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MODEL EXPERIMENTS WITH FIXED BOW ANTIPITCHING FINS

by

George P. Stefun

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Model Experiments With Fixed Bow Antipitching Fins

By George P. Stefun[1]

The purpose of this paper is to provide additional information relative to the problem of designing efficient antipitching devices. The results of seakeeping experiments are presented for a model fitted with several alternate designs of fixed bow fins. The bulk of the experiments is concerned with the effects that fins of different aspect ratios have on the pitching and heaving motions, the phase angles between pitch and heave, the vertical accelerations, and the speed reductions in waves. Results also are presented showing the effects on pitching of fin area and of fin-tip fences.

THE effects of fixed bow antipitching fins on the seakeeping characteristics of ship models have been investigated at the David Taylor Model Basin as part of the fundamental hydromechanics research program, and for specific application to individual U. S. naval ships [1, 2].[2] The present paper gives the results of experiments designed to show the effects of various fin configurations on the pitch and heave, speed loss, phase angles, and vertical accelerations of a 6.6-ft model in regular head seas. The test conditions included a speed range corresponding to Froude numbers from 0 to 0.30, and a range of wave lengths corresponding to wave length-ship length ratios from 0.75 to 1.51.

In general, the results indicate that fixed bow fins produce maximum pitch reductions for ship-speed and wave-length combinations that correspond to near synchronous conditions. For the particular models and test conditions of this investigation, maximum pitch reductions up to 37 per cent were obtained with fins of total plan area equal to 2.0 per cent of the waterplane area and aspect ratio equal to 2.0. Similar fins with an aspect ratio of 0.50 were about 30 per cent less effective than the fins of higher aspect ratio, for corresponding tests conditions.

The results of a brief study of the effects of fin area on pitch reductions indicate that 2.0 per cent fins were twice as effective as 1.0 per cent fins with the same aspect ratio. Fins of 4.0 per cent area, however, were only about three times as effective as the 1.0 per cent fins. Thus, the increase in effectiveness was directly proportional to the increase in area, only if the areas did not become too large.

The various fin configurations caused a 10 to 15 per cent increase in the calm-water resistance of the model. In waves however, this increase was more than offset by a decrease in the motion-induced resistance. In general, therefore, the use of fins resulted in improved ability to maintain speed, especially in synchronous conditions.

[1] David Taylor Model Basin, Navy Department, Washington, D. C.

[2] Numbers in brackets designate references at the end of the paper.

Table 1 Fin Particulars

Fin No.	Span, in.	Chord, in.	Plan area	Aspect ratio	Tip fences (length, width)
1.	5.0	2.5	$0.02\,A_w$	2.0	None
2.	2.5	5.0	$0.02\,A_w$	0.5	None
3.	3.15	2.1	$0.01\,A_w$	1.5	2.1, 0.6
4.	4.50	3.0	$0.02\,A_w$	1.5	3.0, 1.25
4(a)	4.50	3.0	$0.02\,A_w$	1.5	None
5.	6.37	4.25	$0.04\,A_w$	1.5	4.25, 1.5

Nomenclature

A_W = waterplane area
Æ = aspect ratio
B = beam
C_B = block coefficient
F = Froude number
g = acceleration of gravity
H = draft
h = wave height
K = longitudinal radius of gyration
L = length between perpendiculars
V = model speed
Z_F = amplitude of heave with fins installed
Z_0 = amplitude of heave without fins
Δ = displacement
δ = phase angle by which heave lags pitch
λ = wave length
ψ_F = amplitude of pitch with fins installed
ψ_0 = amplitude of pitch without fins

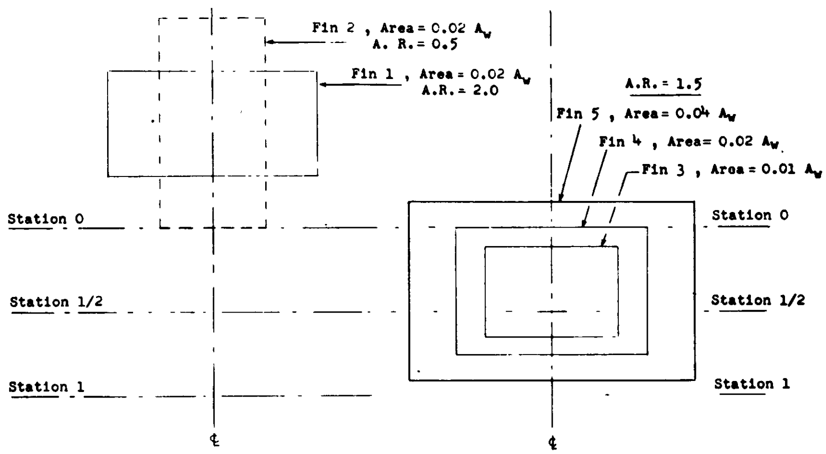


Fig. 1 Planform drawings and fin locations

Fin Configurations

Experiments were conducted on six different fin installations whose principal characteristics are listed in Table 1. All of the fins were simple aluminum plates of rectangular plan and cross section, and were mounted on the keel line of the model.

The fins can be divided into two groups as in Fig. 1, which shows their relative dimensions and locations at the bow. The first group consists of Fins 1 and 2 which had the same areas but different aspect ratios. These fins, with area equal to 2.0 per cent of the waterplane area, A_W, were not equipped with tip fences. They were mounted forward of the forefoot as indicated in the drawings of Fig. 1 and the photograph, Fig. 2(*a*). The location of these fins was impractical from the viewpoint of structural considerations. It was used here to minimize the interference effects due to hull proximity and to locate the centers of area of both fins at the same distance from amidships.

The second group consists of Fins 3, 4 and 5 which had the same aspect ratio but different areas. They were fitted with tip fences and installed in a more normal position with the leading edge located at about the forward perpendicular. The photograph, Fig. 2(*b*), shows a typical fin installation, and indicates the relative dimensions of the fences which were used.

A final fin design, designated as Fin 4(*a*), was obtained by constructing fins with the same dimensions as Fin 4 but without fences installed.

