NACA RM L9L21a

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RESEARCH MEMORANDUM

HYDRODYNAMIC FORCE CHARACTERISTICS OF A STREAMLINE FUSELAGE MODIFIED BY EITHER BREAKER STRIPS OR ROWS OF AIR JETS SIMULATING CHINES

By Bernard Weinflash, Charles L. Shuford, Jr., and Kenneth W. Christopher

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

February 21, 1950

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SUMMARY

Force tests were made to determine the effect of trim on the resistance, hydrodynamic lift, and hydrodynamic moment of a streamline fuselage modified by either strips or rows of air jets simulating chines. Tests were also made of the model modified by the strips for three load-on-the-water conditions and for the model with the longitudinal curvature of the after half of the fuselage bottom eliminated.

An increase in trim above the zero-moment trim of the model modified by chine strips resulted in lower resistance and greater hydrodynamic lift. Resistances close to a minimum would have been obtained by moving the center of gravity aft about 25 percent of the length of the fuselage.

Elimination of the longitudinal curvature of the aft end of the fuselage bottom had a detrimental effect on the trim, resistance, and hydrodynamic lift of the model with chine strips. An increase in the load on the water for the model with chine strips resulted in higher trims, hydrodynamic lifts, and load-resistance ratios.

INTRODUCTION

When a body having a circular or oval cross section moves along the surface of the water at high speeds, the flow of water up around the convex surface creates a suction force which keeps the body deeply immersed. As a result, such a body has very poor hydrodynamic characteristics.

Model experiments in Langley tank no. 2 (reference 1) have shown that the resistance, hydrodynamic lift, and trim characteristics of a typical streamline fuselage can be greatly improved by the use of suitably located rows of small air jets. In further experiments with this model (reference 2), the results obtained with narrow breaker strips simulating chines were the same as those obtained with rows of air jets in the same location. A large number of configurations were tested without applied moments in these investigations.

In the present investigation, trimming moments were applied to determine the effect of trim on the hydrodynamic characteristics of the model with chines simulated by breaker strips or rows of jets. Additional data were obtained for the chine-strip configuration at double and half the assumed normal loads. Tests were also made with the model modified to eliminate the longitudinal curvature of the after half of the fuselage bottom.

DESCRIPTION OF MODEL

The model (fig. 1) was the same streamline fuselage described in reference 1. As shown in figure 2, the length of the model was 42.22 inches and the maximum diameter was 5 inches. The center of gravity was located 21.22 inches from the nose and 0.43 inch below the center line and corresponds to a normal position for a transonic airplane.

Stainless-steel tubes having 0.026-inch inside diameter and spaced 1/4 inch apart were inserted into the bottom of the model normal to the surface in two rows simulating chines. There were 129 jets in each row. The basic model was also modified by 1/16 inch wide strips of triangular cross section in the same location as the rows of jets. Details of the jets and strips are shown in figure 3.

In addition, the model with chine strips was modified to eliminate the longitudinal curvature of the after half of the fuselage bottom (fig. 4). This was done by extending the transverse sections downward so that the after half of the lower profile line became a straight line parallel to the center line.

APPARATUS AND PROCEDURE

Tests were conducted on the small model towing gear in Langley tank no. 2 (fig. 1). The dashpot was used to damp out oscillations in trim. Air was supplied to the jets by means of a flexible hose leading into the air-tight model. Details of the trimming-moment applicator are shown in figure 5. The model was supported at its center of gravity and was towed free to trim and rise. It was statically balanced around the pivot at the center of gravity with the air hose and the moment applicator attached.

Measurements were taken of trim, resistance, and rise at constant speeds up to 60 feet per second for a range of applied trimming moments. Bow-up moments are positive. Because of the excessively high forces encountered, the basic model could not be tested above 22 feet per second. Trim was measured as the angle of the center line of the model with the horizontal. The resistance includes the air drag of the model and was obtained by subtracting the drag of the towing gear from the total resistance measured. The rise measurements were used to obtain the "effective hydrodynamic lift." This lift was calculated by subtracting from the load on the water the static buoyancy corresponding to the immersed volume of the model at the trim and rise measured at each speed.

The load on the water was varied with speed assuming a wing with a constant aerodynamic lift coefficient. No data are presented between 60 feet per second and the assumed take-off speed of 70 feet per second, because at these speeds practically all of the model was out of the water and slight variations in wetted surface caused the readings to become erratic.

Tests were made for a range of trim at each speed on the basic model, the model modified by jets, and the model modified by strips. The air flow for each run with the jet configuration was chosen as 0.025 pound per second in accordance with figure 12 of reference 2.

The model modified by chine strips was also tested for double and half the loads on the normal assumed loading curve. In these tests, the model was run at a fixed trim of 14° and free to trim with zero moment.

In addition, tests were made of the chine-strip model modified to eliminate the longitudinal curvature of the after half of the fuselage bottom. These tests were conducted for the model in a free-to-trim condition with zero moment.

RESULTS AND DISCUSSION

Comparison of Basic and Modified Models

The variation of resistance, effective hydrodynamic lift, and hydrodynamic trimming moment with trim are compared in figure 6 for the basic model, the model modified by strips, and the model modified by jets. The effect of the breaker strips and the rows of jets on these hydrodynamic characteristics was similar.

The strips or jets did not affect the hydrodynamic characteristics of the basic model until a speed of about 12 feet per second. Above 12 feet per second, the model modified by jets or strips showed better lift and resistance characteristics than the basic model; this improvement increased rapidly with speed.

The moment curves for the basic model and the model modified by jets or strips were about the same up to a speed of about 12 feet per second. Above 17 feet per second the moments for the basic model were much more positive than for the modified model. The slopes of the moment curves for the modified model were stable at all speeds. At high speeds, the slopes generally decreased at the higher trims.

Because of the general similarity of the characteristics with strips or jets, the succeeding discussion is based entirely on cross plots against speed of the results obtained with the strips.

Characteristics at Trim for Minimum Resistance

The hydrodynamic characteristics of the model at best trim are compared with those for the zero-moment condition in figure 7. Best trim is the trim at any given speed for which the resistance was a minimum. At some speeds the resistance remained a minimum for trims up to 4° higher than those shown.

To achieve minimum resistance the trim would have to be increased to values as high as 14°. The resistance curve at best trim varied little with speed and had a maximum value of 2.0 pounds. The resistance with zero moment gradually increased with speed until it reached a maximum of 4.0 pounds.

In this investigation, the load on the water was assumed to be the same at all trims. With an acutal wing, the load on the water would be greater at the lower trims than at the higher trims. Therefore, the reduction in hydrodynamic resistance at best trim would have been greater than that shown in figure 7.

The effective hydrodynamic lift at best trim was much higher than that for zero moment. At best trim it was practically equal to the load on the water at speeds from about 40 feet per second up. For zero moment the hydrodynamic lift never equaled the load on the water. The hydrodynamic moments at best trim were large, reaching a maximum of 7.4 pound-feet, bow down.

Characteristics at Constant Trim

Cross plots at constant trims varying from 5° to 16° are given in figure 8. Resistances close to a minimum were obtained for 10°, 13°, and 16° trims. Below 14 feet per second the resistance increased with trim. Above this speed, the resistance decreased with increasing trim up to 10° because the frictional portion of the resistance decreased faster than the remaining portion increased. At higher trims, the resistance did not vary much with further increase in trim.

The maximum hydrodynamic moment for a fixed trim of 10°, for which resistances were generally close to a minimum, was 5.0 pound-feet as compared with 7.4 pound-feet at best trim. The improvement in planing characteristics with increase in trim is shown by the hydrodynamic lift curves. The lift was equal to the load on the water for trims greater than 10° at the higher speeds.

Characteristics at Constant Trimming Moment

Cross plots at various values of trimming moment are given in figure 9. For a hydrodynamic bow-up moment of 4 pound-feet, the resistance increased with speed to 6.5 pounds with no indication of reaching a maximum. The resistances for both 4 and 8 pound-feet bow-down moment were about the same and did not exceed 2.5 pounds.

The hydrodynamic lift increased with hydrodynamic bow-down moment. For a bow-down moment of 8 pound-feet, the lift became almost equal to the total load at about 30 feet per second; for 4 pound-feet, at about 50 feet per second; and for the lower moments, it remained less than the load at all speeds tested.

Characteristics at Various Center-of-Gravity Positions

The relocation of the center of gravity to a position farther aft would have resulted in smaller moments at desirable trims. Moving the center of gravity aft is equivalent to applying a bow-up moment which is approximately equal to the product of the distance moved, the load on the water, and the cosine of the trim. The effect of moving the center of gravity 6 and 12 inches aft of its normal position is shown in figure 10.

The moment equivalent to moving the center of gravity a given distance is proportional to the load on the water; therefore, its effect would be greatest at low speeds and would diminish to zero at take-off. However, figure 10 shows that moving the center of gravity back had an appreciable effect at even the higher speeds. For this model, resistances close to a minimum would generally have been obtained by moving the center of gravity aft about 25 percent of the fuselage length which would bring it to a point about 75 percent of the fuselage length from the nose.

Spray Characteristics

The photographs in figures 11 and 12 show the effect of trim on the spray characteristics of the model. With an increase of trim, the wetted area was decreased and less spray was thrown out. This was more pronounced at 50 feet per second than at 20 feet per second.

The side views show how the narrow strips separate the water from the side of the model. The aft views show more clearly how the strips throw the spray outboard.

Effect of Longitudinal Curvature

The effect of the longitudinal curvature of the after half of the fuselage bottom on the hydrodynamic characteristics is shown in figure 13. The elimination of this fore and aft curvature had its greatest effect at the higher speeds. The trim was considerably reduced, the resistance was greatly increased, and the lift was decreased. The higher trim of the model with longitudinal curvature was evidently caused, not by positive pressures acting forward of the center of gravity, but by negative pressures acting on the after portion of the fuselage bottom.

The results of this test show that the longitudinal curvature of the after half of the fuselage bottom was an important factor in securing the results obtained with the basic model modified by chine strips. By the selection of proper curvature, desirable hydrodynamic characteristics may possibly be obtainable with little hydrodynamic moment.

Spray characteristics of the model with the longitudinal curvature eliminated are shown in figure 14 for speeds of 20, 35, and 50 feet per second.

Effect of Load

A comparison of trim, resistance, and hydrodynamic lift at double, normal, and half loads is shown in figures 15 and 16. The comparison in figure 15 is with the model free to trim with zero moment and that in figure 16 is with the model fixed in trim at 14°.

With the model free to trim, an increase in load resulted in higher trims because of the wetted area extending farther forward. This increase in trim with load was greatest at the hump speed where the additive load was large, and became smaller with increasing speed.

The resistance became higher with an increase in load for both the free-to-trim and the 14° fixed-trim conditions. For each load, there is practically no difference in resistance between these two trim conditions up to about 25 feet per second. Above 25 feet per second the resistances for the 14° fixed trim decreased with speed while those for the free-to-trim condition increased.

The effective hydrodynamic lift was approximately proportional to the load on the water for both the free-to-trim and the 14° fixed-trim condition. The lift was much greater at the 14° fixed-trim condition than the lift for corresponding loads at the free-to-trim condition. For the 14° fixed-trim condition, the lift became equal to the load at the higher speeds for all three loads; but, for the free-to-trim condition, it did not.

The effect of load on the load-resistance ratio Δ/R is shown in figure 17 for both the free-to-trim and the 14° fixed-trim condition. An increase in load resulted in larger Δ/R values for either condition. This trend is similar to that for normal hulls at planing speeds. The Δ/R for each loading condition was greatly improved by fixing the trim at 14°.

CONCLUSIONS

The results of an investigation of the hydrodynamic force characteristics of a streamline fuselage indicate the following conclusions:

1. The hydrodynamic characteristics of a streamline fuselage planing on the surface of the water were greatly improved at all trims by chines simulated by small breaker strips or rows of small air jets. The characteristics were about the same for either the strips or the jets.

2. An increase in trim above the zero-moment trim of the model modified by chine strips resulted in lower resistance and greater hydrodynamic lift.

3. Resistances close to a minimum would have been obtained by moving the center of gravity aft about 25 percent of the length of the fuselage.

4. Elimination of the longitudinal curvature of the aft end of the fuselage bottom had a detrimental effect on the trim, resistance, and hydrodynamic lift of the model with chine strips.

5. An increase in the load on the water for the model with chine strips resulted in higher trims, hydrodynamic lifts, and load-resistance ratios.

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REFERENCES

1. Weinflash, Bernard: The Effect of Air Jets Simulating Chines or Multiple Steps on the Hydrodynamic Characteristics of a Streamline Fuselage. NACA RM L8J21, 1949.

2. Weinflash, Bernard, Christopher, Kenneth W., and Shuford, Charles L., Jr.: The Effect of Air Jet and Strip Modifications on the Hydrodynamic Characteristics of the Streamline Fuselage of a Transonic Airplane. NACA RM L9D20, 1949.

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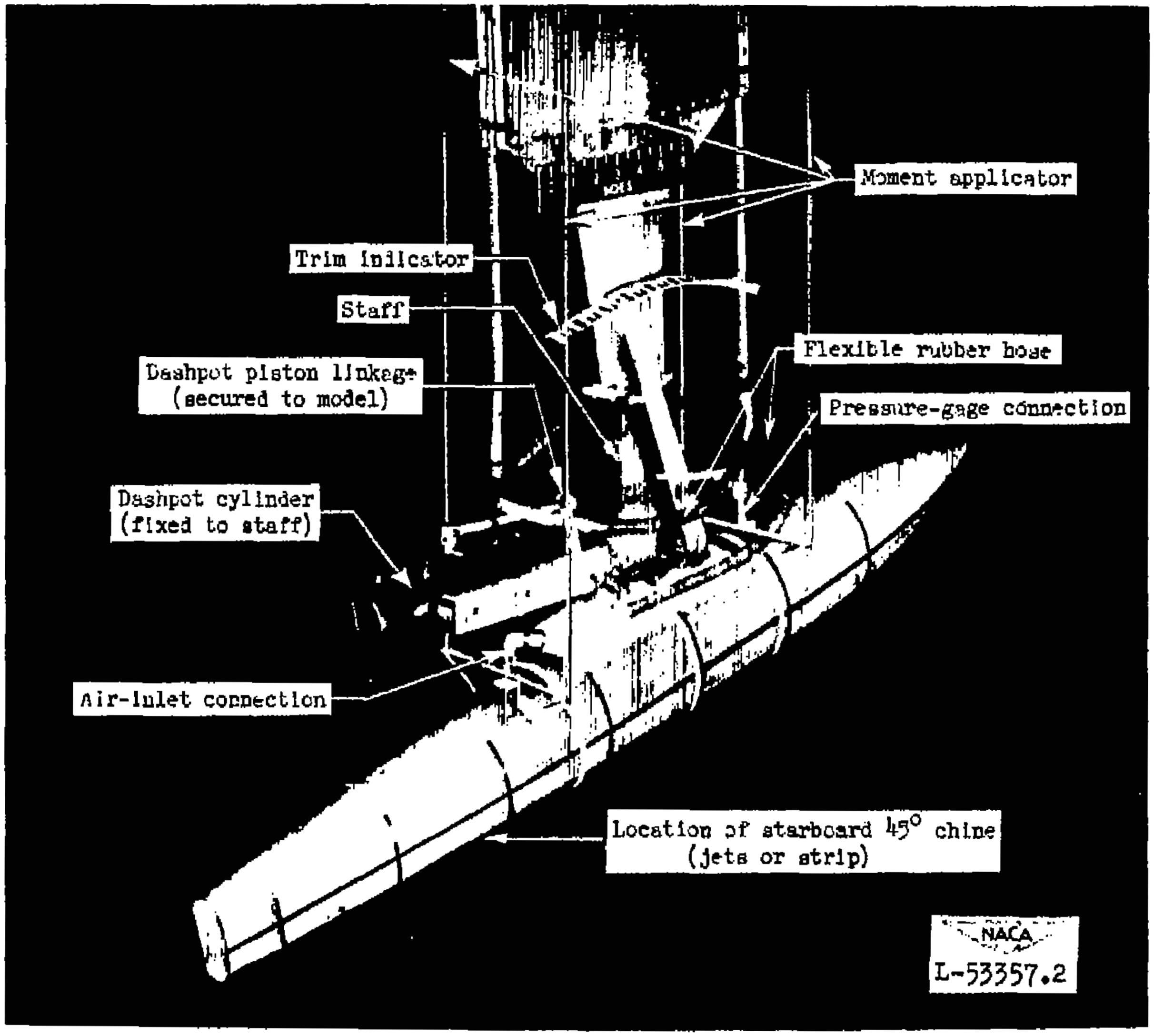

Figure 1.- Model mounted for testing.

