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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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HYDRODYNAMIC QUALITIES OF A HYPOTHETICAL FLYING BOAT WITH A LOW-DRAG HULL HAVING A LENGTH-BEAM RATIO OF 15

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SUMMARY

An investigation of the hydrodynamic qualities of a hypothetical flying boat with a hull having a length-beam ratio of 15 was made in Langley tank no. 1. The flying boat had a design gross weight of 75,000 pounds, a gross load coefficient 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 hull was designed to meet advanced requirements for increased speed and increased range for flying-boat designs and has been shown to have low drag in the Langley 300 MPH 7- by 10-foot tunnel.

The longitudinal stability during take-off was satisfactory, a range of position of the center of gravity of 10 percent mean aerodynamic chord being available for take-off with fixed elevators. Stable landings were made without porpoising at landing trims below 10°; the depth of step of 16.5 percent beam was adequate to avoid skipping during landings. Spray entering the propellers and striking the flaps appeared acceptable; spray from the forebody striking the tail surfaces at high speeds during landing might necessitate raising the horizontal tail. The water resistance and take-off time and distance were approximately the same as for the more conventional hull length-beam ratio of 6. The take-off time and distance were 21 seconds and 1530 feet, respectively. The hydrodynamic qualities are satisfactory and do not differ greatly from those of the related flying boat with the more conventional hull length-beam ratio of 6.

INTRODUCTION

As part of a general investigation of the effect of hull length-beam ratio on the aerodynamic and hydrodynamic characteristics of flying boats, the hydrodynamic qualities of a hypothetical flying boat having a hull with a length-beam ratio of 15 have been determined. This hull is one of a related series with different length-beam ratios designed to have similar resistance and spray characteristics for the same gross weight and to be physically interchangeable on the hypothetical-seaplane design. All the hulls have the same length^2-beam product and, therefore, become longer and narrower as the length-beam ratio is increased. Increasing the length-beam ratio in this manner resulted in a 28-percent reduction in volume and a 42-percent reduction in frontal area when the length-beam ratio was increased from 6 to 15.

The wind-tunnel investigation of the series of hulls (reference 1) has shown that the minimum aerodynamic drag of the hull with a length-beam ratio of 15 is 29 percent less than the drag of the hull with a length-beam ratio of 6. This hull is therefore of particular interest in the design of high-performance flying boats. The low thickness ratio corresponding to the high length-beam ratio is also of basic importance for flight at high Mach numbers.

The hypothetical-seaplane design is a twin-engine propeller-driven flying boat having a design gross weight of 75,000 pounds, a gross load coefficient 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 2) determined in the investigation were the range of position of the center of gravity for take-off, landing stability, spray characteristics, and take-off performance. These qualities were determined from tests of a $\frac{1}{10}$-size powered dynamic model in Langley tank no. 1. In order to provide a basis for comparison with conventional proportions, the same qualities were determined for the model of the series with the hull having a length-beam ratio of 6.

SYMBOLS

C_{Δ_o}	gross load coefficient $\left(\Delta_o/wb^3\right)$
C_L	aerodynamic lift coefficient $\left(\text{Lift}/\frac{1}{2}\rho V^2 S\right)$
C_m	aerodynamic pitching-moment coefficient $\left(M/\frac{1}{2}\rho V^2 S\bar{c}\right)$
Δ_o/P	power loading, pounds per brake horsepower
Δ_o/S	wing loading, pounds per square foot
T_e	effective thrust, pounds $(T - \Delta D = D_c + R)$
a	longitudinal acceleration, feet per second per second
g	acceleration due to gravity (32.2 ft/sec^2)

b maximum beam of hull, feet

$\bar{c}$ mean aerodynamic chord (M.A.C.), feet

D_c drag of model without propellers, pounds

L length of hydrodynamic surfaces (distance from forward perpendicular (F.P.) to sternpost (S.P.)), feet

M aerodynamic pitching moment, foot-pounds

P power, brake horsepower

R resultant horizontal force with power on, pounds

S wing area, square feet

T propeller thrust, pounds

V carriage speed (approx. 95 percent of airspeed), feet per second

w specific weight of water (63.3 for these tests, usually taken as 64 for sea water), pounds per cubic foot

δ_e elevator deflection, degrees

δ_f flap deflection, degrees

ΔD increase in body drag due to slipstream, pounds

Δ_o gross load, pounds

ρ density of air, slugs per cubic foot

τ trim (angle between forebody keel at step and horizontal), degrees

τ_L landing trim, degrees

DESCRIPTION OF MODELS AND APPARATUS

The form, size, and relative locations of the aerodynamic surfaces of the $\frac{1}{10}$-size powered dynamic models corresponded to those of a Navy twin-engine flying boat. The model having a hull length-beam ratio of 15 was designated Langley tank model 224 (fig. 1(a)). The model having a hull length-beam ratio of 6 was designated Langley tank model 213 (fig. 1(b)). The length used for determining the length-beam ratio is the distance from the forward perpendicular (F.P.) to the sternpost (S.P.).

The hulls have the same depth of step, position of the step relative to the mean aerodynamic chord, maximum depth of hull, ratio of forebody to afterbody length, and length^2-beam product. A detailed description of the hulls is given in reference 1. For convenience in making changes to the afterbodies, the fairing after the sternpost (reference 1) was omitted from the tank models and a slight modification was made to the sides of the afterbodies above the chine. These changes would have a negligible effect on the hydrodynamic characteristics.

