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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1828

EFFECT OF FOREBODY WARP ON THE HYDRODYNAMIC QUALITIES OF A HYPOTHETICAL FLYING BOAT HAVING A HULL LENGTH-BEAM RATIO OF 15

By Arthur W. Carter and Irving Weinstein

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EFFECT OF FOREBODY WARP ON THE HYDRODYNAMIC QUALITIES OF A HYPOTHETICAL FLYING BOAT HAVING A HULL LENGTH-BEAM RATIO OF 15

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SUMMARY

The investigation of the effect of forebody warp (progressive increase in angle of dead rise from step to bow) on the hydrodynamic qualities of a hypothetical flying boat having a hull length-beam ratio of 15 was made in smooth water and in waves. The hull of high length-beam ratio was designed to meet advanced requirements for increased speed and increased range for flying-boat designs and has been shown to have low aerodynamic drag. The results obtained for the warped forebody are compared with those for the basic model.

Warping the forebody planing bottom increased appreciably the range of stable trim between the lower and upper trim limits of stability although the center-of-gravity limits of stability were reduced. Landing stability was improved by warping the forebody. Bow spray characteristics were substantially better for the hull with the warped forebody than for the hull with the basic forebody. The high-speed water resistance was slightly greater for the hull with the warped forebody and the over-all take-off performance was slightly inferior to that of the hull with the basic forebody.

Warping the forebody had a negligible effect on the take-off behavior in waves. The maximum vertical and the maximum angular accelerations were reduced during landings in waves but the maximum oscillations in trim and rise were not affected when compared with those for the hull having the basic forebody.

INTRODUCTION

The hydrodynamic qualities of a hypothetical flying boat with a low-drag hull having a length-beam ratio of 15 have been presented in reference 1. Although the range of stable position of the center of gravity was only slightly less than that of the hull of the series with a length-beam ratio of 6, the range of stable trim was reduced appreciably.

In an effort to increase the range of stable trim and to determine the effect of increasing this range on the positions of the center of gravity for stable take-off, extreme warping of the forebody planing bottom (progressive increase in angle of dead rise from step to bow) was incorporated in the hull of high length-beam ratio. Investigations reported in reference 2 have indicated that warping of the forebody bottom lowered the lower limit without causing an appreciable change in the upper limit. This decrease in the lower limit increased the range of stable trim. Unpublished wind-tunnel results have shown that warping the forebody of a hull having a high length-beam ratio caused a slight increase in the minimum aerodynamic drag, but the minimum drag was still considerably less than that of the hull having the conventional length-beam ratio of 6.

The behavior in waves of the hull of length-beam ratio of 15 has been reported in reference 3. Possible advantages of the increase in angle of dead rise of the forebody would be a reduction in height of spray and a decrease in the accelerations during operations in rough water.

The hypothetical seaplane design is a twin-engine propeller-driven flying boat having a design gross load of 75,000 pounds, a gross-load coefficient C_{Δ_o} of 5.88, a wing loading of 41.1 pounds per square foot, and a power loading of 11.5 pounds per brake horsepower for take-off. The hydrodynamic qualities of importance in practical operation (reference 4) determined in the investigation were longitudinal stability during take-off and landing, spray characteristics, and take-off performance in smooth water and take-off and landing behavior and spray characteristics in waves. The qualities were determined from tests of a $\frac{1}{10}$-size powered dynamic model in Langley tank no. 1 and are compared with the same qualities of the seaplane having a hull length-beam ratio of 15 as presented in references 1 and 3.

SYMBOLS

C_{Δ_o}	gross-load coefficient (Δ_o/wb^3)
a	acceleration, feet per second per second
b	maximum beam of hull, feet
g	acceleration due to gravity (32.2), feet per second per second
n_v	vertical acceleration, g units
T	propeller thrust, pounds
V	horizontal velocity (carriage speed), feet per second

V_v	vertical velocity (sinking speed), feet per second
w	specific weight of water (63.4 for these tests, usually taken as 64 for sea water), pounds per cubic foot
α	angular acceleration, radians per second per second
γ	flight-path angle, degrees
δ_e	elevator deflection, degrees
Δ_o	gross load, pounds
τ	trim (angle between forebody keel at step and horizontal), degrees
τ_L	landing trim, degrees

DESCRIPTION OF MODEL AND APPARATUS

The model, designated Langley tank model 224B, was the same as Langley tank model 224 (reference 1) with the exception of the forebody bottom. Photographs and hull lines of the model and general arrangement of the hypothetical flying boat are given in figures 1, 2, and 3, respectively. Additional information regarding dimensions and characteristics may be found in references 1, 3, and 5.

The angles of dead rise, exclusive of chine flare, as compared with those of the basic forebody are given in figure 4. The angle at the step was the same in both cases. From the step forward, the angle was increased at the rate of approximately 7.5° per beam. However, in order to obtain straight buttock and chine lines over the planing bottom from station 7 to the step, the tangent of the angle of dead rise varied as a straight line between those stations. The keel heights, chine half-breadths, and chine flare were the same as those of the basic forebody. Offsets of the warped forebody are given in table I.

The investigation was made in Langley tank no. 1, which is described in reference 6. The apparatus used for the towing of dynamic models is described in reference 7. The setup of the model on the towing carriage and the apparatus are shown in figure 5. The model was free to trim about the pivot, which was located at the center of gravity, and was free to move vertically but was restrained laterally and in roll and yaw. The towing gear was connected to a spring balance which measured the longitudinal force. For the self-propelled tests in waves, the model had approximately 2 feet of fore-and-aft freedom with respect to the towing carriage in order to absorb the longitudinal acceleration introduced by the impacts.

An accelerometer mounted on the towing staff of the model measured the vertical accelerations. Two accelerometers were used to measure the angular accelerations. The apparatus used in testing of models in waves and the wave maker used in Langley tank no. 1 are described in reference 3.

PROCEDURES

Effective thrust and aerodynamic lift and pitching-moment data for Langley tank model 224 are presented in reference 1 and are applicable to Langley tank model 224B.

The hydrodynamic qualities in smooth water and in oncoming waves were determined at the design gross load corresponding to 75,000 pounds, except for the spray investigation in which the gross loads corresponded to loads from 55,000 pounds to 95,000 pounds. The flaps were deflected 20° for all the hydrodynamic tests. All data are presented as full-size values.

Trim limits of stability.- The trim limits of stability were determined at constant speeds by use of the methods described in reference 7. In order to obtain sufficient control moment to trim the model to the trim limits, the lower limit was determined at forward positions of the center of gravity and the upper trim limits were determined at after positions of the center of gravity.

Center-of-gravity limits of stability.- The center-of-gravity limits of stability were determined by making accelerated runs to take-off speed with fixed elevators, full thrust, and a constant rate of acceleration of 1 foot per second per second. Trim, rise, and amplitude of porpoising were continuously recorded during the accelerated run. A sufficient number of center-of-gravity positions and elevator deflections were investigated to cover the normal operating range and to define the center-of-gravity limits of stability.

Landing stability.- The landing stability was investigated by trimming the model in the air to the desired landing trim at a speed slightly above flying speed and then decelerating the towing carriage at a uniform rate of 2 feet per second per second; this technique allowed the model to glide onto the water and simulate an actual landing. The contact trims and behavior on landing were observed visually, and trim and rise were continuously recorded throughout the landing run. The landings were made with one-half full thrust used during the take-off runs and with the center of gravity located at 32 percent mean aerodynamic chord.

Spray characteristics.- The speeds at which light loose spray and the speeds at which heavy blister spray entered the propellers or struck the flaps were determined for gross loads from a lightly loaded to a heavily overloaded condition. Spray photographs were taken with the model free to trim with constant elevator deflection of -10°.

Excess thrust.- The excess thrust (thrust available for acceleration) was determined at constant speeds for several fixed settings of the elevators. The center of gravity was located at 32 percent mean aerodynamic chord.

Taxying and take-off behavior in waves.- The taxying behavior in waves was investigated with full thrust up to hump speed at a forward rate of acceleration of 1 foot per second per second. The take-off behavior in waves was investigated with full thrust up to take-off speed at a forward rate of acceleration of approximately 3.3 feet per second per second. Complete time histories of the taxi and take-off runs were recorded.

Landing behavior in waves.- The landing behavior in waves was investigated by employing the same landing technique and deceleration as in the investigation of the smooth-water landing stability. Results of tests in rough water have shown that, except at dangerously low trims, landing trim had no appreciable effect on either the variation of trim during the landing runout or the maximum accelerations. All landings were consequently made at approximately 8°. The behavior on landing was observed visually, and a time history of the landing behavior was continuously recorded throughout the landing run. The time history included recordings of trim, rise, fore-and-aft position, vertical accelerations, angular accelerations, wave profiles, and speed. The landings were made with power on and with the thrust adjusted so that the model upon initial contact with a wave was approximately a free body.

RESULTS AND DISCUSSION

Longitudinal Stability

Trim limits of stability.- The trim limits of stability are presented in figure 6. The upper limit, increasing trim, for the hull with the warped forebody was almost the same as that for the hull with the basic forebody. At high speeds near take-off the differences in the upper limit, decreasing trim, for the two forebodies were negligible. The lower limit with the warped forebody was shifted to lower speeds with the peak occurring at approximately the same trim. This shift increased the range of stable trim between the lower limit and the upper limit, increasing trim.

As noted with the basic forebody, porpoising of the model at constant forward speed could be allowed to build up to such a large amplitude that the model porpoised across both the upper and lower limits. This porpoising was less violent than that encountered with the basic forebody and occurred over a smaller speed range (50 to 61 mph). As in the case of the basic forebody, during accelerated take-offs this large-amplitude porpoising was encountered only at center-of-gravity positions that were definitely ahead of the forward center-of-gravity limits.

Center-of-gravity limits of stability.- Representative trim tracks are presented in figure 7(a) for several positions of the center of gravity and elevator deflections. Comparable trim tracks for the hull with the basic forebody are presented in figure 7(b). The maximum amplitudes of porpoising that occurred during take-off are plotted against position of the center of gravity in figure 8. The maximum amplitude is defined as the difference between the maximum and minimum trims during the greatest porpoising cycle that occurred during the take-off.

The trends in the plots of maximum amplitude of porpoising against position of the center of gravity for the hull with the warped forebody are generally similar to those noted with the basic forebody. With the warped forebody, the amplitude of lower-limit porpoising did not increase as rapidly with forward movement of the center of gravity as with the basic forebody. The oscillation of upper-limit porpoising for the hull with the warped forebody never exceeded $3\frac{1}{2}^{\circ}$ at the most after position of the center of gravity; whereas, the oscillation of upper-limit porpoising for the hull with the basic forebody never exceeded approximately $2\frac{1}{2}^{\circ}$. With either forebody, the upper-limit porpoising was not violent. Absence of violent upper-limit porpoising with these two hulls is attributed to the relatively long afterbody which apparently was effective in damping the oscillations in trim.

For a given elevator deflection, the practical center-of-gravity limit is usually defined as that position of the center of gravity at which the amplitude of porpoising becomes 2°. A plot of elevator deflection against center-of-gravity position at which the maximum amplitude of porpoising was 2° is presented in figure 9(a). With the warped forebody, the forward limit was moved aft and the after limit was moved forward. The range of stable center-of-gravity position with the warped forebody, therefore, was less than the range of stable center-of-gravity position with the basic forebody. Stable take-offs could be made, however, at positions of the center of gravity from 24 to 36 percent mean aerodynamic chord. With a fixed deflection of the elevators of -10°, the hull with the warped forebody had a stable range of position of the center of gravity for take-off of approximately 5 percent mean aerodynamic chord.

Inasmuch as the upper-limit porpoising was not violent and did not diverge to large amplitudes, a practical definition of the after limit with either forebody becomes difficult. For instance, if 3° amplitude of porpoising were selected as the maximum allowable amplitude, as shown in figure 9(b), the basic forebody would have no after limit of position of the center of gravity and the after limit with the warped forebody would be moved far aft. Inasmuch as the upper-limit porpoising with the warped forebody never exceeded $3\frac{1}{2}^\circ$ and this porpoising with the basic forebody never exceeded approximately $2\frac{1}{2}^\circ$, an after limit of position of the center of gravity might be considered nonexistent.

Increasing the allowable amplitude of porpoising to 3° moved the forward limit forward about 1 percent mean aerodynamic chord. If desired, the forward limits could be made to coincide by a forward movement of the step of the hull with the warped forebody.

Landing stability.- Several typical time histories of landings with the two forebodies are presented in figure 10. The maximum and minimum values of the trim and rise of the flying boat at the greatest cycle of oscillation during the landing run were obtained from these data and are plotted against trim at contact in figure 11.

The hull with the warped forebody did not skip on contact at any landing trim investigated (3° to 14°); therefore the depth of step (16.5 percent beam) provided sufficient ventilation. The hull with the warped forebody did not porpoise on landing at any trim investigated. At contact trims up to 10° the amplitude of oscillation in trim and rise was approximately the same as with the basic forebody. At contact trims above 10°, the amplitude of oscillation in trim and rise obtained with the warped forebody was much less than that obtained with the basic forebody. Inasmuch as the warped forebody did not porpoise on landing, the amplitude of oscillation in trim was approximately constant at landing trims above 10°.

Spray Characteristics

Spray in propellers and on flaps.- The range of speed over which spray entered the propellers and struck the flaps is plotted against gross load in figure 12. At the design gross load (75,000 lb), no spray entered the propellers or struck the flaps of the hull with the warped forebody. The gross load was increased approximately 25 percent (95,000 lb) before the heavy blister spray entering the propellers or striking the flaps was equivalent to the spray of the hull with the basic forebody at the design gross load (75,000 lb).

Spray photographs.- Photographs of bow spray of the two forebodies at the design gross load are presented as figure 13. Stern photographs

are presented as figure 14. These photographs cover the speed ranges of figure 12 where heavy spray entered the propellers and struck the flaps of the model with the basic forebody. The effectiveness of the warped forebody in reducing the bow spray and the difference in the heavy spray between the warped and the basic forebodies are shown in these photographs.

Photographs of spray striking the tail surfaces during a landing run (one-half take-off thrust) are presented as figure 15. The spray from both forebodies struck the horizontal tail surfaces at high speeds. This spray might necessitate raising the horizontal tail. The spray striking the tail surfaces did not differ greatly for the hulls with the basic and warped forebodies.

Spray in rough water.- The range of speed over which spray entered the propellers in oncoming waves, 2 feet high and 110 feet long, is plotted against gross load in figure 16. At the design gross load, spray entered the propellers over the speed range from 19 to 29 miles per hour, whereas no spray entered the propellers in smooth water. In this particular wave, as well as in smooth water, the bow spray characteristics were substantially better for the hull with the warped forebody than with the basic forebody.

Take-Off Performance

Excess thrust.- The excess thrust and trim during take-off with full thrust are shown in figure 17. The curves represent the excess thrust and trim for minimum total resistance except in the speed range where porpoising was encountered. Over this speed range the trim was increased to remain above the lower trim limit of stability.

Comparison of the excess thrust of the warped and basic forebodies indicates that the water resistance was approximately the same up to the hump speed but was slightly greater at high speeds with the warped forebody. At low speeds the warped forebody trimmed lower than did the basic forebody. The maximum trim, however, was approximately the same and occurred at approximately the same speed with each forebody.

Longitudinal acceleration.- The longitudinal acceleration a during take-off is plotted against speed in figure 18. The acceleration was derived from the excess-thrust curves of figure 17 by use of the relationship

$$a = \frac{T}{\Delta_o} g$$

Take-off time and distance.- The take-off time was determined from the area under the curve of $1/a$ plotted against speed; the take-off distance was determined from the area under the curve of V/a plotted against speed. The take-off time and distance for the hull

with the warped forebody were 24 seconds and 1780 feet, respectively. The take-off time and distance for the hull with the basic forebody were 21 seconds and 1530 feet, respectively. The over-all take-off performance of the hull with the warped forebody was therefore slightly inferior to that of the hull with the basic forebody.

Take-Off Behavior in Waves

The results of the investigation of the take-off behavior in waves of the model with the warped forebody are qualitative, but several points are of interest. Although the trim cycles were large in 4-foot waves, the bow did not dig in. Observations indicated, however, that a decrease in forebody length would not be advisable.

Tracings of typical records made during take-offs in waves are shown in figure 19. The model tended to follow the waves in the trim and rise motions at the lower speeds. In 2-foot waves, the oscillations in rise were very small. The oscillations in trim were not great and the trim did not exceed the stall angle during the take-off run. In 4-foot waves, the oscillations in trim and rise were large but did not appear to be dangerous.

A comparison of the records of the take-offs shows the large increase in amplitude of the motions in trim and rise when wave height was increased from 2 feet to 4 feet.

