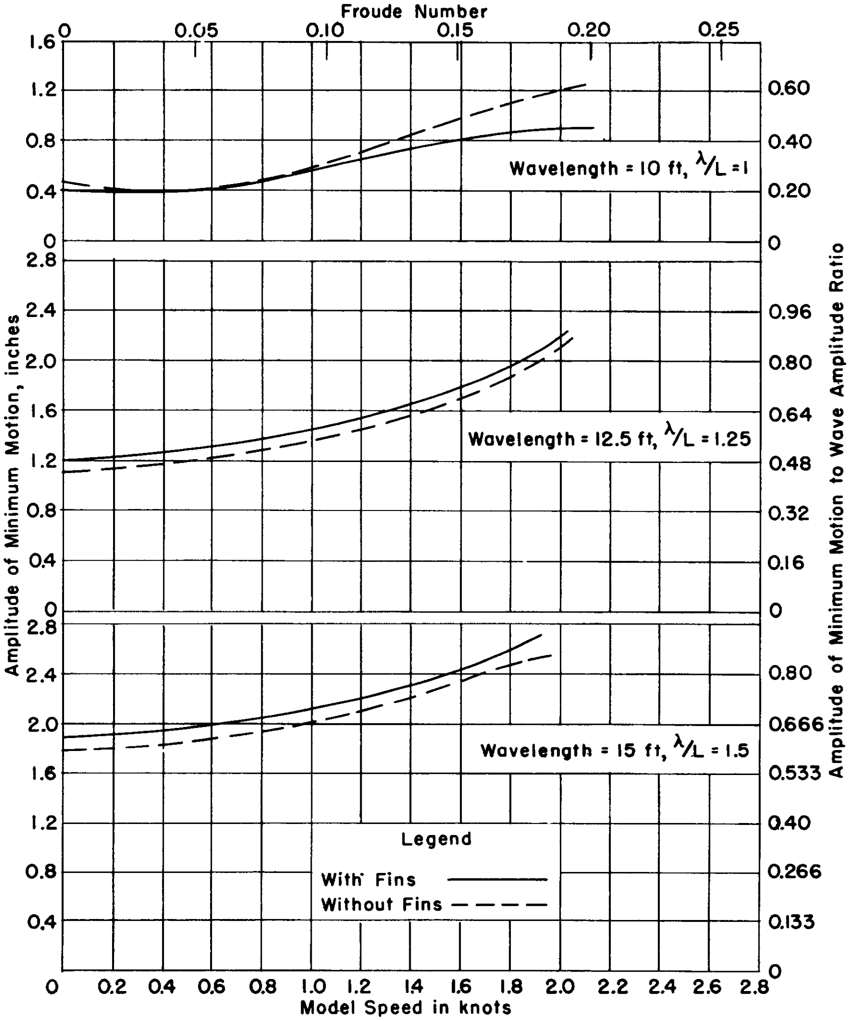


Figure 13 - Computed Vertical Minimum Motion, Wavelength-Height Ratio of 30

INITIAL DISTRIBUTION

Copies	
19	Chief, BuShips, Library (Code 312) 5 Tech Library 1 Deputy & Asst to Chief (Code 101) 1 Tech Asst to Chief (Code 106) 1 Coordinator of Undersea Warfare Planning (Code 108) 1 Res & Dev Planning Br (Code 315) 1 Applied Science (Code 370) 1 Ship Design (Code 410) 2 Prelim Des (Code 420) 1 Prelim Design (Code 421) 1 Model Basin Liaison (Code 422) 1 Performance & Scientific (Code 436) 1 Landing Ships & Craft (Code 529) 1 Minesweeping (Code 531) 1 Propellers & Shafting (Code 554)
2	Chief, BuOrd, Underwater Ordnance 1 Code ReU-1 1 Code A
2	Chief, BuAer Aero & Hydro Br (AD-3)
7	CHONR 1 Math Sciences (Code 430) 1 Math Br (Code 432) 3 Mech Br (Code 438) 1 Naval Sci Div (Code 460) 1 Undersea Warfare Br (Code 466)
10	OPNAV 1 each for Op05, Op30, Op31, Op53, Op55, Op342, Op505, Op55B4, Op313B, Op922F
1	CO, ONR, New York, N.Y.
1	CO, ONR, London, England
1	CO, ONR, Pasadena, Calif.
1	CO, ONR, San Francisco, Calif.
1	CO, ONR, Chicago, Ill.
1	CO, ONR, Boston, Mass.
1	CDR, Portsmouth Naval Shipyard
1	CDR, U.S. Atlantic Fleet, Norfolk, Va.
1	CDR, USNOL, Silver Spring, Md.
1	CO, USNUOS, Newport, R.I.
1	CDR, USNOTS, Pasadena, Calif.
1	CDR, USNOTS, China Lake, Calif.
1	DIR, USNRL
1	Asst Sec of Def (Res & Dev)
1	DIR, Natl BuStand, Washington, D.C.
1	Tech Ref Sec, Bur Recl, Denver, Colo.
1	Document Ser Ctr, ASTIA, Dayton, Ohio
1	DIR, Armour Res Foundation, Chicago, Ill.
1	DIR, Alden Hydraulic Lab, Worcester, Mass.
2	DIR, Appl Physics Lab, Johns Hopkins Univ, Silver Spring, Md.
2	Bethlehem Steel Co., Shipbldg Div, Quincy, Mass.
2	Bath Iron Works Corp, Bath, Me.
1	DIR, Cornell Aero Lab, Cornell Res Foundation, Buffalo, N.Y.
1	DIR, Fluid Mech Lab, Columbia Univ, New York, N.Y.
1	DIR, Fluid Mech Lab, Univ of Calif, Berkely, Calif.
2	DIR, Hydraulic Lab, Carnegie Inst Tech, Pittsburgh, Pa.
1	DIR, Hydro Lab, CIT, Pasadena, Calif.
1	DIR, Scripps Inst of Oceanography, Univ of Calif, LaJolla, Calif.
1	Dept of Civil Engin, Colo., A and M College Fort Collins, Colo.
1	Goodyear Aircraft Corp, Akron, Ohio
2	Harvard Univ, School of Engin, Cambridge, Mass.
1	DIR, Exper Naval Tank, Univ of Mich., Ann Arbor, Mich.
1	DIR, Midwest Rest Inst, Kansas City, Mo.
2	Head, Dept NAME, MIT, Cambridge, Mass.
1	CO, USN Admin Unit, MIT, Cambridge, Mass.
1	DIR, Fluid Mech Lab, New York Univ., N.Y.
1	DIR, Inst for Math & Mech, New York Univ., N.Y.
1	DIR, Res, Technological Inst, Northwestern Univ., Evanston, Ill.
1	DIR, Inst for Fluid Dynamics & Appl Math, Univ of Md., College Park, Md.
2	Newport News Shipbldg & DryDock Co., Newport News, Va. 1 Sr Nav Arch 1 Dir, Hydraulic Lab
1	New York Shipbldg Corp, Camden, N.J.
