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RESEARCH MEMORANDUM

**HYDRODYNAMIC CHARACTERISTICS OF AN
AERODYNAMICALLY REFINED PLANING-TAIL HULL**

By

Robert McKann and Henry B. Suydam

**Langley Aeronautical Laboratory
Langley Field, Va.**

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HYDRODYNAMIC CHARACTERISTICS OF AN
AERODYNAMICALLY REFINED PLANING-TAIL HULL

By Robert McKam and Henry B. Suydam

SUMMARY

The hydrodynamic characteristics of an aerodynamically refined planing-tail hull were determined from model tests made in Langley tank no. 2. Over a wide range of center-of-gravity locations a range of fixed elevator deflections of more than 15° was available for stable take-offs. Sufficient control was available to operate above a rather high lower porpoising limit and no upper porpoising limit was encountered. Resistance was fairly high, being about the same order as that of float seaplanes. Only light spray was encountered with the propellers in a conventional location. Stable landings were obtainable only in the after range of the locations of the center of gravity investigated. There are indications that modifications of the after part of the vertical chine strips will result in considerable improvement in landing stability.

INTRODUCTION

In order to obtain flying boats with increased range and speed over those in present-day use, several refinements of the planing-tail type of hull have been investigated in the Langley 300 MPH 7- by 10-foot tunnel and in Langley tank no. 2.

It was shown in reference 1 that the air drag of a planing-tail flying-boat hull employing a deep step and a full step fairing was considerably less than that of a comparable conventional-type hull. In reference 2 it was found that the hydrodynamic characteristics of this planing-tail hull configuration were generally better than those of the conventional hull. Several modifications of the planing-tail type of hull embodying an airfoil section forebody plan form and a slender "boom-like" afterbody were tested in the wind tunnel and the results reported in reference 3. In that investigation it was found that aerodynamic refinement had resulted in substantially lower air drag than even that obtained with the hulls of reference 1. One of the lowest drag configurations had an "afterbody" which was simply a tapered boom of circular cross section made about as small as would be believed structurally adequate to carry the tail surfaces. (See fig. 1.) At the time

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the wind-tunnel investigation was being made there was doubt that such a small conical boom would be an adequate substitute for an afterbody, hydrodynamically, although tests of reference 4 had indicated that a relatively small cylindrical boom might be sufficient. Consequently, there was included in the wind-tunnel investigation a hull in which a small tail float was faired into the end of the tail boom. (See fig. 2.)

The present paper gives the results of a tank investigation made to determine the hydrodynamic characteristics of the hull with the simple conical boom. Exploratory tank tests were made with the tail float in place, but it was determined that it actually impaired take-off performance and tank tests of it were discontinued in favor of the simpler hull having the lower drag.

SYMBOLS

C_v	speed coefficient (v/\sqrt{gb})
C_R	resistance coefficient (R/wb^3)
C_Δ	load coefficient (Δ/wb^3)
C_{Δ_0}	gross load coefficient (Δ_0/wb^3)
Δ/R	load-resistance ratio
M.A.C.	mean aerodynamic chord
Δ	load on water, pounds
Δ_0	gross load on water, pounds
v	speed, feet per second
g	acceleration of gravity, feet per second per second
b	maximum beam of hull (6.43 feet, full scale)
R	resistance, pounds
w	specific weight of water (63.0 pounds per cubic foot in these tests)

DESCRIPTION OF MODEL

For most of the tank tests a dynamic model of NACA model 237-7B was used. The aerodynamic characteristics and offsets for NACA model 237-7B were given in reference 3. Photographs of the dynamic model are shown in figures 3 and 4. The general arrangement and hull lines are shown in figures 5 and 6, respectively.

The aerodynamic surfaces and the tail arm were those of the XPBB-1 to 1/16 scale. The wing loading of the XPBB-1 was 35.6 pounds per square foot and the power loading was 14.8 pounds per brake horsepower. These conditions were simulated on the model. The wing trailing edge was placed over the step. The wing incidence relative to the base line was 4° . The tail boom on which the tail surfaces were mounted was slightly shorter than the boom tested in the wind tunnel, but it was believed this would have no appreciable effect on the aerodynamic characteristics. The top of the wind-tunnel hull was not reproduced since it would have little effect on the tank results.

The forebody plan form was a modified 16-series symmetrical airfoil section with length-beam ratio of 7.0. For the hydrodynamic tests it was necessary to add chine strips to the configuration tested in the wind tunnel. These strips were 0.05b deep and extended from 0.5b aft of the forward perpendicular to the point of the step where they were faired to zero depth in the last 0.7b of the forebody length.

The dynamic model was of the conventional balsa and tissue construction powered by electrically driven propellers. The gross load corresponded to 60,000 pounds, full size. The model was controlled by means of the elevators which had a range of deflection from -30° to $+20^{\circ}$. The flap deflection throughout the tests was 0° .

PROCEDURE

The testing procedures given in the following discussion are similar to those given in reference 2.

Take-Off Stability

The center-of-gravity limits of stability were determined by making accelerated runs to take-off, with fixed elevators, holding a constant acceleration of 1 foot per second per second. Using full power, a sufficient number of center-of-gravity locations and elevator settings were tested to define the stability limits for the normal range of values. A stability limit is defined as the condition at which the amplitude of trim oscillation reaches a value of 2° . The variation of trim with speed

for the various conditions was also observed during these runs. Trims less than 2° were considered to be below the practical operating trim range. To find the trim limits of stability, the towing carriage was held at constant speeds, while the model trim was slowly increased or decreased until the porpoising limit was crossed. Trim was measured as the angle between the forebody keel and the horizontal.

Landing Stability

The landing stability was investigated by trimming the model in the air to the desired landing trim while the carriage was held at a constant speed slightly above the model flying speed. The carriage was then decelerated at a constant rate of 3 feet per second per second, allowing the model to glide onto the water in simulation of an actual landing. The descent to the water from flight was made from a height of 0.31b above the water. This was done to hold the sinking speeds to reasonable values as in reference 2. After the first contact the rise restriction was removed. Landings were made with the center of gravity located at 20, 30, and 40 percent mean aerodynamic chord, using one-quarter static thrust.

Spray

The load at which spray first entered the propellers was determined by the method given in reference 5. The model was free to trim about the 30 percent mean-aerodynamic-chord location of the center of gravity with the elevators fixed at 0° . Constant-speed runs were made at full power with the model counterweighted. Starting with a light load on the water, the load was increased until spray entered the propellers.

Resistance

The resistance characteristics were obtained with the wing and tail removed. Constant-speed runs were made with the model fixed in trim. The load on the water was assumed to vary as the square of the speed and was applied by dead weights. The take-off speed was changed for each fixed trim tested to correspond with the take-off speeds observed in the take-off stability tests. The range of trims tested at any speed was determined from the stability tests as being the range of stable trims attainable at that speed by the use of the elevators alone. For this procedure the center of gravity was considered to be at 40 percent mean aerodynamic chord. The resistance selected at each speed was the lowest resistance obtained at that speed.

RESULTS AND DISCUSSION

The exploratory tests made with a tail float (fig. 2) indicated that such a configuration operated in a range of trims which was lower than that obtained with the boom alone. Near the take-off speed an action similar to that of skipping on landing was encountered which led to premature take-offs. This action was apparently caused by an undesirable positive moment at high speeds. This moment was thought to be the result of negative air pressures acting on the float bottom as it operated in the trough of water formed in the forebody wake. This was the hydrodynamic feature which, coupled with the increment in air drag due to the float, caused interest to be centered on the hull with the boom alone.

Take-Off Stability and Trims

The center-of-gravity limits of stability of the flying boat are given in figure 7 as a plot of elevator deflection against center-of-gravity location. The range of elevator deflections for stable take-offs increased from 15° at 20 percent mean aerodynamic chord to 30° at 40 percent mean aerodynamic chord. This plot shows stable take-offs over the range of center-of-gravity locations tested for a reasonably wide range of elevator deflections. The region of lower-limit porpoising encountered in this figure with the lower elevator deflections is shown in figure 8 where the trim limits of stability are plotted against speed coefficient. The peak trim at which the lower limit of stability was encountered was 11.3° at approximately 50 percent of the take-off speed. It was advantageous that the lower limit of stability did not occur until well along in the take-off run where the elevators were relatively effective. The lower limit of stability fell away rapidly beyond this trim peak as speed was increased. No upper-limit porpoising was encountered with the model free to trim to 16° . This enabled stable take-offs to be made with full elevator deflection as shown in figure 7. The high peak trim and absence of upper-limit porpoising were probably both due to the fact that the tail boom carried a small proportion of the total load.

In figure 9 variation in trim at constant elevator deflection is plotted against speed coefficient for three locations of the center of gravity. Typical photographs of the model with the center of gravity at 30 percent mean aerodynamic chord and the elevators set at -5° are shown in figure 10. The variation of trim from rest to 50 percent of the take-off speed was relatively small, being a maximum of 4° . In conventional hulls this trim variation is 7° to 8° .