Test Program and Equipment

The 6.6-ft model which was used in the present study represents a typical naval vessel. A list of model particulars is given in Table 2. Appendages on the model included rudders and bilge keels.

The experiments were conducted in the TMB-140 ft basin using a gravity towing system for propelling the model and a pneumatic wavemaker for generating regular waves [3]. The towing system is fixed relative to the wavemaker such that only those headings corresponding to head seas or following seas are possible. The model was restricted to head seas in the present investigation.

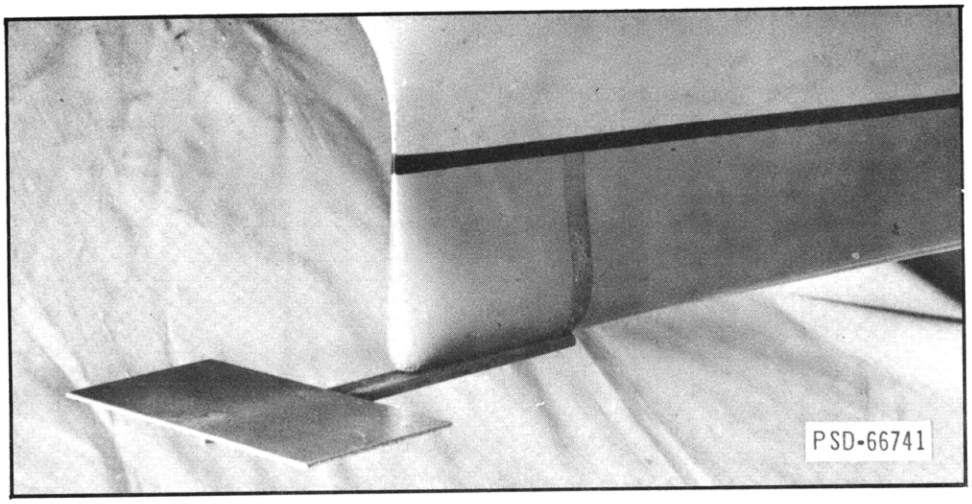
Table 2 Model Particulars

Length BP, ft	6.60
Beam, ft	0.862
Draft, ft	0 224
Displacement, lb	46.50
Waterplane area, sq ft	4.164
Longitudinal gyradius, ft	1.54
Block coefficient	0 61
Waterplane coefficient	0.73
Natural pitch period	0.70 sec.

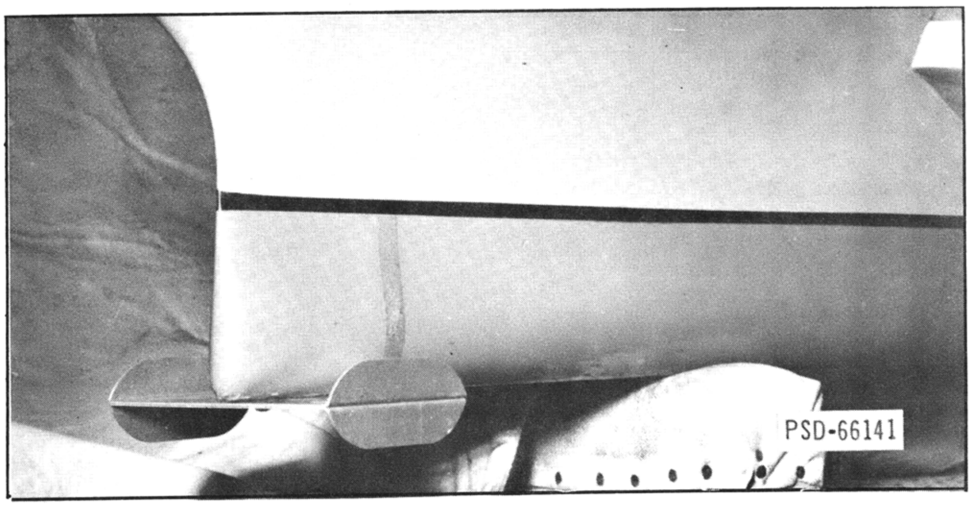
The model was towed at speeds ranging from 0 to 2.6 knots in calm water and in waves of 5, 6, 8 and 10 ft length. Wave heights were kept constant at 2.0 in., resulting in wave length-to-wave height ratios of 30 to 60. The wave conditions were purposely intended to be moderate so that comparisons among the various fin configurations would not be influenced by nonlinearities which usually accompany more severe conditions.

The model and test facility were instrumented so that simultaneous measurements were obtained on a Sanborn 8-channel recorder for wave height, pitch and roll angles, heave accelerations, and the vertical accelerations at two points, one forward and one aft of midships. Instrumentation included a capacitance-type wave-height probe, a Minneapolis Honeywell vertical gyro, and two Giannini vertical accelerometers. Amplitudes of heave were calculated from the amplitudes of vertical acceleration at the center of gravity. Model speeds were measured using a photocell and electronic counter arrangement at the driving wheel of the gravity towing system.

An extensive series of tests was performed on the model without fins and on the model fitted with Fins 1



(a) Fin 1 located forward of Station O



(b) Fin 4 located at Station O

Fig. 2 Typical fin configurations

and 2. The results of these tests provide the basis for a general evaluation of the effects on seakeeping of anti-pitching fins, as well as a specific evaluation of the effects of the aspect-ratio difference between Fins 1 and 2. Experiments with the remaining fin configurations were limited to a few representative test conditions since these were sufficient to characterize the effects due to changes in fin areas and tip fences. A summary of the test conditions for the various fin configurations is given in Table 3.

Pitch and Heave Amplitudes

Curves of pitch and heave amplitudes and the phase angle by which heave lags pitch are plotted against speed in Figs. 3 through 6 for the model with and without fins. The "dashed" portions of the curves represent extrapolations to zero speed which were necessary because of the difficulty of obtaining reliable data at slow speeds.