Tracings of typical records made during take-offs in 4-foot waves of the hull with the warped forebody and with the basic forebody are presented in figures 20(a) and 20(b), respectively. Comparison of the records indicates that warping the forebody of the hull having a high length-beam ratio had a negligible effect on the take-off behavior in waves. The hull with the warped forebody trimmed slightly lower than that with the basic forebody although the amplitude of the trim oscillation was approximately the same with both forebodies.

Landing Behavior in Waves

The results of the landing investigation in waves are presented in table II for use in further analysis. The sinking speeds for the initial landing approach ranged from 175 to 280 feet per minute (0.93 to 1.47 fps, model size) and were small compared to the sinking speeds at the maximum vertical accelerations. The sinking speeds associated with the maximum vertical accelerations ranged from 530 to 930 feet per minute (2.81 to 4.92 fps, model size). The sinking speeds associated with the maximum vertical accelerations for the hull with the basic forebody ranged from 195 to 1070 feet per minute. With the reduction in the maximum sinking speed, a lower maximum vertical acceleration would be expected for the hull with the warped forebody.

Vertical accelerations.- The variation of maximum vertical acceleration with wave length is shown in figure 21. A peak was reached in the maximum vertical accelerations at the shorter wave lengths. The maximum acceleration of approximately 6g at the peak was reduced about 45 percent at the longer wave lengths.

The position of landing on a wave for the initial impact as well as subsequent impacts during the landing runout was not under the control of the operator, and this lack of control accounts for the scatter of the test data. The envelopes of the data indicate the maximum probable accelerations that would be obtained for the range of wave lengths investigated.

The peak maximum vertical acceleration of approximately 6g for the hull having the warped forebody was about 35 percent less than the peak maximum vertical acceleration for the hull having the basic forebody. The peak accelerations occurred at approximately the same wave length for the hulls with the warped and basic forebodies. At the long wave lengths, the maximum accelerations with the two forebodies were approximately the same.

Angular accelerations.- Maximum angular accelerations are plotted against wave length in figure 22. A peak was reached in the maximum positive accelerations (bow rotated upward) at the shorter wave lengths. The maximum acceleration of approximately 6 radians per second per second at the peak was reduced about 60 percent at the longest wave length investigated.

The negative angular accelerations occurred when a bow-down rotation was induced during landing on the sternpost. The variation of negative angular acceleration with wave length was not great.

The peak maximum angular acceleration of approximately 6 radians per second per second for the hull with the warped forebody was about 50 percent less than the peak maximum angular acceleration for the hull with the basic forebody. The negative angular accelerations were increased by warping the forebody.

Motions in trim and rise.- The maximum and minimum trim and rise at the greatest cycle of oscillation that occurred during the landing run are plotted against wave length in figure 23. The variation of trim and rise with wave length was small.

The maximum oscillations in trim and rise were not affected appreciably by warping the forebody and the maximum change in trim was approximately the same for the hulls with the warped and basic forebodies. The maximum trim was approximately 1° less with the warped forebody than with the basic forebody. The maximum rise was the same with the two forebodies at shorter wave lengths but was increased at the longer wave lengths for the hull with the warped forebody. The minimum rise of the two forebodies was the same.

Summary Chart

The hydrodynamic qualities in smooth water of the hypothetical flying boat with a hull of high length-beam ratio having a warped forebody, as determined by the powered dynamic model tests, are summarized in figure 24. This chart gives an over-all picture of the hydrodynamic characteristics in terms of full-scale operational parameters and is therefore useful for comparisons with similar data regarding other seaplanes for which operating experience is available.

CONCLUSIONS

The results of the investigation of the effect of extreme warping (progressive increase in angle of dead rise from step to bow) of the forebody planing bottom on the hydrodynamic qualities of a hypothetical flying boat with a hull having a length-beam ratio of 15, at a gross load of 75,000 pounds (gross-load coefficient of 5.88), led to the following conclusions:

1. The lower trim limit was shifted to lower speeds and the range of stable trim between the lower and upper trim limits of stability therefore was increased appreciably when compared with that for the hull with the basic forebody.

2. With a maximum allowable amplitude of porpoising of 2°, the range of stable position of the center of gravity for take-off with fixed elevators was reduced for the hull with the warped forebody when compared with that for the hull with the basic forebody. With a 3° allowable amplitude of porpoising, however, the hull with the warped forebody had a wide practicable range for satisfactory take-off with fixed elevators.

3. Landing stability was improved by warping the forebody; landings were made at contact trims up to 14° without encountering skipping or porpoising.

4. Bow spray characteristics were substantially better for the hull with the warped forebody than for the hull with the basic forebody; in smooth water a 25-percent increase in gross load was possible before spray in the propellers and on the flaps was equivalent to that of the basic forebody. Spray striking the tail was approximately the same with both forebodies.

5. The high-speed water resistance was slightly greater for the hull with the warped forebody than for the hull with the basic forebody and the over-all take-off performance of the hull with the warped forebody was slightly inferior to that of the hull with the basic forebody.

6. Warping the forebody had a negligible effect on the take-off behavior in waves.

7. During landings in waves, the maximum vertical acceleration of approximately 6g was about 35 percent less than that for the hull having the basic forebody.

8. During landings in waves, the maximum angular acceleration of approximately 6 radians per second per second was about 50 percent less than that for the hull having the basic forebody.

9. The maximum oscillations in trim and rise during landings in waves were not affected appreciably by warping the forebody.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., December 16, 1948

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TABLE I

OFFSETS FOR LANGLEY TANK MODEL 224B
[All dimensions are in inches]

Station	Distance to F.P.	Keel above base line	Chine above base line	Half-beam at chine	Radius and maximum half-beam	Height of hull at center line	Line of centers above base line	Angle of chine flare (deg)	Forebody bottom, height above base line								
									Buttocks								
									0.36	0.71	1.07	1.42	1.78	2.13	2.49	2.85	3.20
F.P.	0	10.30	10.30	0	0	11.00	11.00										
1/2	2.52	5.49	9.34	1.64	1.64	14.29	12.65	10	7.89	8.81	9.19	9.34					
1	5.04	3.76	8.42	2.18	2.18	15.72	13.54	10	5.65	7.15	7.88	8.23	8.39	8.43			
2	10.08	1.83	6.82	2.75	2.75	17.36	14.61	10	3.09	4.31	5.40	6.11	6.53	6.78	6.84		
3	15.12	.80	5.57	3.07	3.07	18.41	15.34	10	1.72	2.61	3.53	4.34	4.93	5.30	5.50	5.58	
4	20.15	.27	4.60	3.28	3.28	19.12	15.84	10	.98	1.67	2.39	3.08	3.73	4.15	4.42	4.57	4.61
5	25.19	.04	3.88	3.41	3.41	19.60	16.19	10	.61	1.17	1.74	2.29	2.86	3.32	3.63	3.82	3.89
6	30.23	0	3.35	3.48	3.48	19.88	16.40	5	.47	.92	1.39	1.85	2.31	2.71	3.03	3.24	3.34
7	35.27	0	2.91	3.50	3.50	19.99	16.49	0	.39	.77	1.15	1.53	1.91	2.29	2.58	2.79	2.89
8	40.31	0	2.52	3.505	3.505	20.00	16.49	0	.33	.67	.99	1.32	1.65	1.97	2.23	2.40	2.50
9	45.34	0	2.14	3.505	3.505	20.00	16.49	0	.28	.56	.83	1.12	1.39	1.67	1.89	2.04	2.13
10	50.38	0	1.76	3.505	3.505	20.00	16.49	0	.23	.46	.69	.92	1.14	1.37	1.56	1.69	1.76
11	55.42	0	1.38	3.505	3.505	20.00	16.49	0	.18	.35	.54	.72	.89	1.07	1.21	1.32	1.38
12F	60.51	0	1.00	3.505	3.505	20.00	16.49	0	.13	.25	.39	.52	.64	.77	.88	.95	1.00

TABLE II

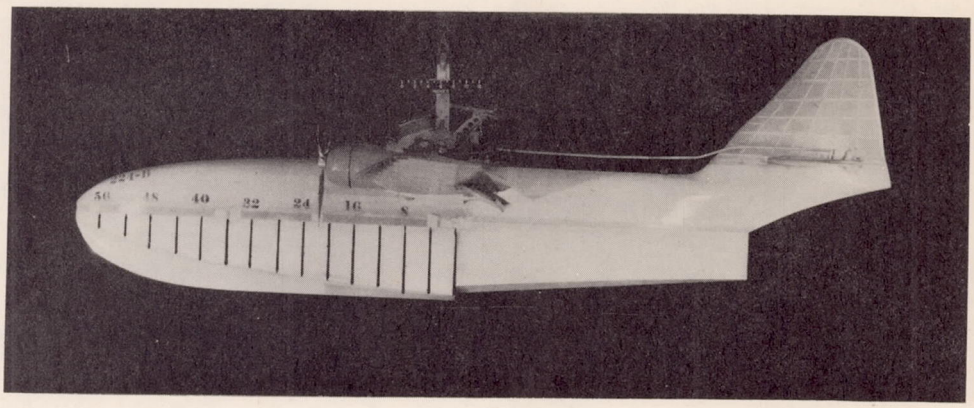
DATA OBTAINED DURING LANDINGS IN WAVES
FOR LANGLEY TANK MODEL 224B

[All values are model size]

Landing	Wave height (ft)	Wave length (ft)	Initial impact						Maximum acceleration						
			τ_L (deg)	V_v (fps)	V (fps)	γ (deg)	n_v (g)	α $\left(\frac{\text{radians}}{\text{sec}^2}\right)$	Impact	τ (deg)	V_v (fps)	V (fps)	γ (deg)	n_v (g)	α $\left(\frac{\text{radians}}{\text{sec}^2}\right)$
1	0.4	16.0	8.5	1.32	38.0	2.0	1.4	0	5	4.6	3.85	29.6	7.4	4.1	44
2	.4	16.5	8.5	1.20	38.5	1.8	1.0	0	3	5.2	3.79	33.7	6.4	3.8	36
									a5	2.7	2.90	30.3	5.5	2.8	49
3	.4	16.1	8.5	1.10	38.0	1.7	0	0	2	5.2	3.02	34.9	4.9	4.0	33
									a4	3.0	4.25	30.2	8.0	2.8	50
4	.4	17.0	8.5	1.23	37.8	1.9	1.0	0	3	5.1	3.67	32.9	6.4	3.8	38
5	.4	15.7	8.4	1.17	38.5	1.7	2.2	18	5	4.2	2.92	30.4	5.5	3.4	40
									a7	3.3	3.66	26.7	7.8	2.2	45
6	.4	16.2	8.4	1.47	38.5	2.2	1.2	0	5	4.5	3.75	28.8	7.4	4.0	46
7	.4	15.5	8.4	1.01	37.5	1.5	2.3	18	5	7.7	3.91	26.6	8.4	3.7	28
									a4	3.2	4.39	28.6	8.7	2.1	39
8	.4	15.6	8.4	1.41	38.1	2.1	0	0	3	5.0	3.43	32.6	6.0	4.0	31
									a6	2.5	3.04	27.9	6.2	2.7	50
9	.4	17.6	8.1	1.12	38.0	1.7	1.5	0	7	7.3	4.62	26.9	9.7	4.0	30
									a6	2.6	3.35	29.0	6.6	2.0	43
10	.4	17.3	8.3	1.19	38.0	1.8	1.2	0	5	2.2	3.01	30.0	5.7	3.7	63
11	.4	16.8	8.2	1.23	38.1	1.8	1.0	0	2	4.0	3.91	34.7	6.4	3.4	38
									a3	3.8	4.23	31.5	7.6	2.2	40
12	.4	17.5	8.4	1.29	38.3	1.9	2.3	19	2	6.3	2.86	35.0	4.7	3.1	14
									a6	2.0	4.39	22.0	9.2	2.4	50
13	.4	17.8	8.6	1.22	38.0	1.8	1.6	5	5	7.0	3.33	29.2	6.5	2.9	12
									a4	4.2	2.55	31.3	4.7	2.3	31
14	.4	17.7	8.5	1.14	37.8	1.7	1.2	-16	6	7.0	3.12	29.5	6.1	2.4	25
									a7	2.5	3.08	27.7	6.3	2.0	43
15	.4	18.3	8.5	1.20	38.4	1.8	.8	-14	2	5.5	3.43	34.9	5.6	5.0	41
16	.4	16.7	8.2	1.14	37.7	1.7	2.2	16	2	6.5	2.81	34.8	4.6	2.4	15
									a6	2.7	2.86	26.9	6.0	1.4	30
17	.4	17.1	8.2	1.05	37.7	1.6	1.0	0	4	4.4	3.71	33.0	6.4	3.5	40
18	.4	20.6	7.9	1.07	37.7	1.6	.4	0	3	3.9	3.69	33.9	6.2	6.0	70
19	.4	19.4	8.0	1.33	38.8	2.0	2.0	20	6	4.7	4.67	26.1	10.2	3.4	44
20	.4	19.5	8.0	1.19	36.4	1.9	1.3	0	4	5.2	4.30	30.0	8.2	3.2	20
									a3	3.0	2.32	33.3	4.0	1.6	28
21	.4	20.1	8.0	1.26	37.5	1.9	0	0	4	6.3	4.24	30.1	8.0	4.4	32
22	.4	19.3	8.1	1.10	37.8	1.7	1.8	0	7	5.7	4.49	27.8	9.2	3.5	33
23	.4	19.6	8.0	1.35	37.8	2.0	.6	0	4	4.6	4.92	30.6	9.1	5.8	58
24	.4	20.0	8.5	1.02	37.5	1.6	2.0	15	4	6.5	3.69	30.4	6.9	3.6	27
									a3	1.9	3.65	32.6	6.4	2.6	40
25	.4	20.1	8.2	1.05	38.1	1.6	0	-10	4	6.2	4.29	29.0	8.4	3.0	20
									a3	3.3	4.42	31.4	8.0	2.1	29
26	.4	19.6	8.2	1.12	38.0	1.7	1.3	11	7	5.7	4.82	27.2	10.0	3.0	35
									a6	3.4	4.05	29.2	7.9	2.3	40
27	.4	23.0	8.0	1.08	38.4	1.5	2.2	25	2	4.0	3.87	34.1	6.5	3.8	33
28	.4	23.1	8.0	1.15	38.5	1.7	2.0	11	3	7.0	4.23	32.0	7.5	3.6	28
									a2	3.5	4.23	35.2	6.9	2.2	32
29	.4	23.5	8.0	.93	38.0	1.4	1.6	10	4	6.0	4.23	29.9	8.1	3.0	16
									a3	3.0	2.82	32.6	3.2	1.9	33
30	.4	24.0	8.0	1.02	37.5	1.6	1.9	12	5	5.0	4.78	28.1	9.6	2.9	31
31	.4	24.1	8.0	1.26	37.5	1.9	2.0	22	6	6.6	3.40	23.8	8.1	2.6	29
									a3	3.0	3.58	30.5	6.7	1.9	33
32	.4	23.0	8.0	1.04	37.1	1.6	1.8	20	5	8.7	3.61	25.2	8.2	3.4	-22
									a4	3.9	4.30	26.5	9.2	1.8	27
33	.4	23.0	8.4	1.10	37.6	1.7	1.7	10	4	5.4	4.04	29.7	7.7	3.0	25
									a3	4.2	2.65	32.2	4.7	2.0	29
34	.4	23.5	8.4	1.30	37.6	2.0	1.9	0	6	5.8	4.22	29.3	8.2	3.8	30
35	.4	29.4	8.0	1.09	36.9	1.7	1.0	-11	4	5.0	4.50	30.2	8.5	2.5	20
									a6	4.4	3.97	25.4	8.9	2.2	23
36	.4	27.2	7.9	1.34	38.0	2.0	1.9	0	3	4.9	3.51	32.2	6.2	2.6	22
37	.4	27.6	8.0	1.19	38.4	1.8	2.0	20	3	6.8	4.70	31.3	8.5	3.7	22
									a2	2.9	4.25	34.5	7.0	3.0	37
38	.4	27.2	8.0	1.16	38.5	1.7	1.3	21	2	5.0	3.72	34.3	6.2	2.9	30
39	.4	28.6	8.0	1.20	38.3	1.8	1.8	18	3	5.3	3.99	31.4	7.2	3.4	26
									a2	4.3	4.13	34.0	6.9	3.2	31
40	.4	26.5	8.0	1.07	37.4	1.6	1.6	0	7	6.4	4.00	25.3	9.0	2.7	24
41	.4	27.2	8.4	1.12	36.8	1.7	1.5	8	3	6.3	3.99	30.3	7.5	3.0	22
42	.4	27.7	8.5	1.33	37.5	2.0	1.8	20	3	6.7	4.61	30.8	8.5	3.5	32
43	.4	35.7	7.5	.99	38.9	1.5	1.0	5	5	7.8	3.20	28.8	6.3	2.6	19
									a7	5.9	2.48	25.1	5.6	1.5	21
44	.4	34.6	7.3	1.10	39.2	1.6	1.2	0	3	5.1	3.93	33.3	6.7	3.3	24
									a6	4.8	3.97	25.9	8.7	2.9	29
45	.4	35.5	8.0	1.09	38.0	1.6	0	0	6	6.9	3.90	28.5	7.8	2.8	12
									a8	4.7	3.73	24.7	8.6	2.3	26
46	.4	35.7	8.0	1.20	38.2	1.8	1.8	0	5	7.2	3.82	29.7	7.3	2.4	-25
									a7	4.8	3.03	26.1	6.6	2.3	22
47	.4	36.4	8.0	1.38	38.1	2.1	1.9	0	3	4.1	4.66	32.1	8.3	2.9	29
48	.4	34.6	8.4	1.03	37.6	1.6	0	0	6	7.7	4.00	25.4	9.0	4.1	30
49	.4	34.2	8.4	1.21	37.4	1.9	1.6	10	5	7.8	3.52	27.6	7.3	3.3	25
									a7	8.0	3.77	24.5	8.8	2.2	30

[a] Impact for maximum angular acceleration.