1	DIR, Robinson Hydraulic Lab, Ohio State Univ, Columbus, Ohio
1	Head, Dept of Aero Engin, Penn State Univ, State College, Pa.
1	Head, Dept of Aero Eng & Appl Mech, Polytech Inst of Brooklyn, Brooklyn, N.Y.
1	DIR, Hydraulics Lab, Penn State Univ, State College, Pa.
1	Dept of Mech Eng, Stanford Univ, Calif.
2	DIR, ETT, SIT, Hoboken, N.J.
1	Vitro Corp of America, Silver Spring Lab
1	DIR, Woods Hole Oceanographic Inst, Woods Hole, Mass., Attn: Messrs. A.C. Vine, R.L. Rather, Von Arx
2	Administrator, Webb Inst of Naval Arch, Glen Cove, N.Y.
1	DIR, Hydraulic Lab, Univ of Wis., Madison, Wis.
1	DIR, Hydraulics Lab, Univ of Washington, Seattle, Washington
1	Editor, Engin Index, New York, N.Y.
1	Librarian, Amer Soc of Mech Engr, New York, N.Y.
1	Librarian, Amer Soc of Civil Engr, New York, N.Y.
1	Librarian, Franklin Inst, Philadelphia, Pa.
1	Librarian, Inst of the Aero Sciences, New York, N.Y.
1	Main Library, Carnegie Inst of Tech, Pittsburgh, Pa.
1	Tech Library, Consol Vultee Aircraft Corp., San Diego, Calif.
1	Tech Library, Glenn L. Martin Co., Baltimore, Md.
1	Tech Library, Grumman Aircraft Engin Corp., Bethpage, Long Island, N.Y.
1	Tech Library, Lockheed Aircraft Corp, Burbank, Calif.
1	Librarian, Mech Res Libr. Ill. Inst of Tech Chicago, Ill.
1	Librarian, Pacific Aero Libr, Los Angeles, Calif.
1	Prof. M.L. Albertson, Head of Fluid Mech Res, Colo. A & M College, Ft Collins, Colo.
1	Prof. M.A. Abkowitz, Dept of NAME, MIT, Cambridge, Mass.
1	Prof. G. Birkhoff, Dept of Math, Harvard Univ, Cambridge, Mass.
1	Mr. J.P. Breslin, Dept of Civil Engin, SIT, Hoboken, N.J.
1	Prof. R.C. Binder, Dept of Mech Engin, Purdue Univ, Lafayette, Ind.
1	Prof. N.W. Conner, School of Engin, N.C. State College, Raleigh, N.C.
1	Dr. E.O. Cooper, USNOTS, Pasadena, Calif.
1	Dr. F.H. Clauser, Chairman, Dept of Aero, Johns Hopkins Univ, Baltimore, Md.
1	Mr. John D. Cooney, Associate Editor, Product Engin, New York, N.Y.
1	VADM E.L. Cochrane USN (Ret.) MIT, Cambridge, Mass.
1	Prof. K.J. DeJuhasz, Engin Exper Station, Penn State Univ, State College, Pa.
1	CAPT Walter S. Diehl, USN (Ret.) 4501 Lowell St., N.W., Wash, D.C.
1	Mr. Hollinshead deLuce, Central Tech Div, Bethlehem Steel Co., Quincy, Mass.
1	Prof. R.A. Dodge, Dept of Engin Mech, Univ of Mich., Ann Arbor, Mich.
1	Dr. D. Gunther, Head, Dept of Math, Cornell Univ, Ithaca, N.Y.
1	Dr. D. Gilbarg, Dept of Math, Indiana Univ, Bloomington, Ind.
1	Prof. W.S. Hamilton, Civil Engin Dept, Technological Inst, Northwestern Univ, Evanston, Ill.
1	Prof A.D. Hay, School of Engin, Princeton Univ, Princeton, N.J.
1	Dr. A.T. Ippen, DIR, Hydro Lab, Dept of Civil & Sanitary Engin, MIT, Cambridge,, Mass.
1	Dr. A. Kantrowitz, Cornell Univ, Ithaca, N.Y.
1	Dr. G.H. Keulegan, Natl Hydraulic Lab, Natl BuStand
1	Prof. B.V. Korvin-Kroukovsky, SIT, Hoboken, N.J.