In order to facilitate the comparison of the stabilized and unstabilized motions, faired values from Figs. 3 through 6 are replotted for constant speeds in Figs. 7 and 8 to a base of the wave length-ship length ratio λ/L. Fig. 7 shows the pitch reduction effected by the fins, defined by $100\ (\psi_0 - \psi_F)/\psi_0$ where ψ_0 is the pitch amplitude without fins and ψ_F is the corresponding amplitude with fins. Similarly, Fig. 8 shows the change in heave amplitudes in terms of $100(Z_0 - Z_F)/Z_0$ where Z_0 is the heave amplitude without fins and Z_F is the amplitude with fins.

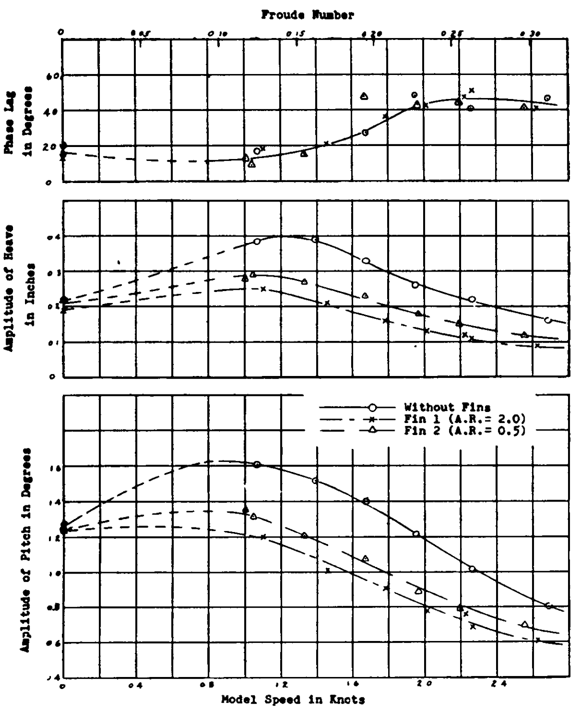


Fig. 3 Motions of model in waves 5 ft long, 2 in. high

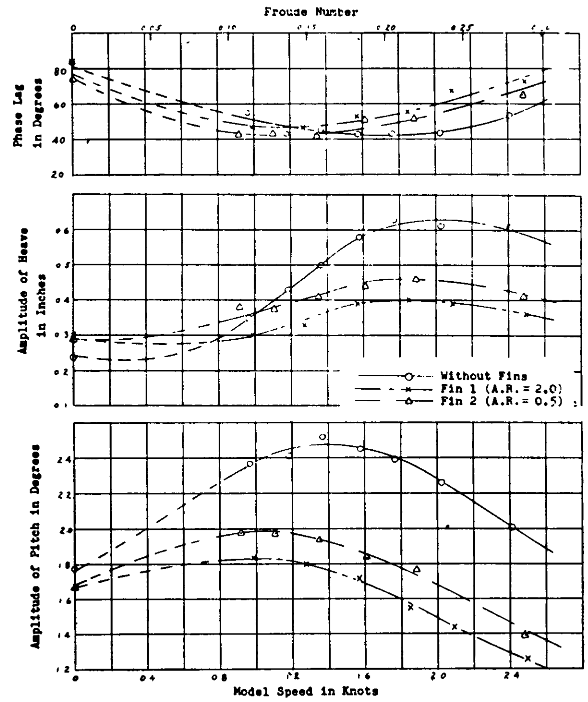


Fig. 4 Motions of model in waves 6 ft long, 2 in. high

Table 3 Test Conditions

	Speed range, knots	Wave length, ft	λ/L	h, in.	λ/h
Without fins	0–2 6	5, 6, 8, 01	0 75–1.51	2	30–60
Fins 1 and 2	0–2.6	5, 6, 8, 10	0.75–1.51	2	30–60
Fins 3, 4a, 5	0–2 6	5	0 75	2	30
Fin 4	0–2 6	5, 6	0 75, 0 91	2	30

The curves of Fig. 7 indicate that the greatest pitch reductions occur for wave-length and speed combinations which result in periods of encounter that are near the model's natural pitch period. In other words, the fins attain their maximum effectiveness at synchronous conditions. The curve for 2.4 knots speed, for example, reaches a maximum at $\lambda/L = 1.05$ and then declines rapidly for longer wave lengths. The curves for very slow speeds never reach a peak value since the synchronous wave lengths corresponding to these speeds are below the range of this investigation.

The curves of Fig. 8 indicate that the fins can have the adverse effect of increasing the heave motion, especially in the longer waves. In general, the curves show an increase in heave at all speeds in waves longer than $1.4L$, and heave reductions at all speeds in waves shorter than $0.75\ L$. In waves of intermediate length, the fins cause an increase in heave at low speeds and a decrease at high speeds.

Vertical Accelerations

Amplitudes of vertical accelerations are plotted versus speed in Figs. 9 through 12 for the several test conditions. One accelerometer was located at a point 18.5 in. forward of the center of gravity of the model, and another was 18.5 in. aft. The algebraic sum of the two signals was obtained electrically to provide a record of the acceleration at the position of the center of gravity. The three records give the vertical accelerations at positions which correspond approximately to the midpoint (station 10) and to the two quarter points (stations 5 and 15) of the model length. The results indicate that the amplitudes of accelerations at various points on the model are generally reduced through the use of fins at the bow by an amount proportional to the motion reduction. The largest accelerations, which occur at the ends of a ship, are reduced in proportion to the amount of pitch reduction since for these points, the pitching motion contributes a major component of the vertical acceler-