NACA



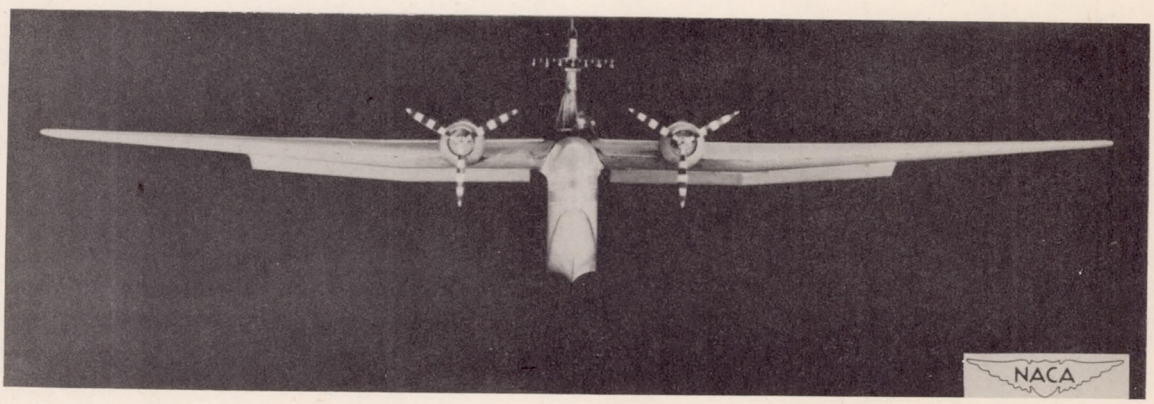


Figure 1.- Side and front views of model.

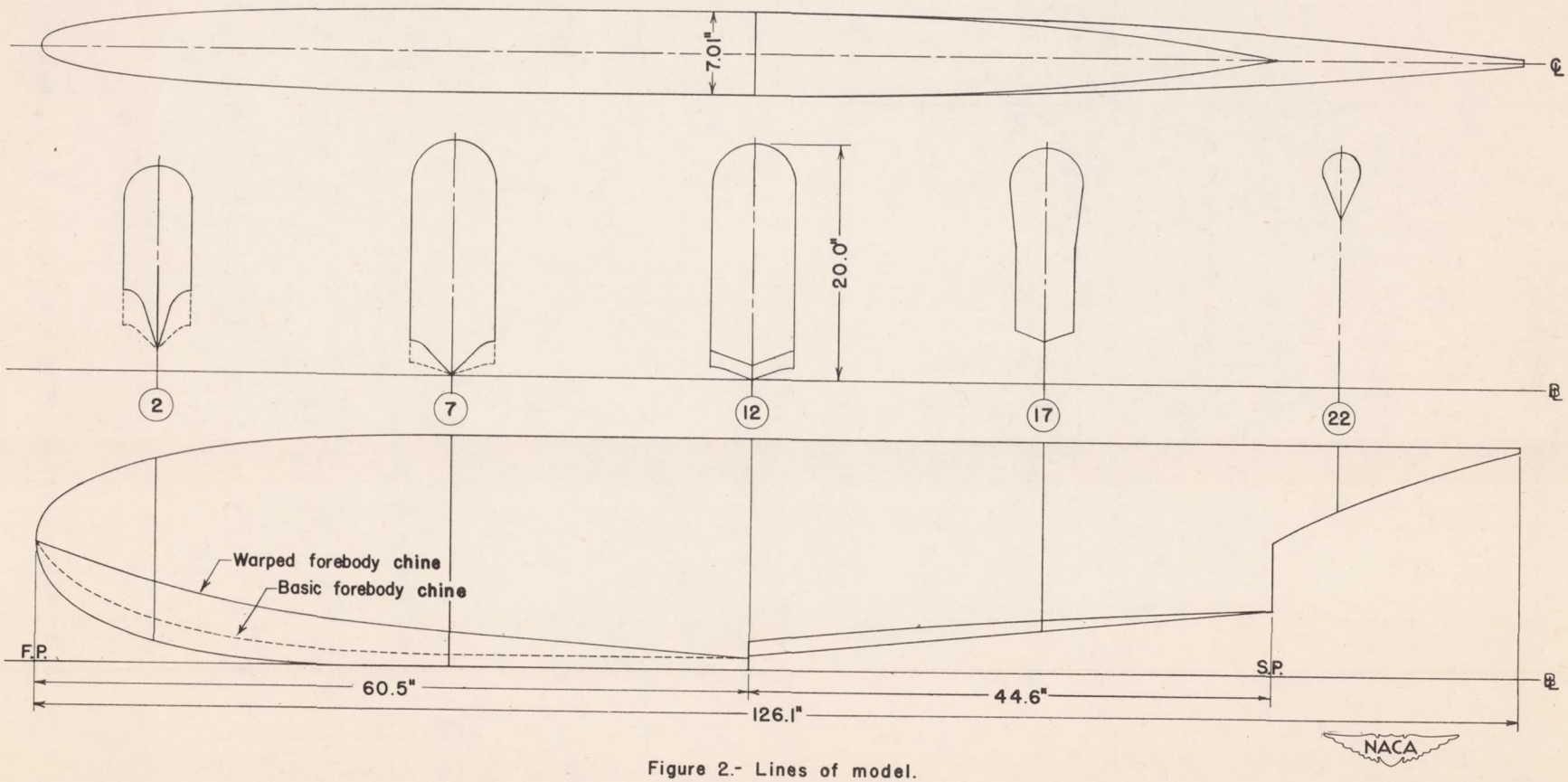


Figure 2.- Lines of model.

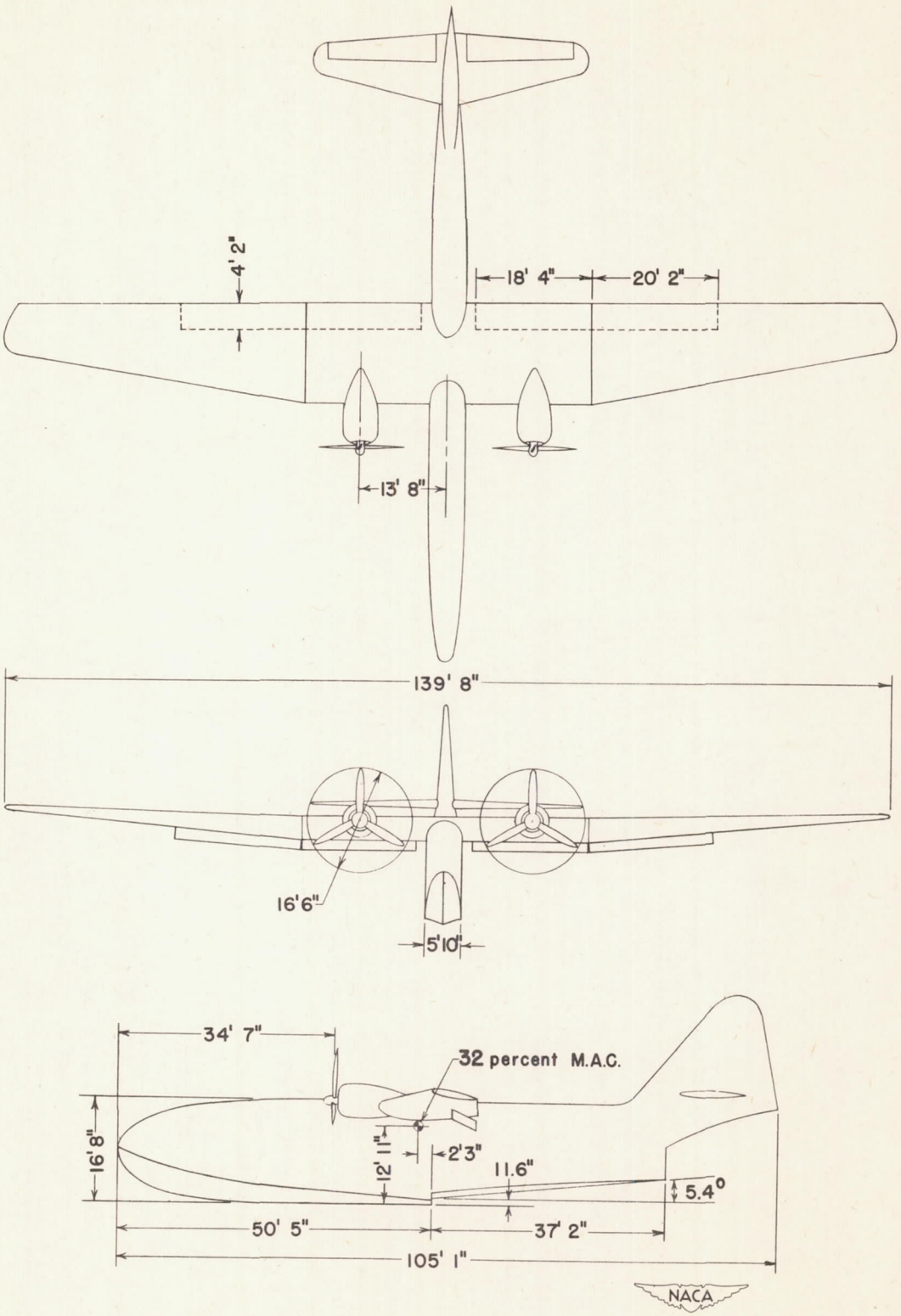


Figure 3.- General arrangement of hypothetical flying boat.

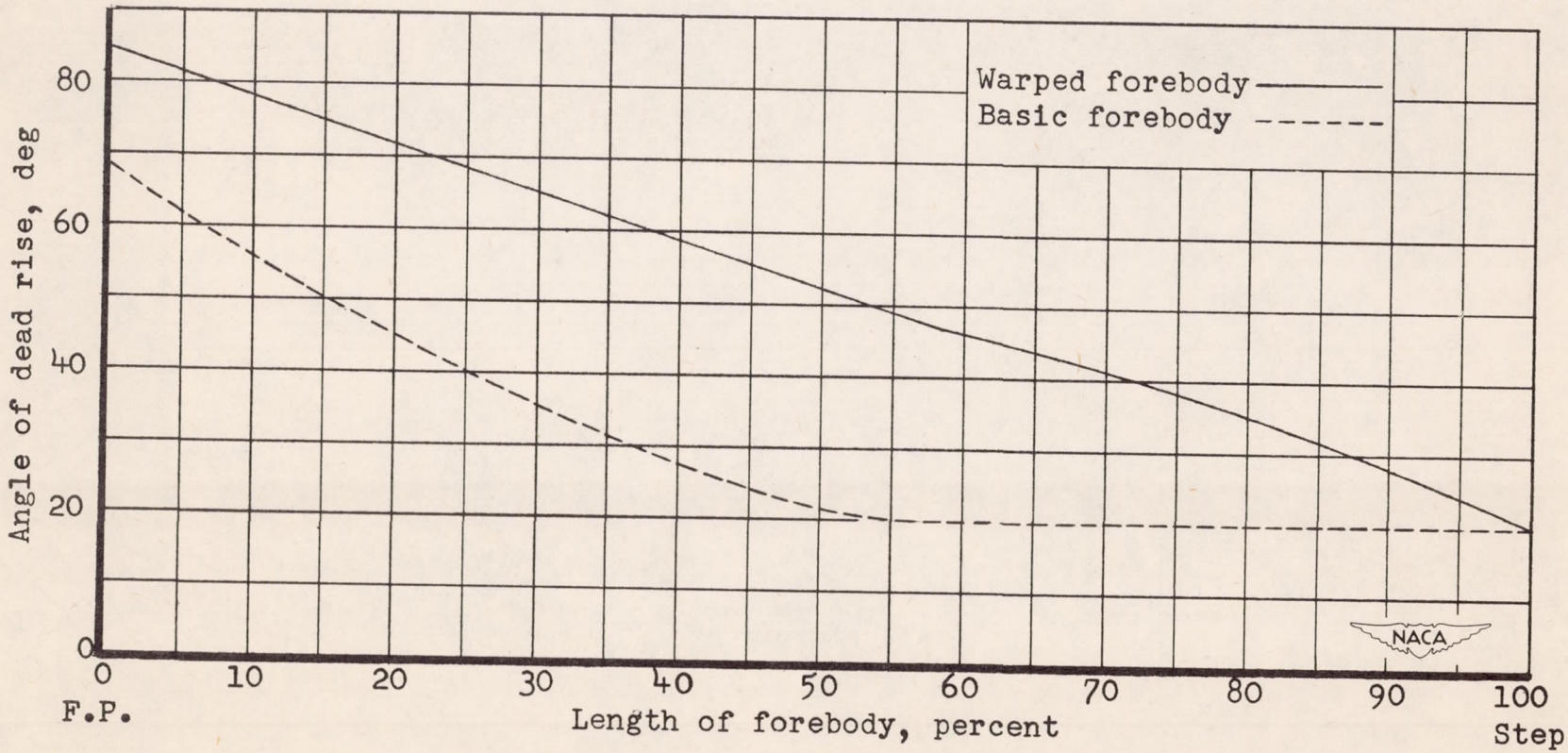
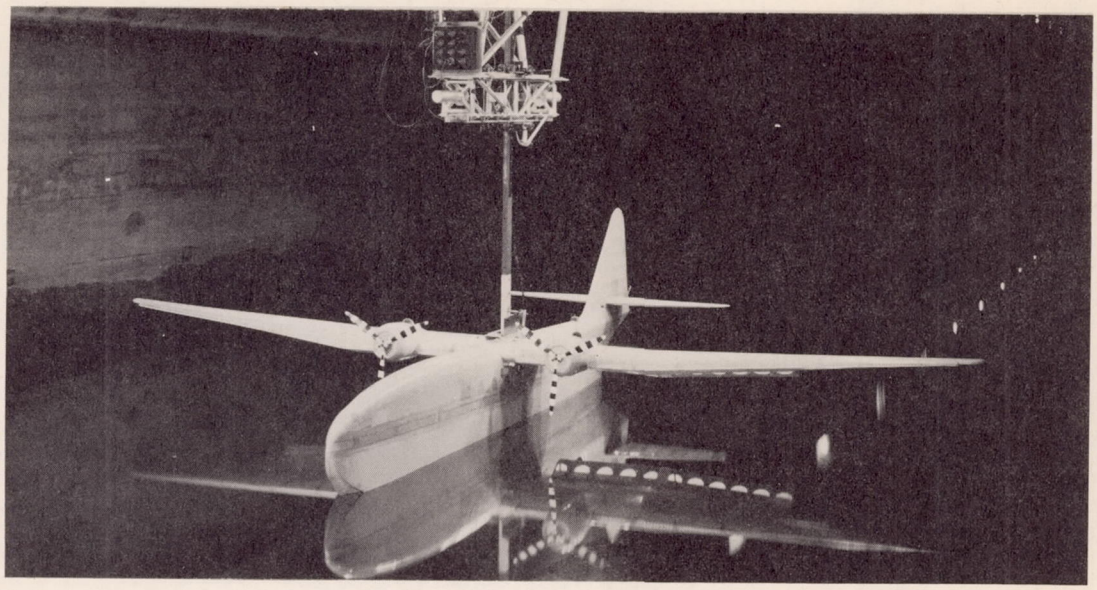
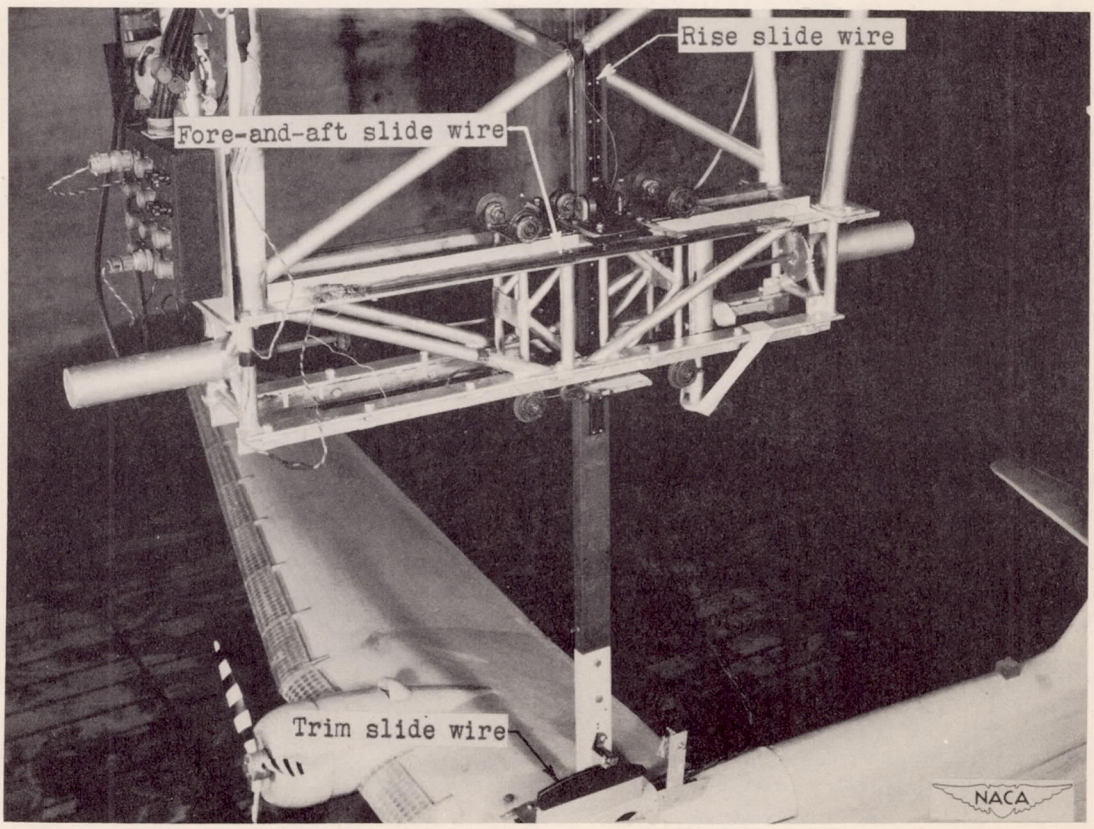