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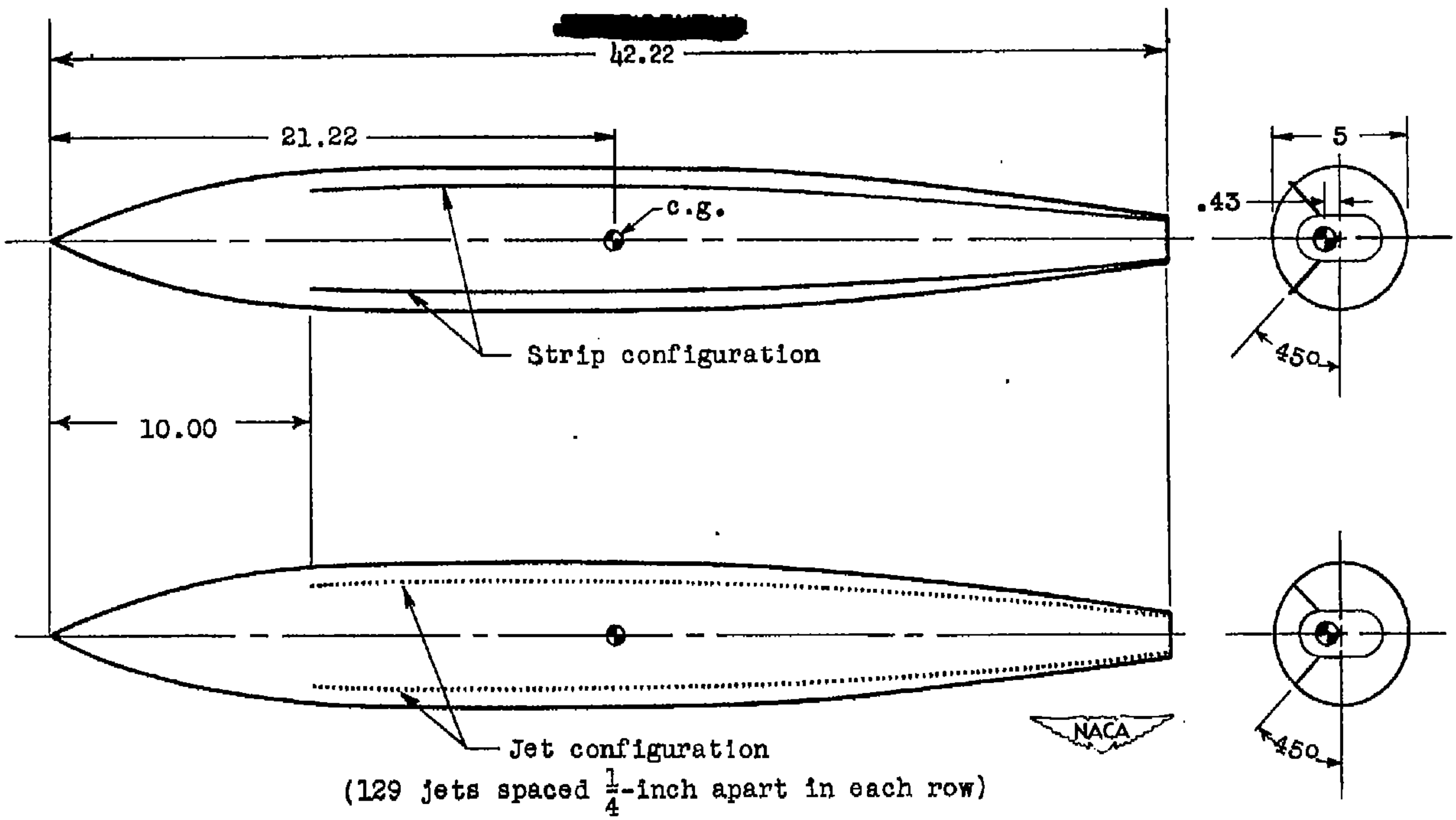

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Figure 2.- Bottom and end views of model showing simulated chine configurations. (Dimensions are in inches.)

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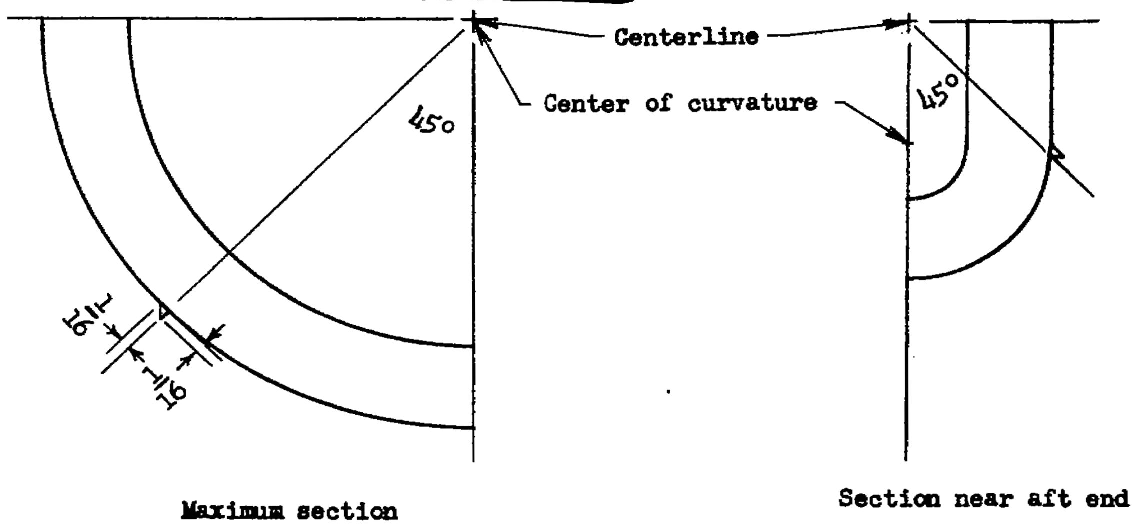
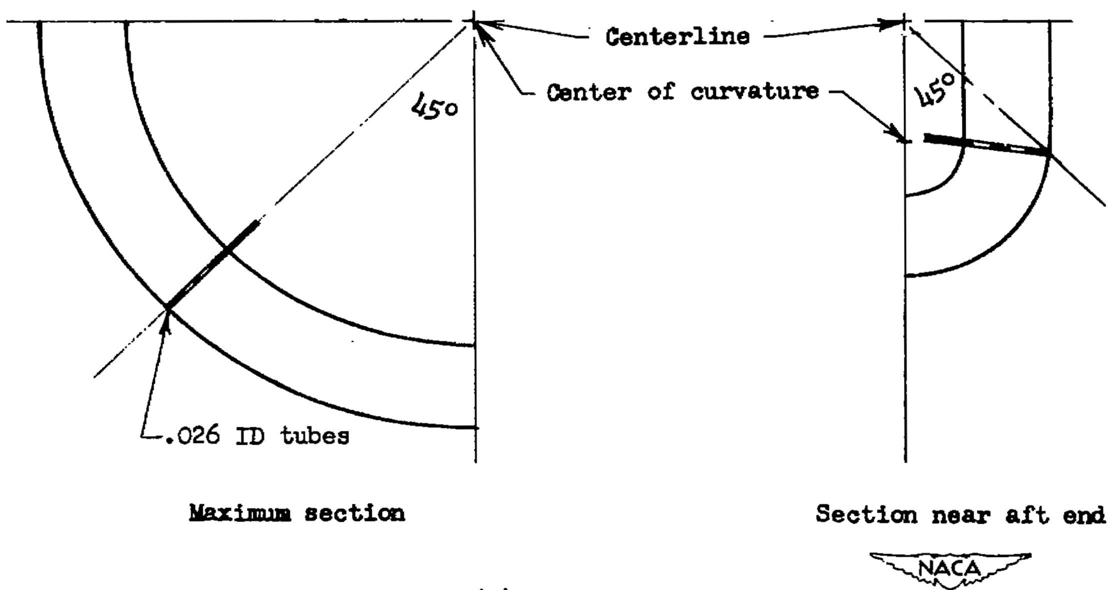


(a) Strips.



(b) Jets.

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Figure 3.- Details of strips and jets. (Dimensions are in inches.)

[redacted]

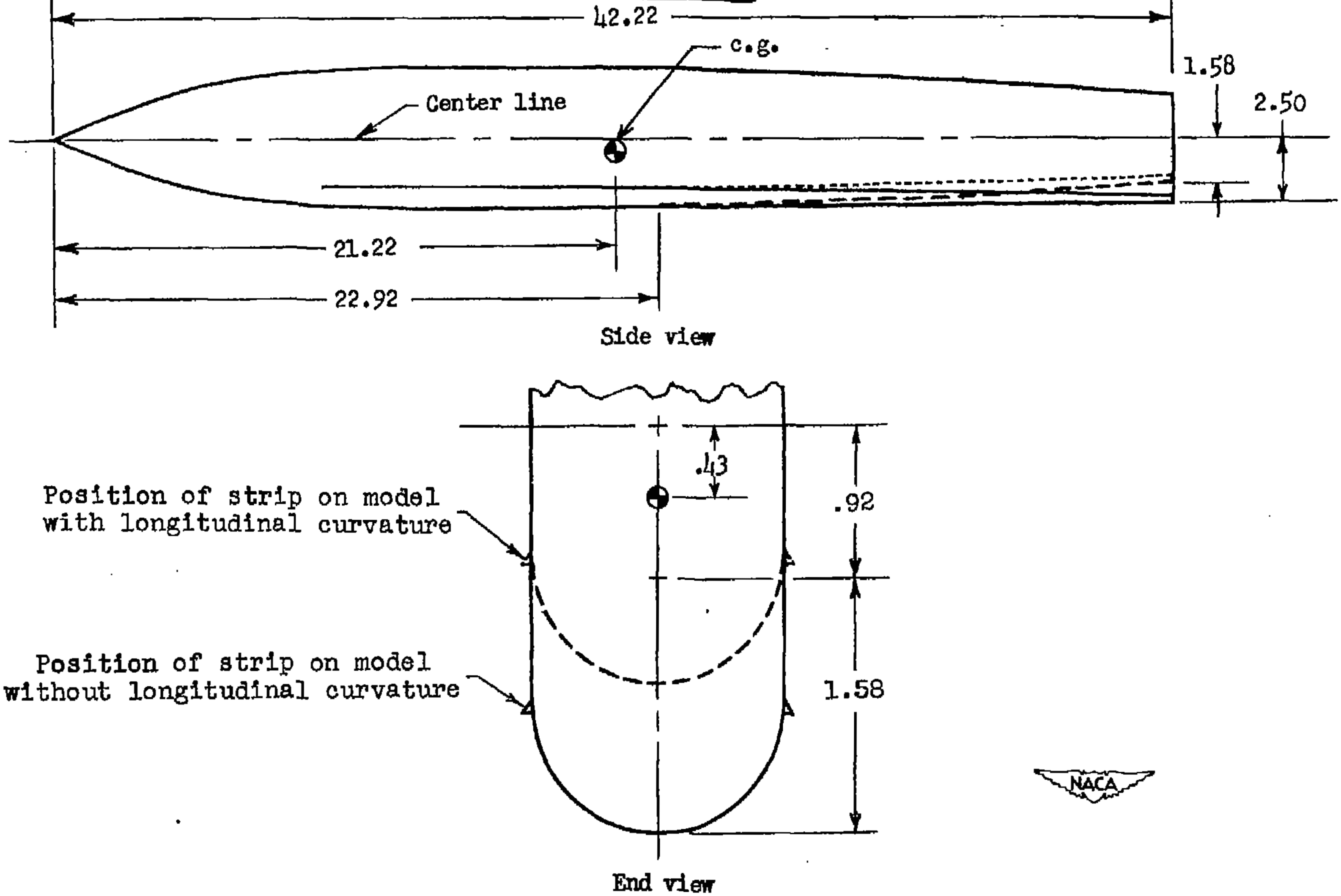

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Figure 4.- Model with longitudinal curvature eliminated at aft end. (Dimensions are in inches.)

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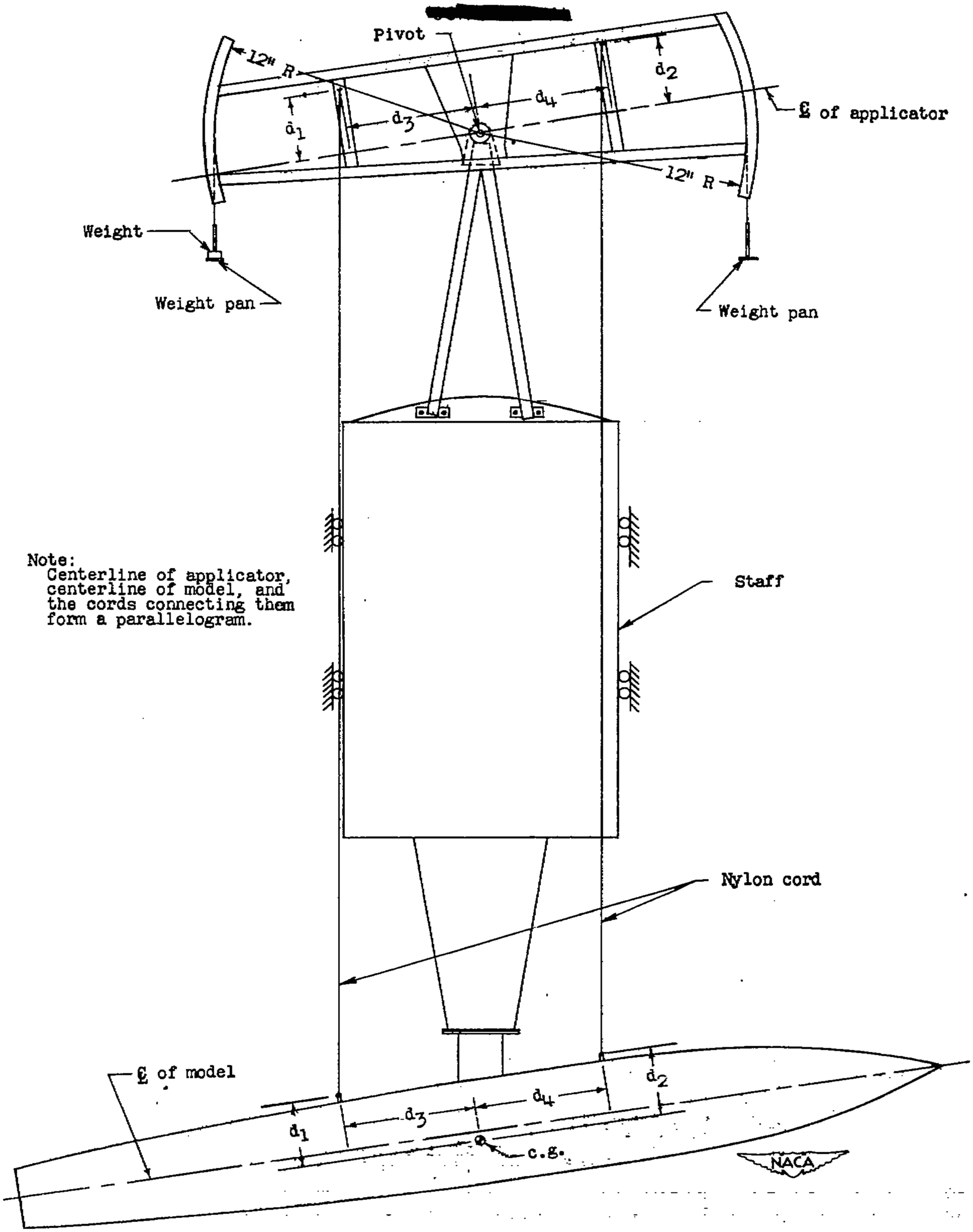

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Figure 5. - Diagrammatic sketch of moment applicator.