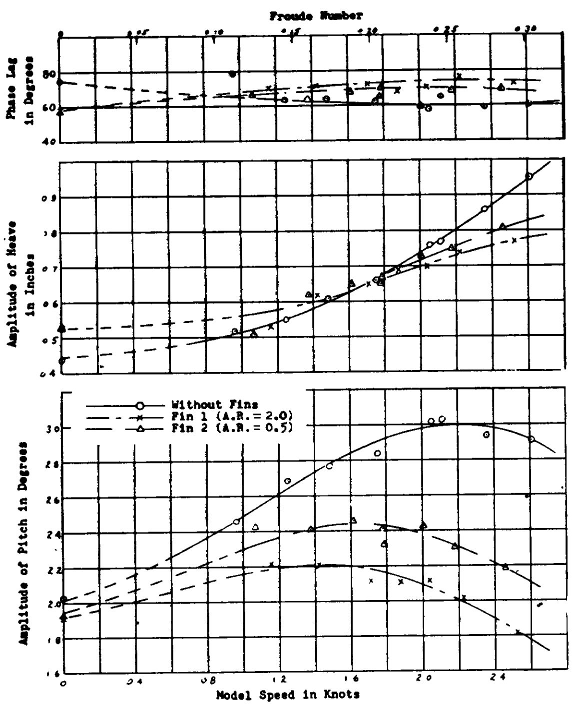


Fig. 5 Motions of model in waves 8 ft long, 2 in. high

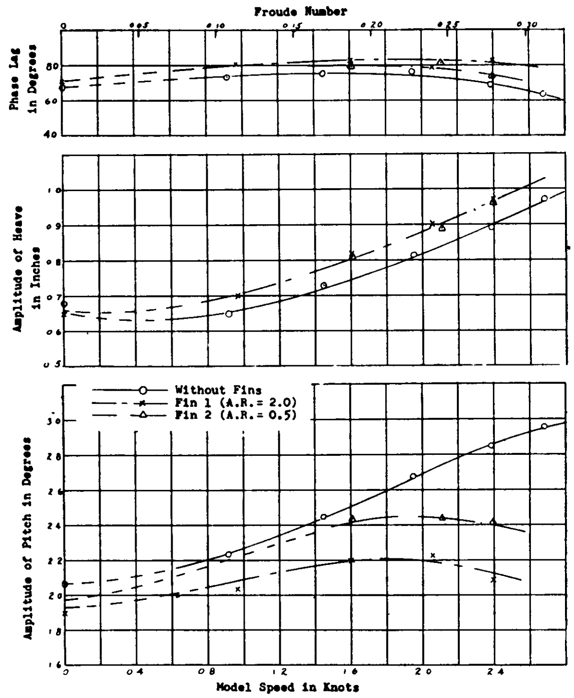


Fig. 6 Motions of model in waves 10 ft long, 2 in. high

ations. For positions near or somewhat aft of midship, however, the use of fins can sometimes cause an increase in the accelerations, corresponding to an increase in the heave component of the motion. These accelerations are small enough so that any increase due to fins may not be important except in cases where ship instruments or other equipment may require locations near points of minimum motion.

Resistance

The model resistance in calm water and in waves is plotted in Figs. 13, 14 and 15 in terms of the tow force required to obtain a given speed. A comparison of Fig. 13 (without fins) with Figs. 14 and 15 (with fins) indicates that the fins generally increase the resistance in calm water and in waves longer than about 120 per cent of the ship length. The resistance in waves with lengths between 75 and 120 per cent of the ship length, however, is less than that without fins. The improved resistance characteristics can be attributed to the motion reductions effected by the fins since the lower resistance measurements were obtained for test conditions which correspond roughly to the region of maximum motion reduction, Figs. 7 and 8.

Faired values from the resistance curves of Figs. 13, 14 and 15 are replotted in Fig. 16 for the model with and without fins. The speed in waves corresponding to a given calm-water tow force is plotted against the wave length-ship length ratio λ/L. The curves show a maximum speed reduction for wave lengths of about 90 per cent of the ship length. The amount of speed loss due to waves, relative to the calm-water speed, was consistently less for the fin-equipped model except for very long waves.

It is, of course, realized that the rectangular cross sections and the keel-line locations of the fins used in this investigation are not suitable for optimum resistance characteristics, especially in calm water. However, this has little bearing on the major observations and comparisons which result from the resistance measurements, since these are based on the relative performance of various fins of similar shape and orientation and on the relative performance of fins in calm water and in waves. Also, differences in resistance or in speed-maintaining ability are a function mainly of differences in motion characteristics, which are little affected by shape of fin sections or by minor variations in fin alignment.

Fin Aspect Ratio

A comparison of the pitch-amplitude results obtained for Fins 1 and 2 Fig. 7, indicates that a large change in fin aspect ratio has a significant effect on the amount of pitch reduction that can be accomplished. For the particular model and test conditions which were used in this investigation, nns of aspect ratio 0.5 were roughly