Figure 4.- Variation of angle of dead rise with length of forebody.



(a) Setup of model on towing apparatus.



(b) Details of fore-and-aft gear.

Figure 5.- Model and towing apparatus.

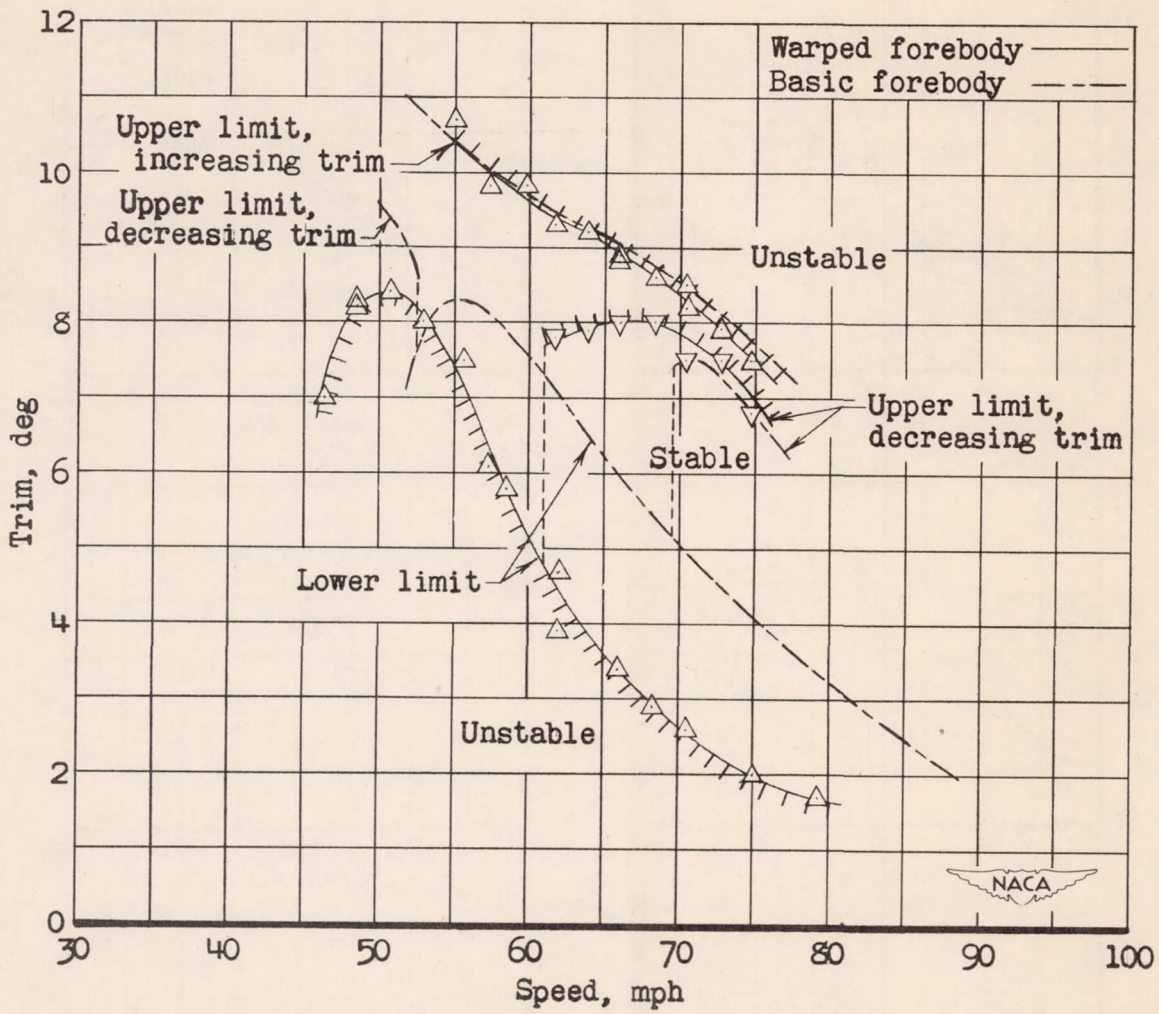


Figure 6 .- Trim limits of stability.

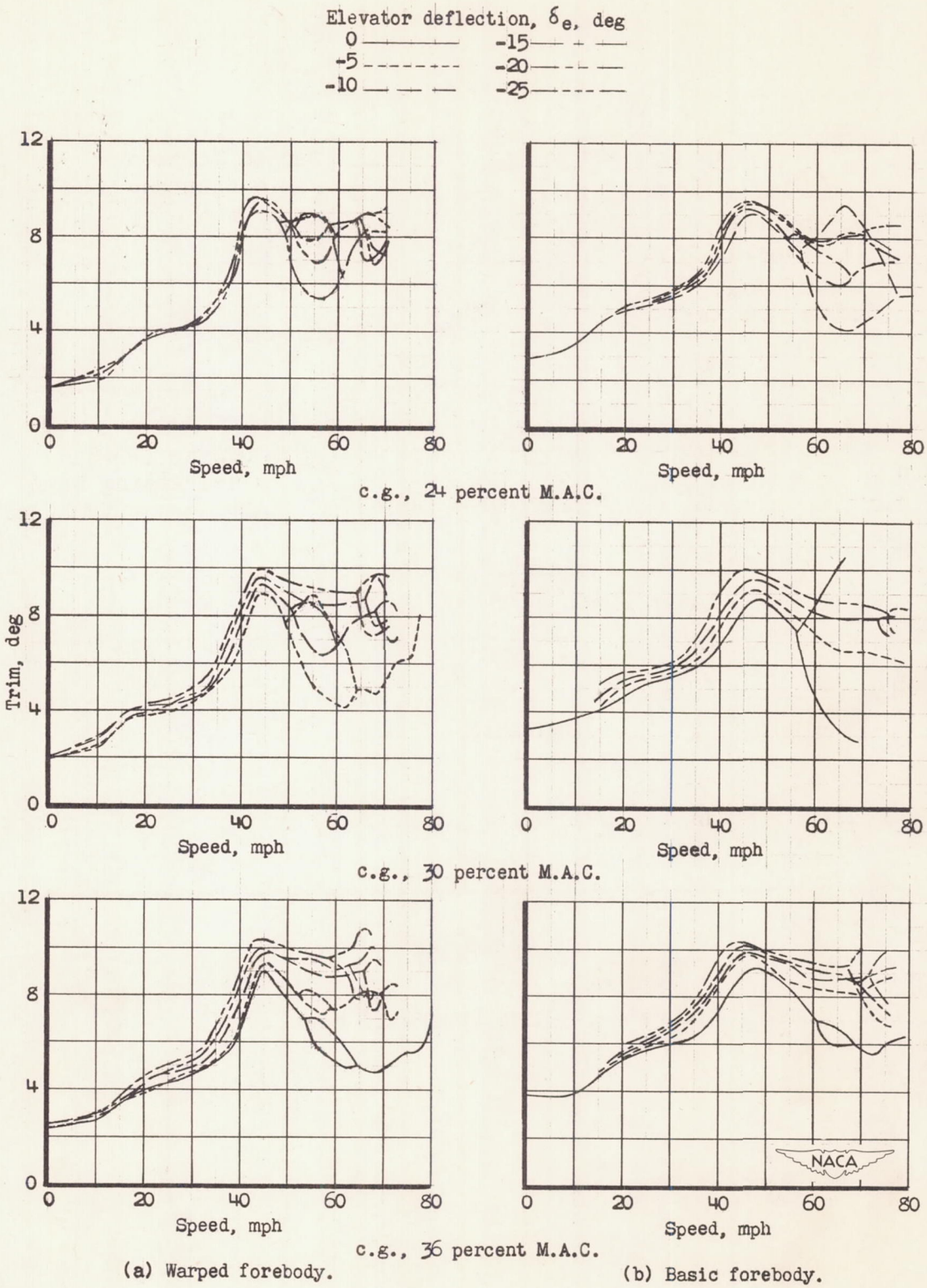


Figure 7.- Variation of trim with speed.

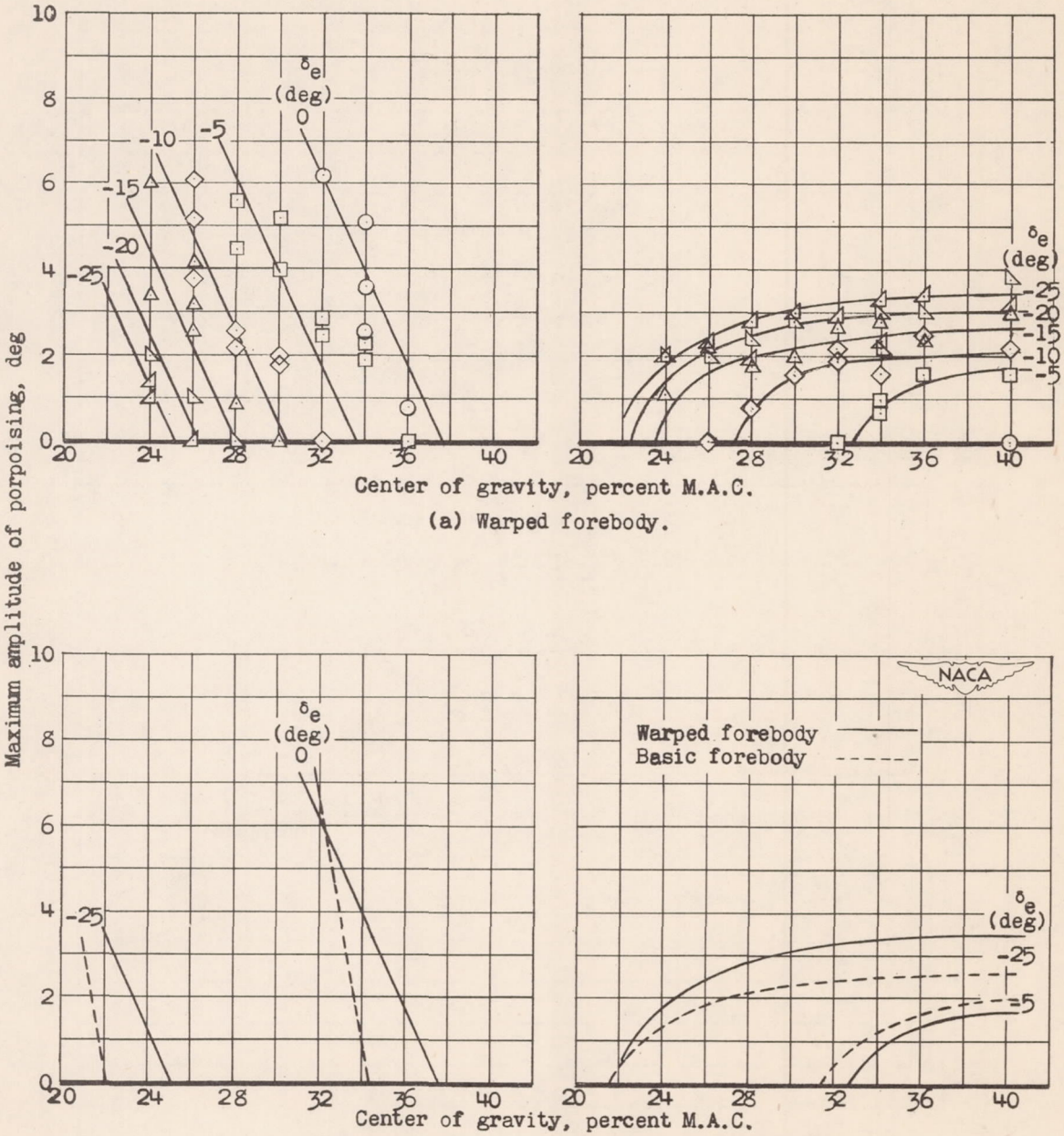
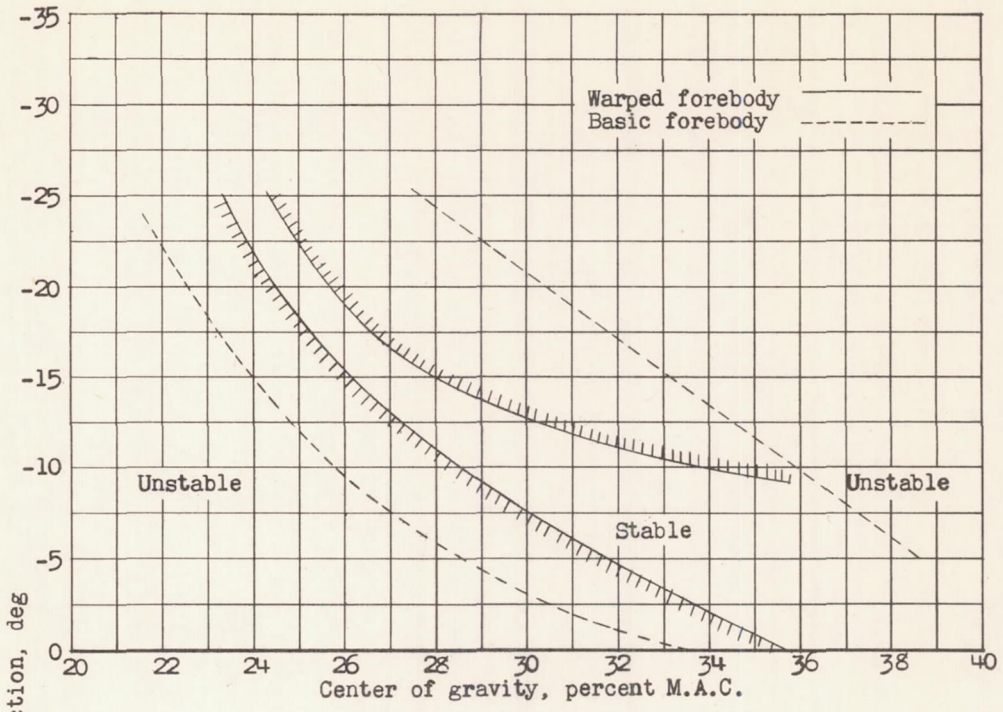
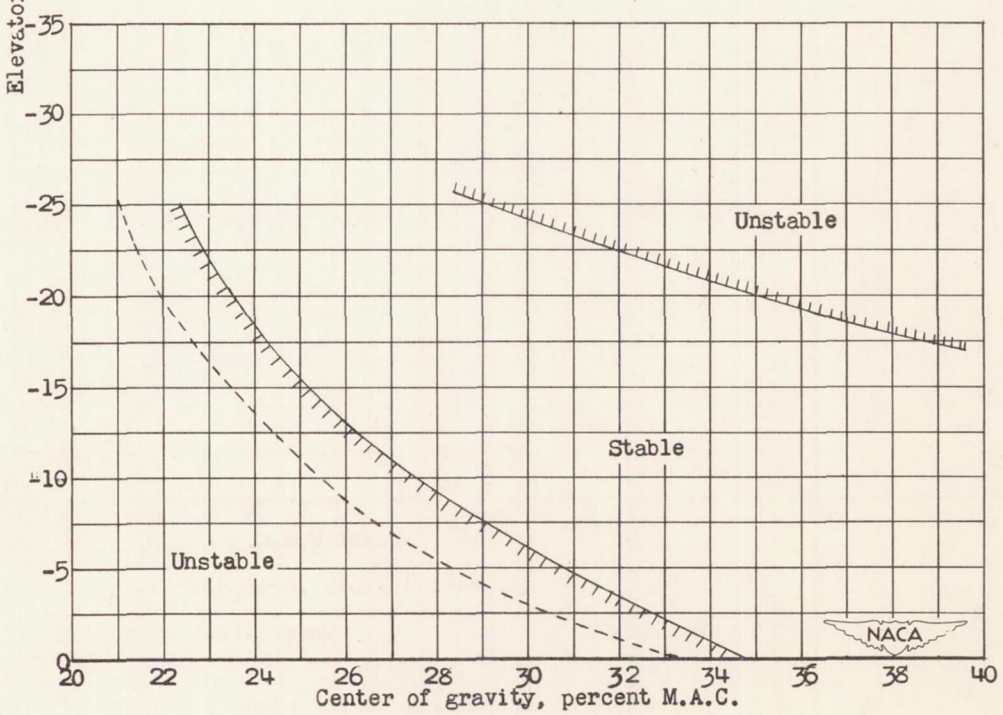


Figure 8.- Maximum amplitude of porpoising at different positions of the center of gravity.