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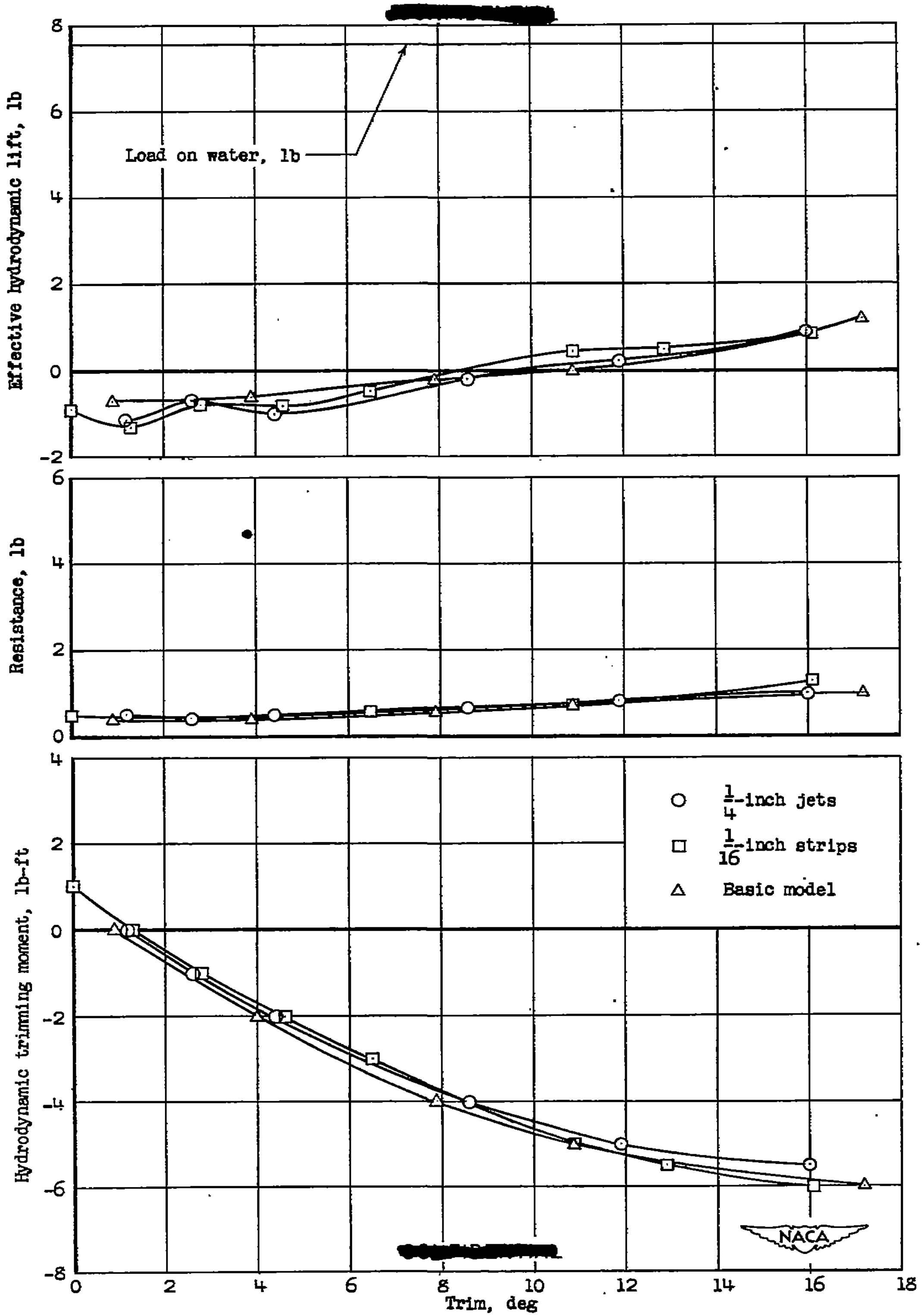

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(a) Speed, 5 feet per second.

Figure 6 .- Comparison of hydrodynamic characteristics of a streamline fuselage modified by either air jets or strips simulating chines.

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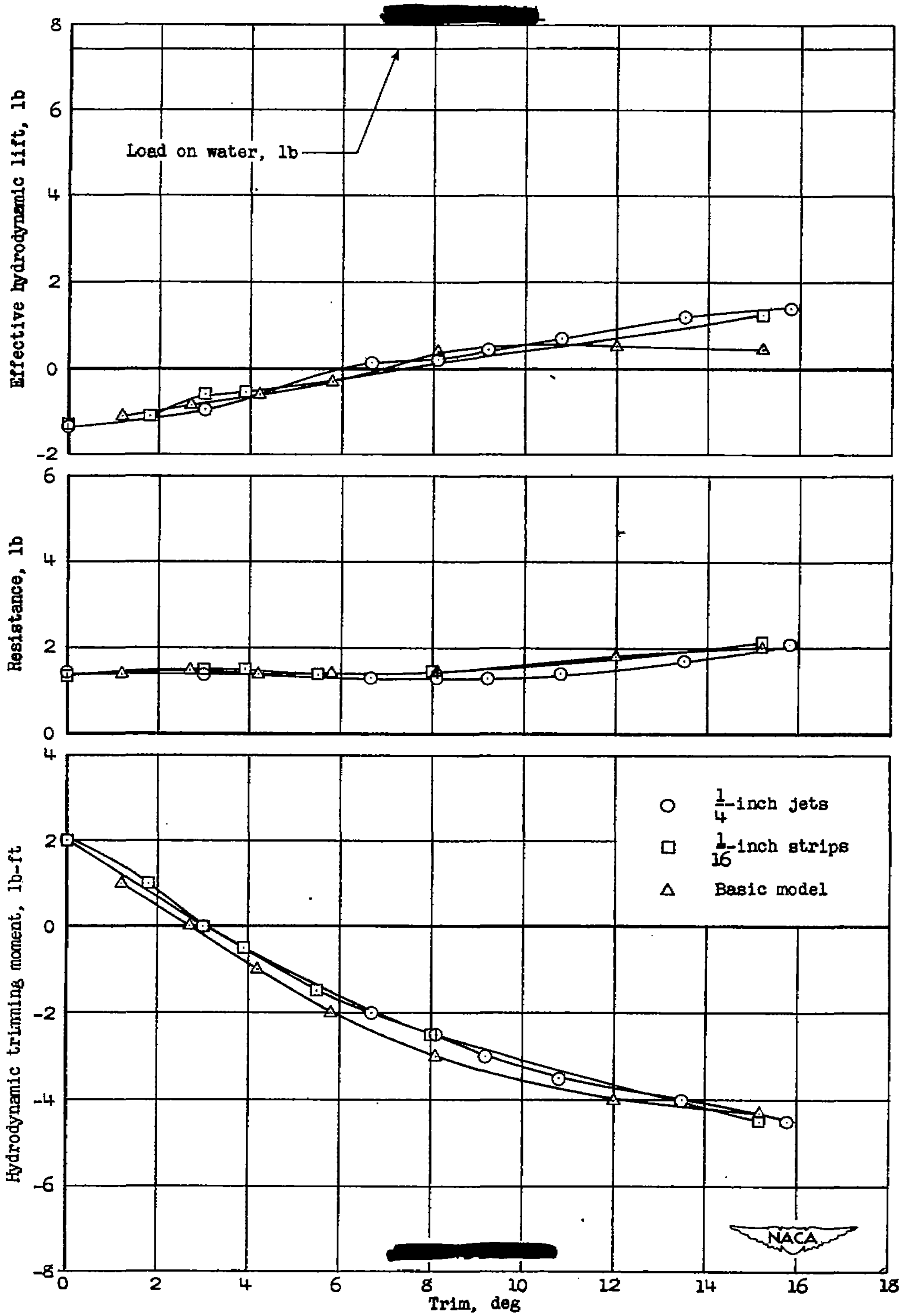

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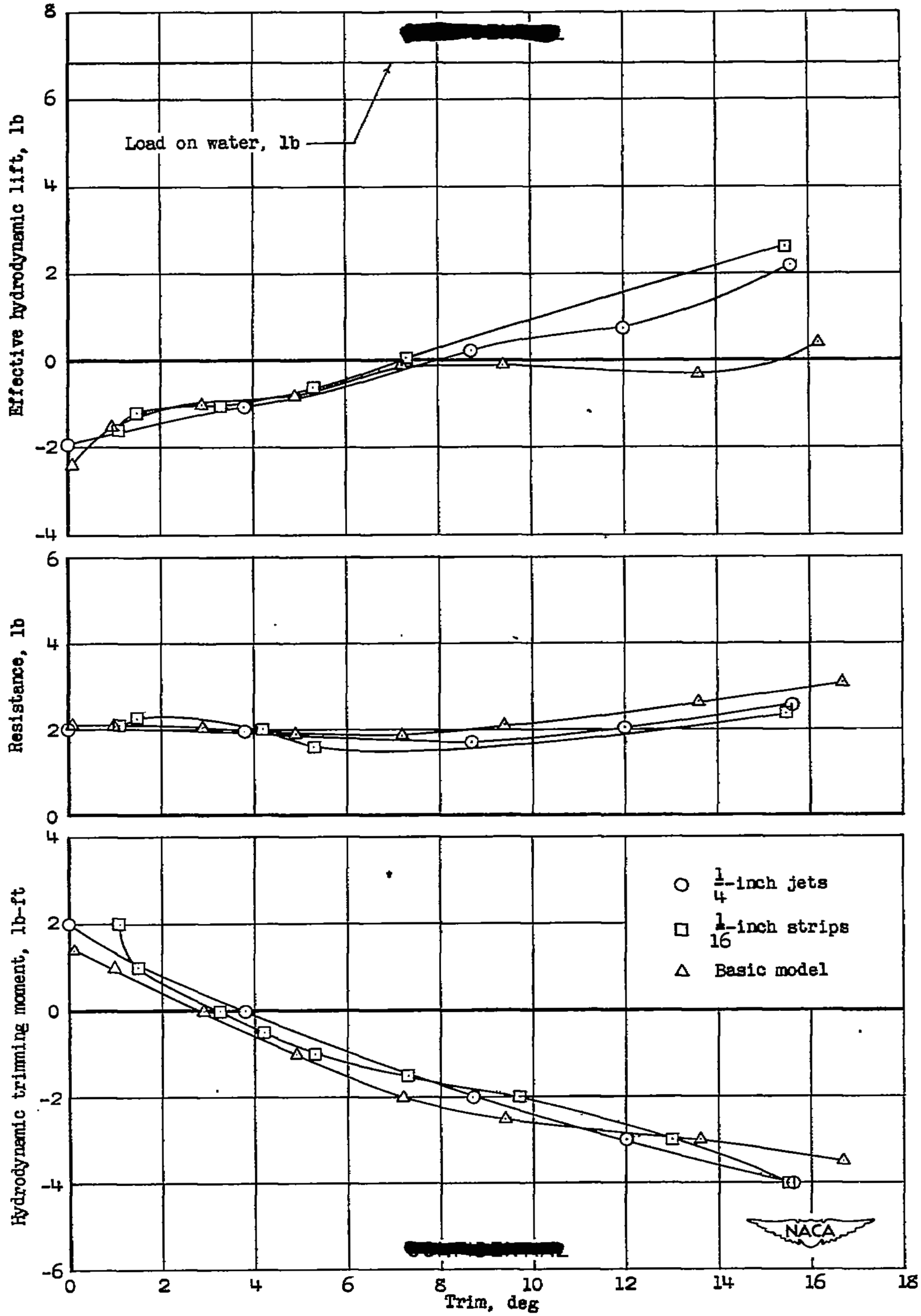
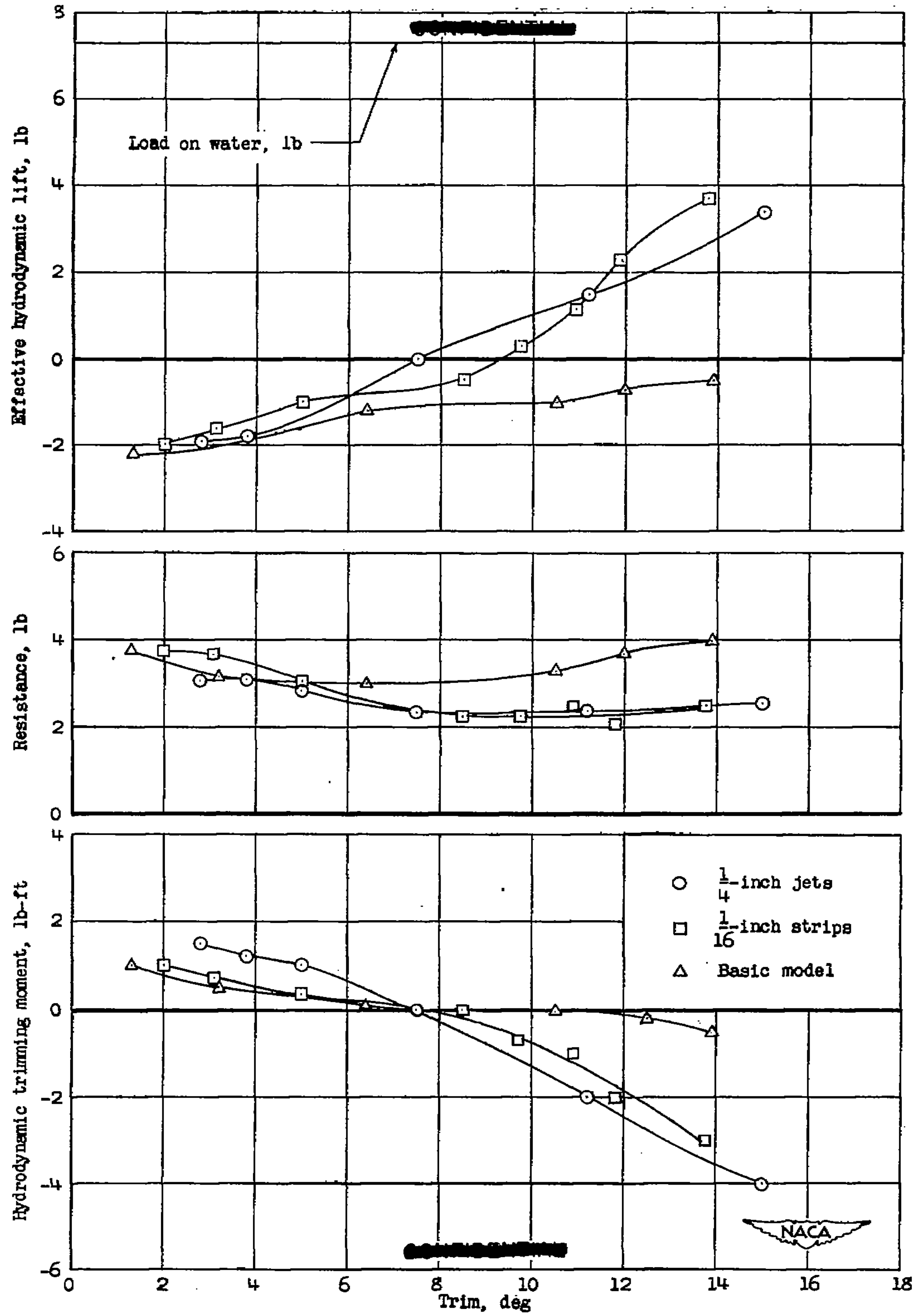
(b) Speed, 10 feet per second.

Figure 6 .- Continued.



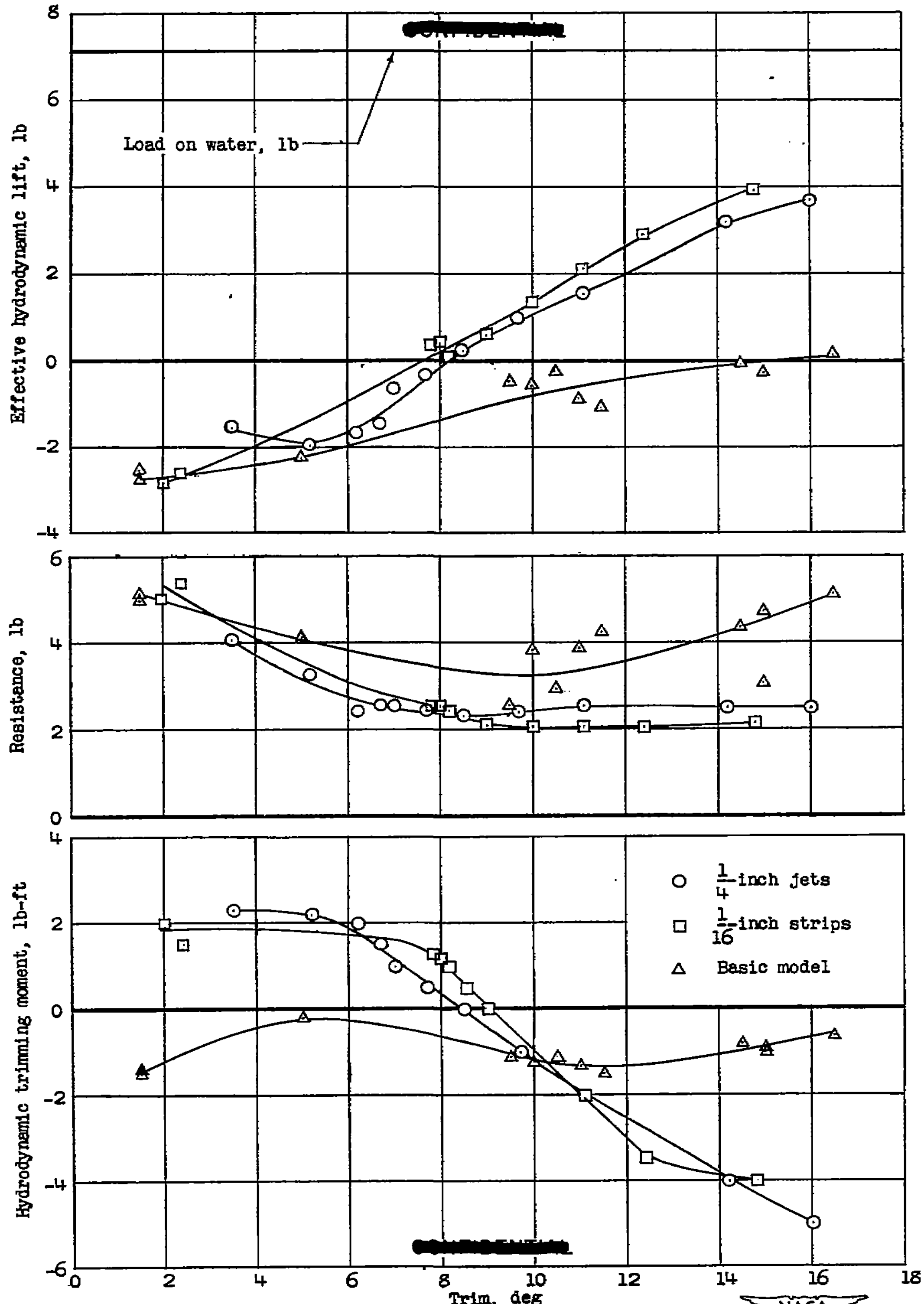
(c) Speed, 12 feet per second.