As shown in figure 7, the lowest elevator setting with which a stable take-off was possible was determined by the lower limit of

stability for the greater part of the center-of-gravity range. However, with the center of gravity located at 40 percent mean aerodynamic chord and the elevators set at 1° , the model trimmed down to 2° . Although the trim track during this run was above the lower trim limit at all speeds, the limiting trim of 2° was reached before a take-off could be made. It is seen in figure 9 that with only a slight increase in elevator deflection to 0° , a stable take-off at 4° trim was made.

Landing Stability

In figure 11 the amplitudes of the maximum oscillations in trim are plotted against landing trims. In figure 12 the amplitudes of the maximum vertical motions at the center of gravity are plotted against landing trims.

From these figures it may be seen that during landings made with the center of gravity located at 20 percent mean aerodynamic chord the model experienced violent changes in trim and rise during all landings. At landing trims above 8° , the amplitudes of trim and rise were great. At landing trims less than 8° , the model trimmed down violently at impact against the trim stop which was set at 2° . Landings at this center-of-gravity location were not considered feasible. With the center of gravity located at 30 percent mean aerodynamic chord, landings at the higher trims (about 12°) appeared to be stable enough to be practical, but at lower trims they were violent. With the center of gravity at 40 percent mean aerodynamic chord, a considerable range of contact trims could be used without excessive instability.

Data from unpublished tests indicate that the after part of the vertical chine strips was the major cause of the poor landing stability. It appears possible that a substantial improvement might be effected by the alteration of this part of the chines.

An undesirable feature of the design is that a large proportion of the total volume of the configuration lies forward of the center of gravity. This problem of airplane balance may restrict the use of this type of hull to special-purpose, high-performance aircraft.

Spray

In figure 13 the load coefficient at which spray entered the propellers at various speeds is shown. This figure indicates that at the gross load used for the stability tests (60,000 pounds, full size) the propellers were operating in spray through a speed-coefficient range from 1.35 to 3.75. In the tests it was found that this spray was light

due to a combination of the high trims and vertical chine strips. Without the vertical chine strips the spray was so high it went over the wing, creating a serious hazard to the electric motors used to power the model. The unusually heavy spray may be explained by the load distribution between the forebody and afterbody. With conventional hulls, as much as 50 percent of the total load is carried by the afterbody in the spray range. Evidently the tail boom carries only a small fraction of this load. Hence the forebody of this model would be expected to throw heavier spray than normally indicated since it is proportionately more heavily loaded than the forebody of the conventional hull.

Vertical chine strips effectively reduced this spray. Figure 13 shows that with the chine strips in place only about 13-percent decrease in the normal gross load was required to bring the propellers clear of spray. Figures 10(b) and 10(c) are photographs of the model made at normal gross load in the spray region. The vertical chine strips broke the spray into a confused pattern. This spray struck the propellers intermittently rather than in a continuous sheet.

The increment of air drag due to the chine strips was indicated in unpublished wind-tunnel data to be small, especially if the rear portion was removed.

Resistance

In figure 14 best trim resistance coefficient and load-resistance ratio are plotted against speed coefficient. In figure 15 the trims and load coefficients at which the resistance coefficients plotted in figure 14 were obtained are plotted against speed coefficient. The curve of resistance coefficient against speed coefficient shows a high hump resistance. The trim corresponding to this resistance is also high (about 11.6°). Shortly after the resistance hump the best trim reaches 12° and remains at this value to take-off. Typical cross-plots of resistance coefficient against trim are shown in figure 16.

The load-resistance ratio corresponding to hump resistance was about 3.6. This value is lower than that obtainable with well-designed conventional hulls, but is about the same as that obtained with Navy single-float seaplanes. The hump trims of the model are similar to those of the single-float seaplanes.

During the last third of the take-off run, even though the tail boom was clear of the water, the high-speed resistance was greater than would be expected for the forebody alone. Undoubtedly the after part of the vertical chines contributed to this resistance.

Directional Stability

No quantitative study was made of directional stability. However, the model was attached to a tubular staff which was slightly flexible torsionally, and a decided tendency to yaw was noticed at a speed coefficient of about 4.0. The yawing force was evidently produced by a roach from the forebody which rose from the point of the step and struck the tail boom. This yawing tendency was noticed only over a very short speed range.

CONCLUSIONS

The results of model tests to determine the hydrodynamic characteristics of an aerodynamically refined planing-tail seaplane hull having a single cone-shaped boom for an afterbody indicate the following conclusions:

1. Over a wide range of center-of-gravity locations a range of fixed elevator deflections of more than 15° was available for stable take-offs.
2. The peak lower trim limit of stability, which occurred at about 50 percent of take-off speed, was high (11.3). However, trims obtainable were great enough to permit operating above the lower trim limit and no upper trim limit of stability was found.
3. The resistance was higher than for conventional hulls; however, it was not greatly different from the resistance of single-float seaplanes (hump load - resistance ratio = 3.6).
4. The relatively high operating trims and the chine strips compensated for the extra load thrown on the forebody by the very small "afterbody" to such an extent that the propellers located in a conventional location were struck by only light spray.
5. Stable landings were obtainable only in the aft range of the center-of-gravity locations investigated. There are, however, indications

that modifications of the after part of the vertical chine strips will improve landing stability.

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2. Suydam, Henry B.: Hydrodynamic Characteristics of a Low-Drag, Planing-Tail Flying-Boat Hull. NACA RM No. L7I10, 1947.
3. Riebe, John M., and Naeseth, Rodger L.: Aerodynamic Characteristics of a Refined Deep-Step Planing-Tail Flying-Boat Hull with Various Forebody and Afterbody Shapes. NACA RM No. L8F01, 1948.
4. Wadlin, Kenneth L.: Preliminary Tank Experiments with a Hydrofoil on a Planing-Tail Seaplane Hull. NACA RB No. L4C28, 1944.
5. Dawson, John R., and Walter, Robert C.: The Effects of Various Parameters on the Load at Which Spray Enters the Propellers of a Flying Boat. NACA TN No. 1056, 1946.