Photographs of the models and lines of the hulls are shown as figures 1 and 2, respectively. The general arrangement of the flying boat is shown as figure 3. Offsets of the hulls are given in reference 1. Pertinent characteristics and dimensions of the flying boats are given in table I.

The models were powered with three-blade metal propellers driven by two variable-frequency motors. Slats were attached to the leading edge of the wing in order to delay the stall to an angle of attack more nearly equal to that of the full-size airplane. The pitching moment of inertia of the ballasted models was 6.8 and 5.8 slug-feet square for length-beam ratios of 15 and 6, respectively.

The investigation was made in Langley tank no. 1, which is described in reference 3. The apparatus used for the towing of powered dynamic models is described in reference 4. The models were free to trim about the pivot, which was located at the center of gravity, and were free to move vertically but were restrained in roll and yaw. The towing gear was connected to a spring balance which measured the horizontal force.

PROCEDURES

Aerodynamic

Effective thrust.- The effective thrust, defined as the actual propeller thrust in the presence of a body minus the increase in body drag due to slipstream, was determined at various speeds from rest to take-off for the model having a hull length-beam ratio of 15. The model was supported in the air so that its center of gravity was 3.4 beams above the water. The effective thrust was determined at the following conditions: $\tau = 0^{\circ}$, $\delta_f = 20^{\circ}$, and $\delta_e = 0^{\circ}$. The effective thrust was calculated from the relation

$$T_e = T - \Delta D = D_c + R$$

This effective thrust, converted to full-size units, is plotted against speed in figure 4.

Aerodynamic lift and pitching moment.- In order to provide data from which the load on the water can be approximated, the aerodynamic lift and pitching moment with full thrust were determined with the flaps deflected 20°. The lift and pitching-moment data were determined at various speeds and trims with the model in the air in the same position as for the determination of the thrust. The center of moments was located at 24 percent mean aerodynamic chord. The results, converted to full-size units, are presented in figure 5. Aerodynamic lift and pitching-moment coefficients at a speed of 86 miles per hour (full size) are plotted against trim in figure 6. The results include the ground effect due to the proximity of the water.

Hydrodynamic

The determination of the hydrodynamic qualities was made at the design gross load corresponding to 75,000 pounds, except for the spray investigation in which the gross loads corresponded to loads from 45,000 pounds to 85,000 pounds. The flaps were deflected 20° for all the hydrodynamic tests. The results have been converted to full-size units and all data are presented as full-size values.

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.

Trim limits of stability.- The trim limits of stability were determined at constant speeds by use of the methods described in reference 4. 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.

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. The towing carriage was then decelerated at a uniform rate of 2 feet per second per second, which allowed the model to glide onto the water and simulate an actual landing. The sinking speeds ranged from 75 to 150 feet per minute (full size). 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 of 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 models 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.

RESULTS AND DISCUSSION

Longitudinal Stability

Center-of-gravity limits of stability.- Representative trim tracks for a length-beam ratio of 15 are presented in figure 7(a) for several positions of the center of gravity and elevator deflections. Comparable trim tracks for a length-beam ratio of 6 are presented in figure 7(b). In figure 8 the maximum amplitudes of porpoising that occurred during take-off are plotted against position of the center of gravity. 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.

With the length-beam ratio of 15, the amplitude of lower-limit porpoising increased rapidly with forward movement of the center of gravity (fig. 8(a)). A forward movement of the center of gravity of 4 percent mean aerodynamic chord caused the amplitude to increase from 0° to 11°. The comparable increase in amplitude of lower-limit porpoising for the length-beam ratio of 6 (fig. 8(b)) was less rapid.

At after positions of the center of gravity the amplitude of upper-limit porpoising increased less rapidly for the length-beam ratio of 15 than for the length-beam ratio of 6 (fig. 8). The longer afterbody for the hull with the high length-beam ratio apparently was effective in damping the oscillation in trim. This oscillation with the hull of high length-beam ratio did not exceed $2\frac{1}{2}^{\circ}$ at the most after position of the center of gravity.

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. With the high length-beam ratio, the range of stable center-of-gravity position is approximately $2\frac{1}{2}$ percent mean aerodynamic chord less than that for the low length-beam ratio. There is, however, a wide practicable range of position for satisfactory take-off (10 percent M.A.C. with elevators deflected -10°) of the hull having the length-beam ratio of 15, and the take-off stability of that hull is considered satisfactory. With the power available in the hypothetical airplane, the acceleration would be several times that used in the tests. Tests of other models have indicated that an increase in acceleration tends to move the forward center-of-gravity limit forward and the after limit aft with a resultant small increase in the stable range; consequently, the take-off stability shown in figure 9 is probably conservative for the flying boat.

Trim limits of stability.- The trim limits are not in themselves significant hydrodynamic qualities because the actual instability encountered during take-off or landing depends on the relation of the trim limits to the trim tracks of the flying boat. The trim limits, however, are of interest in that they define the stable range of trim between the upper and lower trim limits.