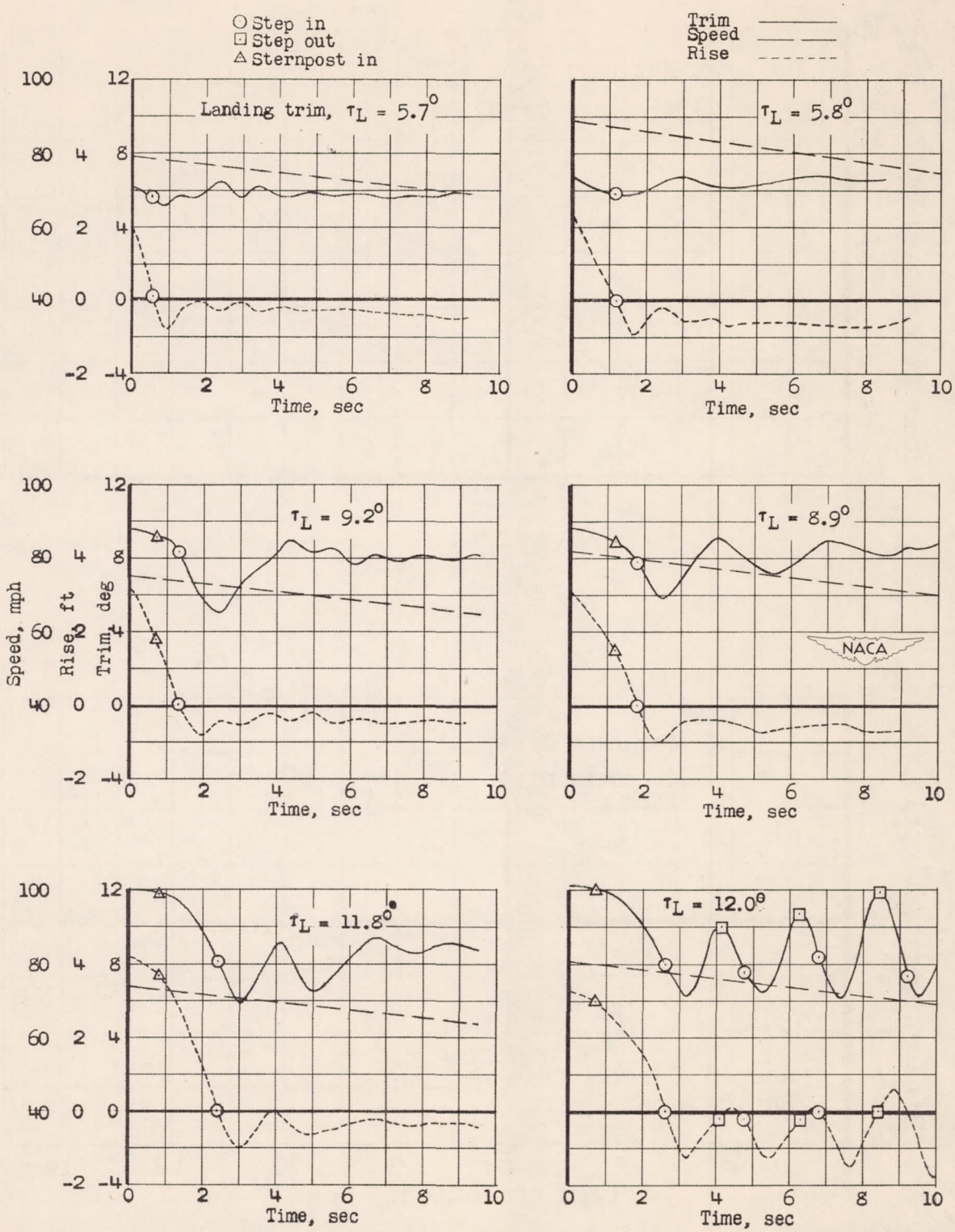


(a) 2° amplitude of porpoising.



(b) 3° amplitude of porpoising.

Figure 9.- Variation of center-of-gravity limits of stability with elevator deflection.



(a) Warped forebody. (b) Basic forebody.

Figure 10.- Variation of trim, rise, and speed with time during landings.

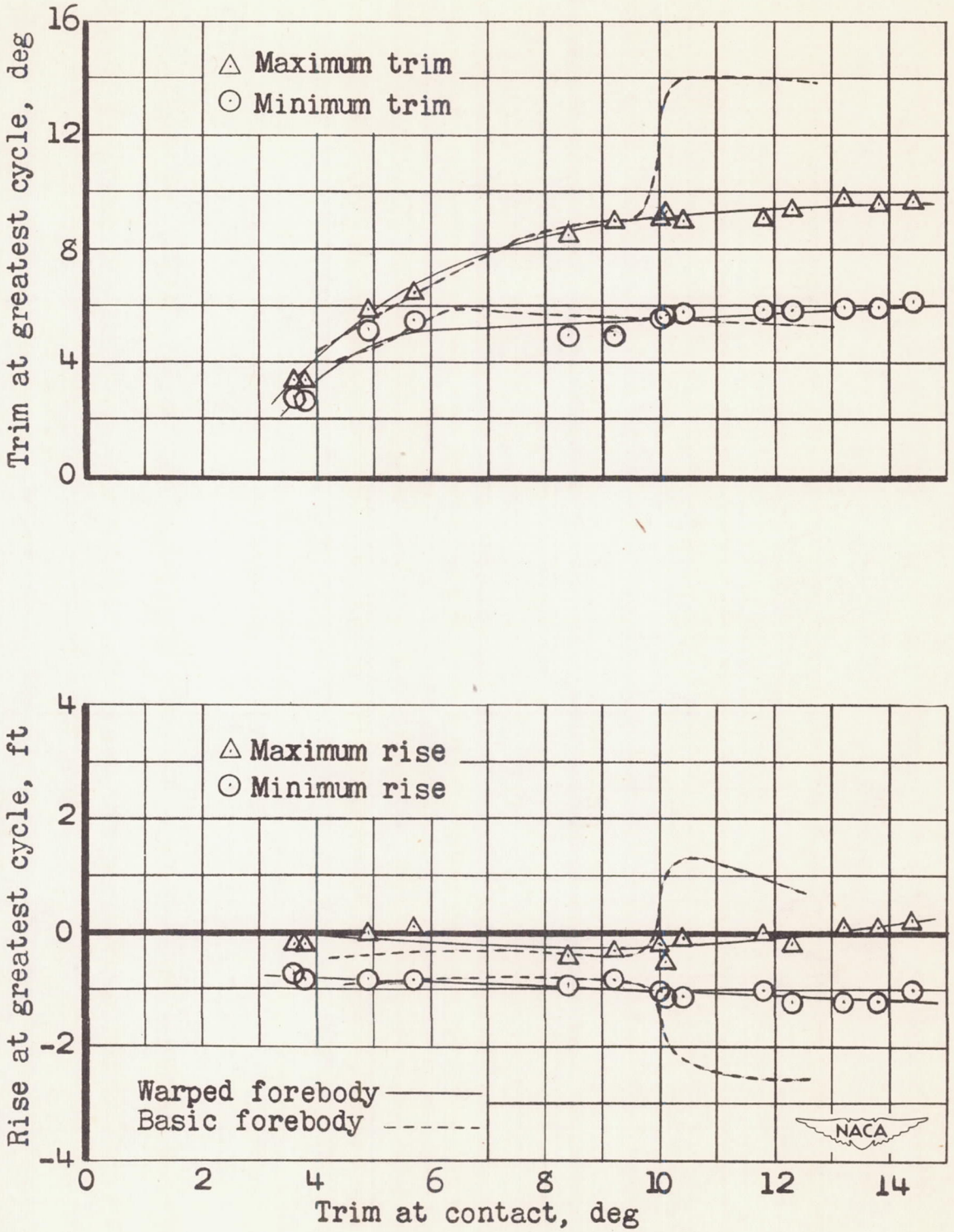


Figure 11.- Variation of maximum and minimum trim and rise with trim at contact.

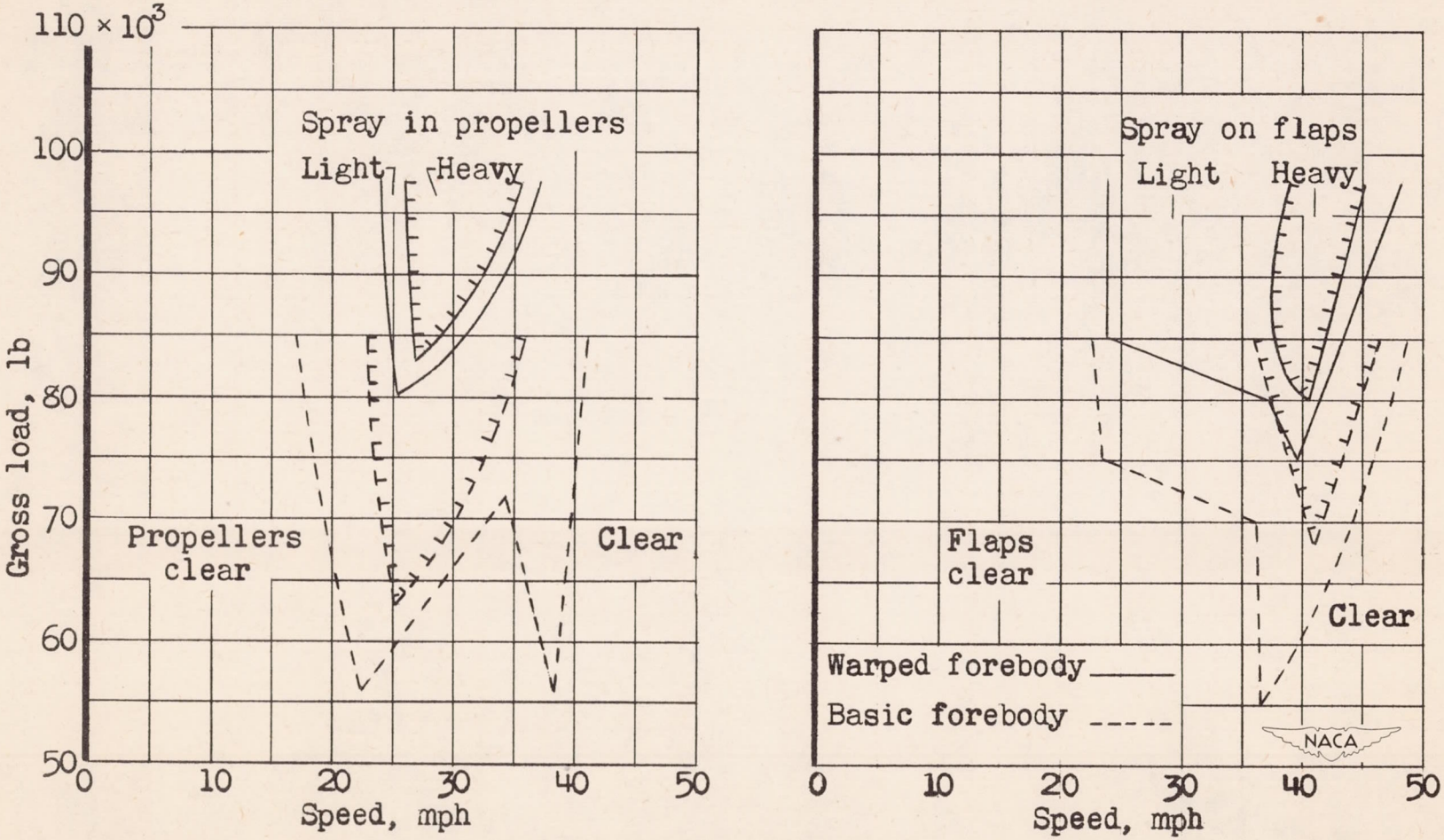
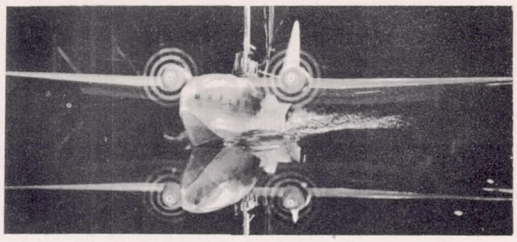
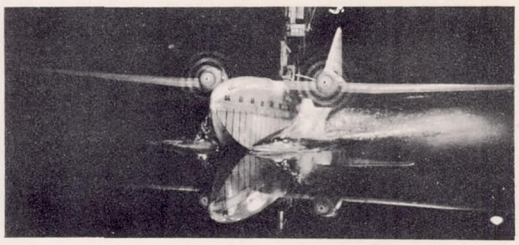


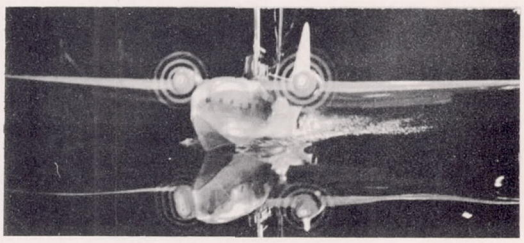
Figure 12.- Variation of range of speed for spray in propellers and on flaps with gross load.