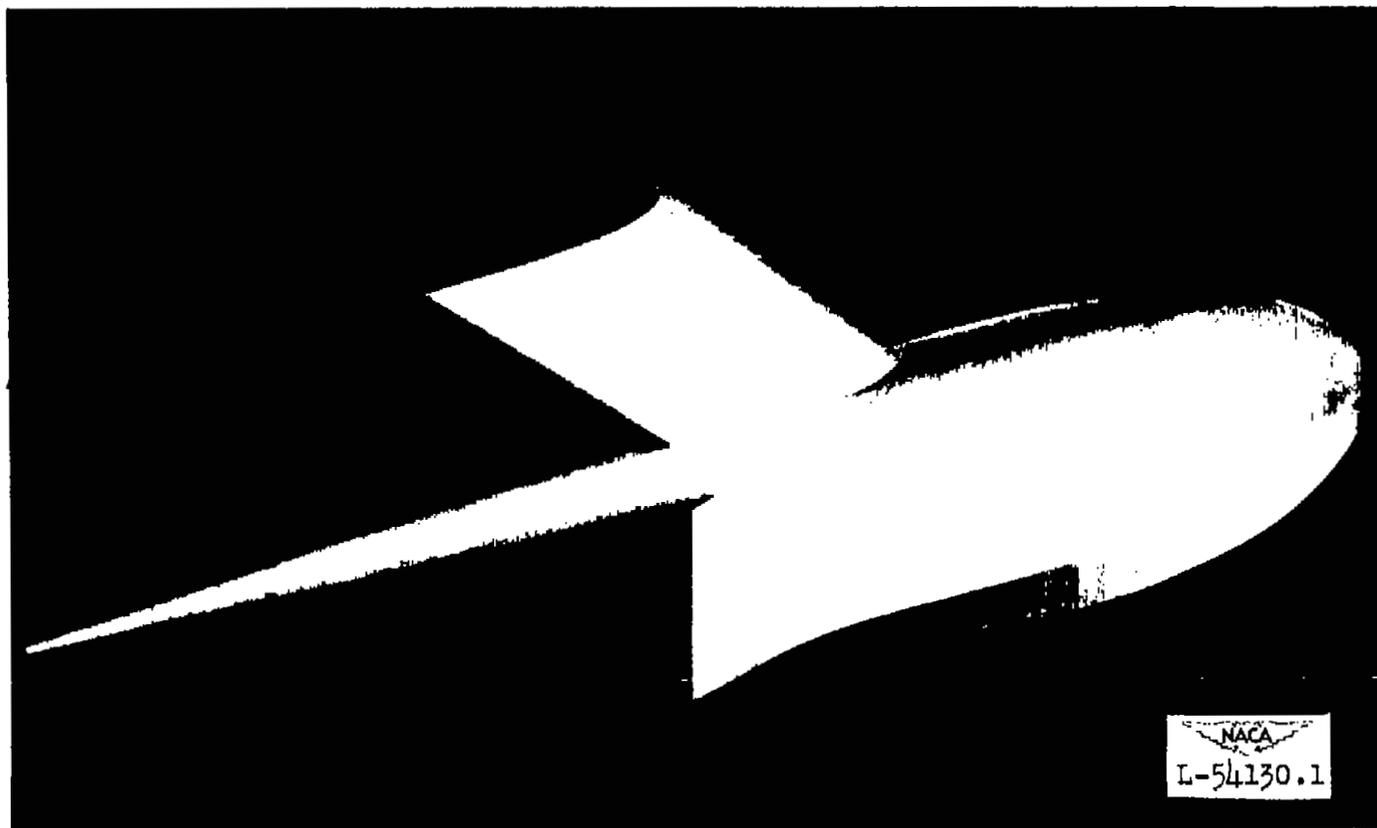
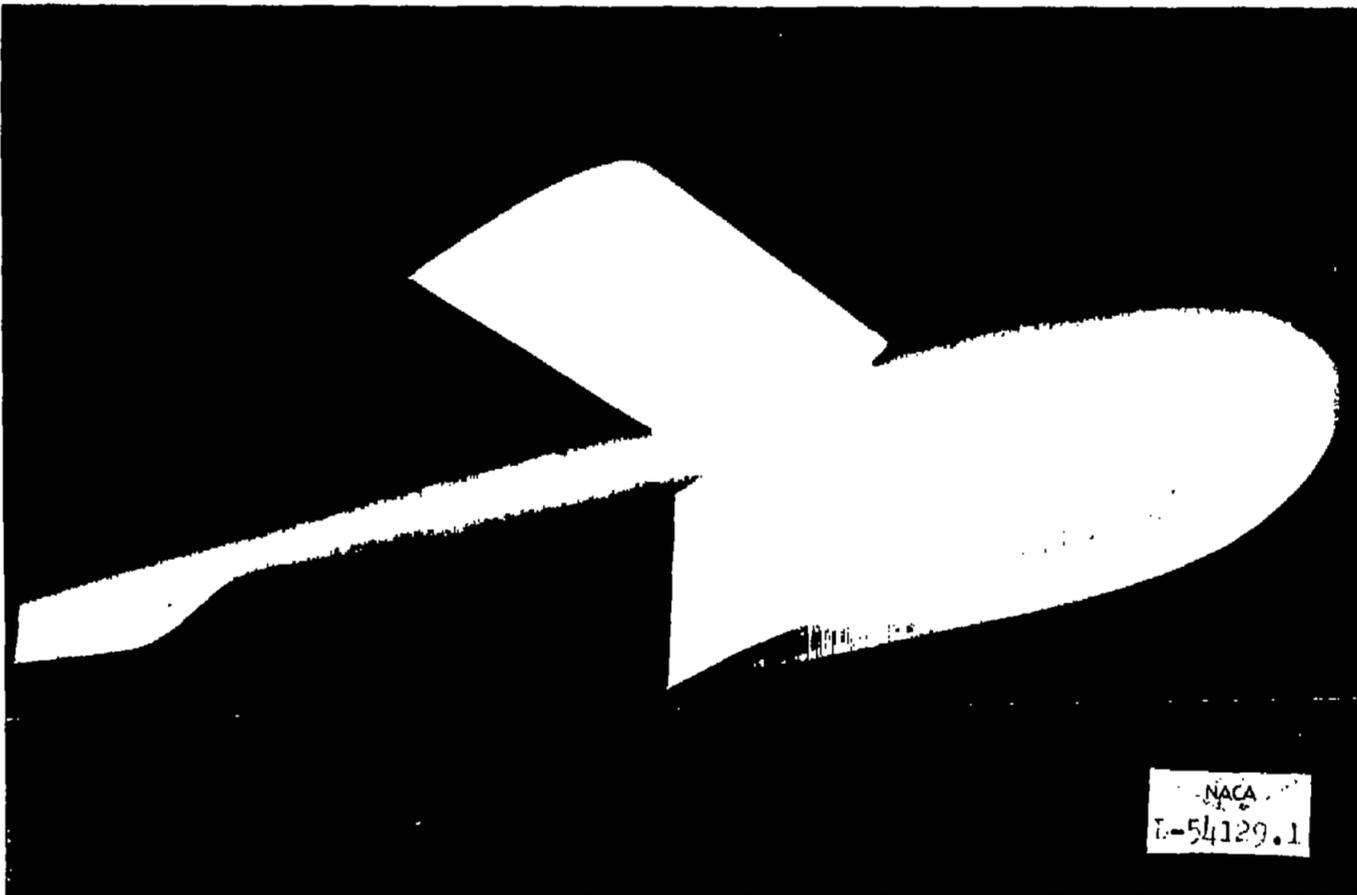


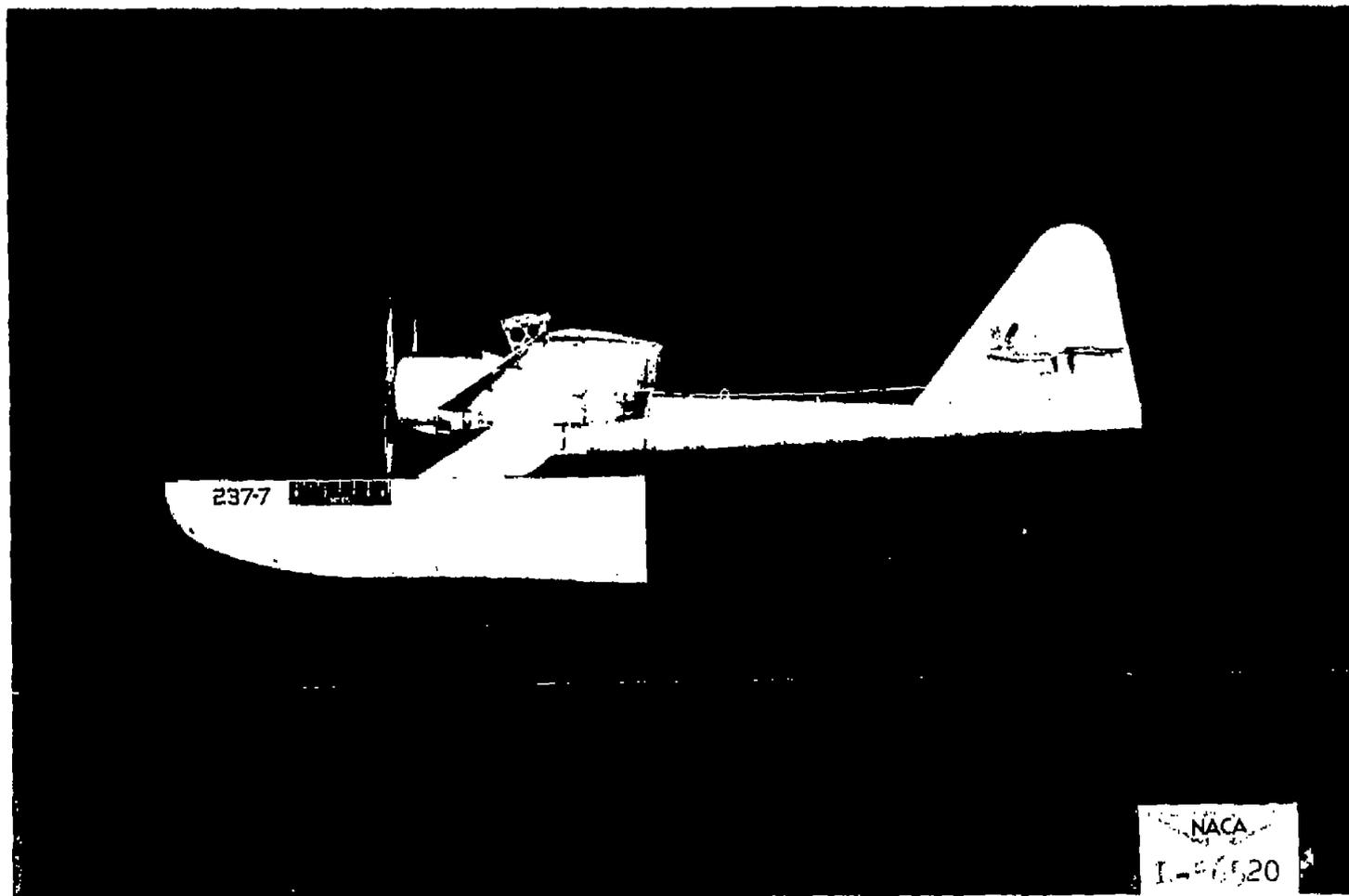
Figure 1.- Wind-tunnel model with conical boom. Model 237-7B.