The trim limits of stability are presented in figure 10. The upper limit, increasing trim, was almost the same for both length-beam ratios. At high speeds the effect of length-beam ratio on the upper limit, decreasing trim, was small. The lower limit for the high length-beam ratio was shifted bodily to higher speeds. This shift, approximately 15 miles per hour, appreciably reduced the range of stable trim between the lower limit and the upper limit, increasing trim. The hydrodynamic moments apparently were changed by the increase in length-beam ratio in such a manner that this reduction in the range of stable trim had little effect on the range of stable position of the center of gravity.

Between 52 and 70 miles per hour, the upper and lower trim limits for the length-beam ratio of 15 are very close together. When constant-speed tests were made in this speed range, porpoising of the model could be allowed to build up to such a large amplitude that the model porpoised across both the upper and lower limits. Under such conditions, recovery from this violent porpoising by use of the elevators was not possible. Similar behavior has been noted for models of flying boats with hulls of conventional length-beam ratios and is therefore not attributed solely to the high length-beam ratio. During accelerated take-offs, this violent porpoising was encountered only at center-of-gravity positions that were definitely forward of the forward center-of-gravity limit. In actual flying-boat take-offs, operation at center-of-gravity positions and elevator deflections which would result in exceeding the forward center-of-gravity limit (thereby encountering instability) would be such an abnormal maneuver that the violent porpoising thus encountered is not considered to be too greatly significant in the evaluation of the longitudinal stability during take-off.

Landing stability.- Several typical time histories of landings with the two hulls are presented in figure 11. 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 first contact in figure 12.

The hull having the high length-beam ratio did not skip on first contact at any contact trim investigated, which indicated that the depth of step (16.5 percent beam) provided sufficient ventilation. At contact trims up to 6.9° (the sternpost angle) the amplitude of oscillation, both in trim and rise, was very small and was of approximately a constant amplitude. At trims between 6.9° and 10° the sternpost entered the water first and caused a slight increase in the amplitude of the trim oscillation, which damped out after one or two cycles. At contact trims above 10°, upper-limit porpoising was encountered as a consequence of landing above the upper limit of stability.

In comparison, the landing data for the hull of low length-beam ratio indicate similar trends. This hull also had no tendency to skip during landing. At contact trims up to 10°, the trim and rise oscillations were small. Above contact trims of 10°, porpoising was encountered, but this porpoising was less severe than that encountered for the hull of high length-beam ratio. In normal seaplane operations, however, landings at trims greater than 10° would be avoided because of the danger of reaching a stalled attitude.

Spray Characteristics

Spray ranges 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 13 for both hulls. With the length-beam ratio of 6, the heavy (blister) spray entered the propellers and struck the flaps at a lower gross load than with the length-beam ratio of 15. As the gross load was increased, the speed ranges over which the heavy spray entered the propellers or struck the flaps became slightly greater for the hull of high length-beam ratio.

Spray photographs.- Photographs of spray which entered the propellers at the design gross load of 75,000 pounds are presented as figures 14(a) and 14(b) for the length-beam ratios of 15 and 6, respectively. Photographs of the spray which struck the flaps are presented as figure 15. These photographs cover the speed ranges of figure 13 in which heavy spray is involved. The spray entering the propellers or striking the flaps at the gross load of 75,000 pounds did not differ greatly for the two hulls. Based on the observation of the spray characteristics of a large number of models of successful conventional flying boats, the spray entering the propellers or striking the flaps at the gross load of 75,000 pounds was acceptable.

Photographs of spray striking the tail surfaces during a landing run (one-half take-off thrust) are presented as figure 16. The spray from the forebody struck the horizontal tail surfaces at high speeds (above 38 mph) for the hull of high length-beam ratio. This spray might necessitate raising the horizontal tail. For the length-beam ratio of 6, the horizontal tail was relatively clear of spray.

Take-Off Performance

Excess thrust.- The excess thrust and trim during take-off with full thrust are presented in figure 17. The curves shown 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 limit of stability.

Comparison of the excess thrust for the two length-beam ratios indicates that the water resistance is approximately the same. The maximum trims are also about the same although the speed at which they occur is considerably higher for the hull of high length-beam ratio than for the hull of low length-beam ratio.

Longitudinal acceleration.- The variations of longitudinal acceleration during take-off a, $1/a$, and V/a are plotted against speed in figure 18. These quantities were derived from the excess-thrust curves of figure 17 by use of the relationship

$$a = \frac{Tg}{\Delta_o}$$

Take-off time and distance.- The take-off time is the area under the curve of $1/a$; the take-off distance is the area under the curve of V/a. The computed take-off time and distance for the length-beam ratio of 15 was 21 seconds and 1530 feet. In comparison, the computed take-off time and distance for the length-beam ratio of 6 was 22 seconds and 1600 feet. The over-all take-off performance of the low-drag hull is therefore approximately the same as that of the conventional hull.

Summary Chart

The hydrodynamic qualities of the hypothetical flying boat with the hull of low drag and high length-beam ratio, as determined by the powered-dynamic-model tests, are summarized in figure 19. This chart gives an over-all picture of the hydrodynamic characteristics in terms of full-scale operational parameters. It 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 hydrodynamic qualities of a hypothetical flying boat with a low-drag hull having a length-beam ratio of 15 at a gross load corresponding to 75,000 pounds (gross load coefficient of 5.88) indicate that the hydrodynamic qualities are satisfactory and do not differ greatly from those of the related flying boat with the more conventional hull length-beam ratio of 6 as indicated by the following:

1. A practicable range of position of the center of gravity (10 percent M.A.C. with elevators deflected -10°) was available for take-off.