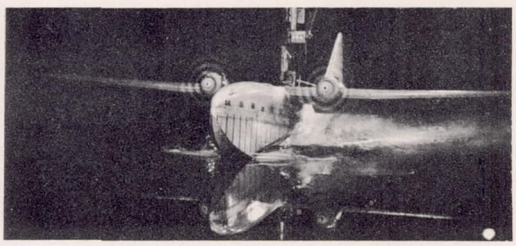
$\tau = 4.2^\circ$ V = 23.7 mph



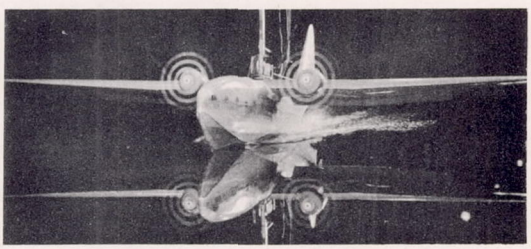
$\tau = 6.0^\circ$



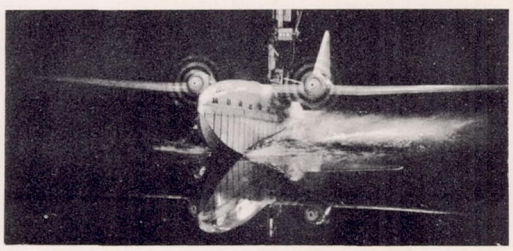
$\tau = 4.3^\circ$ V = 25.9 mph



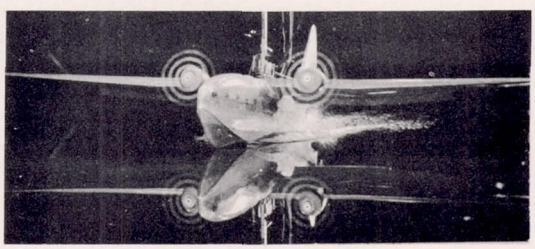
$\tau = 6.1^\circ$



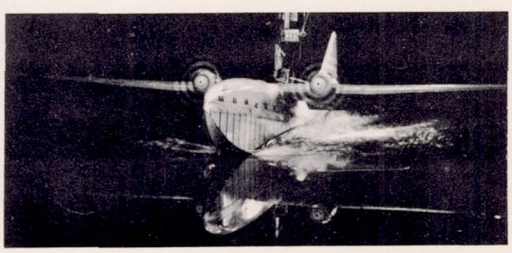
$\tau = 4.7^\circ$ V = 30.2 mph



$\tau = 6.4^\circ$



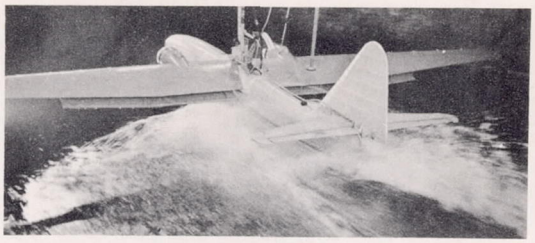
$\tau = 5.1^\circ$ V = 32.3 mph



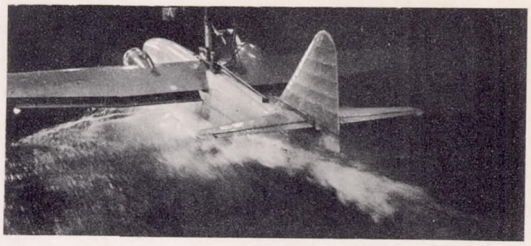
$\tau = 6.7^\circ$

(a) Warped forebody. (b) Basic forebody.

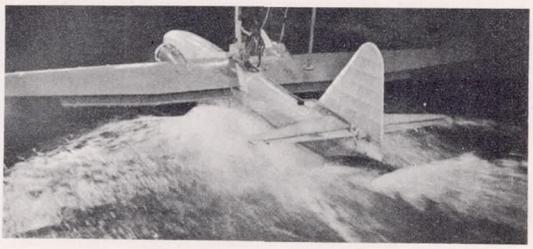
Figure 13.– Spray in propellers during take–off.



$\tau = 8.7^\circ$ V = 38.8 mph



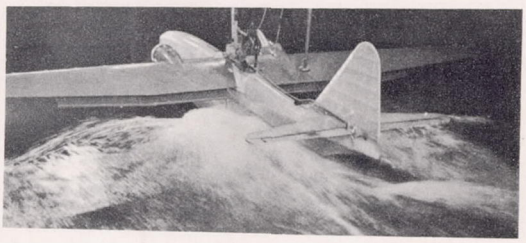
$\tau = 8.7^\circ$



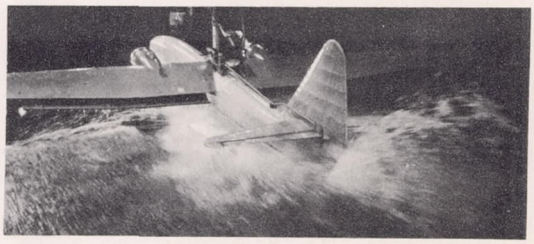
$\tau = 9.5^\circ$ V = 41.0 mph



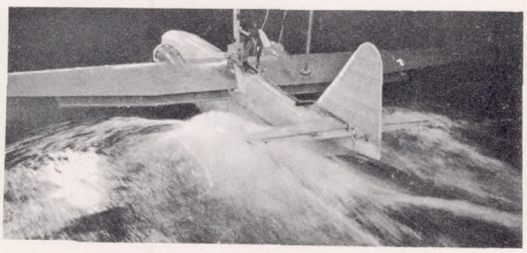
$\tau = 9.4^\circ$



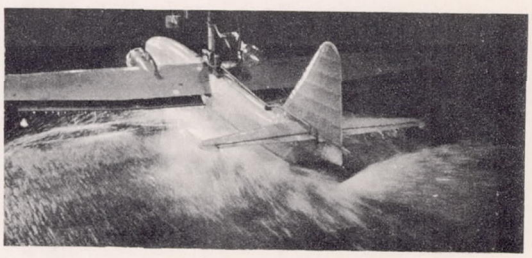
$\tau = 9.7^\circ$ V = 43.1 mph



$\tau = 9.9^\circ$



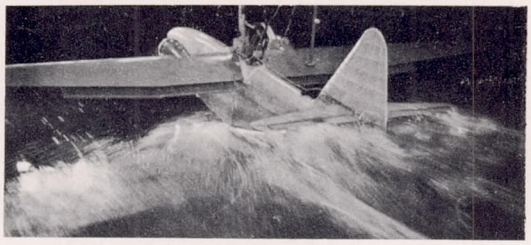
$\tau = 9.5^\circ$ V = 45.3 mph



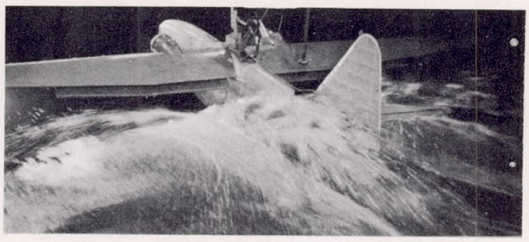
$\tau = 10.5^\circ$

(a) Warped forebody. (b) Basic forebody.

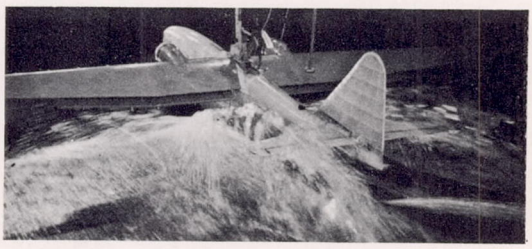
Figure 14.– Spray on flaps during take–off.



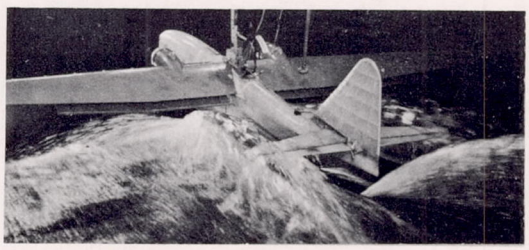
$\tau = 9.1^{\circ}$ V = 64.7 mph $\tau = 10.5^{\circ}$



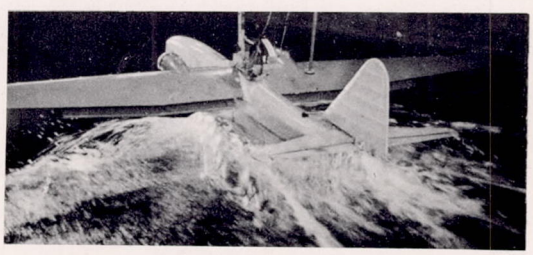
$\tau = 10.9^{\circ}$ V = 53.9 mph $\tau = 11.9^{\circ}$



$\tau = 12.0^{\circ}$ V = 47.4 mph $\tau = 12.5^{\circ}$



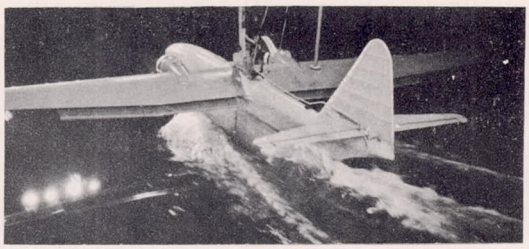
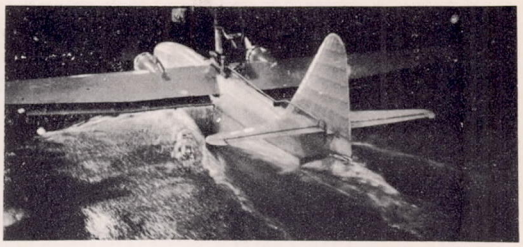
$\tau = 12.4^{\circ}$ V = 43.1 mph $\tau = 12.4^{\circ}$



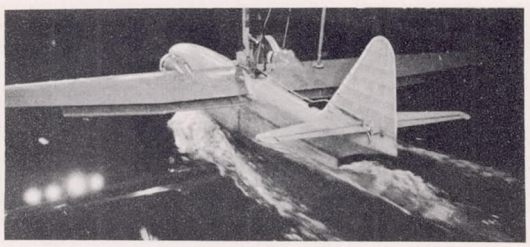
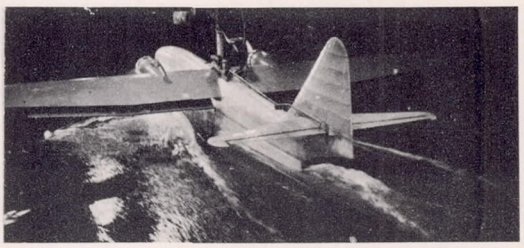
$\tau = 11.3^{\circ}$ V = 38.8 mph $\tau = 11.8^{\circ}$

(a) Warped forebody. (b) Basic forebody.

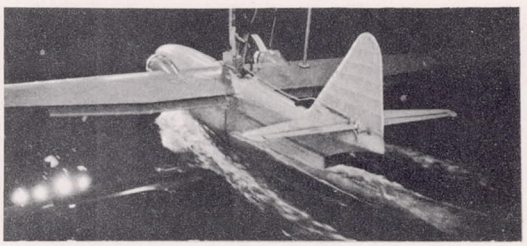
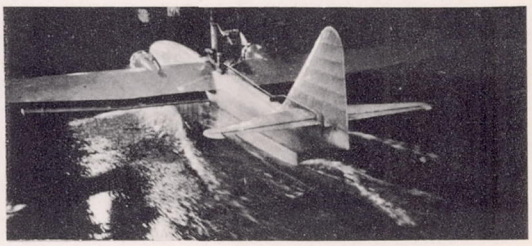
Figure 15.– Spray on tail surfaces during landing.

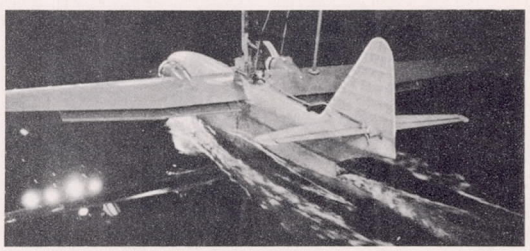
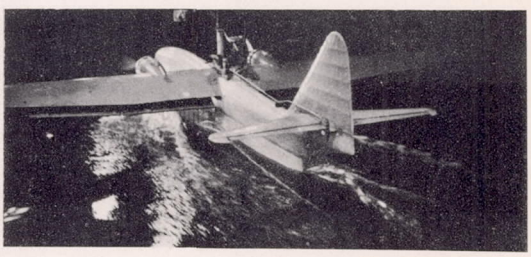
$\tau = 7.8^\circ$ V = 34.5 mph $\tau = 9.0^\circ$

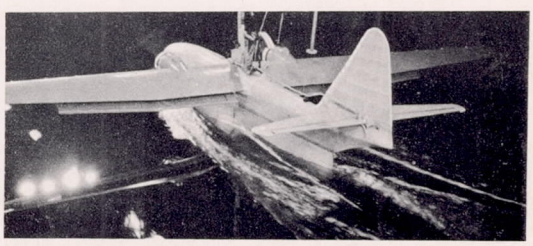
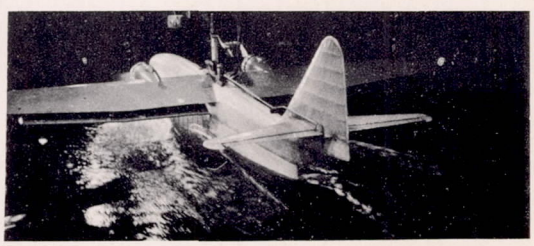
$\tau = 7.2^\circ$ V = 32.3 mph $\tau = 8.7^\circ$

$\tau = 6.7^\circ$ V = 30.2 mph $\tau = 8.2^\circ$

$\tau = 6.3^\circ$ V = 28.0 mph $\tau = 7.7^\circ$

$\tau = 6.2^\circ$ V = 25.9 mph $\tau = 7.6^\circ$

(a) Warped forebody. (b) Basic forebody.

Figure 15.– Concluded.

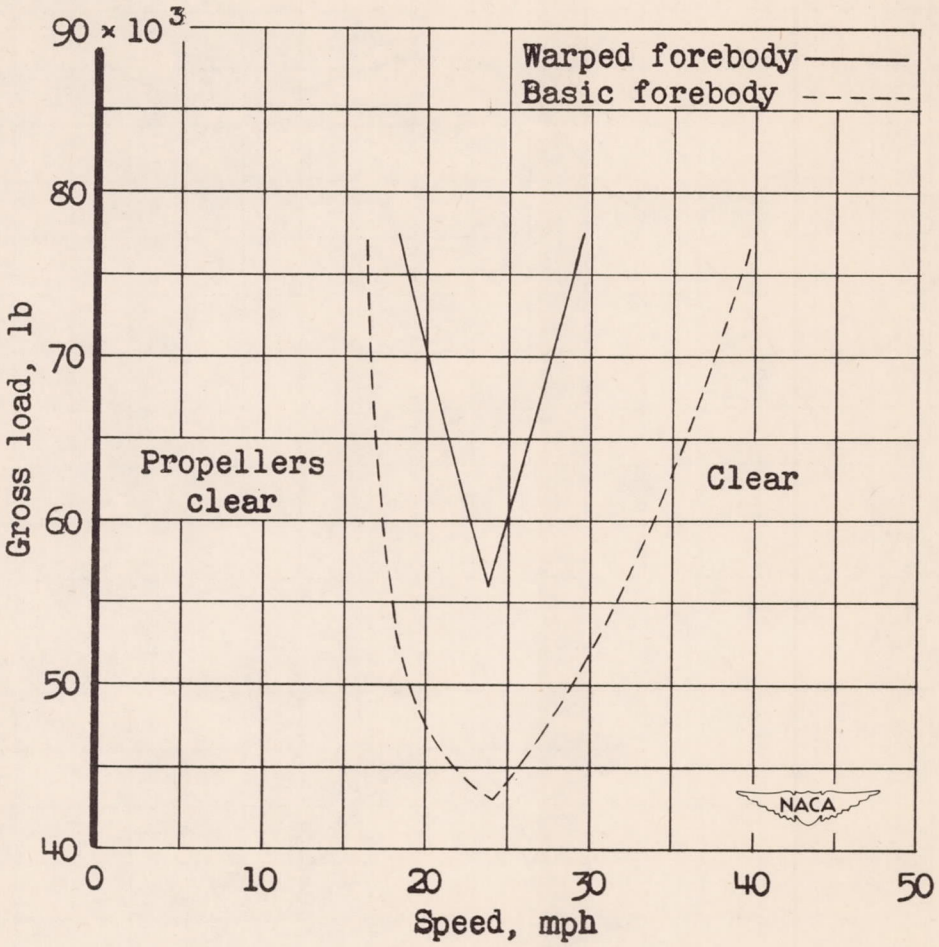


Figure 16.- Variation of range of speed for spray in propellers with gross load in oncoming waves. Waves 2 feet high and 110 feet long.