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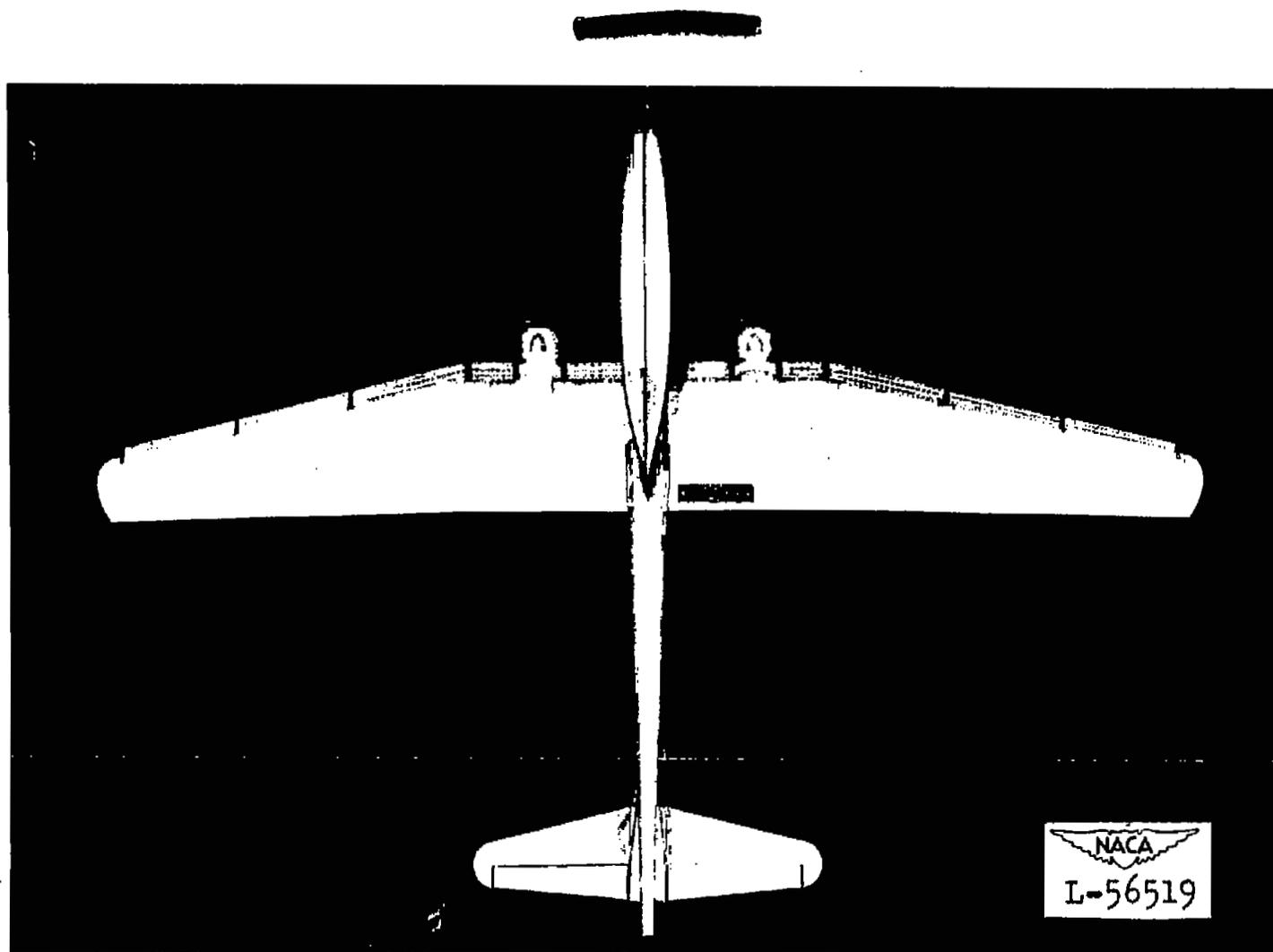
Figure 2. -- Wind-tunnel model with tail float. Model 237-7F1.

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Figure 3.- Profile view of NACA dynamic model 237-7B.



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Figure 4.- Bottom view of NACA dynamic model 287-7B.

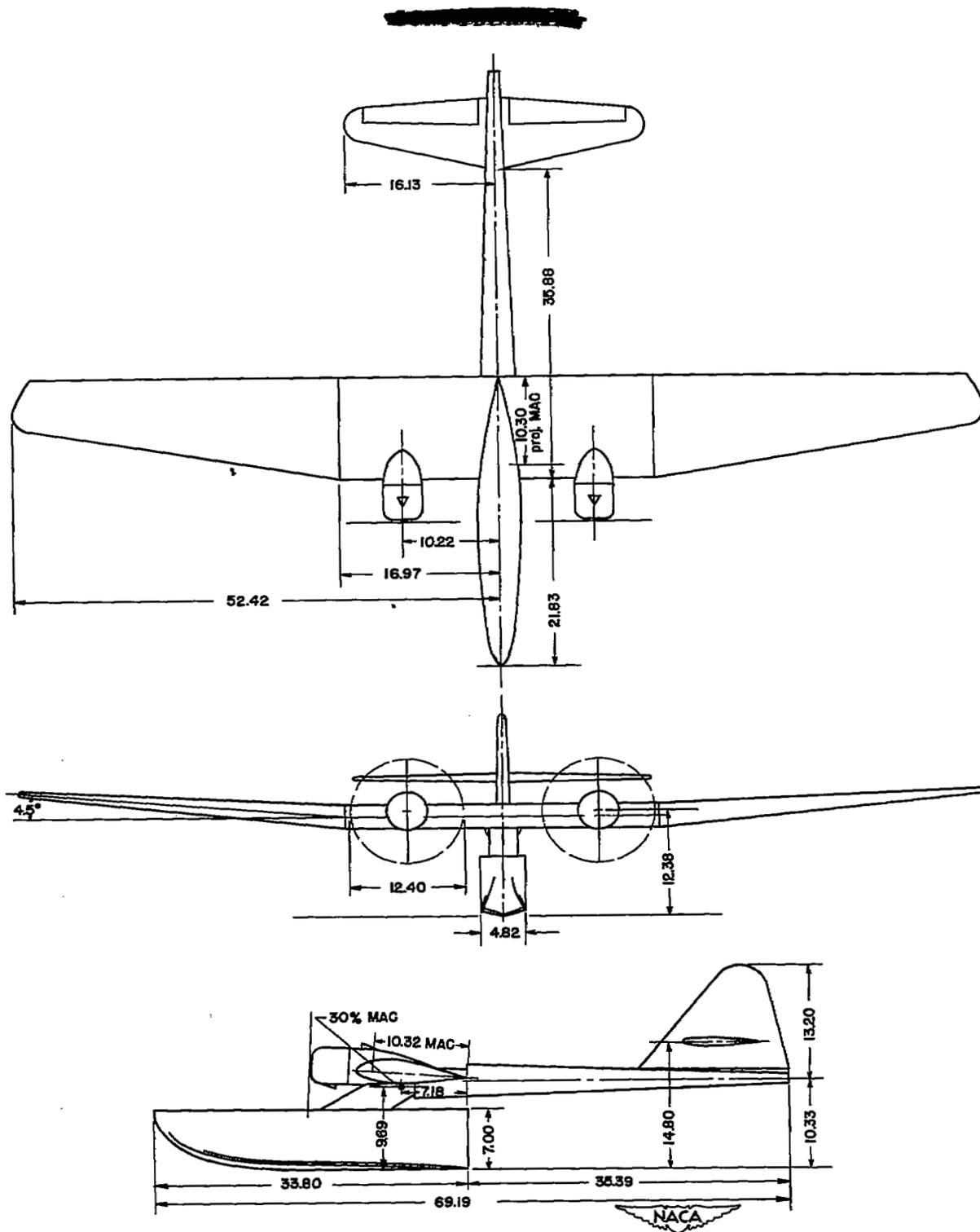


Figure 5.- General arrangement of model 237-7B.

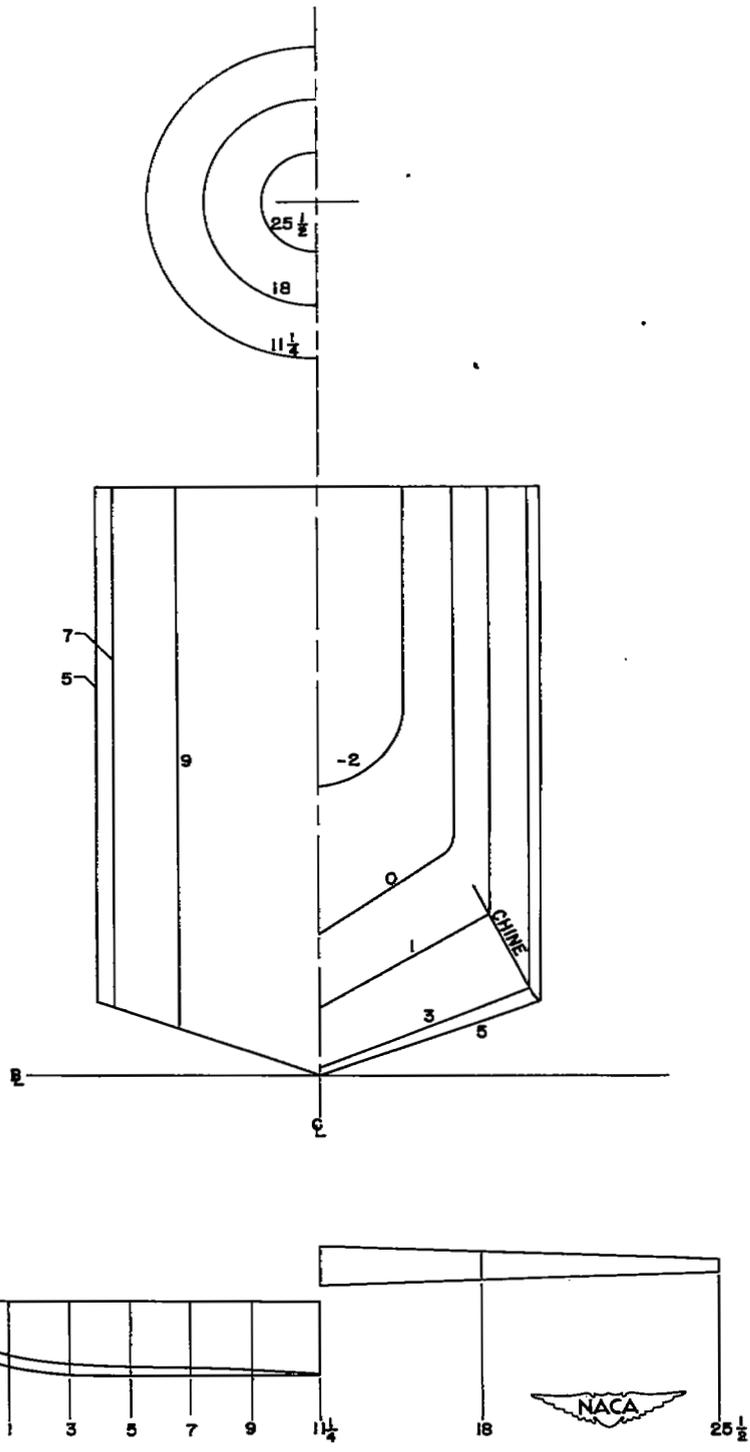


Figure 6.-Hull lines of NACA model 237-7B.