Figure 6 .- Continued.



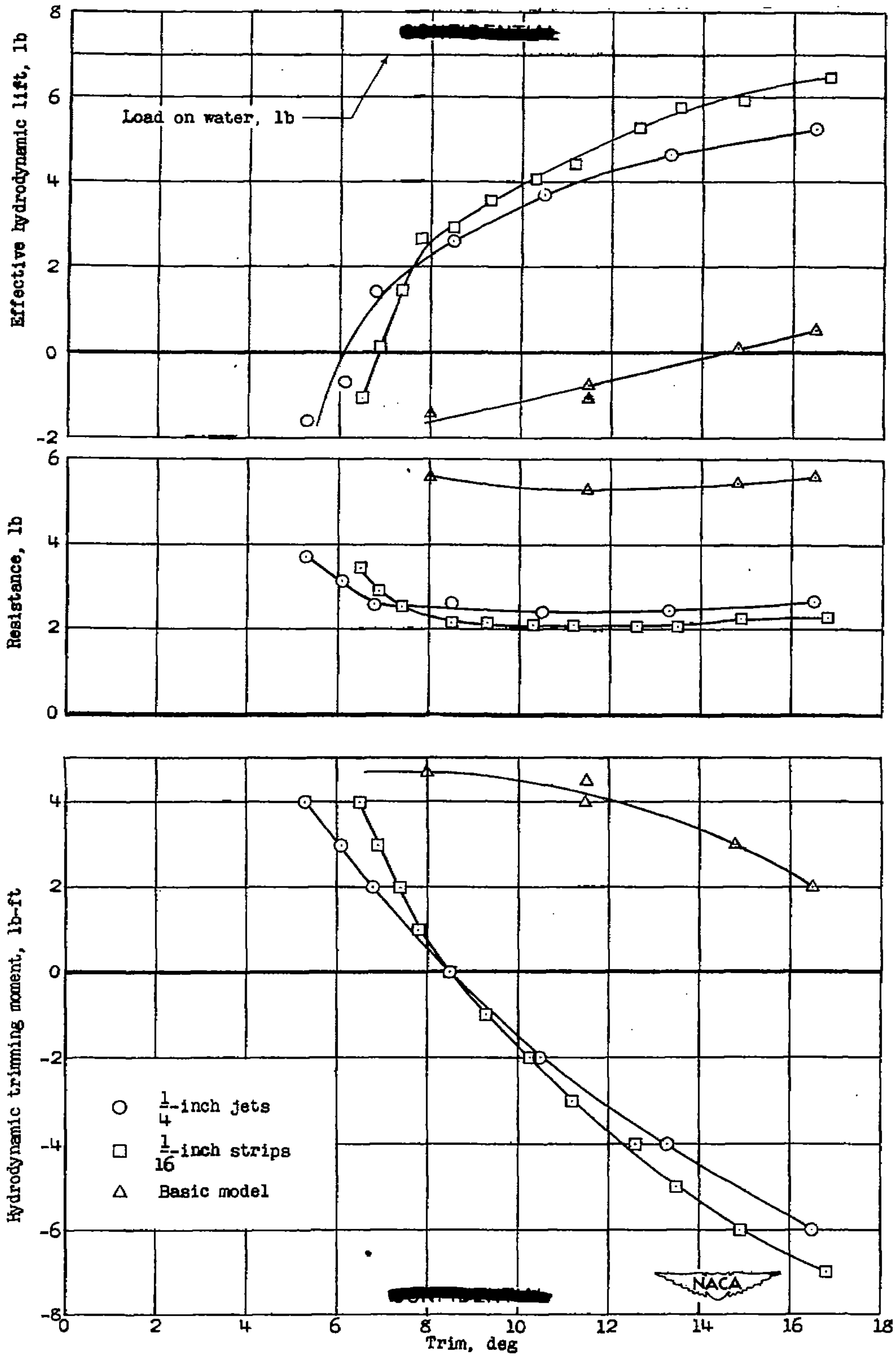
(d) Speed, 15 feet per second.

Figure 6 .- Continued.



(e) Speed, 17 feet per second.

Figure 6 .- Continued.



(f) Speed, 20 feet per second.

Figure 6 .- Continued.

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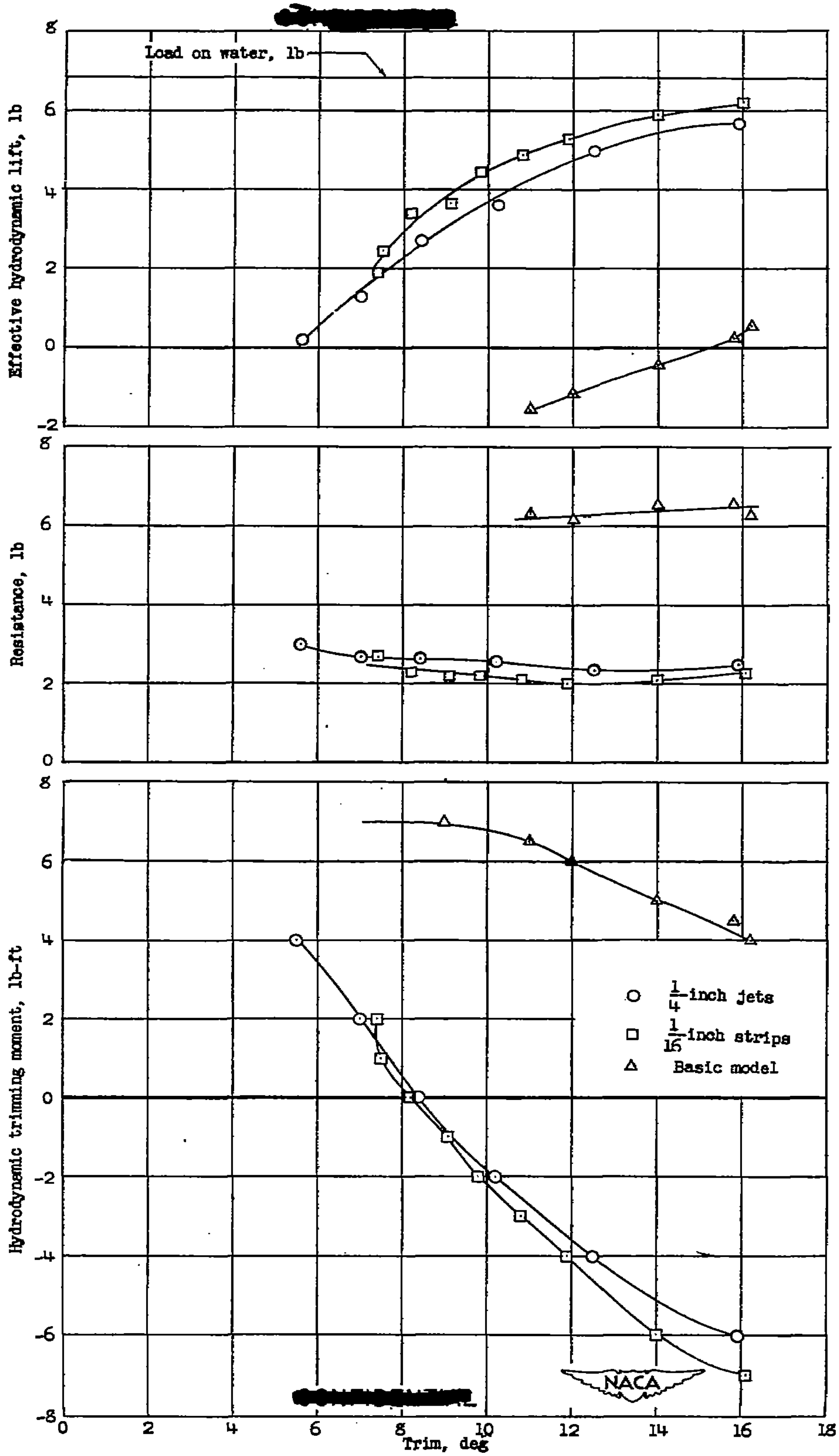

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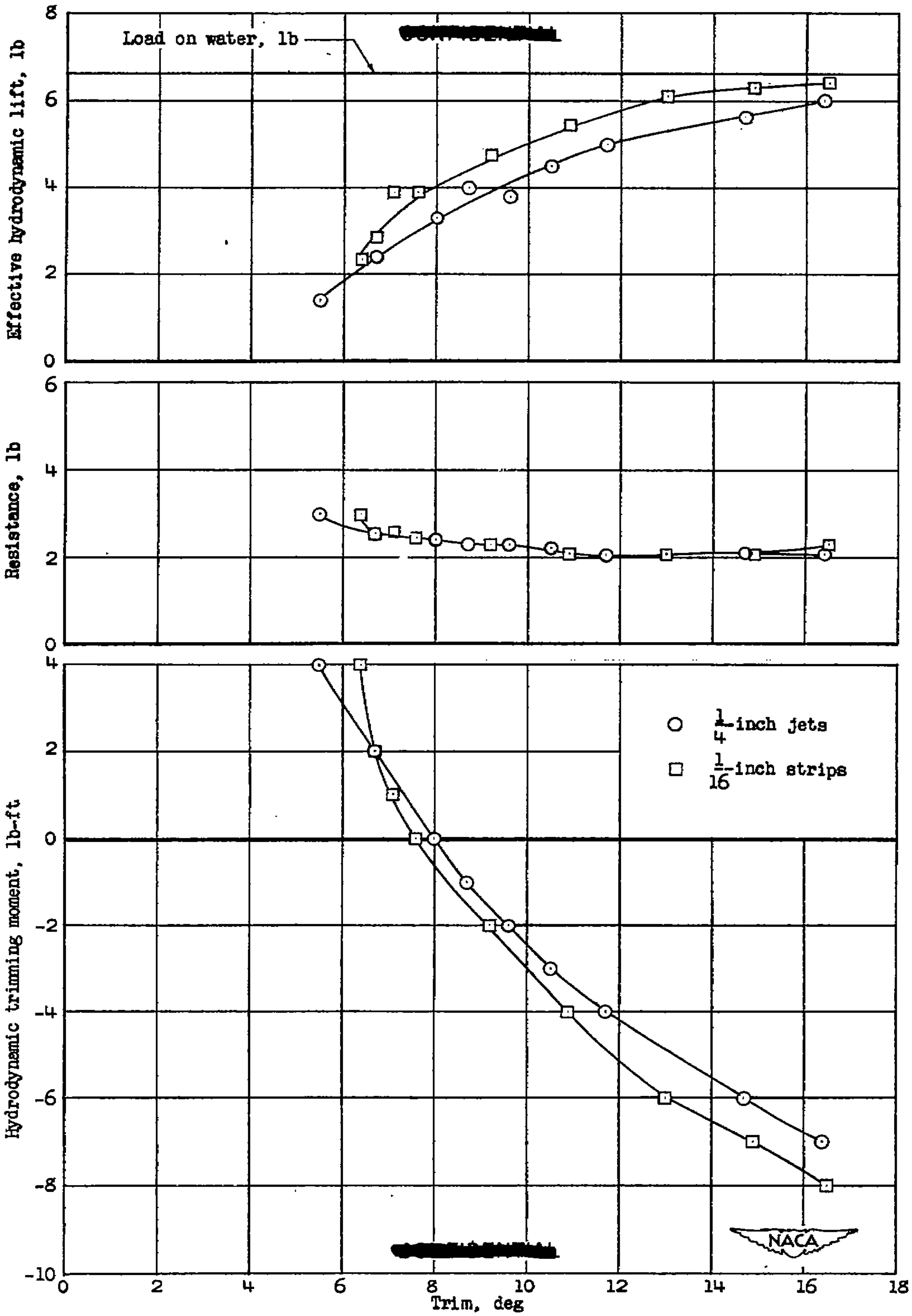
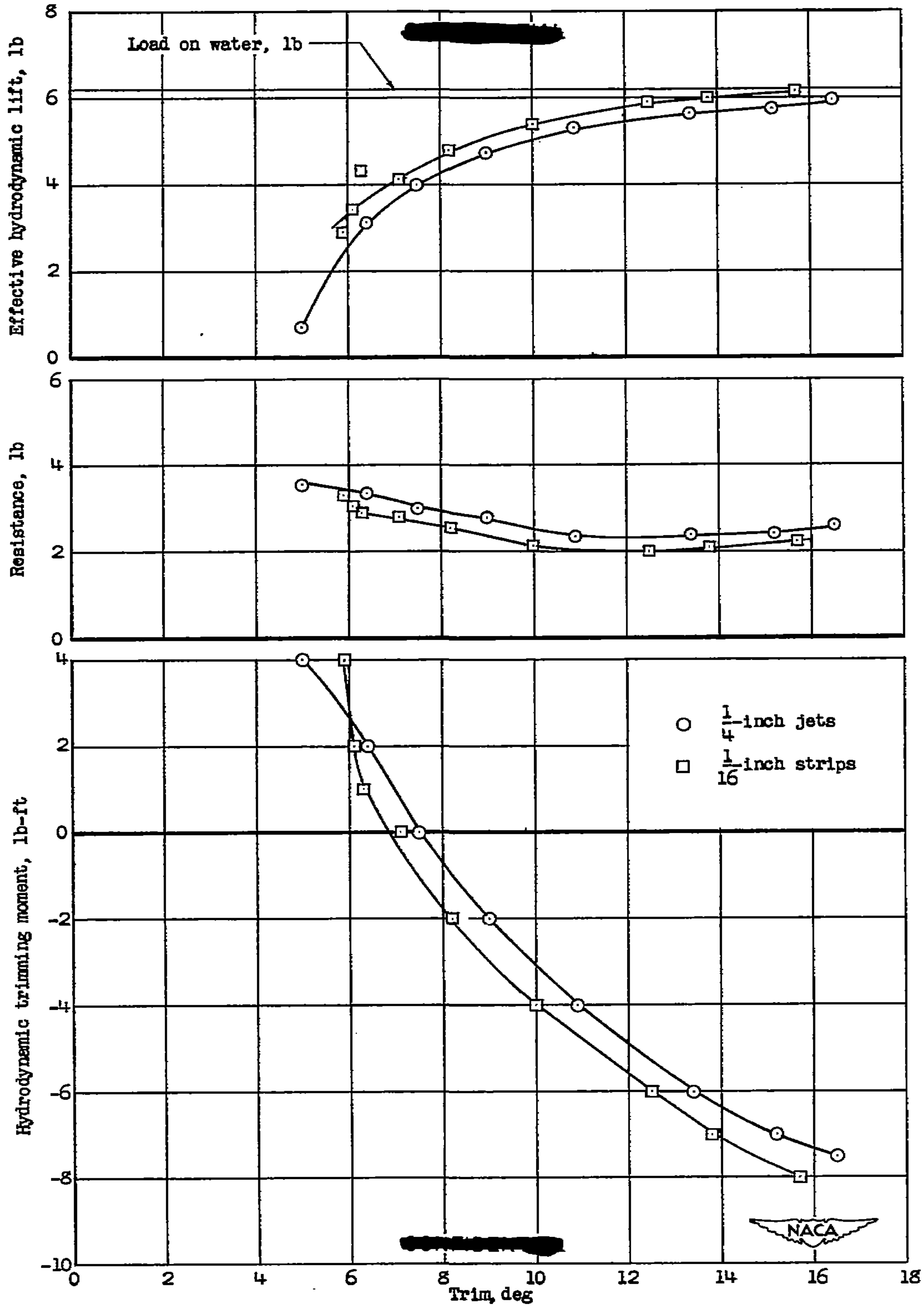
(g) Speed, 22 feet per second.