2. Stable landings were made without encountering porpoising at landing trims below 10°. The depth of step of 16.5 percent beam was adequate to avoid skipping.

3. Spray entering the propellers and striking the flaps was acceptable. Spray from the forebody striking the tail surfaces at high speeds during landings might necessitate raising the horizontal tail.

4. The water resistance and the take-off time and distance were approximately the same as for the more conventional flying boat having a hull length-beam ratio of 6. The take-off time and distance were 21 seconds and 1530 feet, respectively.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., January 9, 1948

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3. Truscott, Starr: The Enlarged N.A.C.A. Tank, and Some of Its Work. NACA TM No. 918, 1939.

4. Olson, Roland E., and Land, Norman S.: Methods Used in the NACA Tank for the Investigation of the Longitudinal-Stability Characteristics of Models of Flying Boats. NACA Rep. No. 753, 1943.

TABLE I

PERTINENT CHARACTERISTICS AND DIMENSIONS OF FLYING BOATS

HAVING HULL LENGTH-BEAM RATIOS OF 15 AND 6

	$\frac{L}{b} = 15$	$\frac{L}{b} = 6$
General		
Design gross load, lb	75,000	75,000
Gross load coefficient, C_{Δ_0}	5.88	0.94
Wing area, sq ft	1826	1826
Take-off horsepower	6500	6500
Wing loading, Δ_0/S, lb/sq ft	41.1	41.1
Power loading, Δ_0/P, lb/hp	11.5	11.5
Hull		
Maximum beam, ft	5.84	10.76
Length:		
Forebody, bow to step, ft	50.4	37.1
Forebody length-beam ratio	8.6	3.5
Afterbody, step to sternpost, ft	37.2	27.4
Afterbody length-beam ratio	6.4	2.5
Tail extension, sternpost to aft perpendicular, ft	17.5	27.3
Over all, bow to aft perpendicular, ft	105.1	91.8
Step:		
Type	Transverse	Transverse
Depth at keel, in.	11.6	11.6
Depth at keel, percent beam	16.5	9.0
Angle of forebody keel to base line, deg	0	0
Angle of afterbody keel to base line, deg	5.4	5.4
Angle of sternpost to base line, deg	6.9	7.4
Angle of dead rise of forebody:		
Excluding chine flare, deg	20	20
Including chine flare, deg	16.5	16.5
Angle of dead rise of afterbody, deg	20	20
Wing		
Span, ft	139.7	139.7
Root chord, ft	16.0	16.0
Mean aerodynamic chord (M.A.C.):		
Length, projected, ft	13.8	13.8
Leading edge aft of bow, ft	41.5	28.2
Leading edge forward of step, ft	6.7	6.7
Leading edge above base line, ft	15.3	15.3
Angle of incidence, deg	4	4

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TABLE I — Concluded

PERTINENT CHARACTERISTICS AND DIMENSIONS OF FLYING BOATS — Concluded

	$\frac{L}{b} = 15$	$\frac{L}{b} = 6$
Horizontal tail surfaces		
Area, sq ft	33.3	33.3
Span, ft	43.0	43.0
Angle of stabilizer to wing chord, deg . .	-4	-4
Elevator root chord, ft	3.20	3.20
Elevator semispan, ft	16.7	16.7
Length from 25 percent M.A.C. of wing to hinge line of elevators, ft	49.5	49.5
Height above base line, ft	19.0	19.0
Propellers		
Number of propellers	2	2
Number of blades	3	3
Diameter, ft	16.5	16.5
Angle of thrust line to base line, deg . .	2	2
Clearance above keel, ft	8.3	8.3