Copies	
1	Dr. Th. von Kármán, 1051 S. Marengo St, Pasadena, Calif.
1	Dr. R.T. Knapp, Hydro Lab, CIT, Pasadena, Calif.
1	Dr. C.C. Lin, Dept of Math, MIT, Cambridge, Mass.
1	RADM P.F. Lee, USN (Ret.), VP, Gibbs & Cox, Inc., New York, N.Y.
1	Dr. J.H. McMillen, Natl Science Foundation, Washington, D.C.
1	Dr. A. May, Aero Div, USNOL
1	Dr. George C. Manning, Prof., Naval Arch, MIT, Cambridge, Mass.
1	RADM A.I. McKee, USN (Ret.), Gen Mgr, General Dynamics Corp, Groton, Conn.
1	Mr. J.B. Parkinson, Aero Lab, Langley Field, Va.
1	Dr. W. Pell, GDAM, Brown Univ, Providence, R.I.
1	Dr. M.S. Plesset, Hydro Lab, CIT, Pasadena, Calif.
1	Dr. H. Rouse, DIR, Iowa Inst of Hydraulic Res, State Univ of Iowa, Iowa City, Ia.
1	Mr. Jas. B. Robertson, Jr. U.S. Coast Guard Hdqtrs, Washington, D.C.
1	Mr. Vito L. Russo, Chief, Div of Ship Des, U.S. Maritime Admin., Wash, D.C.
1	Dr. J.M. Robertson, Dir of Water Tunnel, ORL, Penn State Univ, State College, Pa.
1	Prof. A. Weinstein, Dept of Math, Univ of Maryland, College Park, Md.
1	Dr. J.V. Wehausen, Executive Editor, Math Reviews, Providence, R.I.
1	Prof. L.I. Schiff, Dept of Physics, Stanford Univ, Calif.
1	Dr. L.G. Straub, DIR, St. Anthony Falls Hydraulic Lab, Univ of Minn, Minneapolis, Minn.
1	Dr. V.L. Streeter, DIR, Fundamental Fluids Res, Ill. Inst of Tech, Chicago, Ill.
1	Dr. F.B. Seely, Fluid Mech & Hydraulics Lab, Univ of Ill., Urbana, Ill.
1	Dr. C.R. Soderberg, Dept of Mech Engin, MIT, Cambridge, Mass.
1	Dr. K.E. Schoenherr, College of Engin, Univ of Notre Dame, Ind.
1	Prof. W. Sears, Graduate School of Engin, Cornell Univ, Ithaca, N.Y.
1	Dr. Stanley Corrsin, Dept of Aero, Johns Hopkins Univ, Baltimore, Md.
1	Dr. C.A. Truesdell, Dept of Math, Univ of Ind., Bloomington, Ind.
1	Mr. F.L. Thompson, Langley Aero Lab, Langley Field, Va.
1	Prof. J.K. Vennard, DIR, Hydraulic Lab, Stanford Univ, Calif.
3	M. Rosenblatt & Son, 253 Broadway, N.Y., N.Y.