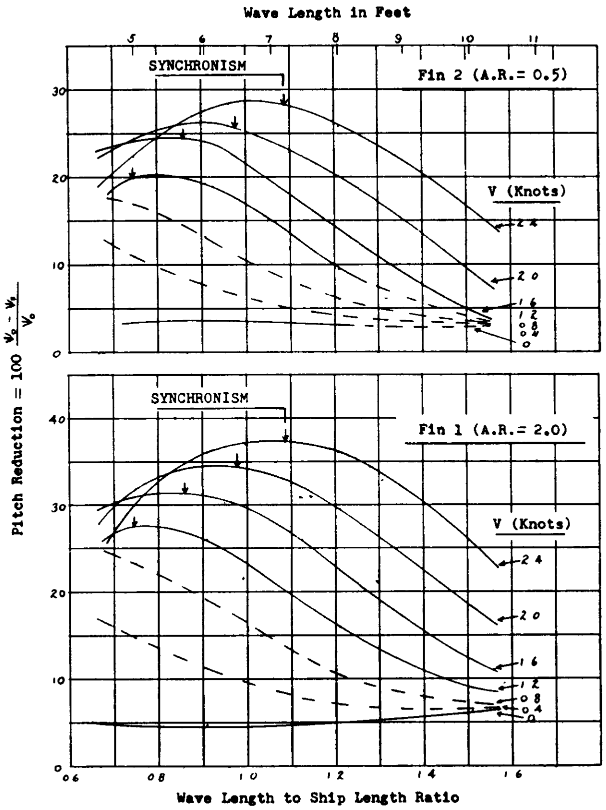


Fig. 7 Pitch reductions effected by fins 1 and 2

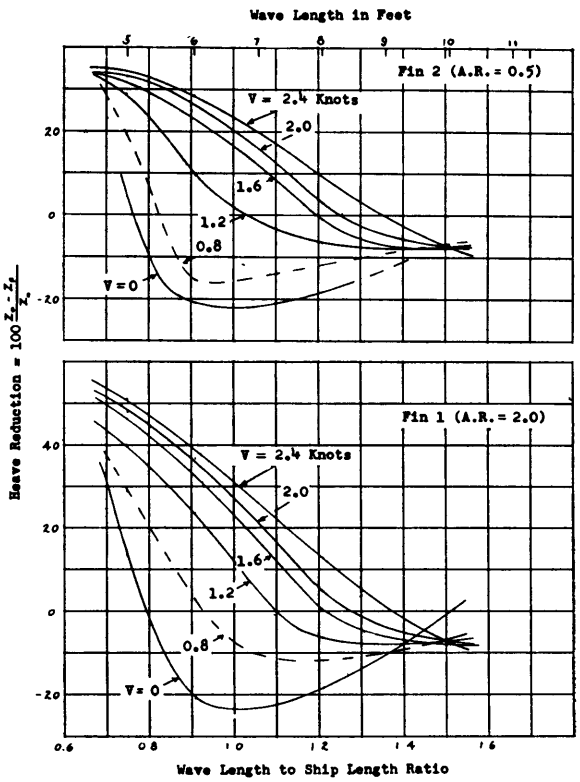


Fig. 8 Heave reductions effected by fins 1 and 2

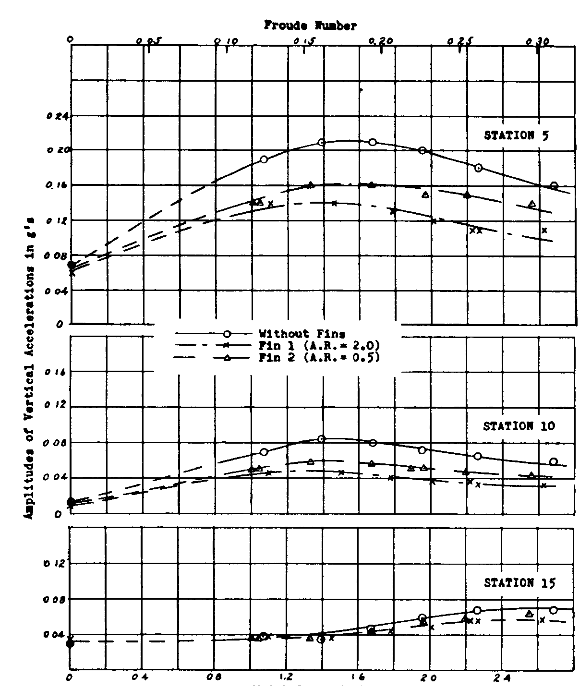


Fig. 9 Accelerations of model in waves 5 ft long, 2 in. high

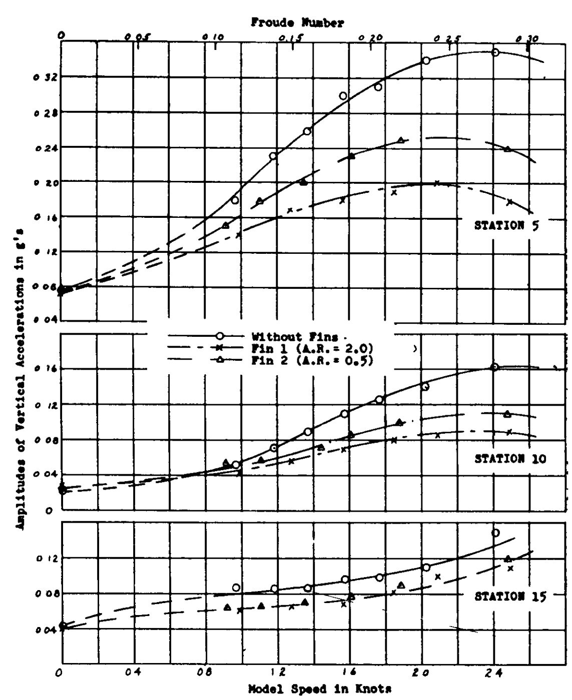


Fig. 10 Accelerations of model in waves 6 ft long, 2 in. high

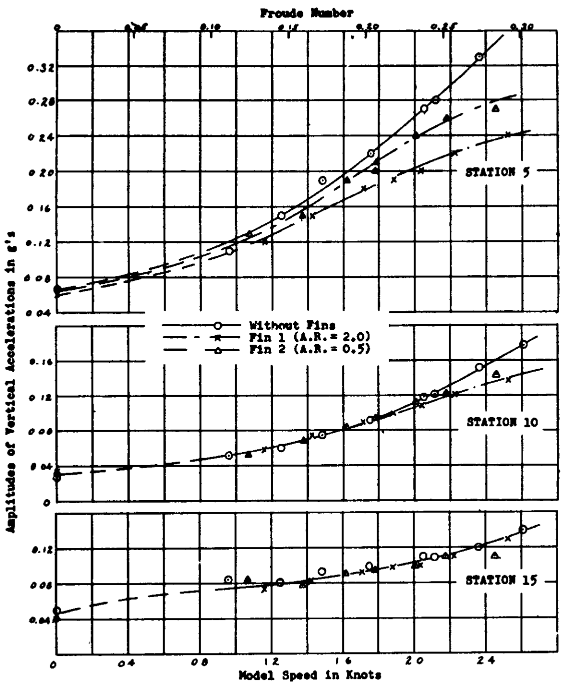


Fig. 11 Accelerations of model in waves 8 ft long, 2 in. high

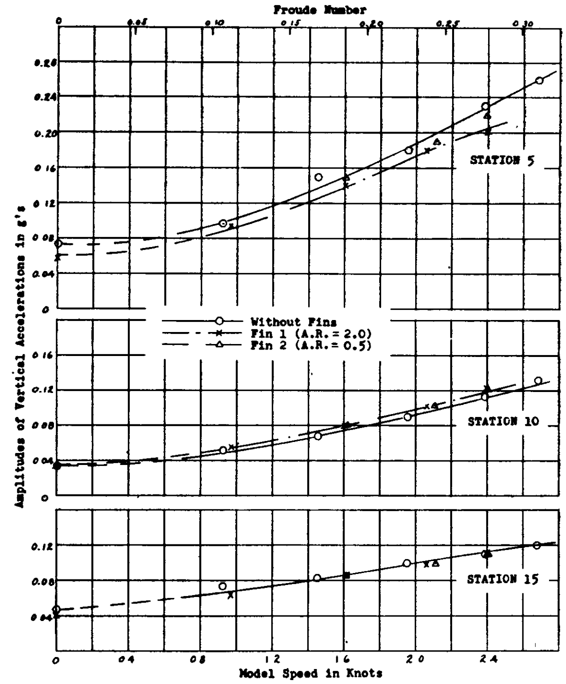


Fig. 12 Accelerations of model in waves 10 ft long, 2 in. high

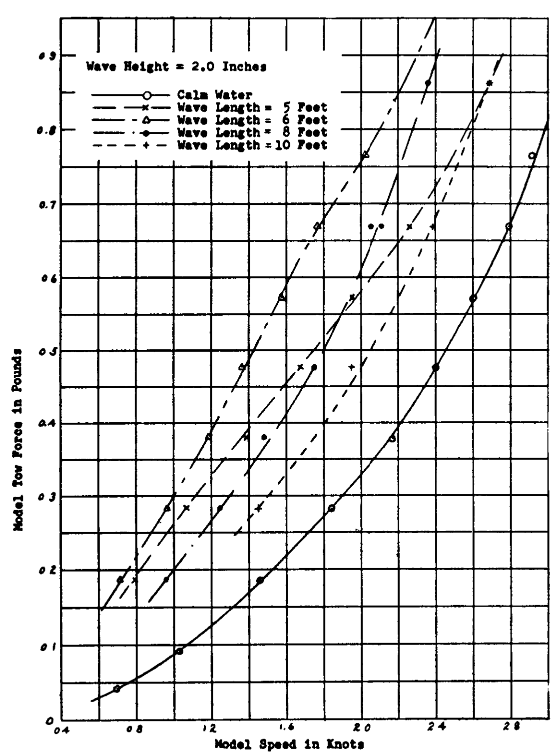


Fig. 13 Resistance of model without fins

30 per cent less effective in reducing pitch amplitudes than were similar fins of aspect ratio 2.0. It should be noted that the increased effectiveness was obtained by a 300 per cent increase in the value for aspect ratio. Small changes in fin dimensions that leave the fin area unaltered, therefore, can be expected to have negligible effects on pitch reductions.

As indicated in Fig. 16, an increase in fin aspect ratio also improved the resistance characteristics of the model both in calm water and in waves. In calm water, where the bare hull resistance was increased by the addition of fins at the bow, the fins of aspect ratio 2.0 caused a lesser increase than did those of aspect ratio 0.5. In the present case, the increases were about 10 and 15 per cent respectively. For wave lengths of the order of the ship length, fins improved the resistance of the model as compared with that for the bare-hull condition. The improvement due to the higher aspect ratio fins were somewhat greater than that due to those of lower aspect ratio. For wave lengths corresponding to $\lambda/L = 1.5$, fins again caused an increase in resistance, but differences due to aspect ratio tended to disappear. Judging from the results obtained for a large change in fin aspect ratio, minor variations in fin dimensions should have a negligible effect on resistance or speed in waves.

Fin Area

The fins designated as 3, 4 and 5 were tested under a single wave condition consisting of a wave length equal