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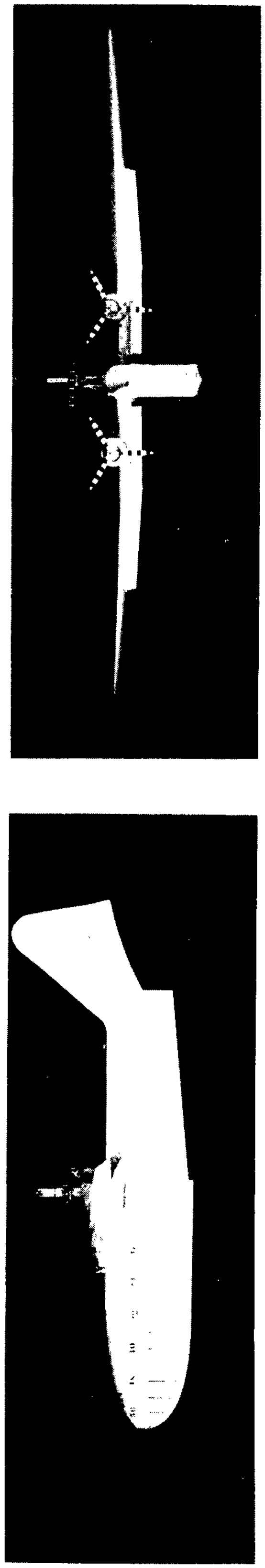
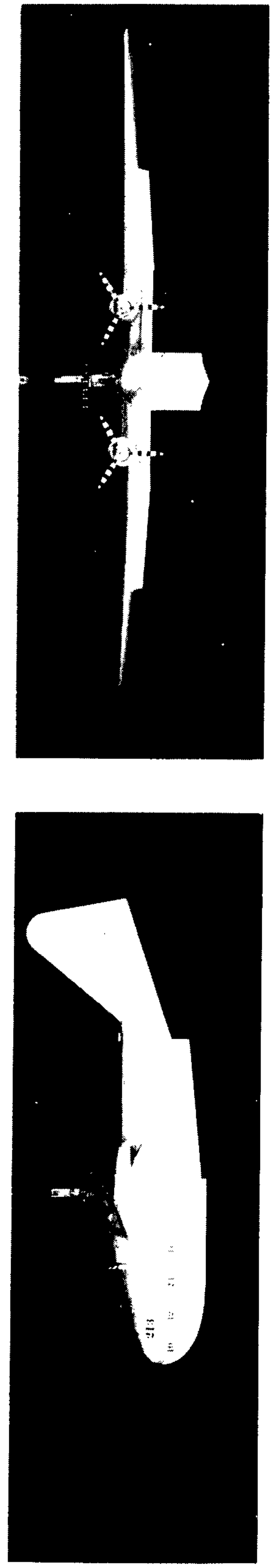
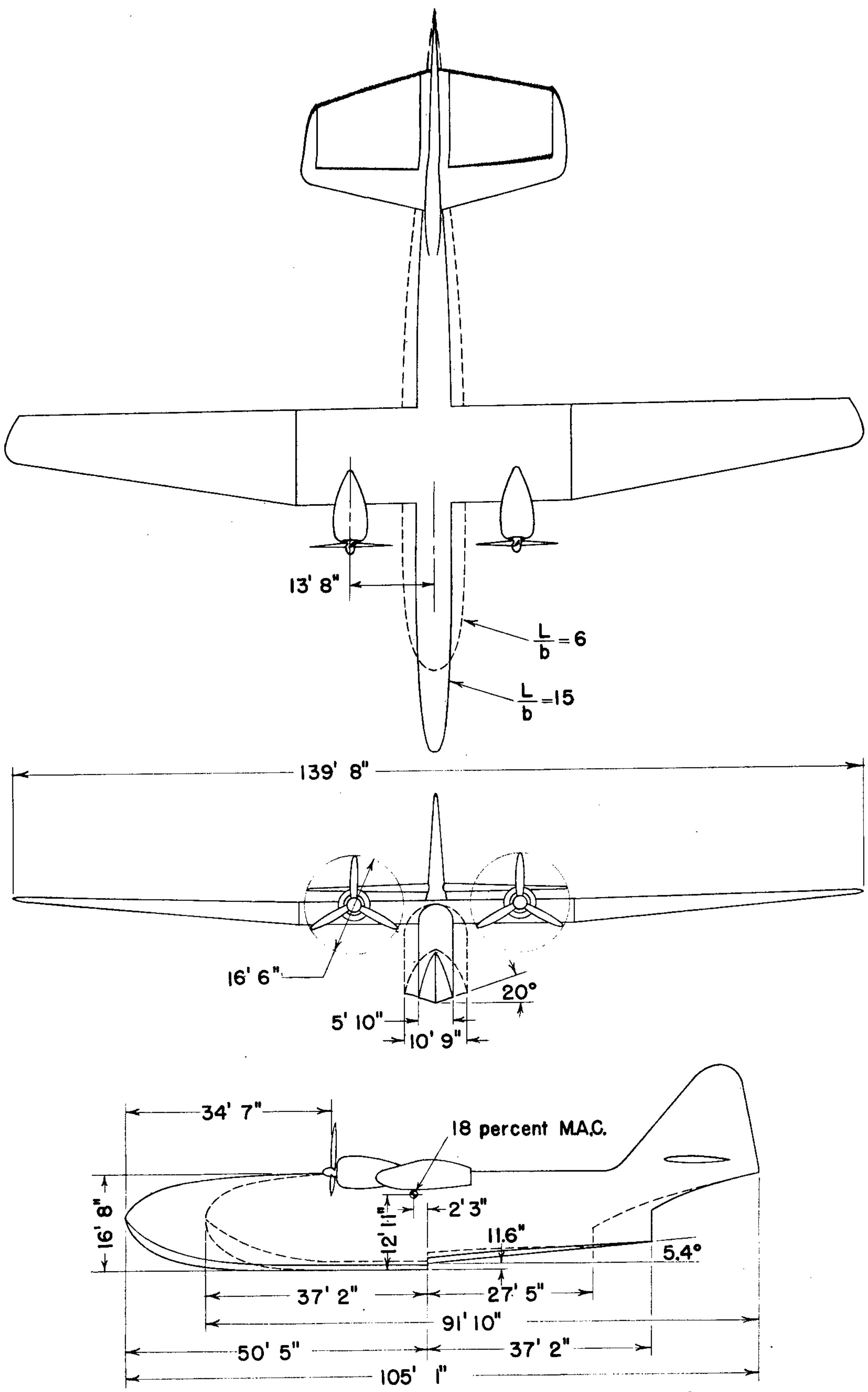


(a) Hull of $\frac{L}{b} = 15$.



(b) Hull of $\frac{L}{b} = 6$.

Figure 1.- Hull length-beam ratio models.