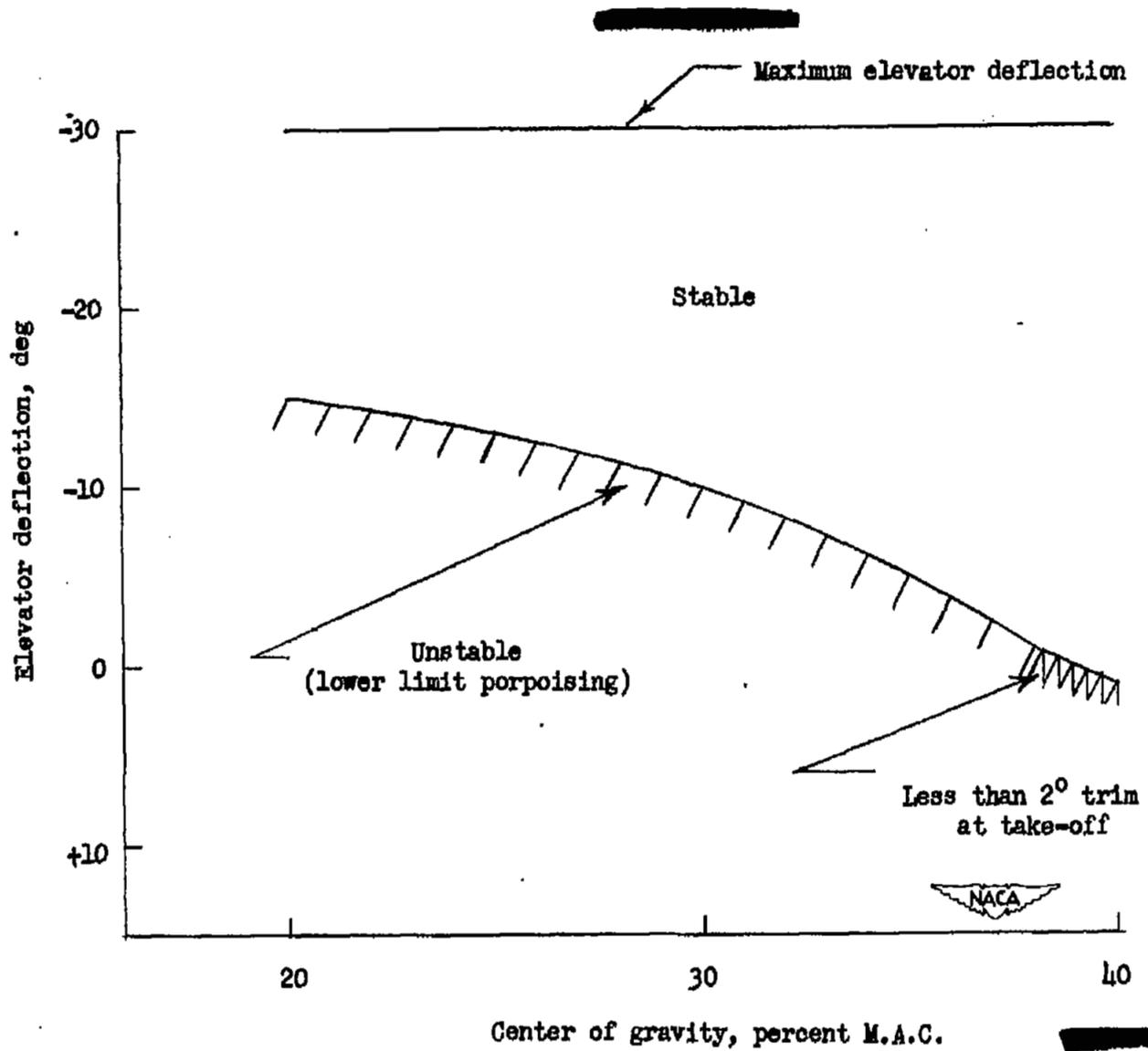


Figure 7.- Center-of-gravity limits of stability. Gross load coefficient, 3.87; full power.

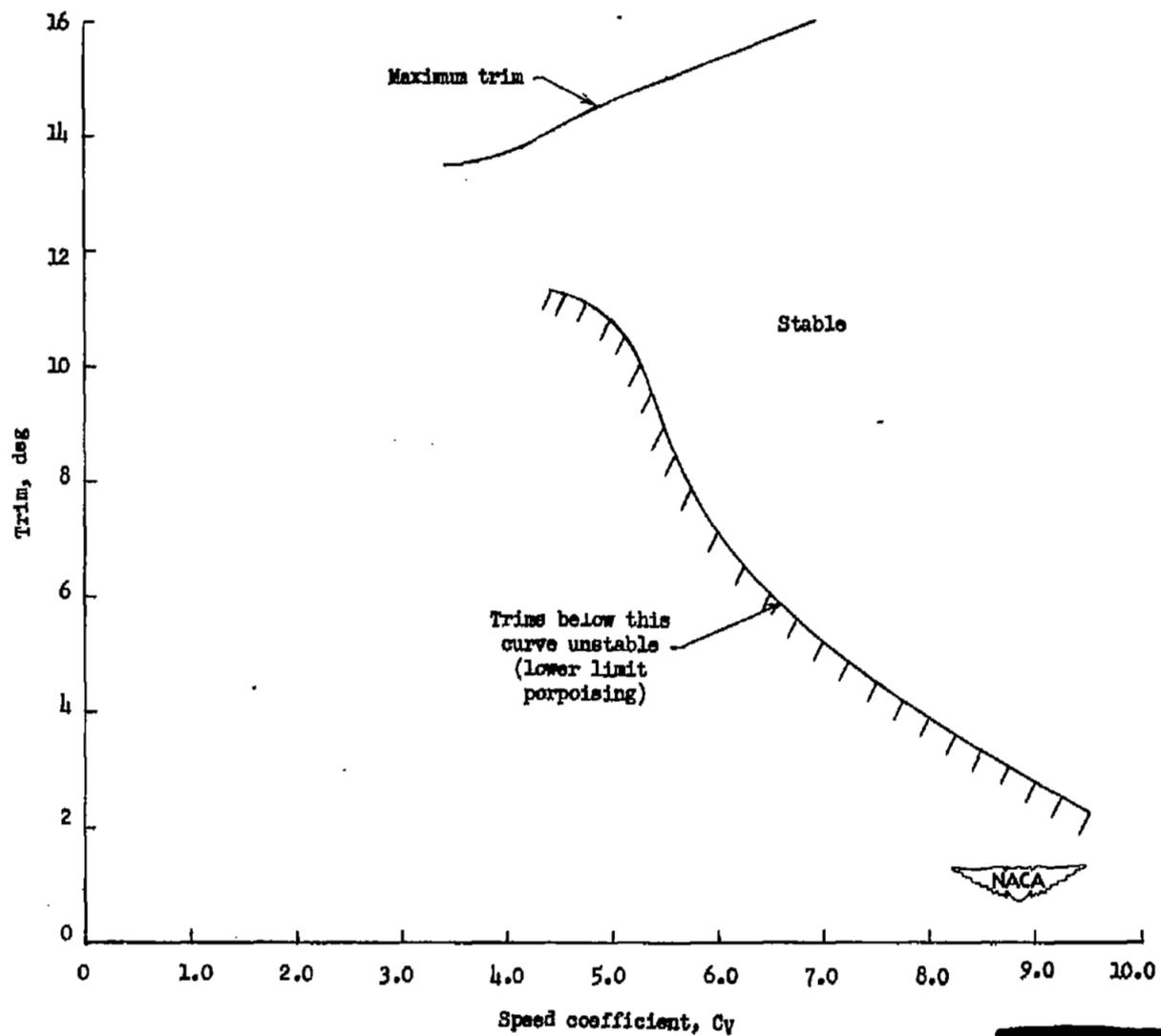
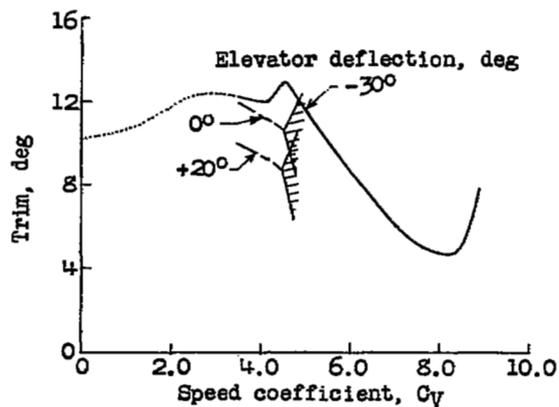
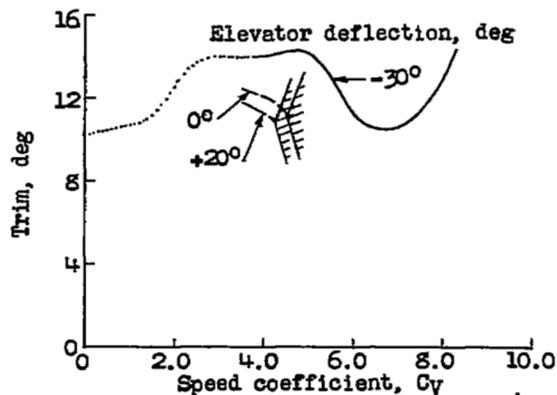