Figure 6 .- Continued.



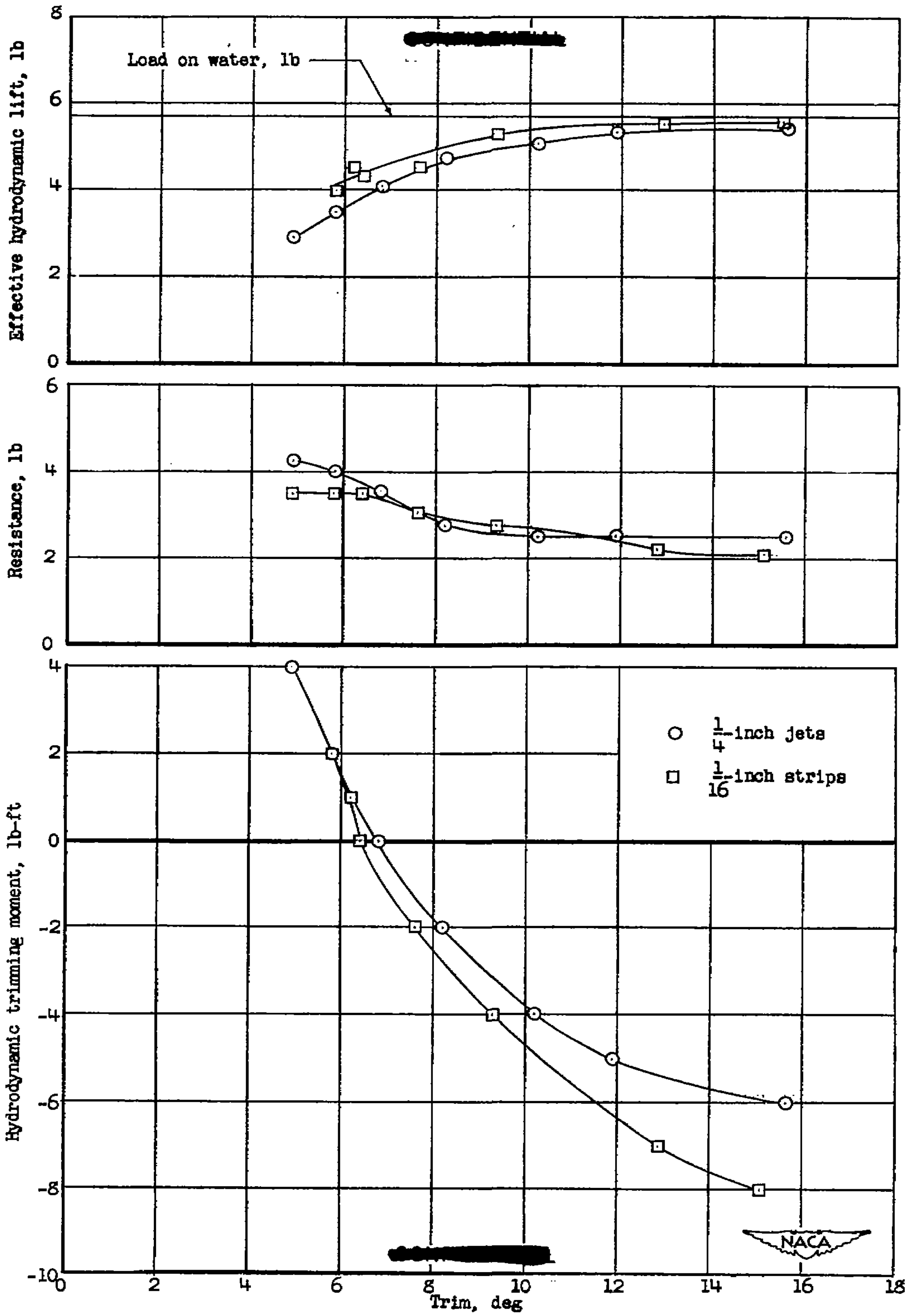
(h) Speed, 25 feet per second.

Figure 6 .- Continued.



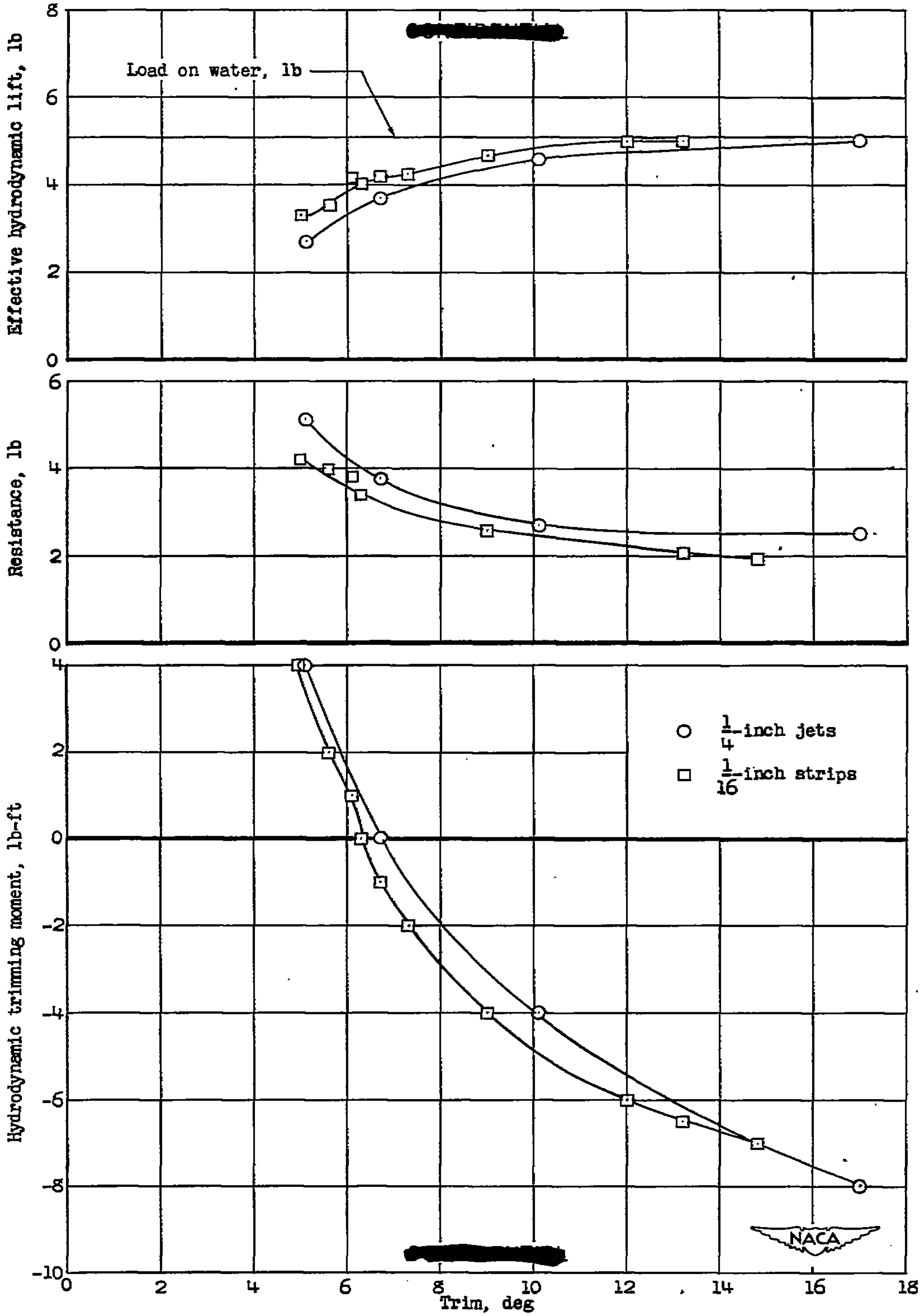
(i) Speed, 30 feet per second.

Figure 6 .- Continued.



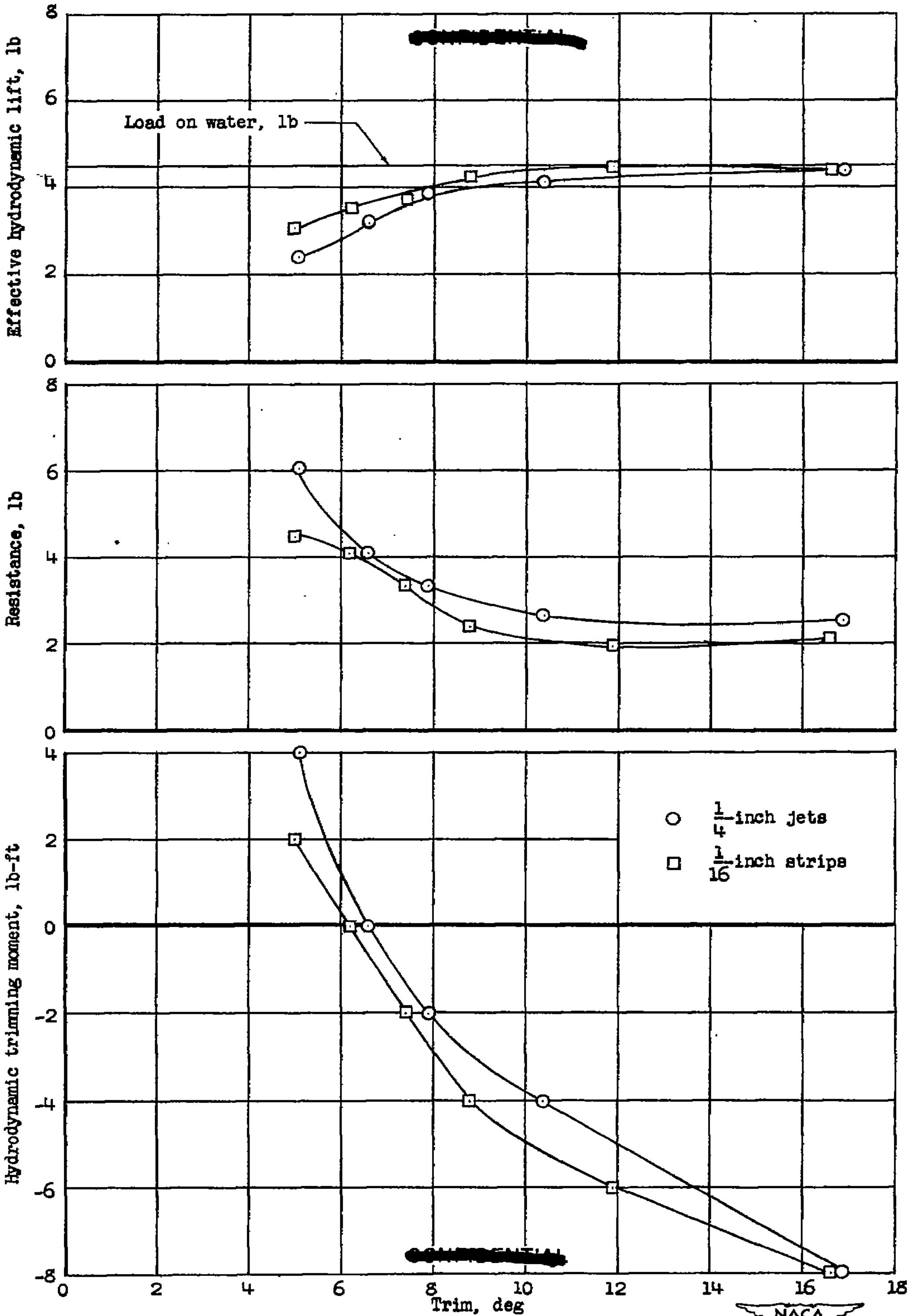
(j) Speed, 35 feet per second.

Figure 6 .- Continued.



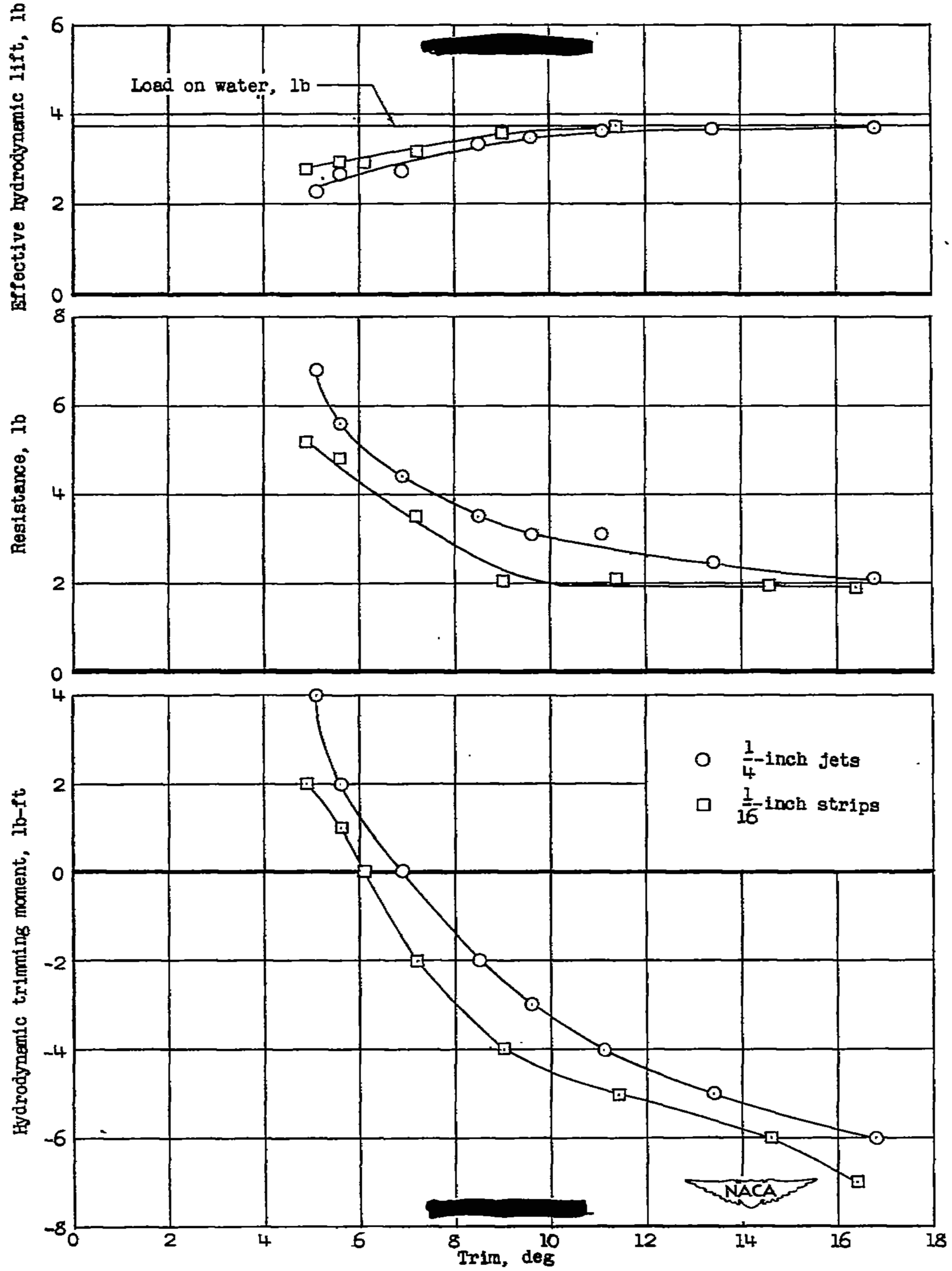
(k) Speed, 40 feet per second.

Figure 6 .- Continued.