Copies	
1	Dr. L. Trilling, MIT, Cambridge, Mass.
1	Prof. J.J. Stoker, Inst for Math & Mech, New York Univ, N.Y.
1	Mr. R. Skalak, Dept of Civil Engin, Columbia Univ, N.Y.
1	Prof. N.A. Christensen, School of Civil Engin, Cornell Univ, Ithaca, N.Y.
1	Hull Structural Committee, SNAME, New York, N.Y.
1	Dr. W.I. Pierson, Jr., Dept of Meteorology, New York Univ, N.Y.
1	Office of Scientific Attache of Netherlands Embassy, Washington, D.C.
1	Head, Aero Dept, Royal Aircraft Estab, Farnborough, Hants, England
1	Admiralty Res Lab, Teddington, Middlesex, England
1	Armament Res Estab, Kent, England
1	The DIR & SEC, The Science Museum, South Kensington, London S.W. 7, England
1	The Univ of Liverpool, Math Inst, Dept of Appl Math, Liverpool, England
1	DIR, British Shipbldg Res Assoc, London W.I., England
1	Sr. M. Acevedo-y Campoamor, DIR, Canal de Experiencias Hidrodnamicas, ElPardo, Madrid, Spain
1	CAPT R. Brard, Directeur du Bassin des Essais des Carenes, Paris XV, France
1	Prof. G.K. Batchelor, Trinity College, Cambridge Univ, England
1	Prof. O.J.M. Campos, Jefe de Lab del Inst de Maguimas, Montevideo, Uruguay
1	Dr. J. Dieudonne, DIR, Inst de Rechercnes de la Const Nav, 1 Boulevard Haussmann, Paris, France
1	Dr. S. Goldstein, Haifa Inst of Tech, Haifa, Israel
1	Mr. le Prof. L. Escande, DIR del'Ecole Natl Superieure, D'Electrotechnique et d'Hydraulique 4 Boulevard Riquet, Toulouse, France
1	Prof. T.H. Havelock, 8 Westfield Drive, Gosforth, Newcastle-on-Tyne 3, England
1	Prof. Harold Jeffreys, St John's College, Cambridge, England
1	Mr. W.P. Jones, Natl Phys. Lab, Aero Div, London, England
1	Prof. J. Kampe de Feriet, Faculte des Sciences, Universite de Lille, Lille (Nord) France
1	Prof. J.K. Lunde, Skipsmodelltanken, Tyholt, Trondheim, Norway
1	Dr. L. Malavard, Office National d'Etudes et de Recherches Aero, 25 Avenue de la Division-LeClerc, Chatillon, Paris, France
1	Lt. W.H. Warnsinck RNN, Torenstraat 172, Bureau Scheepsbouwkundig, The Hague, Holland

Copies	
1	Prof. H. Nordstrom, DIR, Statens Skeppsprovningsanstalt, Goteborg, Sweden
1	Gen. Ing. U. Pugliese, Presidenza, Instituto Nazionale per Studed Esperienze, di Architettura Navale, Via della Vasca Navale, Rome, Italy
1	Prof. L. Rosenhead, Univ of Liverpool, England
1	Sir R.V. Southwell, Oxford, England
1	Superintendent, Nederlandsh Scheepsbouwkundig Proefstation, Haagsteeg 2, Wageningen, The Netherlands
1	Dr. Georg P. Weinblum, Universitaet Hamburg, Berliner Tor 21, Hamburg, Germany
1	Mr. C. Wigley, 6-9 Charterhouse Square, London EC-1, England
1	Mr. J.L. Kent, Surbiton, Surrey, England
1	Dr. R.W.L. Gawn, Supt, Adm Exp Works, Haslar, Gosport, Hampshire, England
1	Mr. W.P. Walker, William Denny Bros. Ltd., Exper Tank, Dunbarton, Scotland
1	Dr. G. Vedeler, DIR & Manager, Det Norske Veritas, Oslo, Norway
1	Dr. O. Grim, Berlinertor 21, Hamburg, Germany
1	Dr. G. Kempf, Berlinertor 21, Hamburg, Germany
1	Dr. W.P.A. van Lammeren, Haagsteeg 2, Wageningen, Holland
1	Dr. J.J. Rahola, Tekniska Hogskolan, Helsingfots, Finland
1	Mr. W.H.H. van der Vorm, Westersingel 105, Rotterdam, Holland
1	Sir Victor G. Shepheard, Director Naval Construction, Admiralty, Whitehall, London SW1, England
1	Australian Scientific Liaison Office, Wash, D.C.
8	ALUSNA, London
9	BJSM (NS)
3	CJS

NAVY DPPO PRNC WASH DC