13' 8"
L/b = 6
L/b = 15
139' 8"
16' 6"
20°
5' 10"
10' 9"
34' 7"
18 percent M.A.C.
16' 8"
12' 1"
2' 3"
11.6"
5.4°
37' 2"
27' 5"
91' 10"
50' 5"
37' 2"
105' 1"

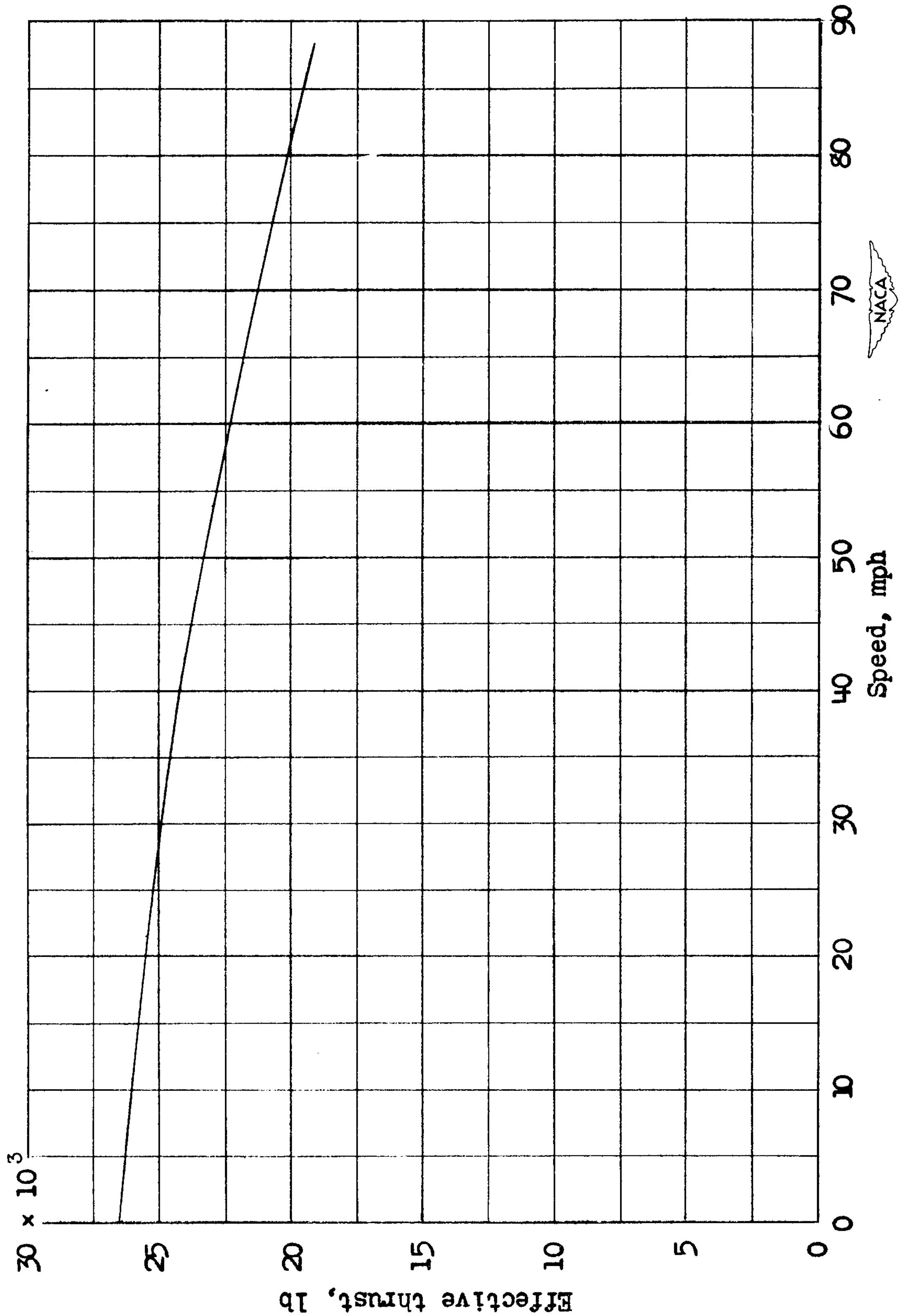
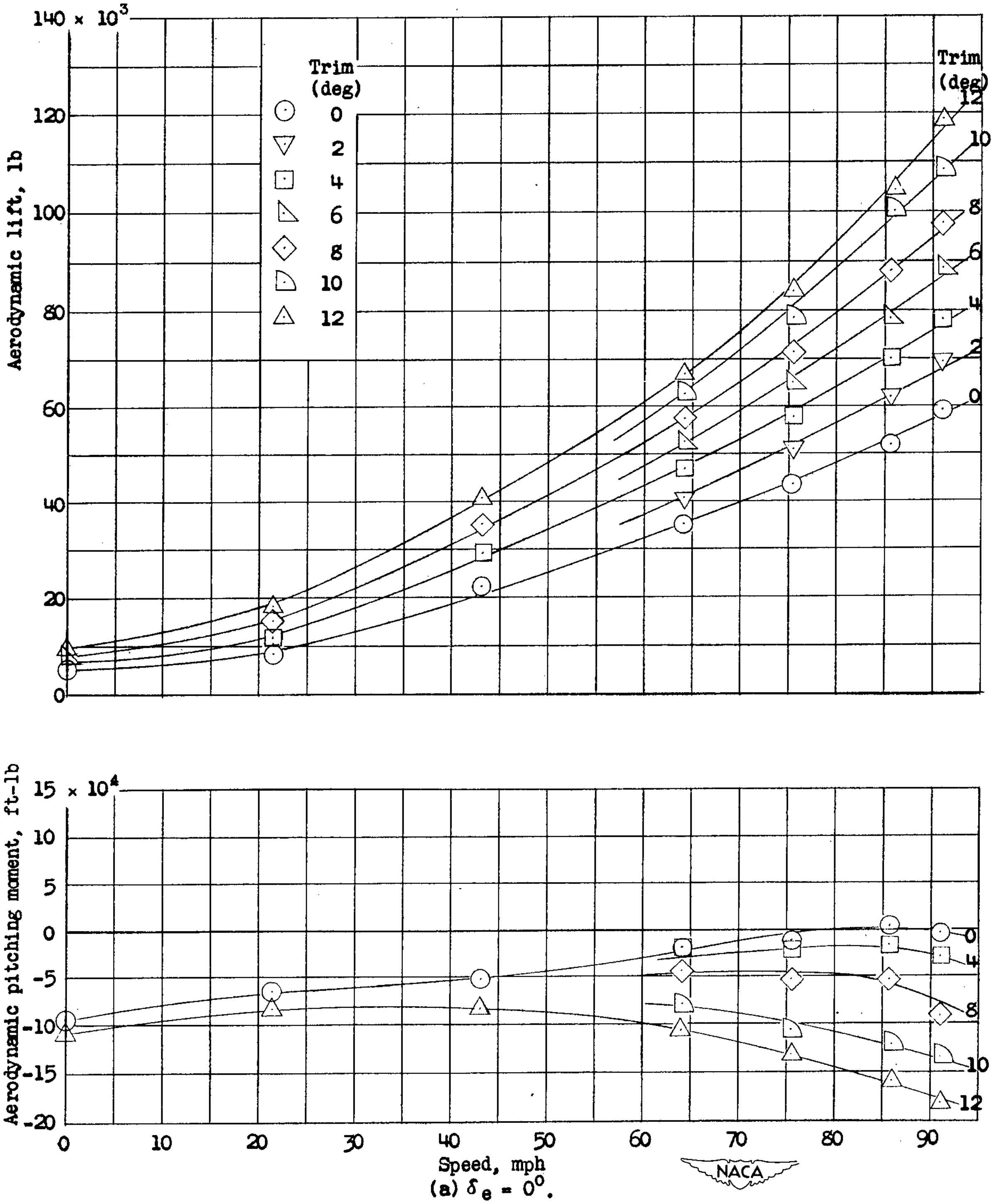
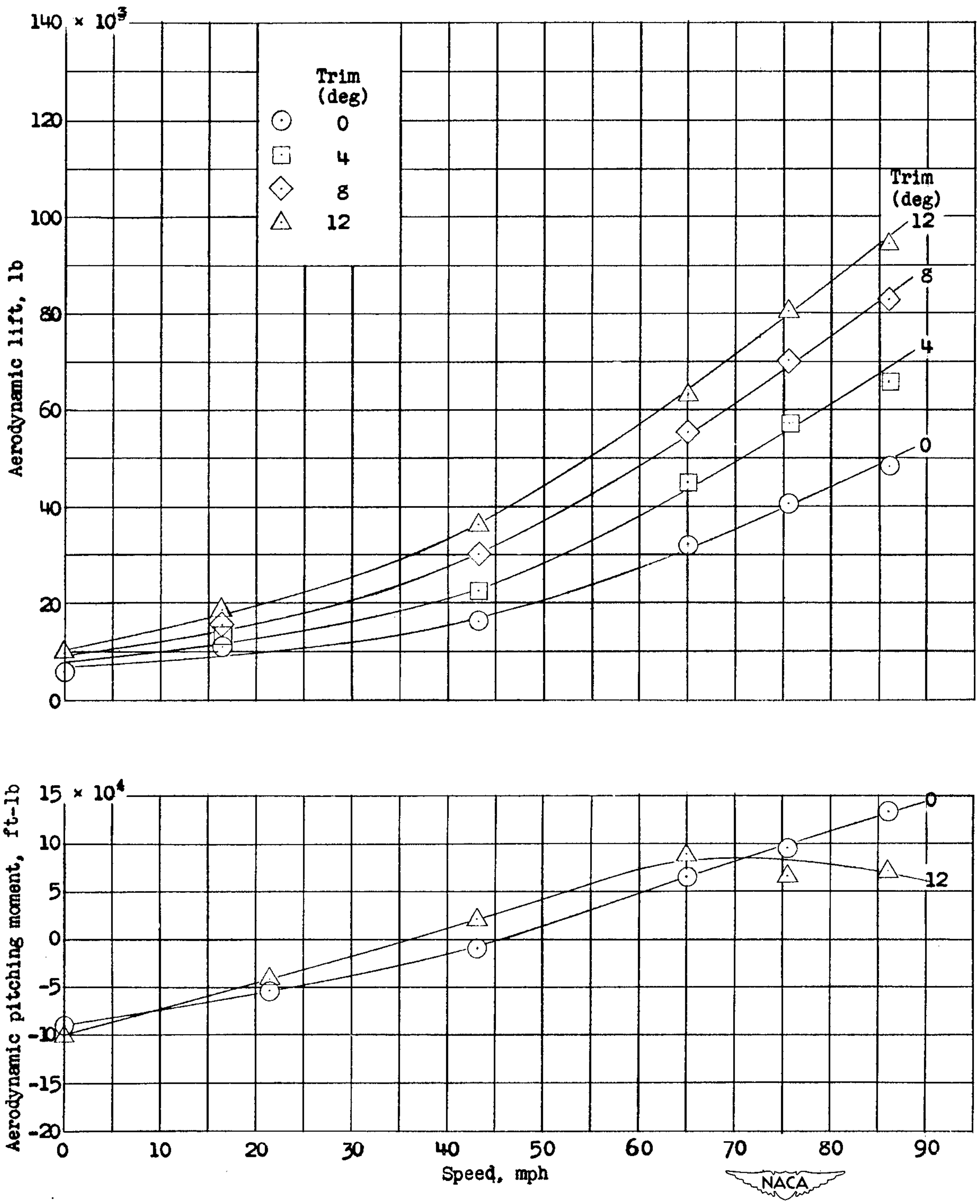