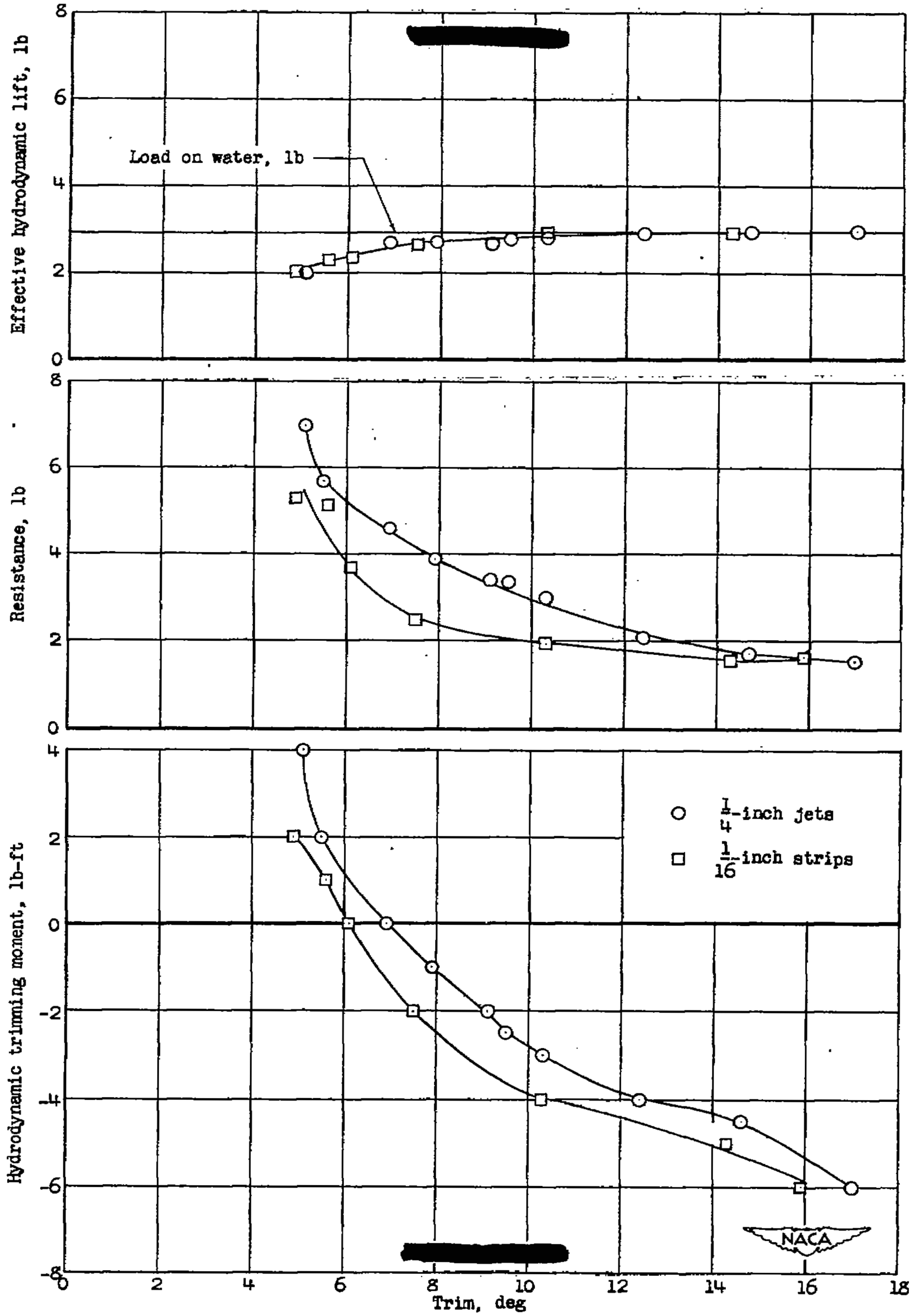
(l) Speed, 45 feet per second.

Figure 6 .- Continued.



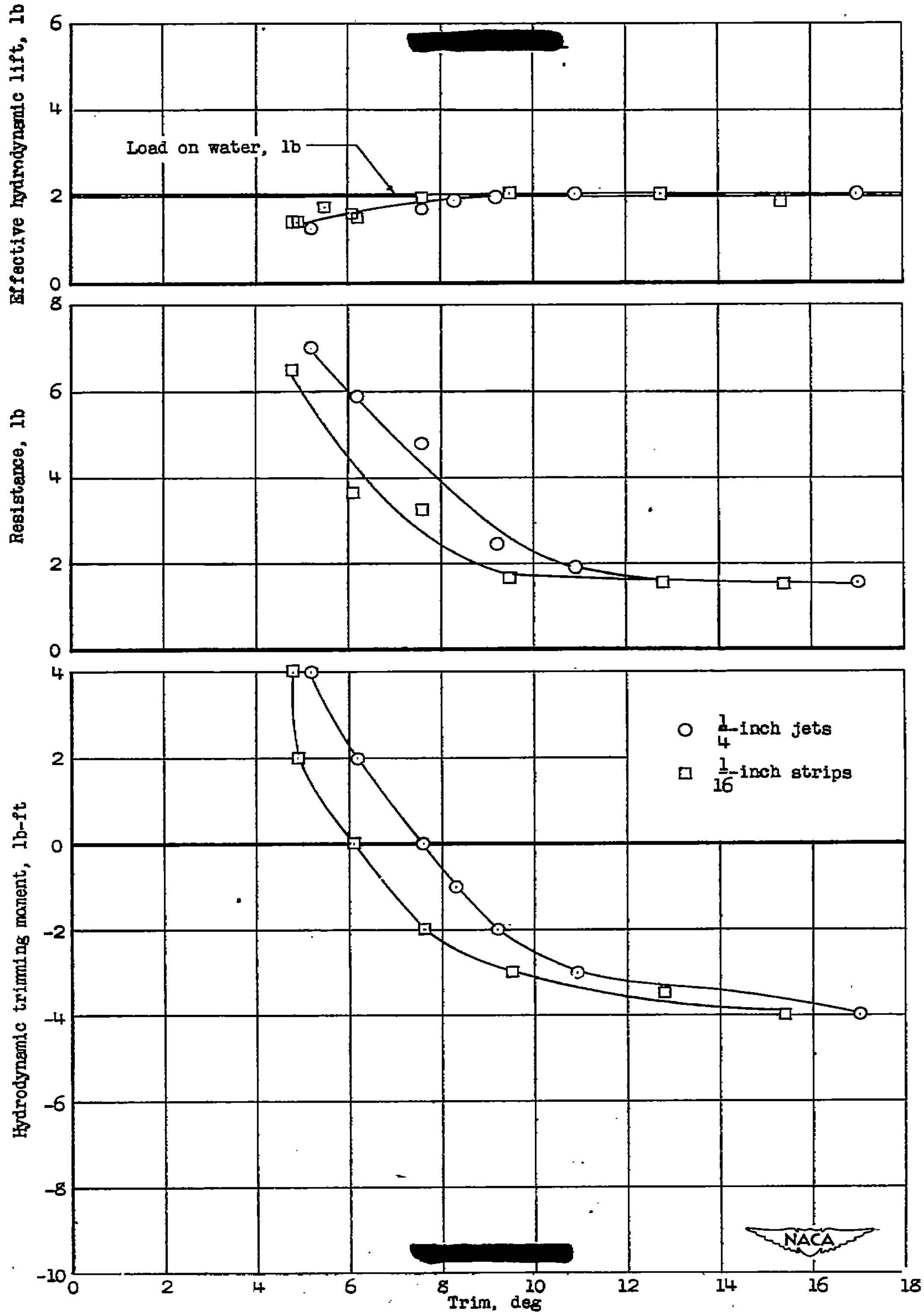
(m) Speed, 50 feet per second.

Figure 6 .- Continued.



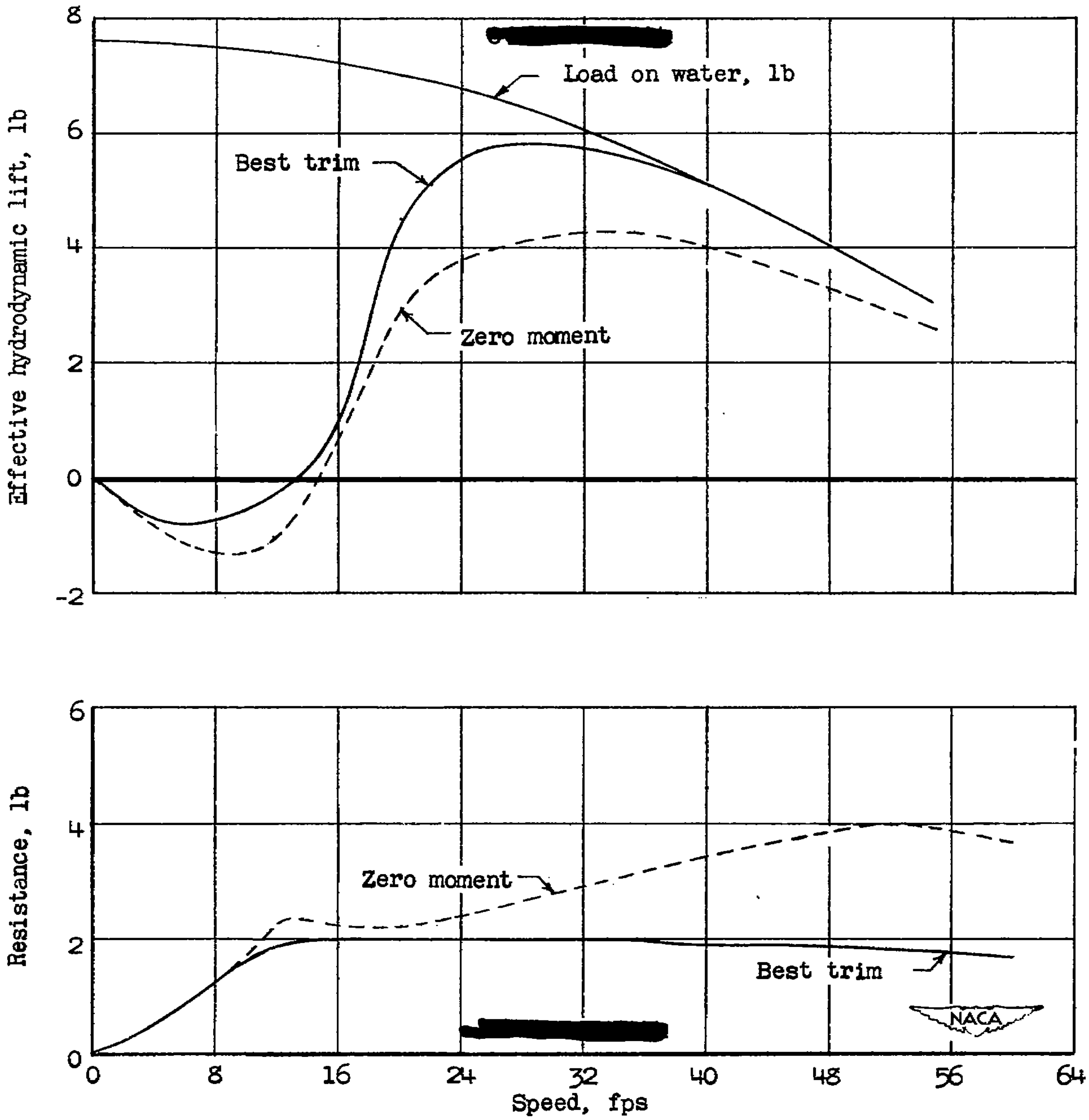
(n) Speed, 55 feet per second.

Figure 6 .- Continued.



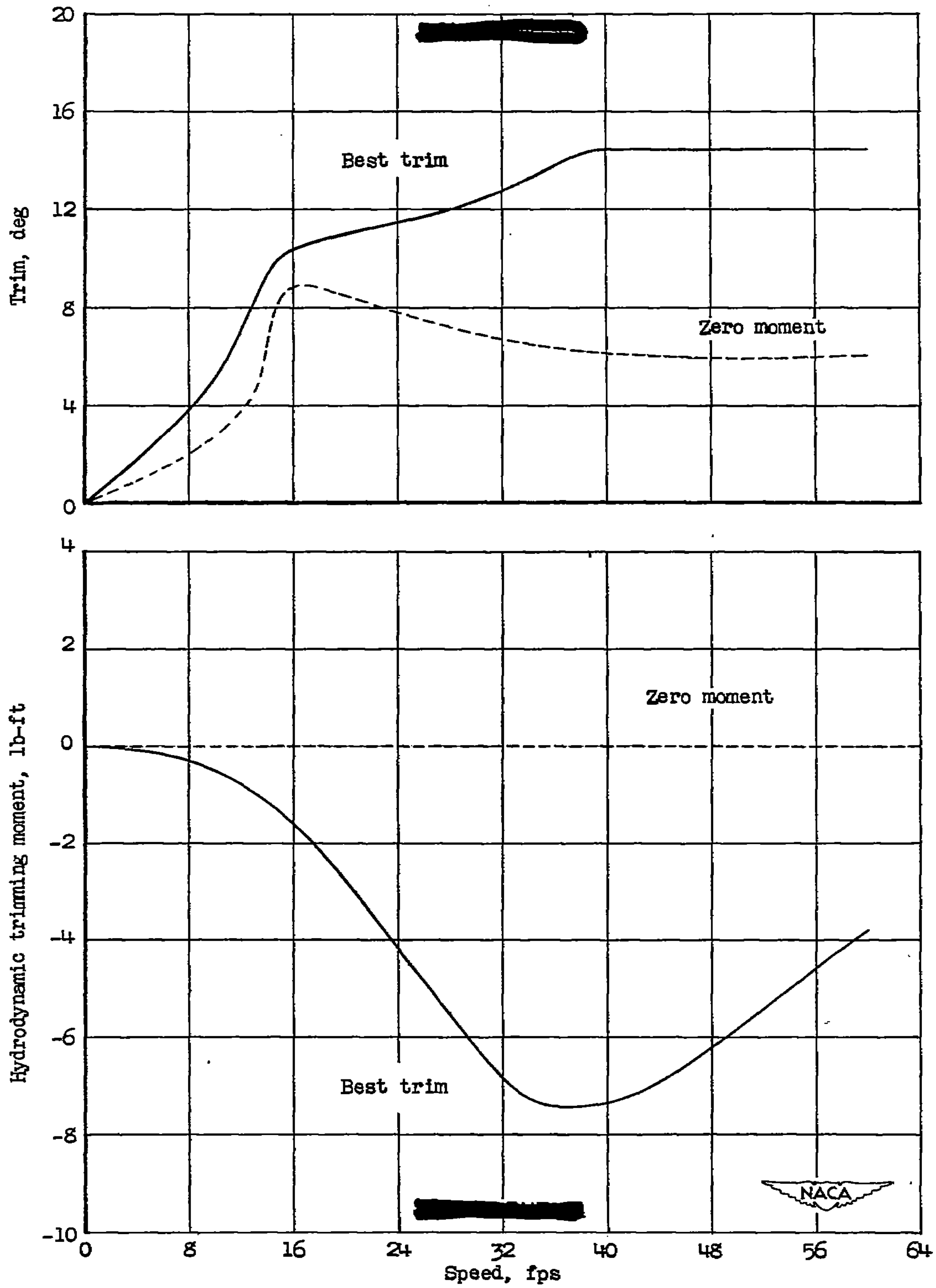
(c) Speed, 60 feet per second.

Figure 6 .- Concluded.



(a) Resistance and effective hydrodynamic lift.

Figure 7. - Comparison of the hydrodynamic characteristics at best trim and at zero moment. (Model modified by chine strips.)



(b) Hydrodynamic moment and trim.

Figure 7. - Concluded.