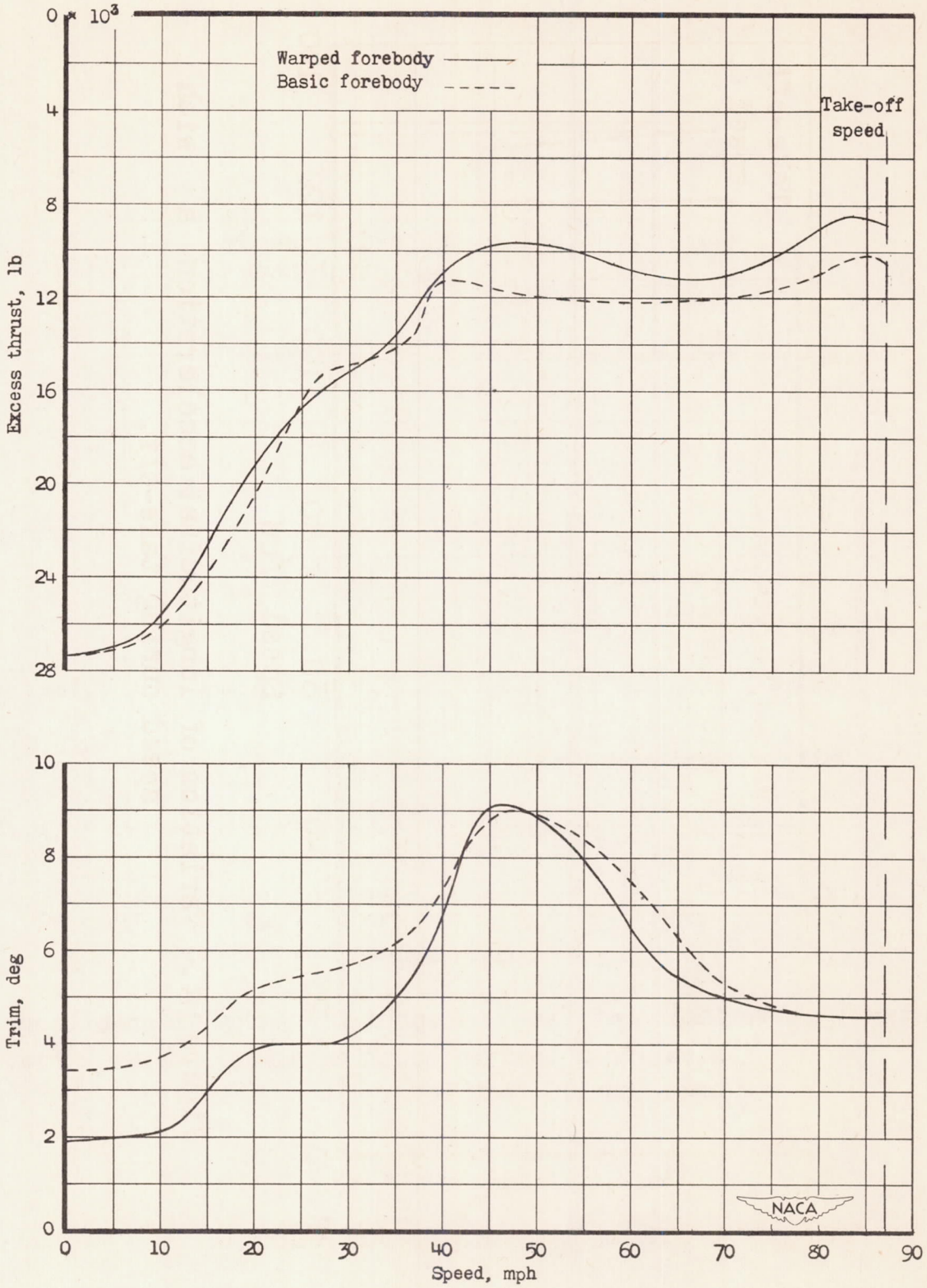


Figure 17.- Variation of excess thrust and trim with speed during take-off.

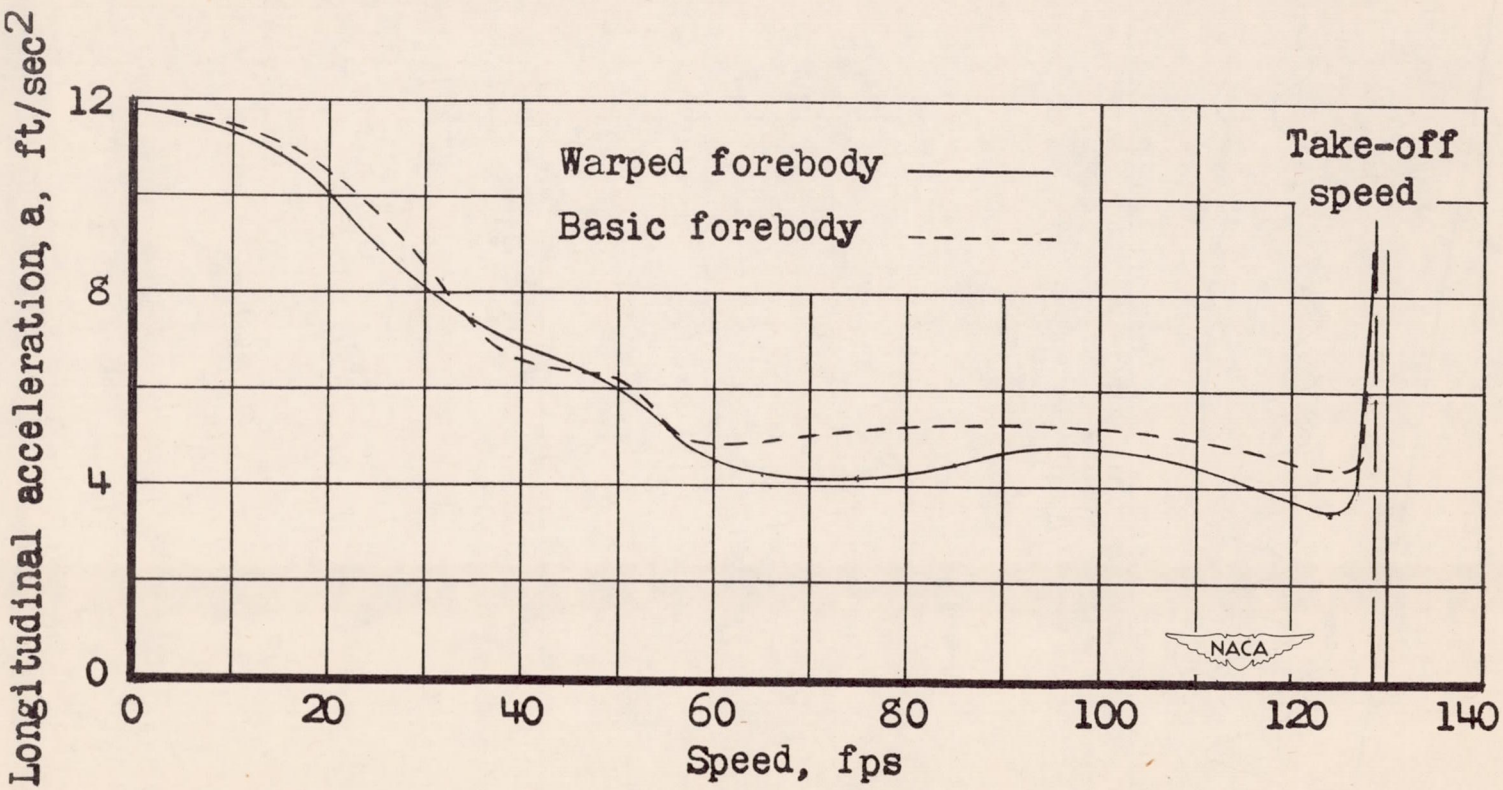
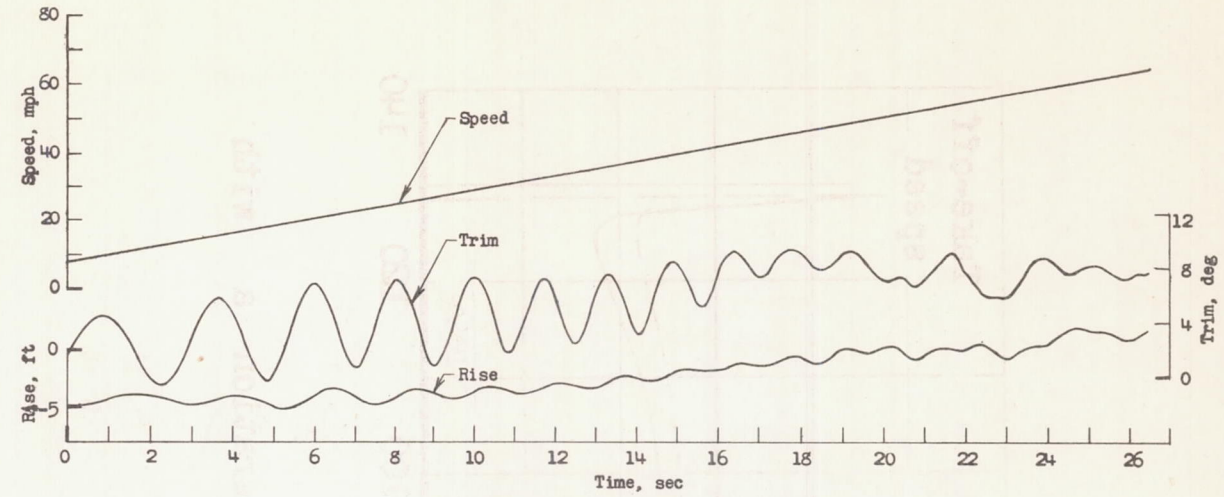
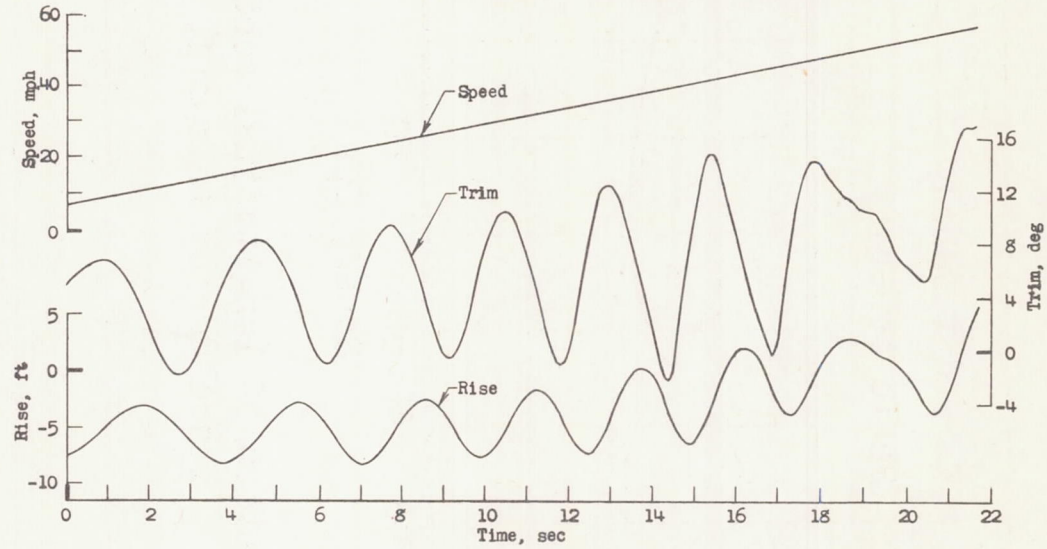


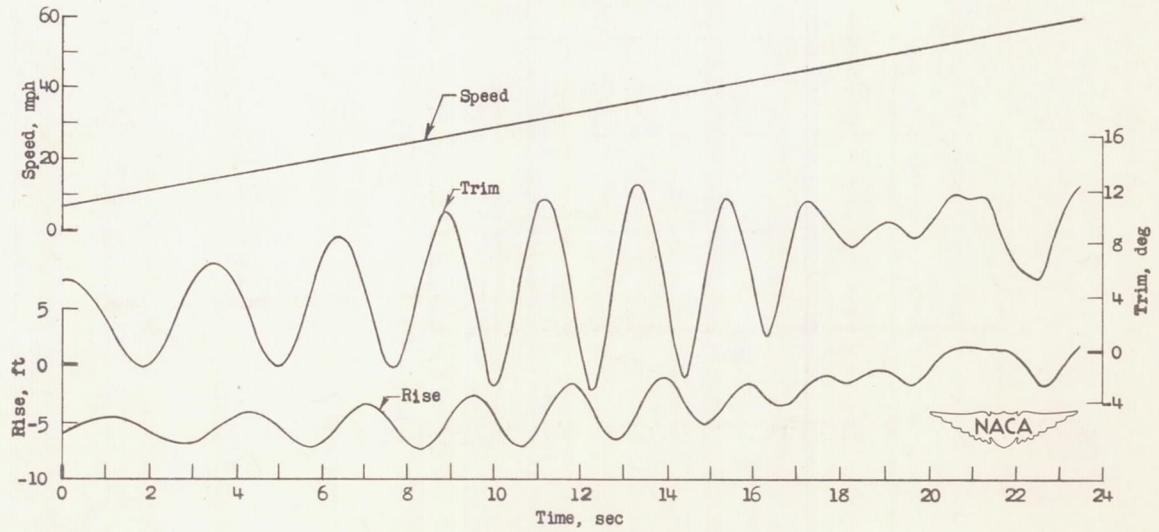
Figure 18.- Variation of longitudinal acceleration a with speed during take-off.



(a) Waves 2 feet high and 110 feet long.

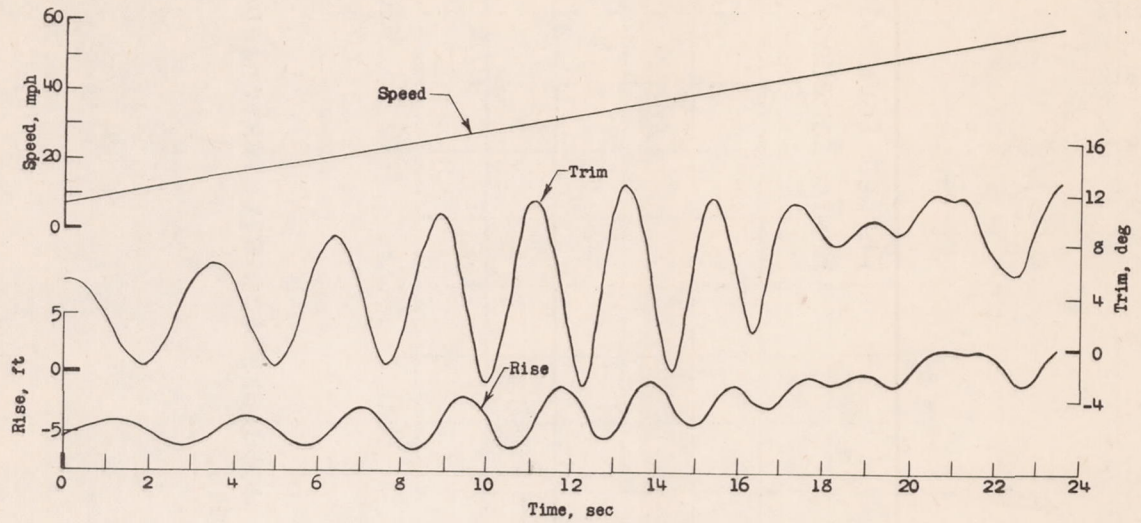


(b) Waves 4 feet high and 200 feet long.

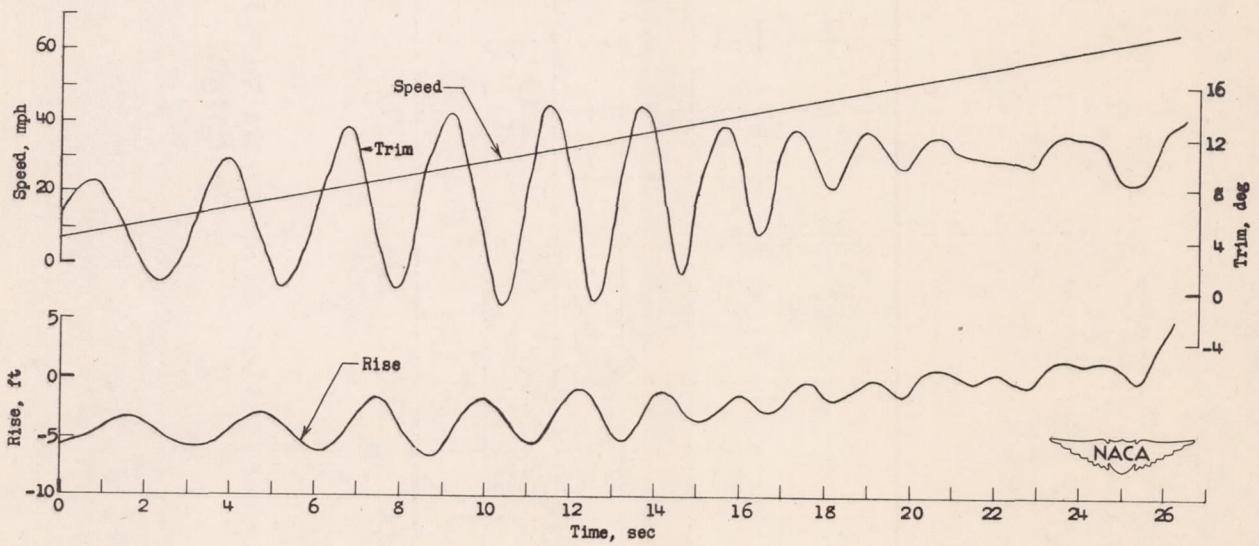


(c) Waves 4 feet high and 150 feet long.