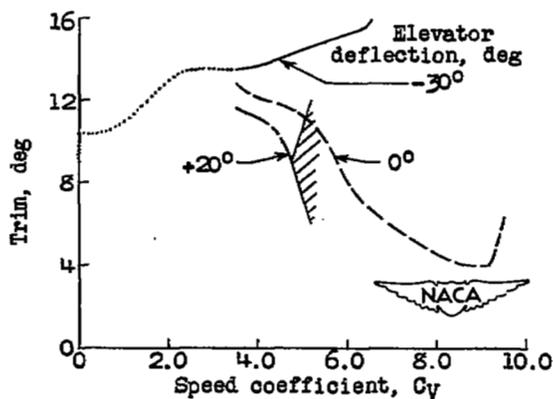
Figure 8.- Trim limits of stability.



(a) C.G., 20 percent M.A.C.

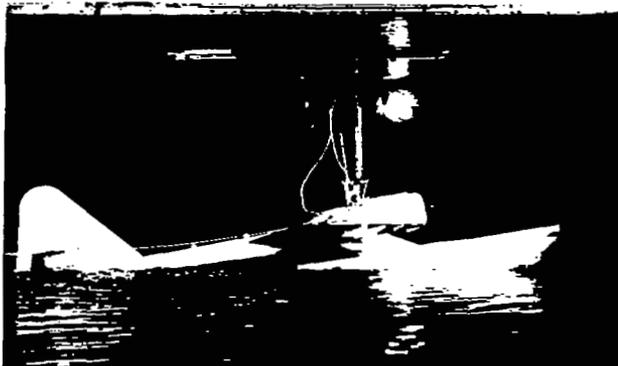


(b) C.G., 30 percent M.A.C.

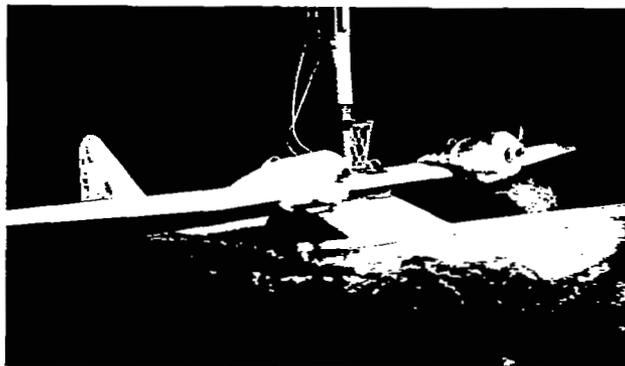


(c) C.G., 40 percent M.A.C.

Figure 9.- Trim tracks.



(a) $C_y = 0$; trim = 10.2°



(b) $C_y = 1.94$; trim = 11.4°



(c) $C_y = 3.62$; trim = 12.4°



(d) $C_y = 8.35$; trim = 2.9°
(porpoising)

Figure 10.- Photographs of model being tested. Full power; gross load coefficient, 3.87.

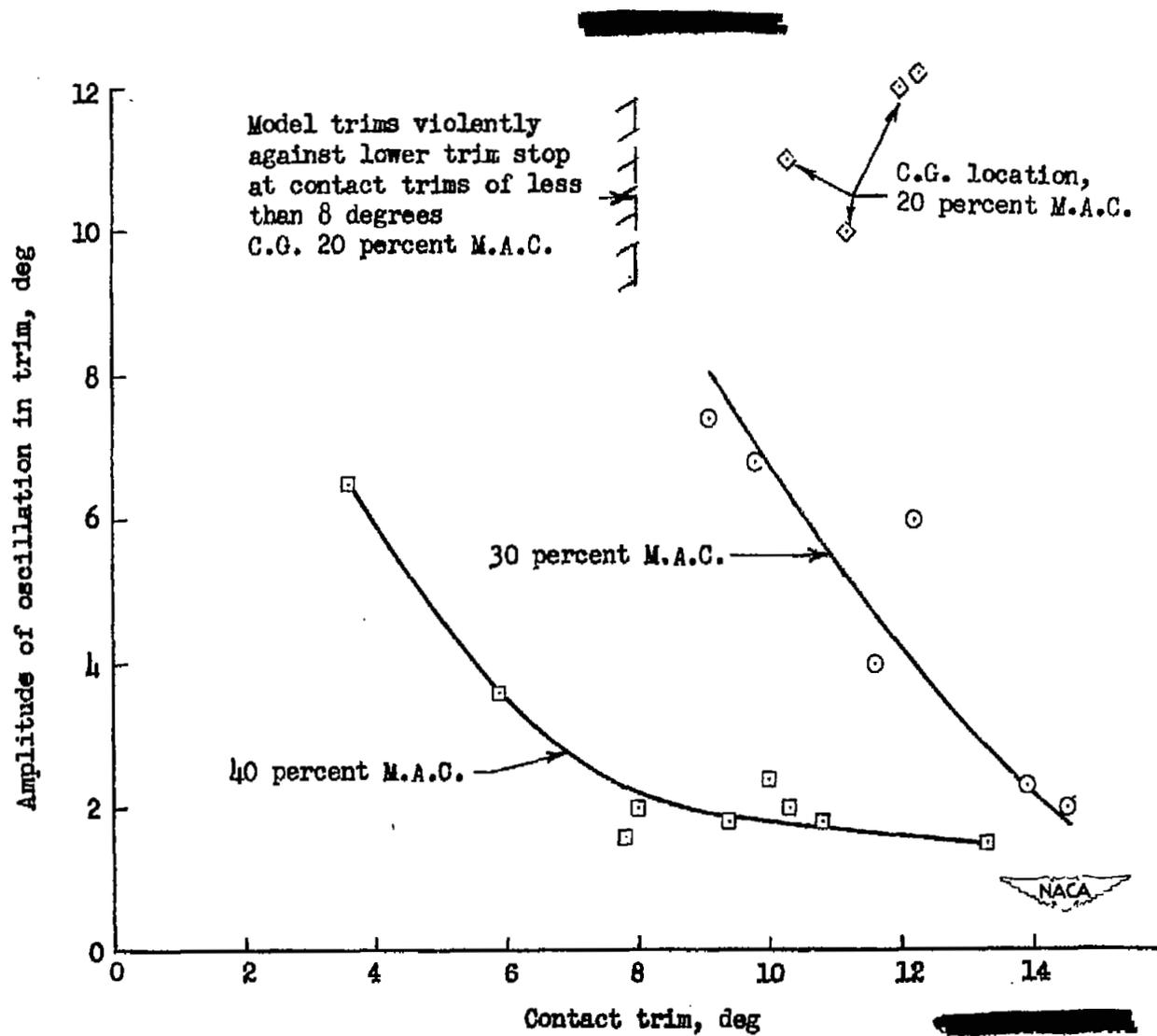


Figure 11.- Amplitudes of trim oscillations in landings.