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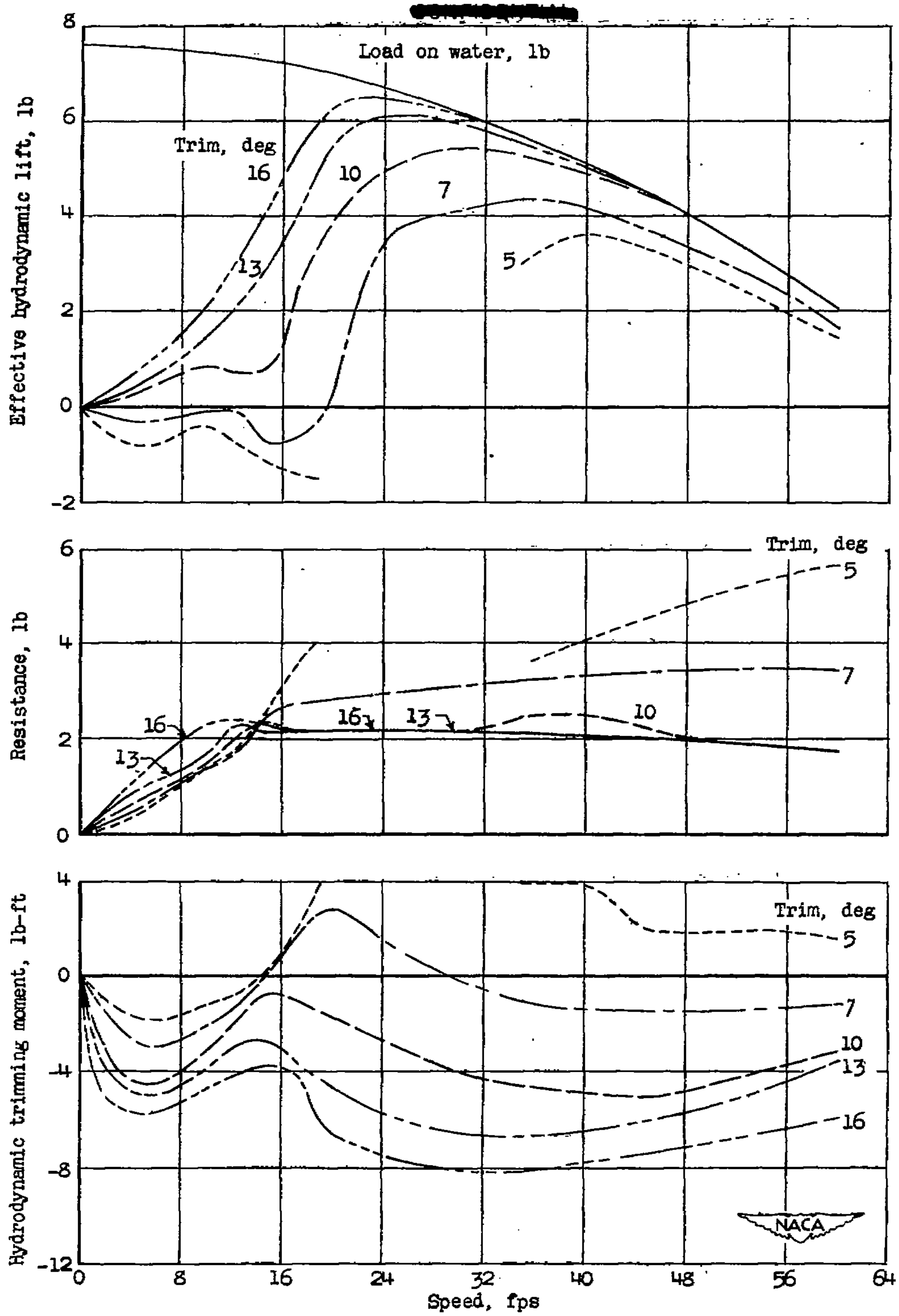

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Figure 8 .- Variation of moment, resistance, and lift at constant trim.

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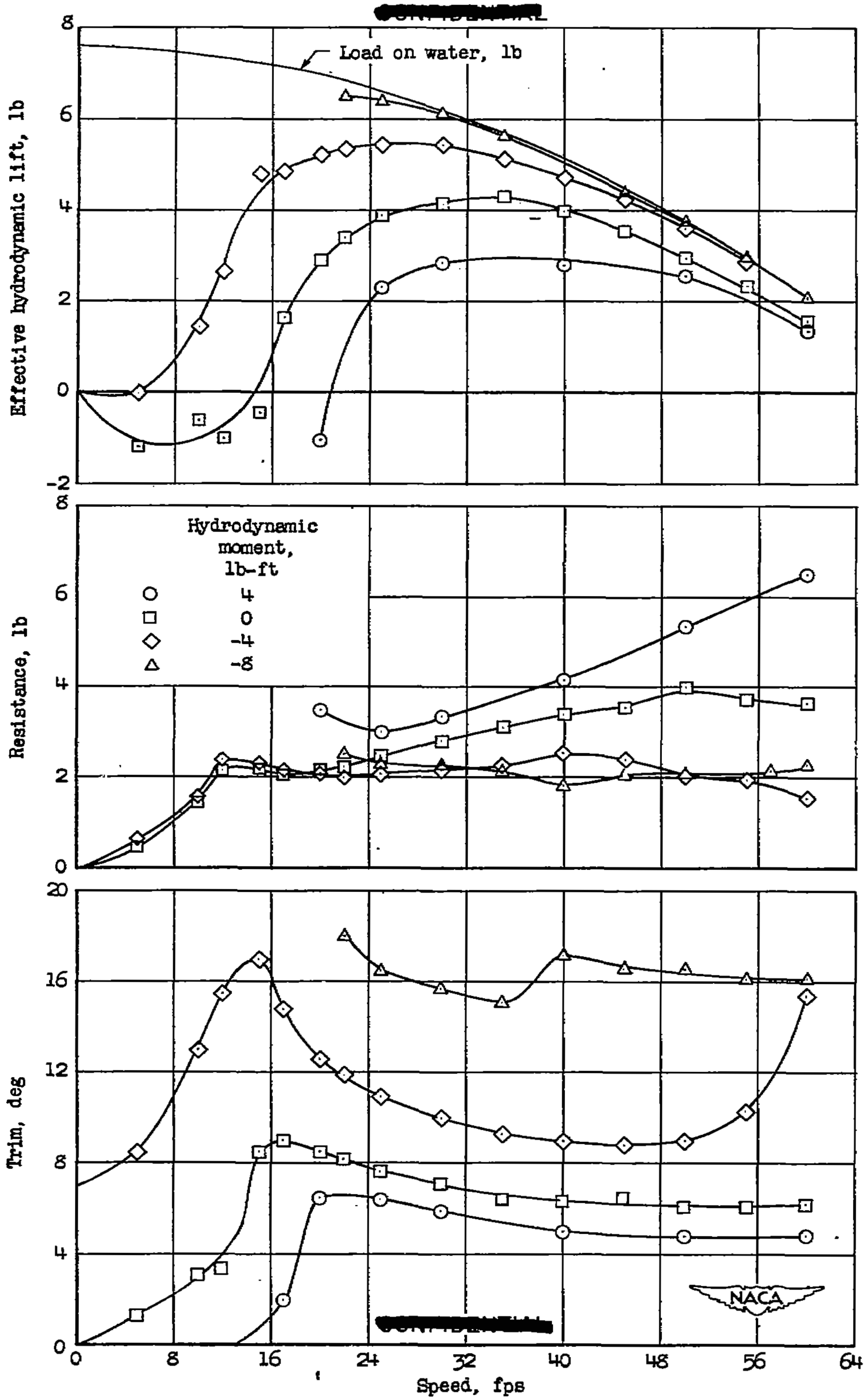

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Figure 9. - Variation of trim, resistance, and lift with constant hydrodynamic moment. (Model modified by chine strips.)

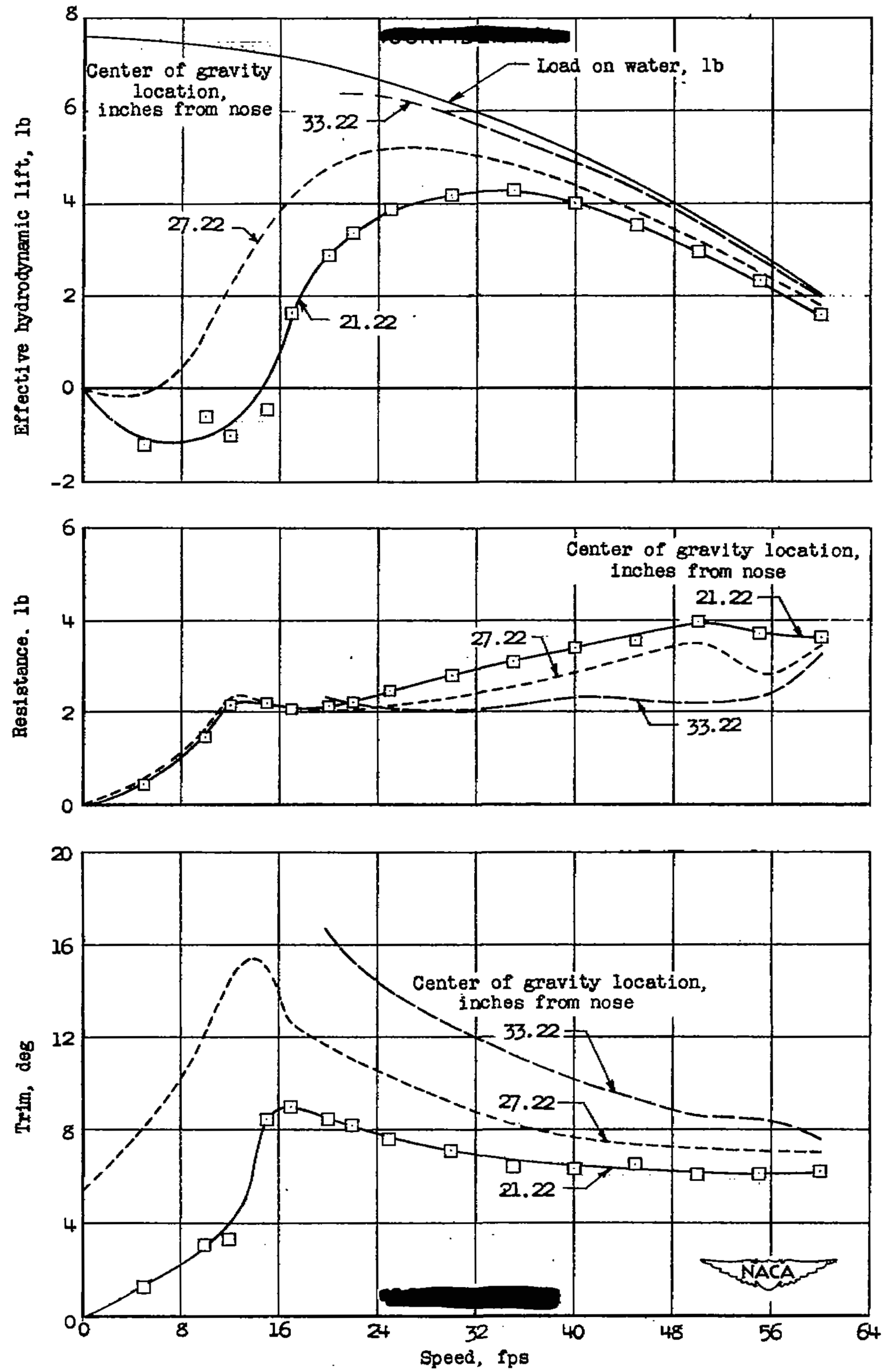
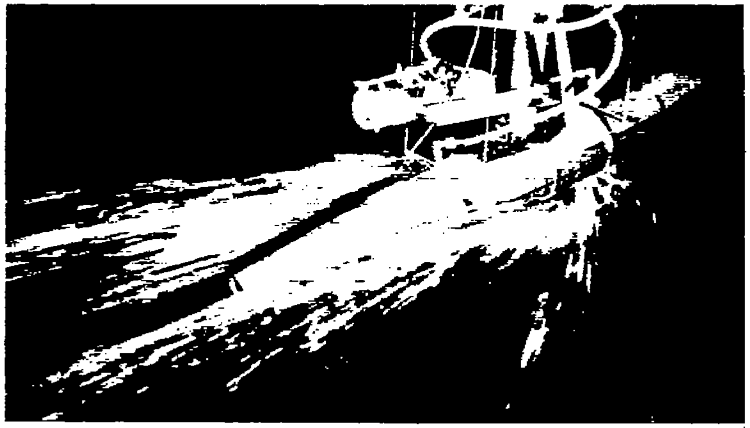
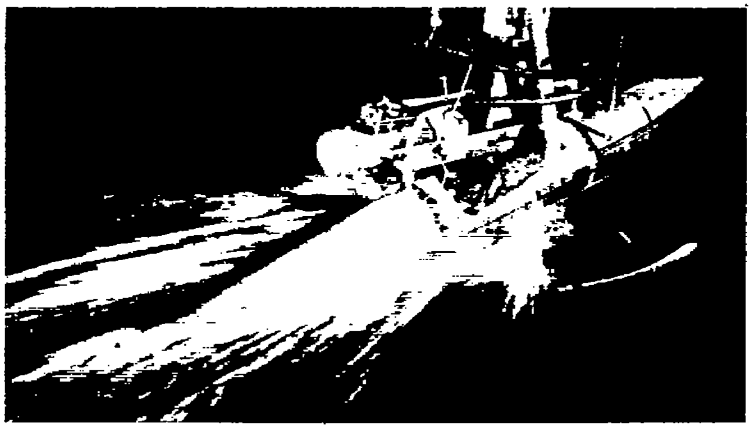


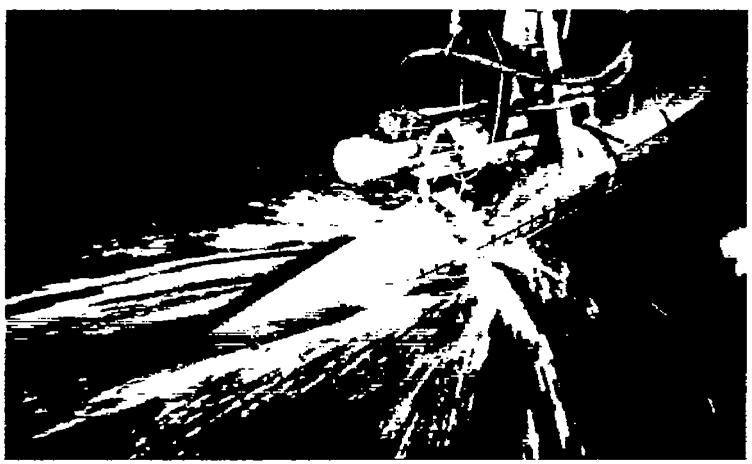
Figure 10 .- Calculated effects of assumed center-of-gravity relocation. (Model modified by chine strips.)



(a) Trim, 8.5°; zero moment.



(b) Trim, 10.3°; hydrodynamic moment, -2 lb-ft.



(c) Trim, 12.5°; hydrodynamic moment, -4 lb-ft.

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Figure 11.- Spray comparison at various trims. Model modified by chine strips. Speed, 20 fps.

[redacted]

(a) Trim, 7.2°; hydrodynamic moment, -2 lb-ft

(b) Trim, 9.0°; hydrodynamic moment, -4 lb-ft.

(c) Trim, 14.6°; hydrodynamic moment, -6 lb-ft.

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Figure 12.- Spray comparison at various trims. Speed, 50 fps. (Model modified by chine strips.)