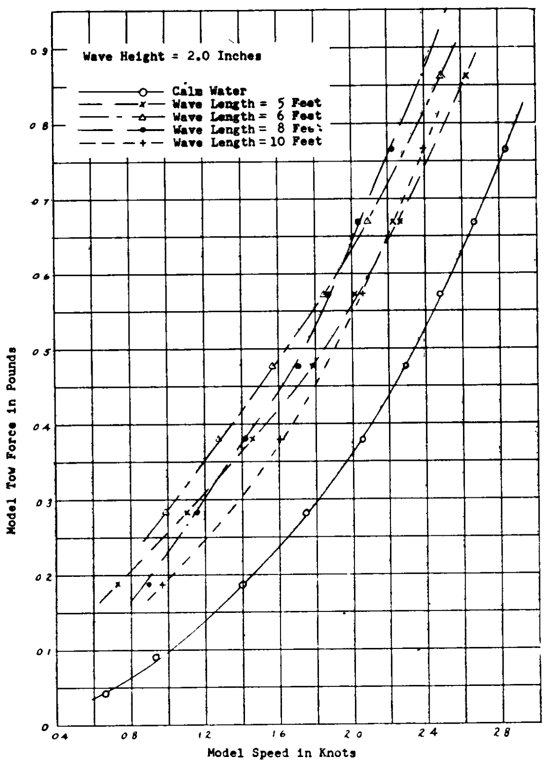


Fig. 14 Resistance of model with fin 1

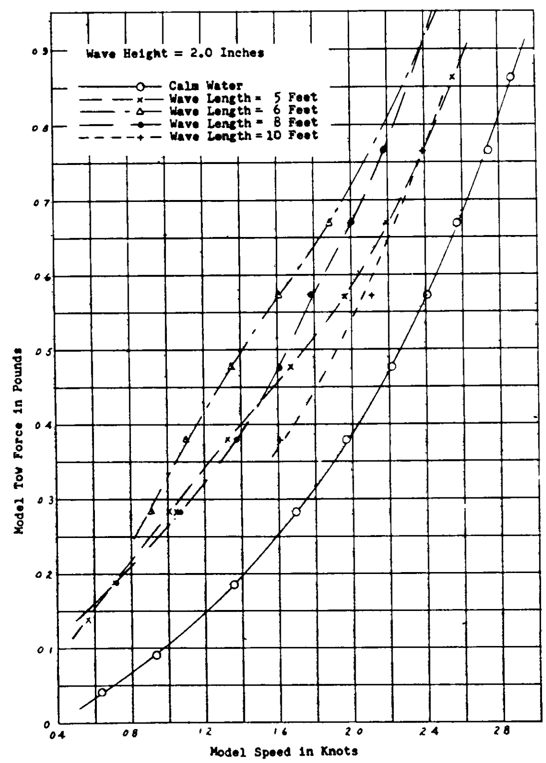


Fig. 15 Resistance of model with fin 2

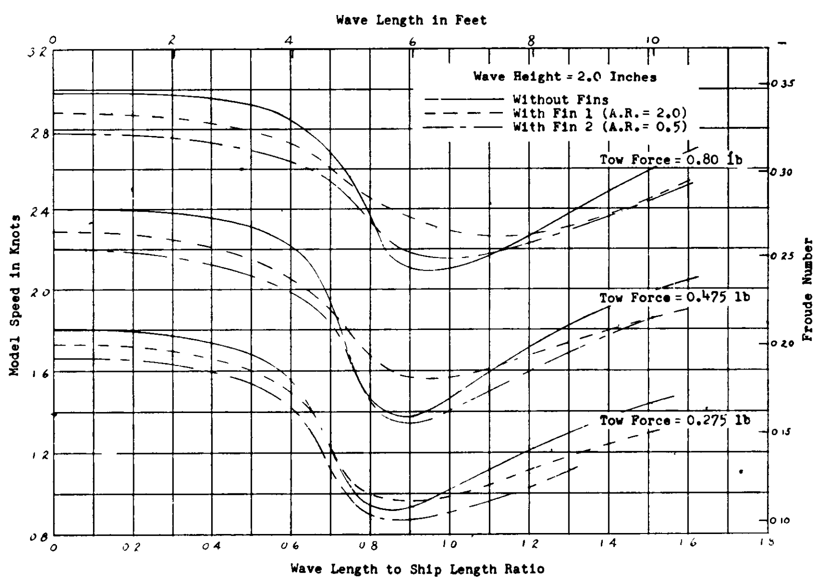


Fig. 16 Speed reductions for constant tow force

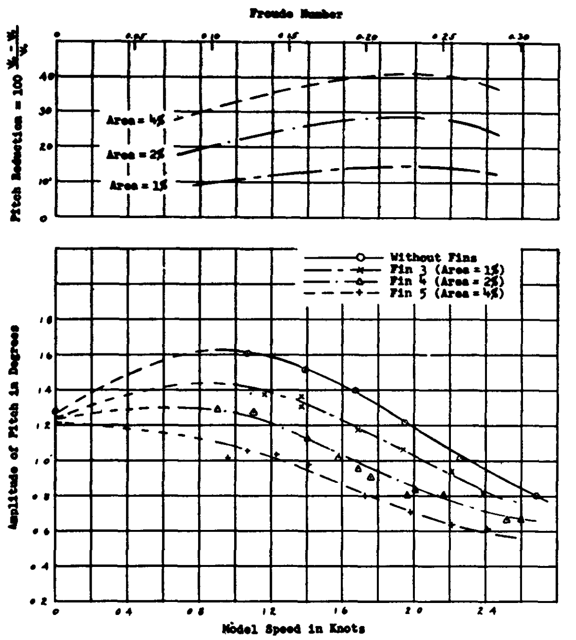


Fig. 17 Pitch amplitudes and pitch reductions in waves 5 ft long, 2 in. high

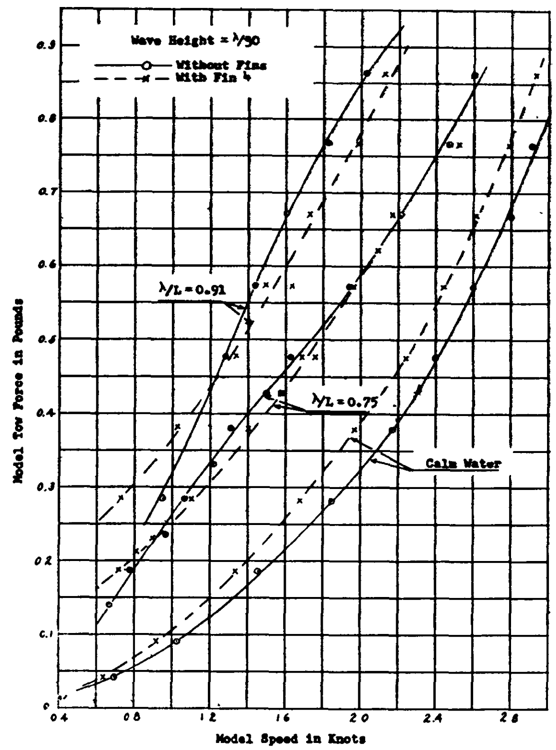


Fig. 18 Resistance of model with fin 4

to 75 per cent of the ship length, and a wave length to height ratio of 30. A speed range corresponding to Froude numbers of 0 to 0.3 was obtained. All these fins had an aspect ratio of 1.5 but had areas of 1, 2 and 4 per cent of the waterplane area, respectively. All were equipped with tip fences and were mounted on the keel with the leading edge located at about the forward perpendicular.

The effects of increased fin area on pitch amplitudes are given by the curves in Fig. 17. Pitch amplitudes as well as pitch reductions are plotted against speed for the model with and without fins. As would be expected, the results indicate that fins of larger area produce larger pitch reductions. However, for these specific test conditions, fins with an area greater than 2 per cent of the waterplane area did not produce reductions in direct proportion to the increase in area. For example, while the 2 per cent fin was twice as effective as the 1.0 per cent fin, the 4 per cent fin was only about three times as effective even though it had four times the area. Test conditions corresponding to longer wave lengths were not included in the present investigation, but the trends with respect to fin areas should be roughly similar in long waves to those obtained in the short wave length.