Figure 19.- Tracings of typical records made during take-offs in waves.



(a) Warped forebody.



(b) Basic forebody.

Figure 20.- Tracings of typical records made during take-offs in waves 4 feet high and 150 feet long. Length-beam ratio, 15.

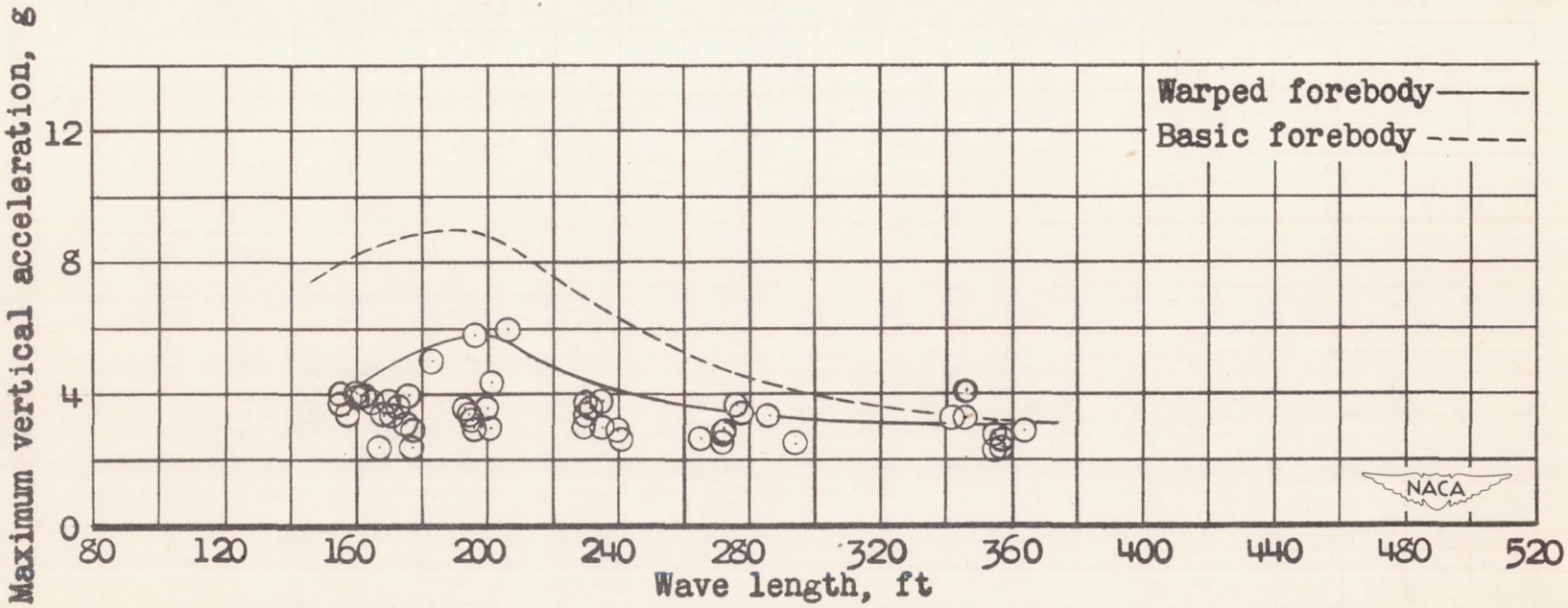


Figure 21.- Variation of maximum vertical acceleration with wave length. Wave height, 4 feet.

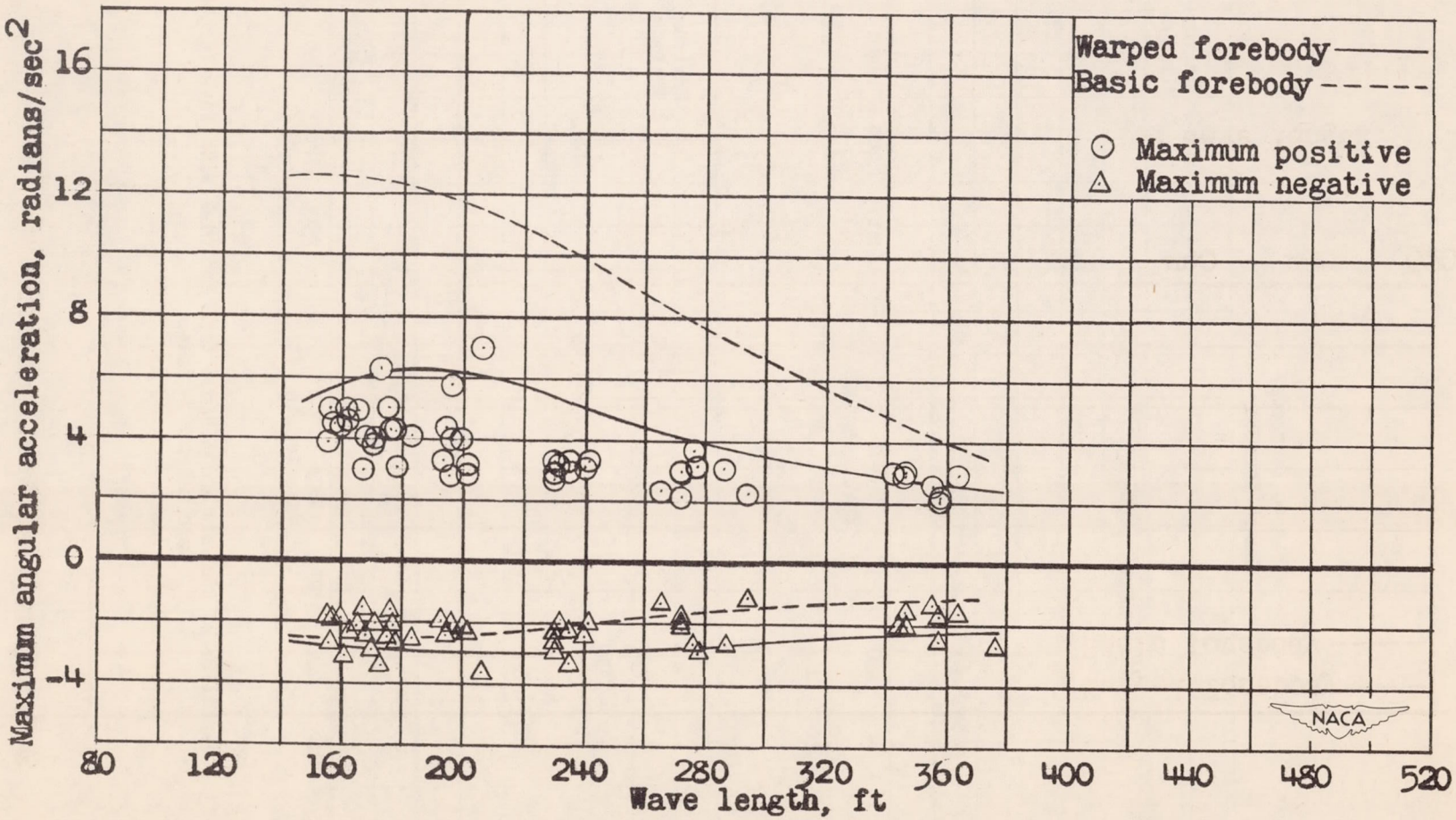


Figure 22.- Variation of maximum angular acceleration with wave length. Wave height, 4 feet.

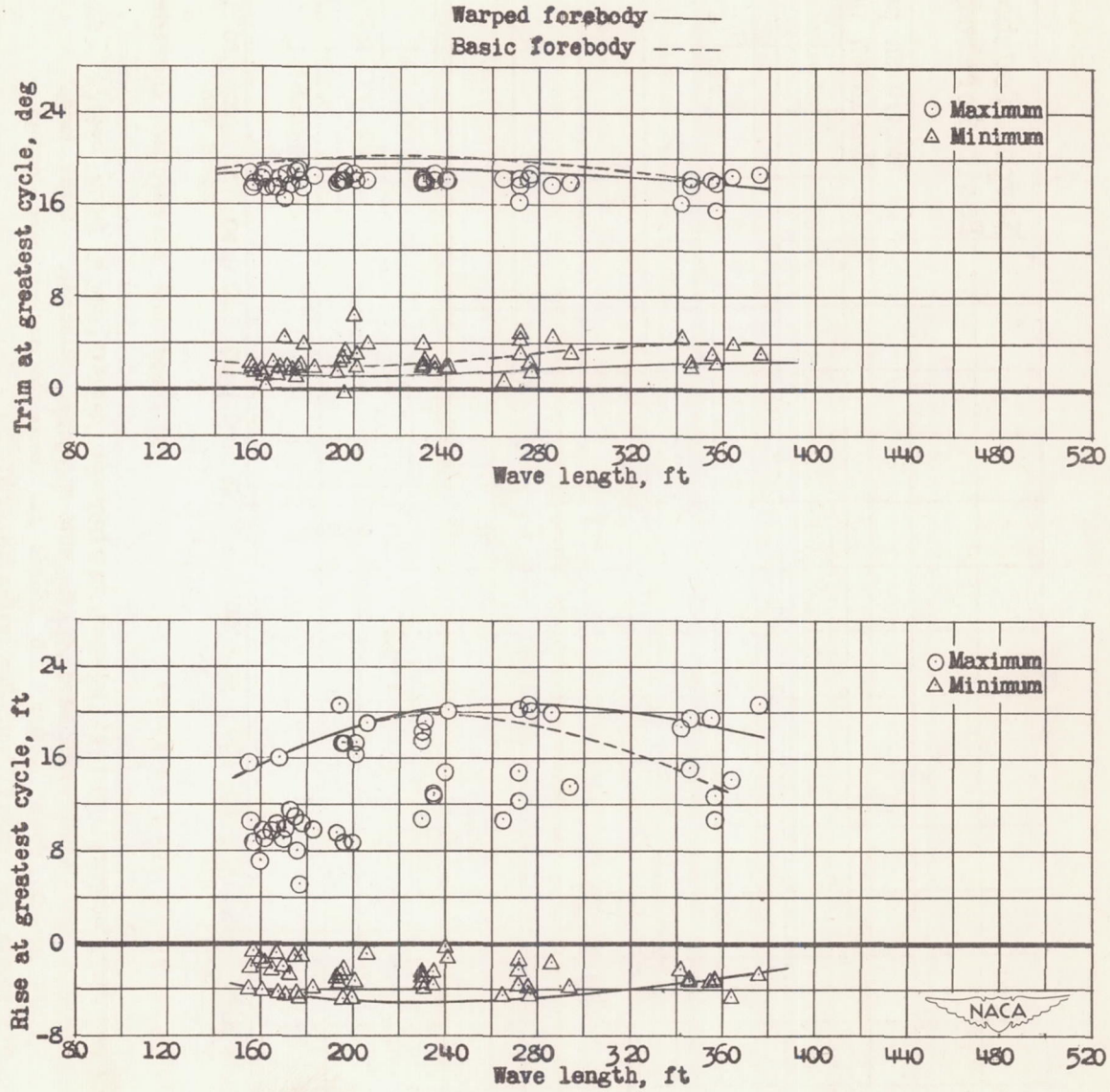
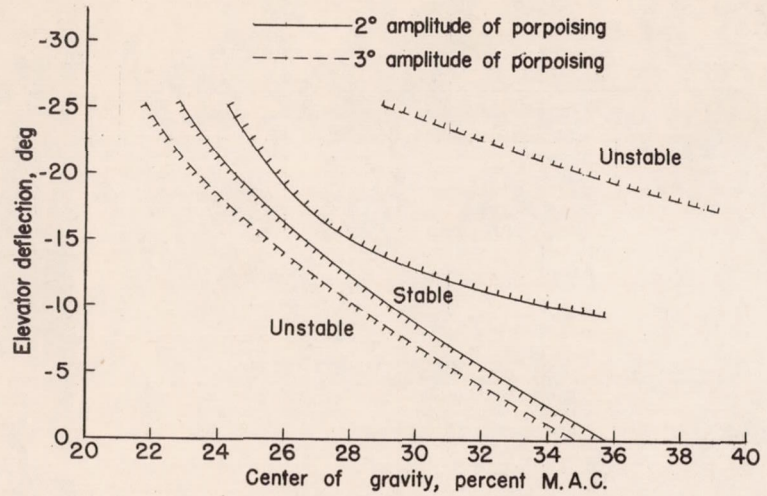
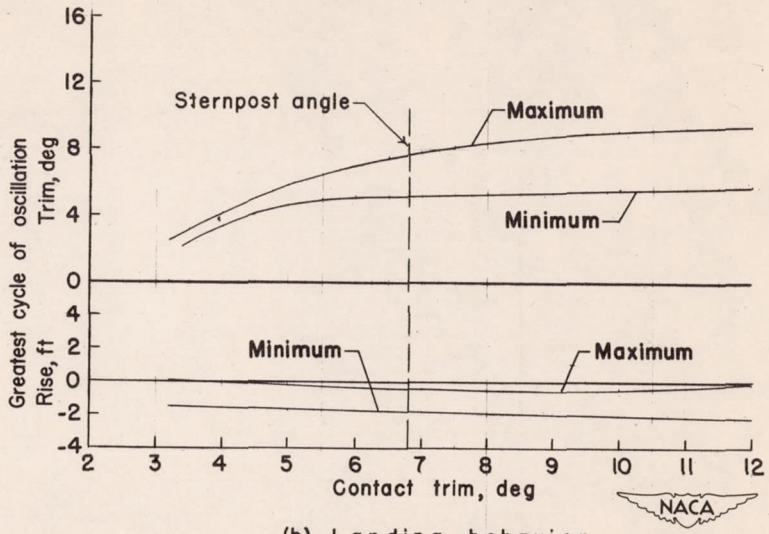


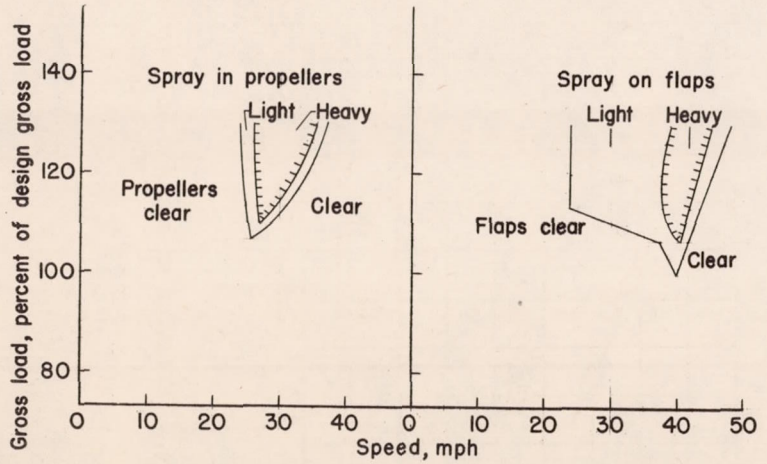
Figure 23.- Variation of maximum and minimum trim and rise with wave length. Wave height, 4 feet.



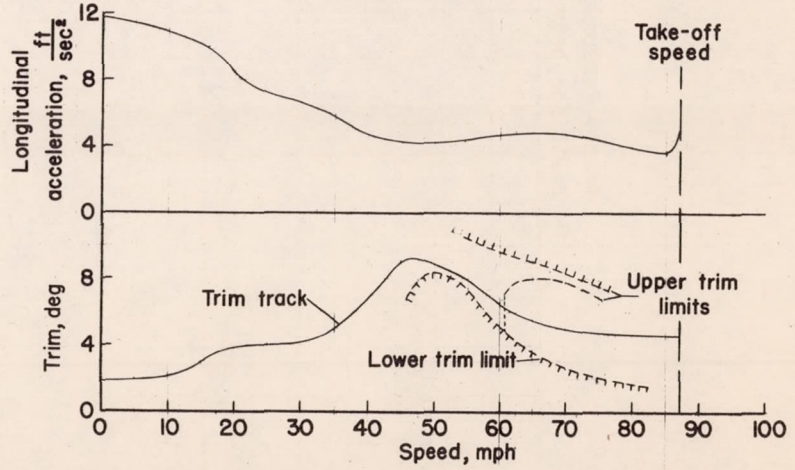
(a) Stable take-off range.



(b) Landing behavior.



(c) Effect of gross load on spray.



(d) Longitudinal acceleration and trim track.

Figure 24.— Summary chart of principal hydrodynamic qualities of a flying boat having a hull length-beam ratio of 15 with a warped forebody. Gross load, 75,000 pounds; power loading, 11.5 pounds per brake horsepower; wing loading, 41.1 pounds per square foot; flap deflection, 20°.