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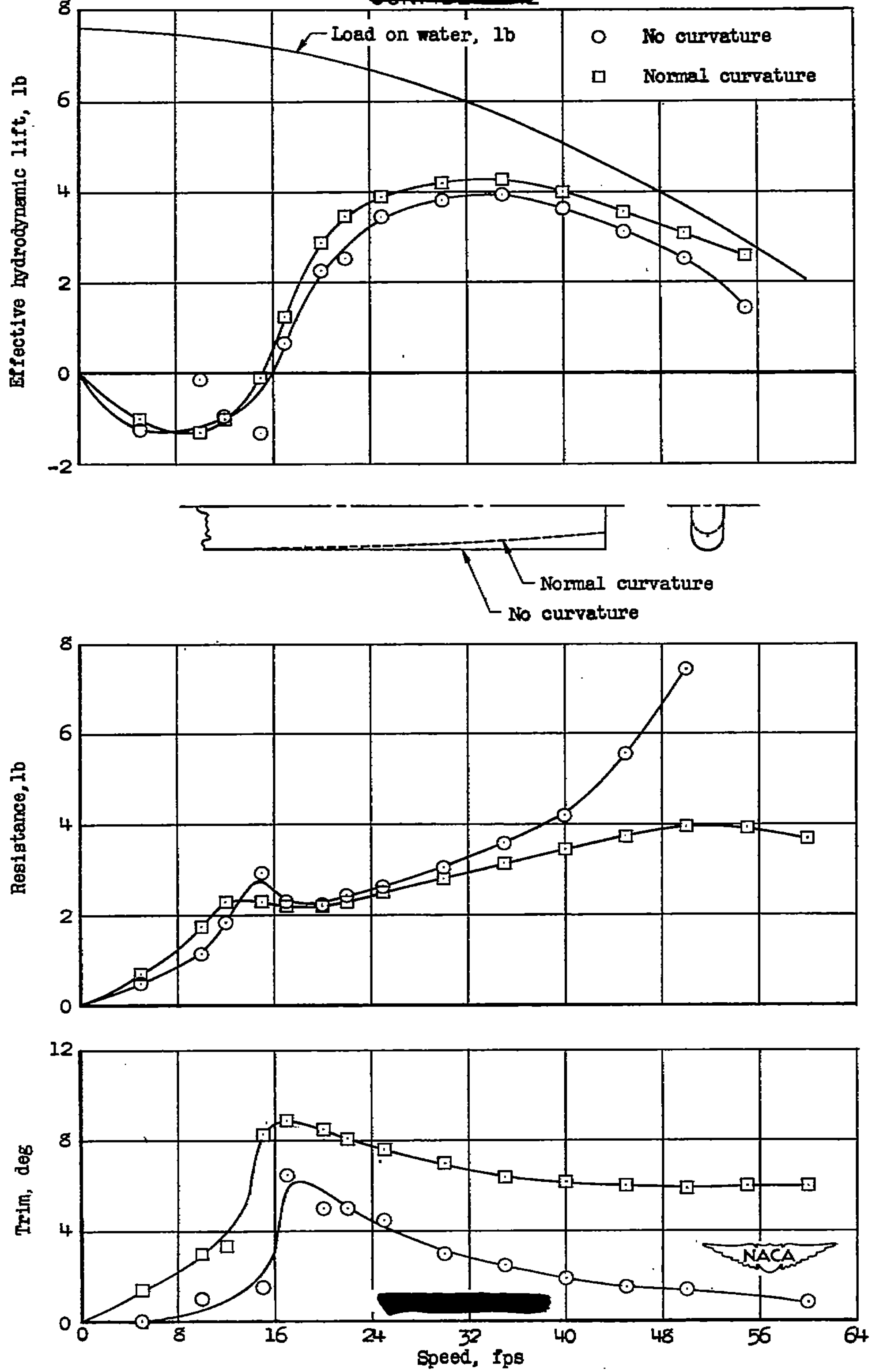
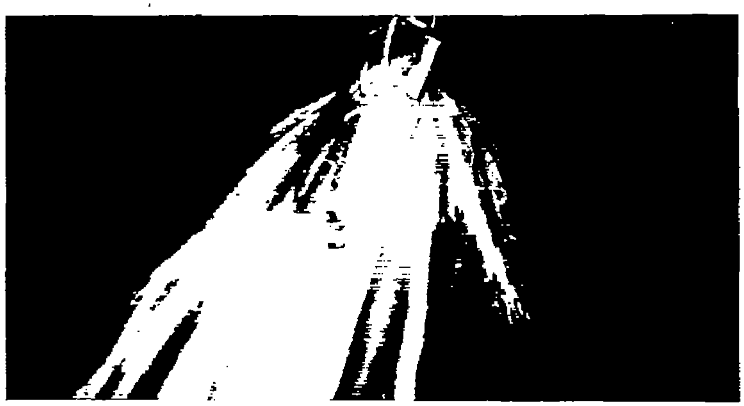
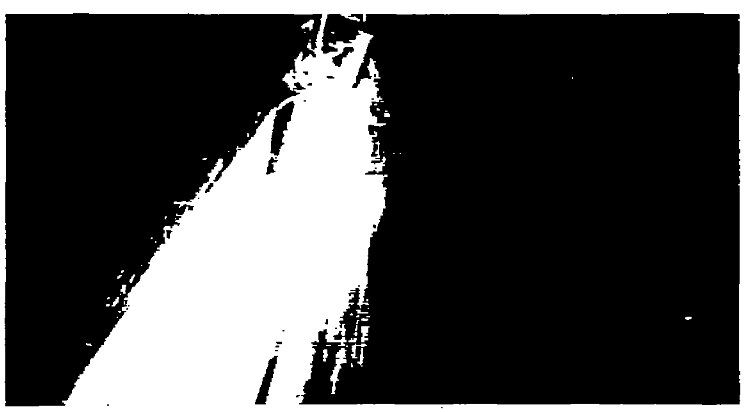


Figure 13.- Effect of curvature of lower profile line; zero moment condition. (Model modified by chine strips.)

(a) Speed, 20 fps; trim, 5.0°.



(b) Speed, 35 fps; trim, 2.5°.



(c) Speed, 50 fps; trim, 1.4°.

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Figure 14.- Spray comparison at various speeds. Longitudinal curvature of the after half of the fuselage bottom eliminated. (Model modified by chine strips.)

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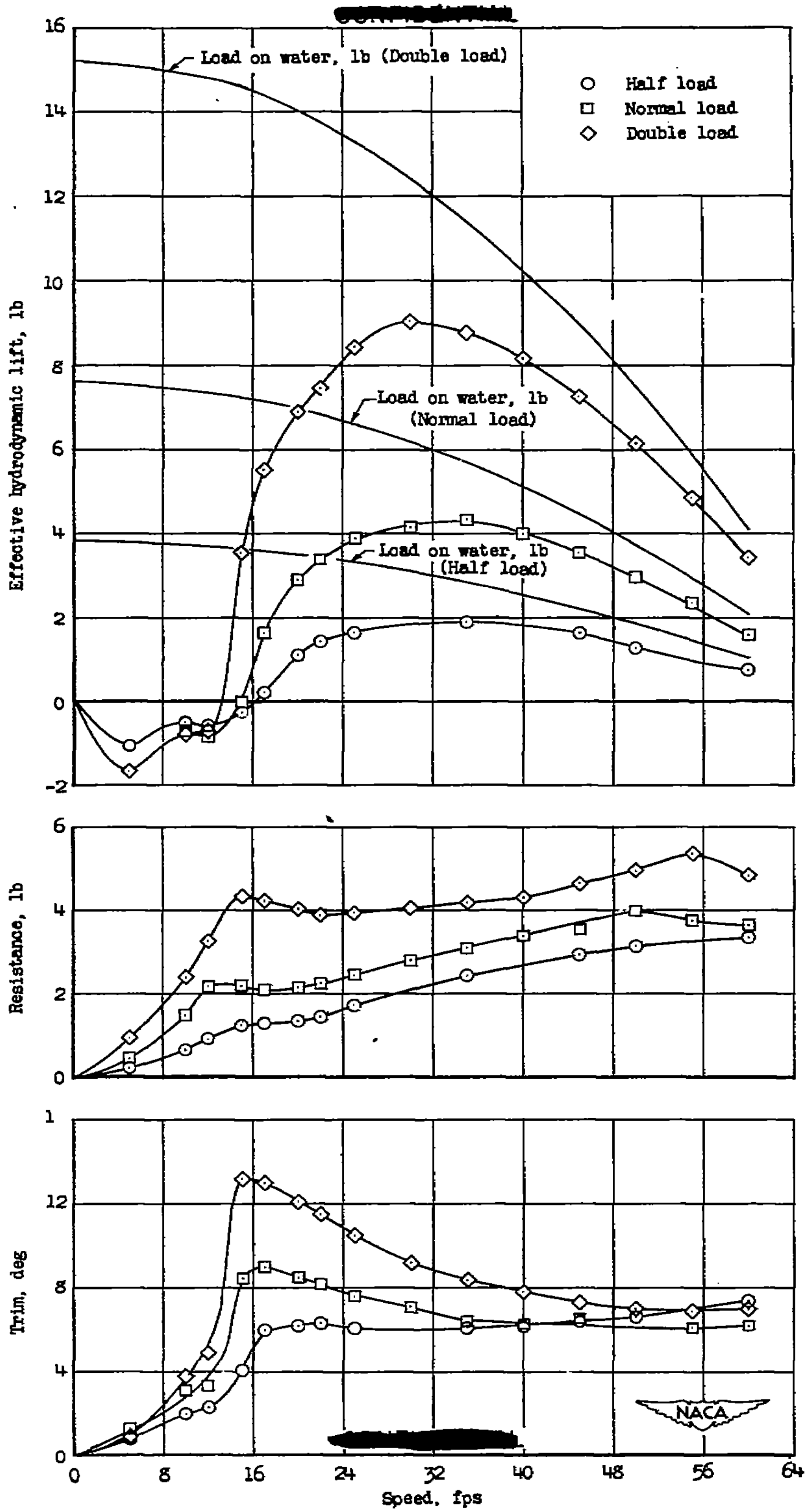

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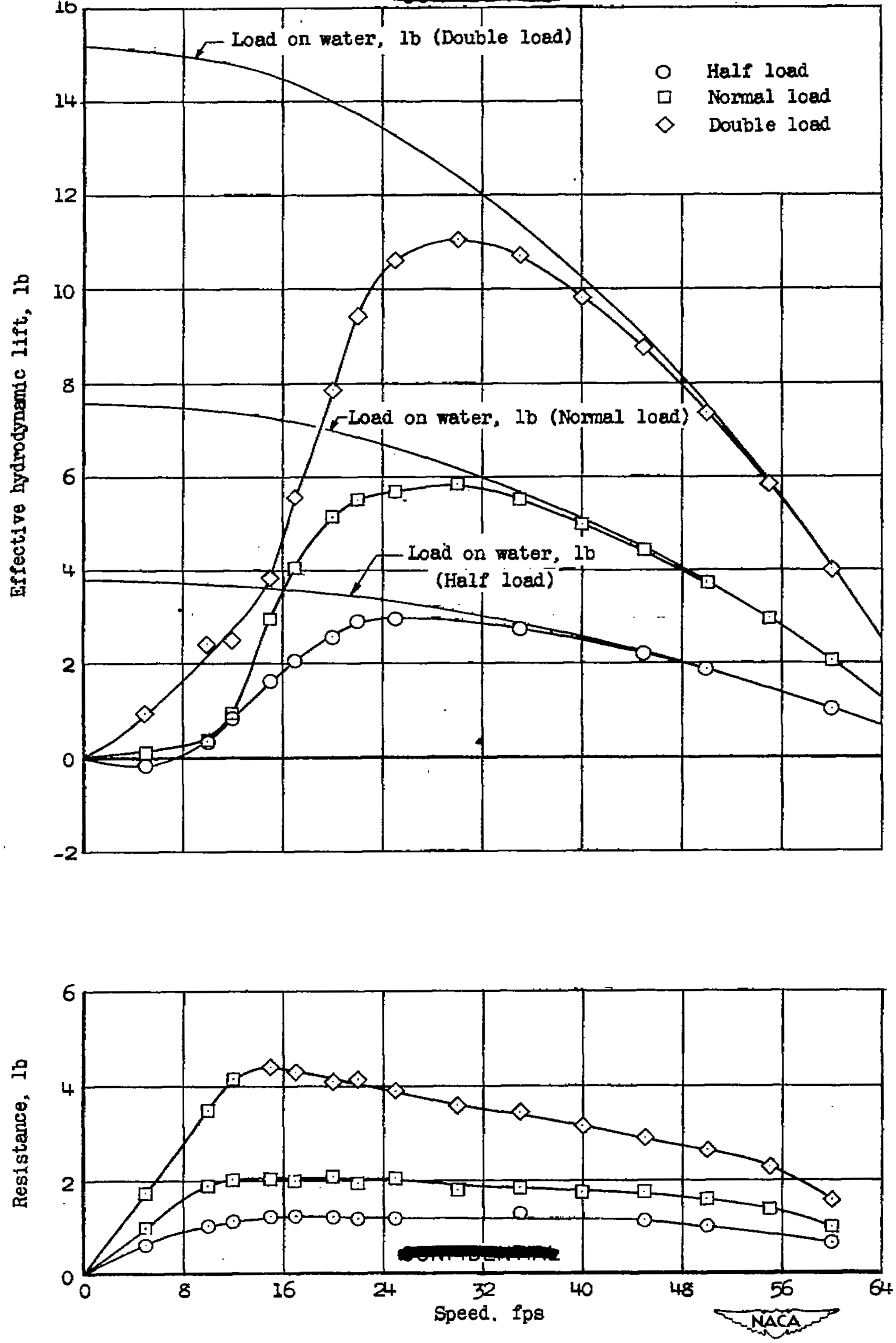
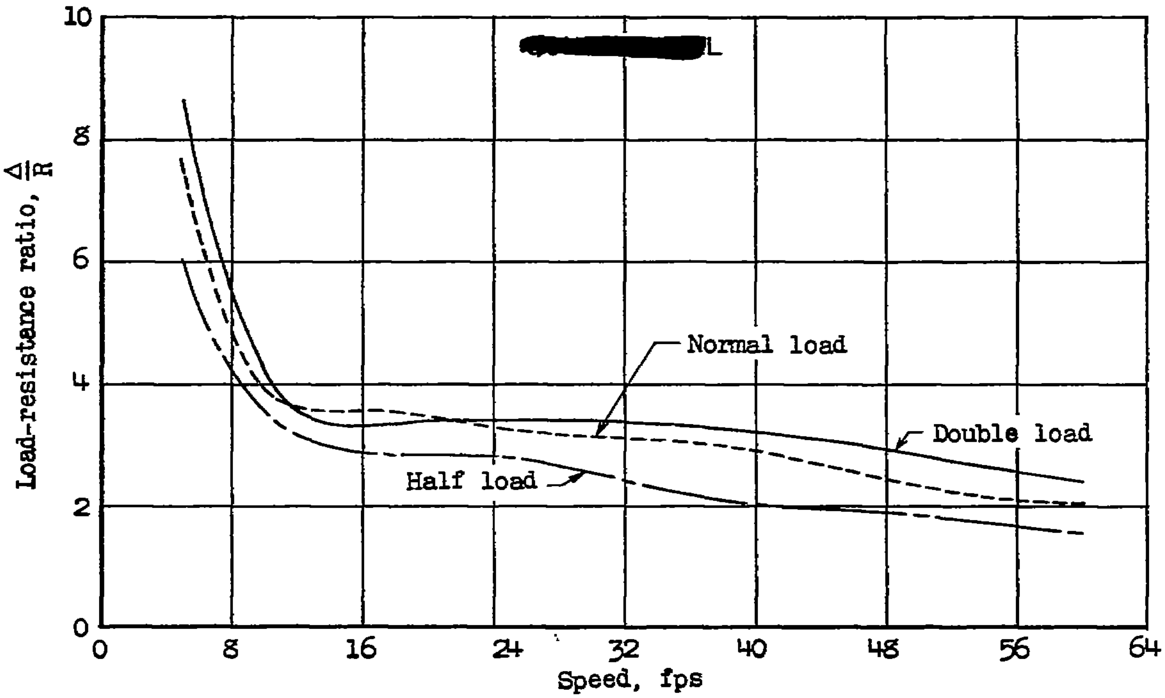
Figure 15. - Effect of load on trim, resistance, and lift for the model free to trim with zero moment. C.G. = 21.22. (Model modified by chine strips.)

[redacted]

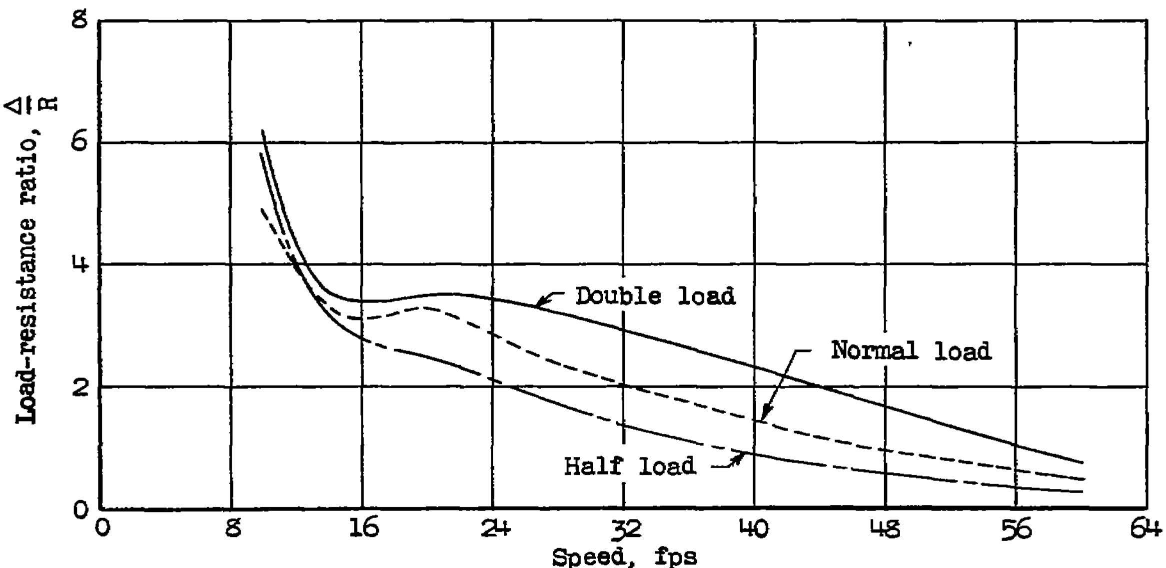


[redacted]

Figure 16 .- Effect of load on resistance and lift with constant trim, 14°. (Model modified by chine strips.)



(a) Fixed trim, 14°.



[redacted]

(b) Free to trim.

Figure 17 .- Comparison of load-resistance ratios for half, normal, and double loads.