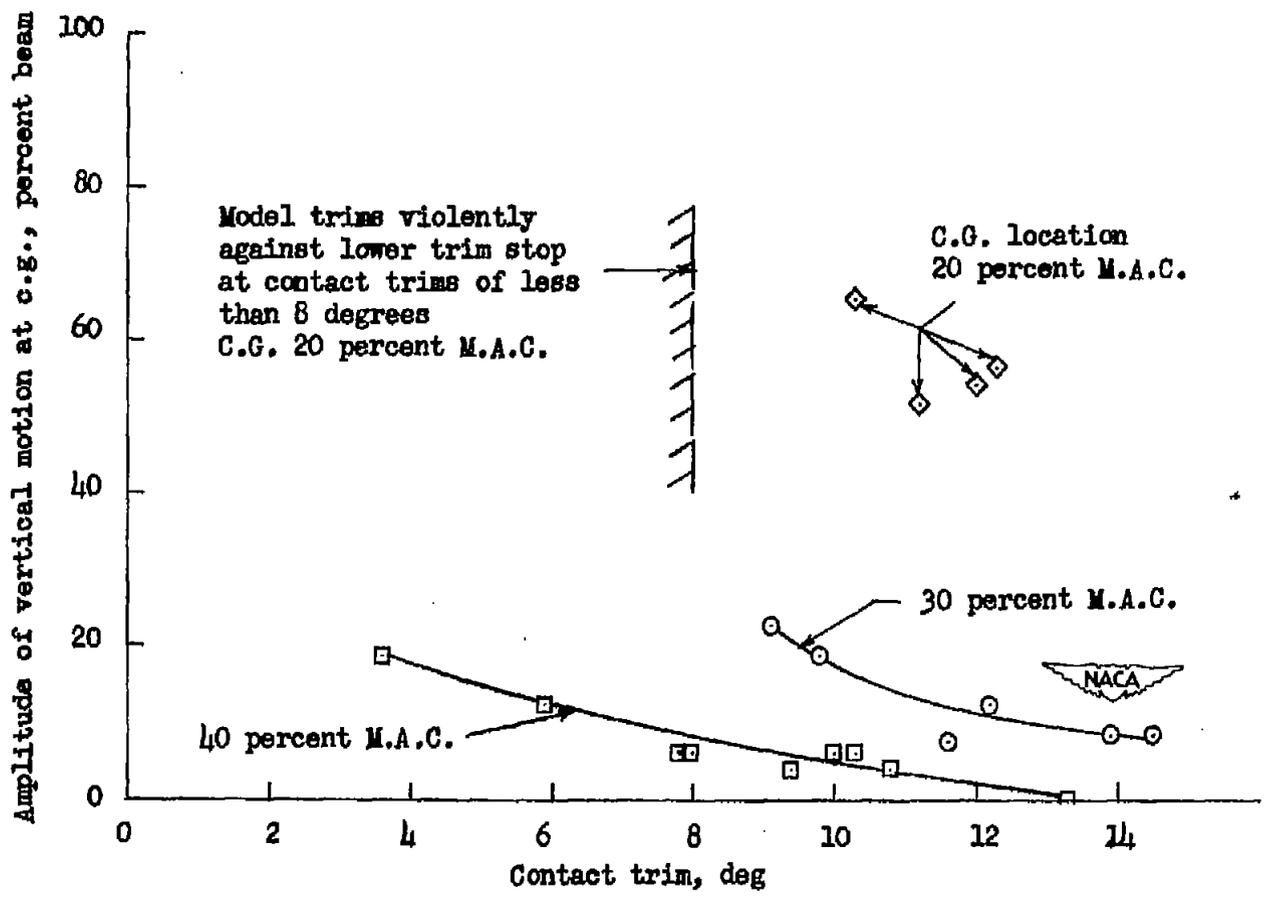


Figure 12.- Amplitudes of vertical motions in landings.

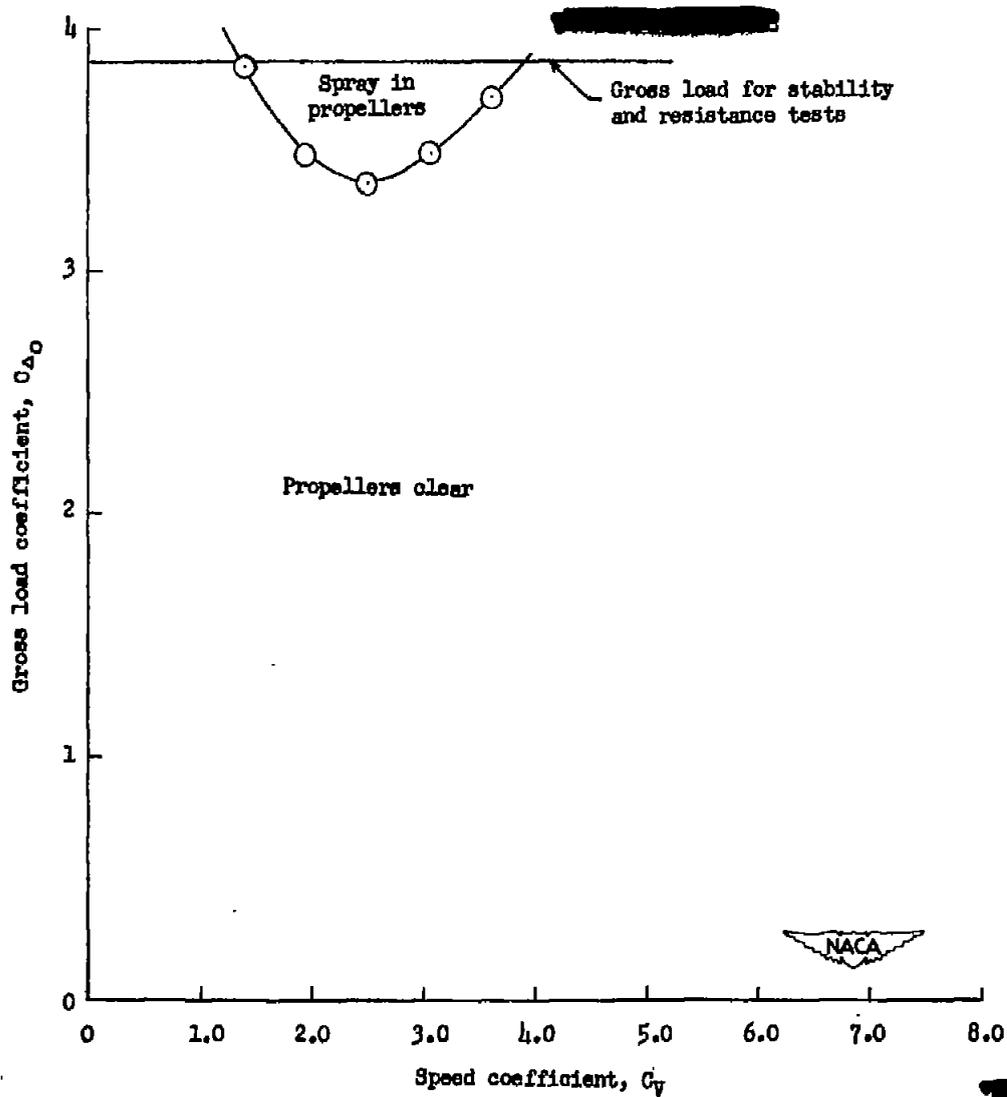


Figure 13.- Gross load coefficient at which spray entered propellers.

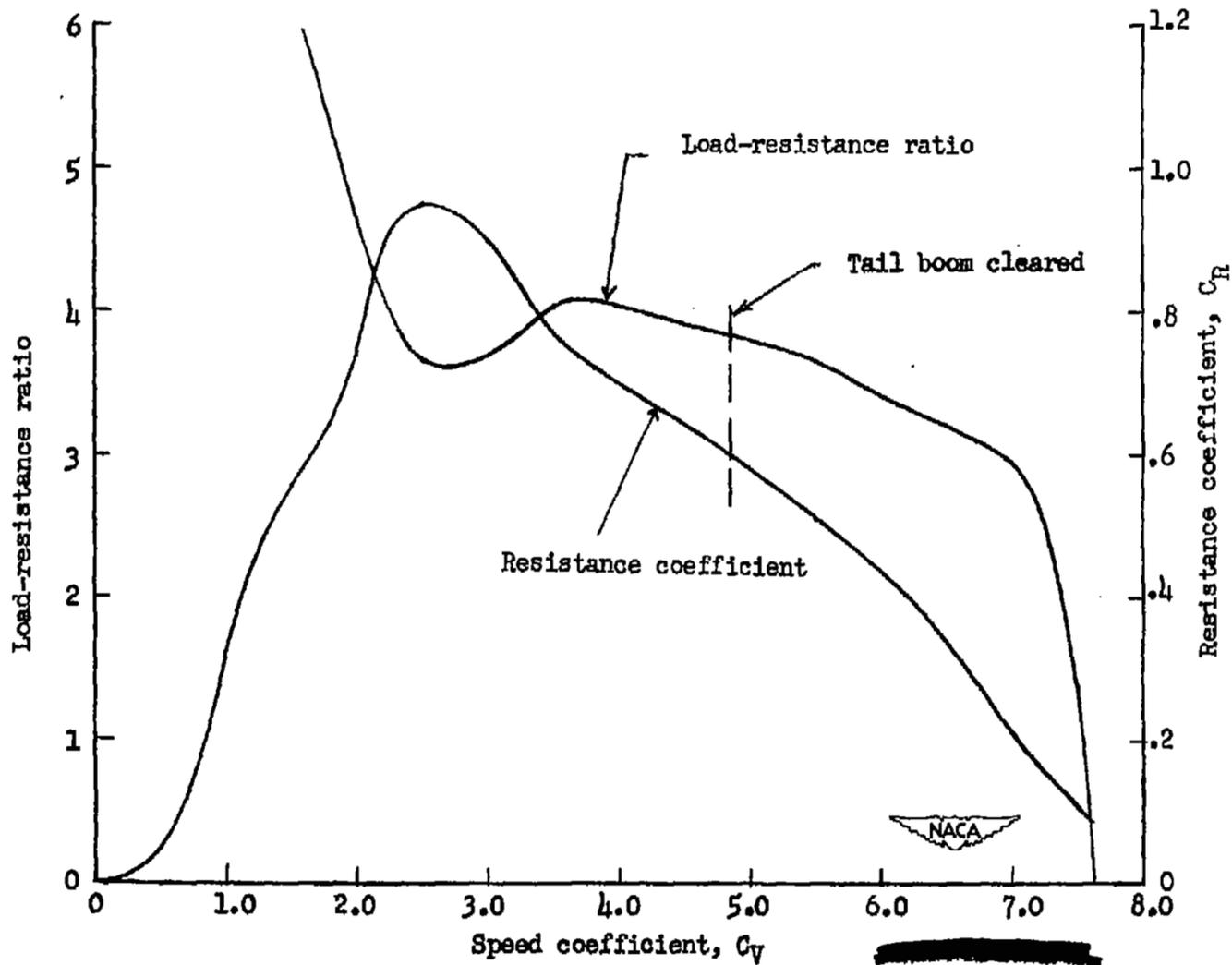


Figure 14.- Resistance coefficient and load-resistance ratio.