The resistance curves for Fin 4 in calm water and in waves are presented in Fig. 18. A comparison of this figure with Figs. 14 and 15 indicates that the resistance results obtained for the "normal" configuration of Fin 4 are entirely similar to those obtained for the "special" configurations of Fins 1 and 2. Also, the pitch reductions of Fins 3, 4 and 5, Fig. 17, show the same trends as those of Fins 1 and 2, Figs. 3 and 7, for corresponding test conditions. Accordingly, the conclusions obtained from the more complete investigation of Fins 1 and 2 can be extended to "normal" fin configurations. In other words the results indicate that for normal fin locations, information with respect to conditions for maximum pitch reductions, or minimum speed loss in waves, for example, can be inferred from the data obtained for fins mounted forward of the forefoot. Quantitative data also can be obtained for normal locations, but these will be simple approximations. For example, the tests indicate 28 per cent pitch reduction for Fin 4 at 2 knots in 5-ft waves, compared with 31 per cent for Fin 1 under the same conditions. It is reasonable to expect, therefore, that Fin 4 should show about 33 per cent reduction at 2.4 knots in 7-ft waves since the tests indicate 37 per cent reduction for Fin 1 under these conditions.

Tip Fences

Vertical end plates, commonly called tip fences, were installed on the fins used in the studies of references [1] and [2]. Their use was based on a consideration of elementary flow principles which indicate that the plates should help eliminate vorticity about the fin tips and

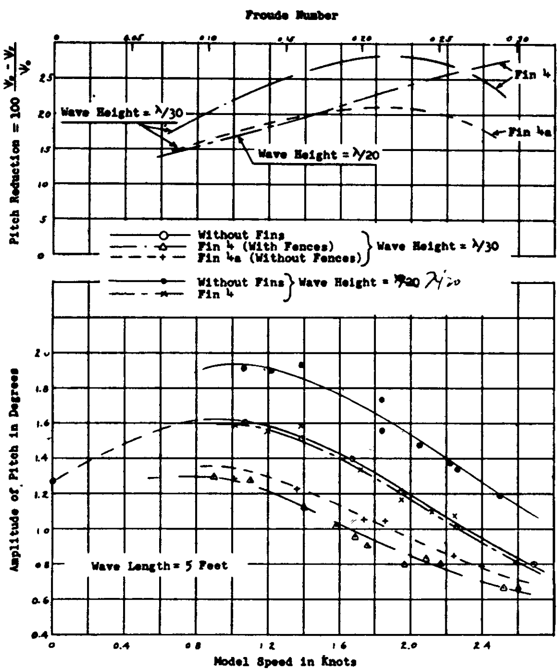


Fig. 19 Pitch amplitudes and pitch reductions for fins 4 and 4a

thus increase the effective aspect ratio and area of the fins. Also, observations from model tests have indicated that fences tend to reduce somewhat the adverse flow separation effects that are experienced when the fins have large amplitudes of motion [2].

Fin 4(*a*) was tested in waves of length equal to 75 per cent of the ship length in order to obtain an estimate of the effects of tip fences on pitch reduction, from a comparison with the results obtained for Fin 4. Fin 4(*a*) with $Æ$ = 1.5 and area = 0.02 A_W was exactly the same as Fin 4 with fences removed. The results of the comparison are presented in Fig. 19, where pitch amplitudes and pitch reductions are plotted against speed for both fins. The curves indicated that the use of fences provided an additional pitch reduction of about 5 per cent above that obtained for the fins without fences. Further experiments are needed to determine the effects on pitching of fences that are considerably smaller than the large fences used in the present investigation.

Future Research

The experimental results presented in this paper were intended to provide primarily, much needed information for the design of efficient antipitching fins. They were also to serve, however, as the basis for evaluating and improving existing theoretical methods. It was believed, for example, that an investigation of large changes in fin aspect ratio, thus effecting large changes in fin-lift characteristics, should provide a valid basis for evaluating the hydrodynamic-lift theory of antipitching fins. It soon became apparent, however, that firm conclusions could not be reached without a more accurate knowledge of, among other things, the lift, drag, and inertia characteristics of oscillating hydrofoils. The necessary fundamental research has not been accomplished at TMB as yet because efforts have been directed toward problems of more immediate consequence. The experimental results are published here with the hope that others will be stimulated and aided in their work of a more basic nature.

One of the problems currently being investigated at TMB is that of transverse hull vibrations associated with antipitching fins. The study is directed toward determining the nature and cause of adverse fin-induced vibrations, and the corrective measures which may be necessary to eliminate or reduce these vibrations. In addition, the study will provide further information with respect to the effectiveness for pitch reductions of a large variety of fin shapes, locations, and orientations.

Other work which is planned for future research includes an investigation of the effectiveness of antipitching fins under confused-seas conditions. Such a study is necessary in order that predictions based on regular-wave tests can be accepted with greater confidence. In addition, the results should be of value for model and full-scale correlations.

Acknowledgments

Some of the experimental results presented in this paper were obtained by Mr. S. E. Lee, whose comments and suggestions throughout the course of the investigation are also greatly appreciated. The author is indebted also to Mr. J. Bonilla-Norat who helped with the testing and data analysis and to Mrs. F. Poole who helped with the data reduction and computations.

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MODEL EXPERIMENTS WITH FIXED BOW ANTIPITCHING FINS, by George P. Stefun. Dec 1959. 11p. illus., photos., tables, refs. (Reprinted from The Journal of Ship Research, Vol. 3, No. 2, Oct. 1959) UNCLASSIFIED

The purpose of this paper is to provide additional information relative to the problem of designing efficient antipitching devices. The results of seakeeping experiments are presented for a model fitted with several alternate designs of fixed bow fins. The bulk of the experiments is concerned with the effects that fins of different aspect ratios have on the pitching and heaving motions, the phase angles between pitch and heave, the vertical accelerations, and the speed reductions in waves. Results also are presented showing the effects on pitching of fin area and of fin-tip fences.

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