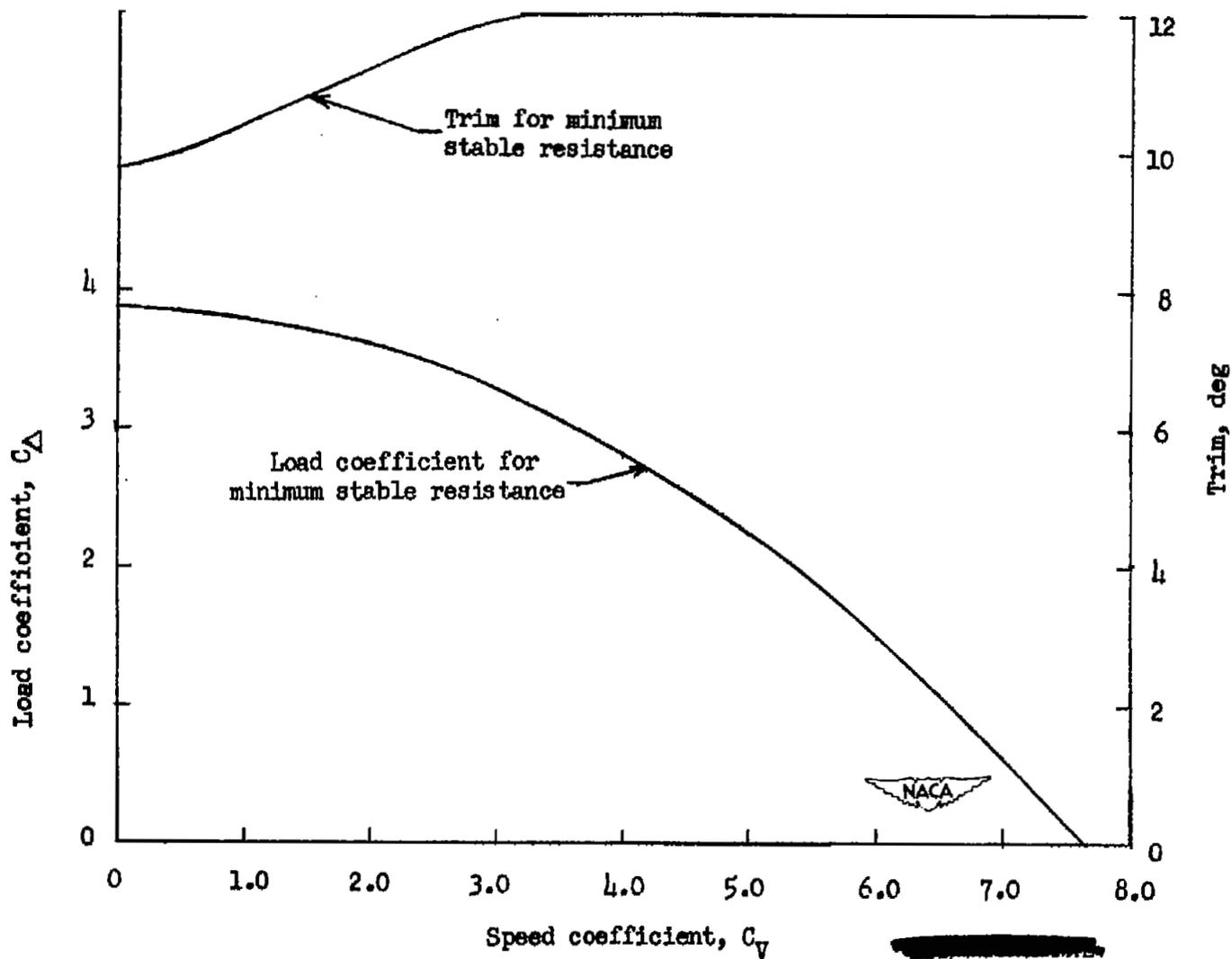


Figure 15.- Trim and load coefficient.

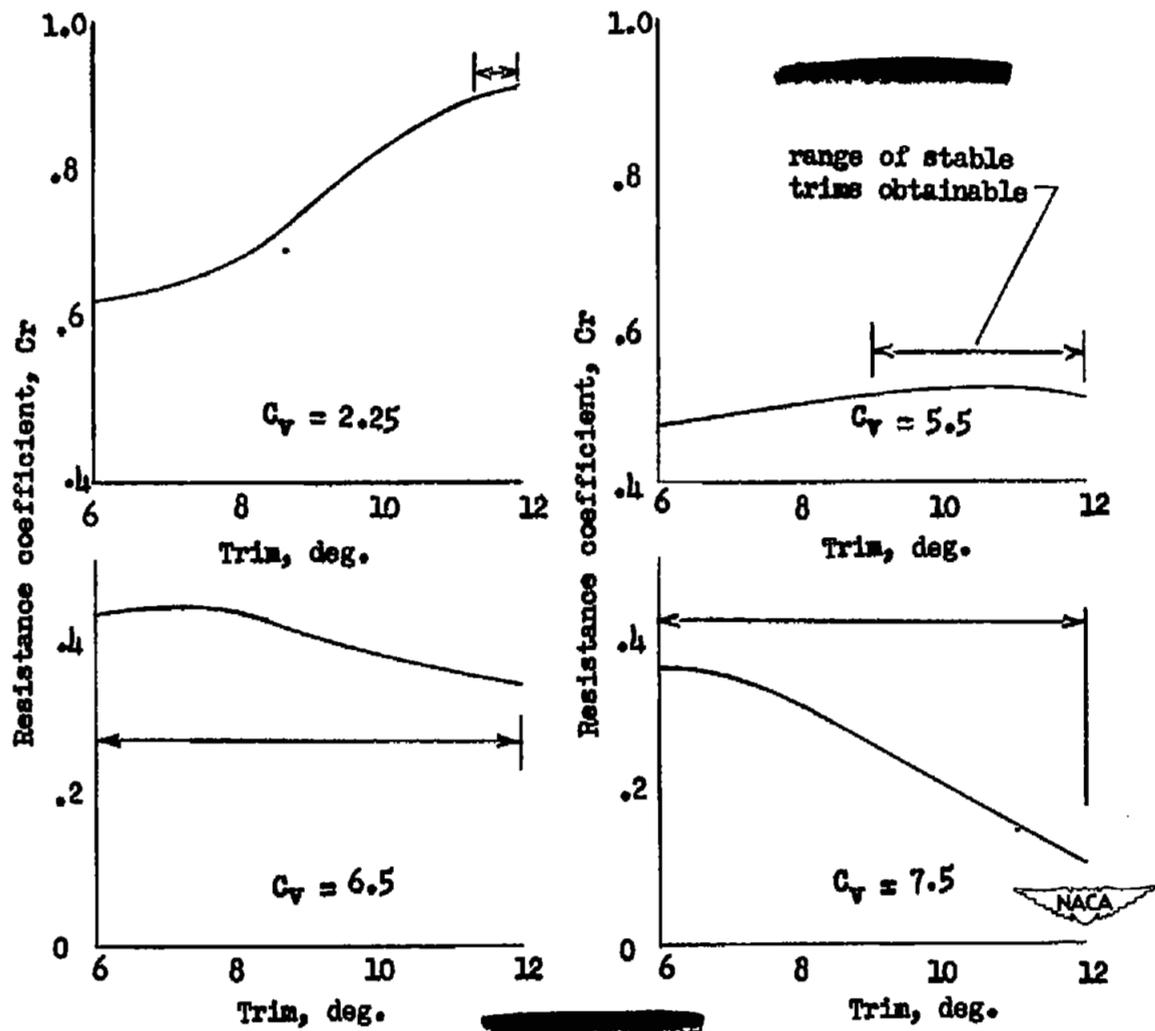


Figure 16.- Variation of resistance coefficient with trim (load varied to correspond to the change in wing lift with trim).

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ABSTRACT

The hydrodynamic characteristics of an aerodynamically refined planing-tail hull were determined from dynamic model tests in Langley tank no. 2. Stable take-offs could be made for a wide range of locations of the center of gravity. The lower porpoising limit peak was high, but no upper limit was encountered. Resistance was high, being about the same as that of float seaplanes. A reasonable range of trims for stable landings was available only in the aft range of center-of-gravity locations.