Figure 4.- Variation of effective thrust with speed.



(a) $\delta_e = 0^{\circ}$.

Figure 5.- Variation of aerodynamic lift and pitching moment with speed.



(b) $\delta_e = -20^{\circ}$.

Figure 5.- Concluded.

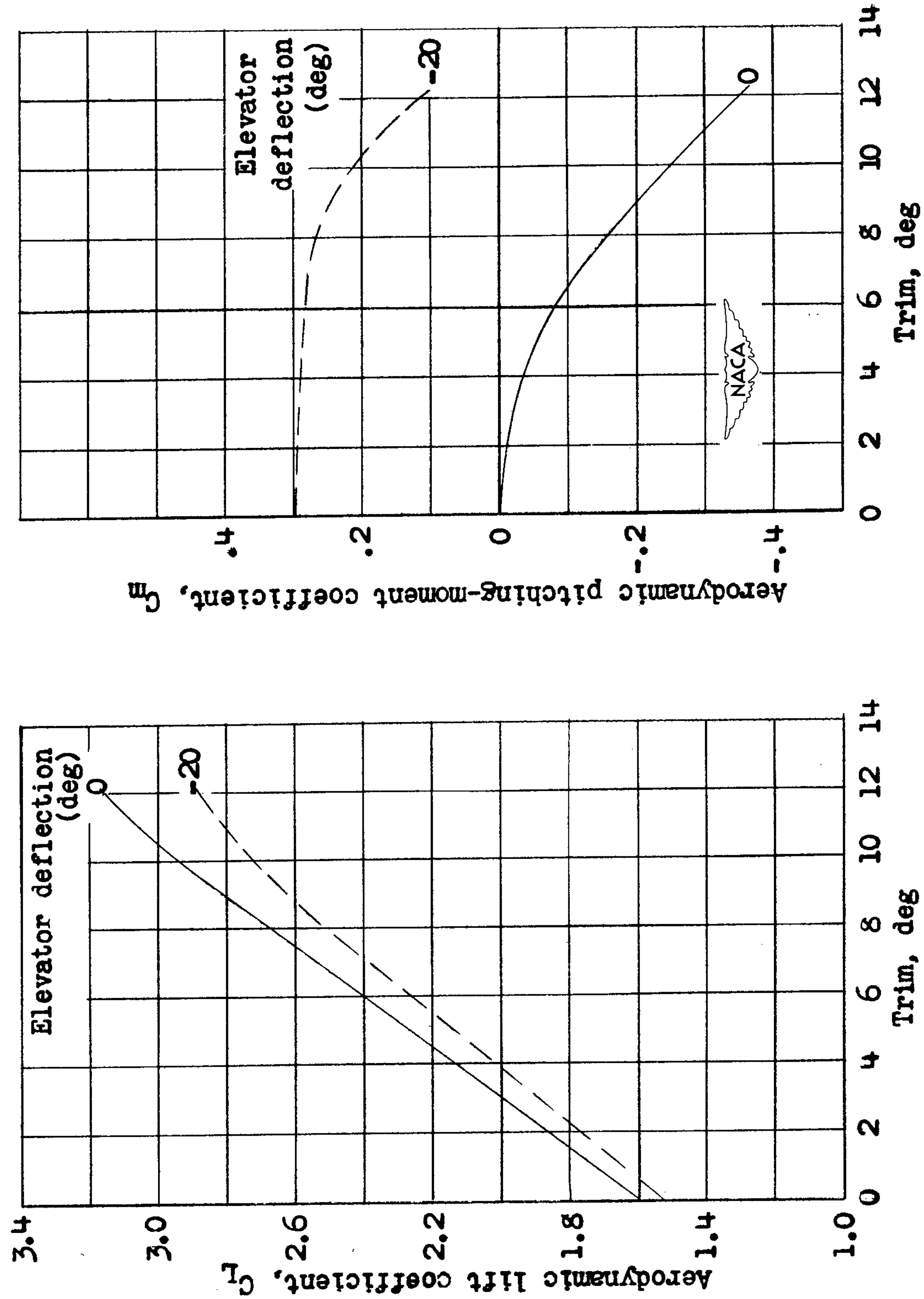
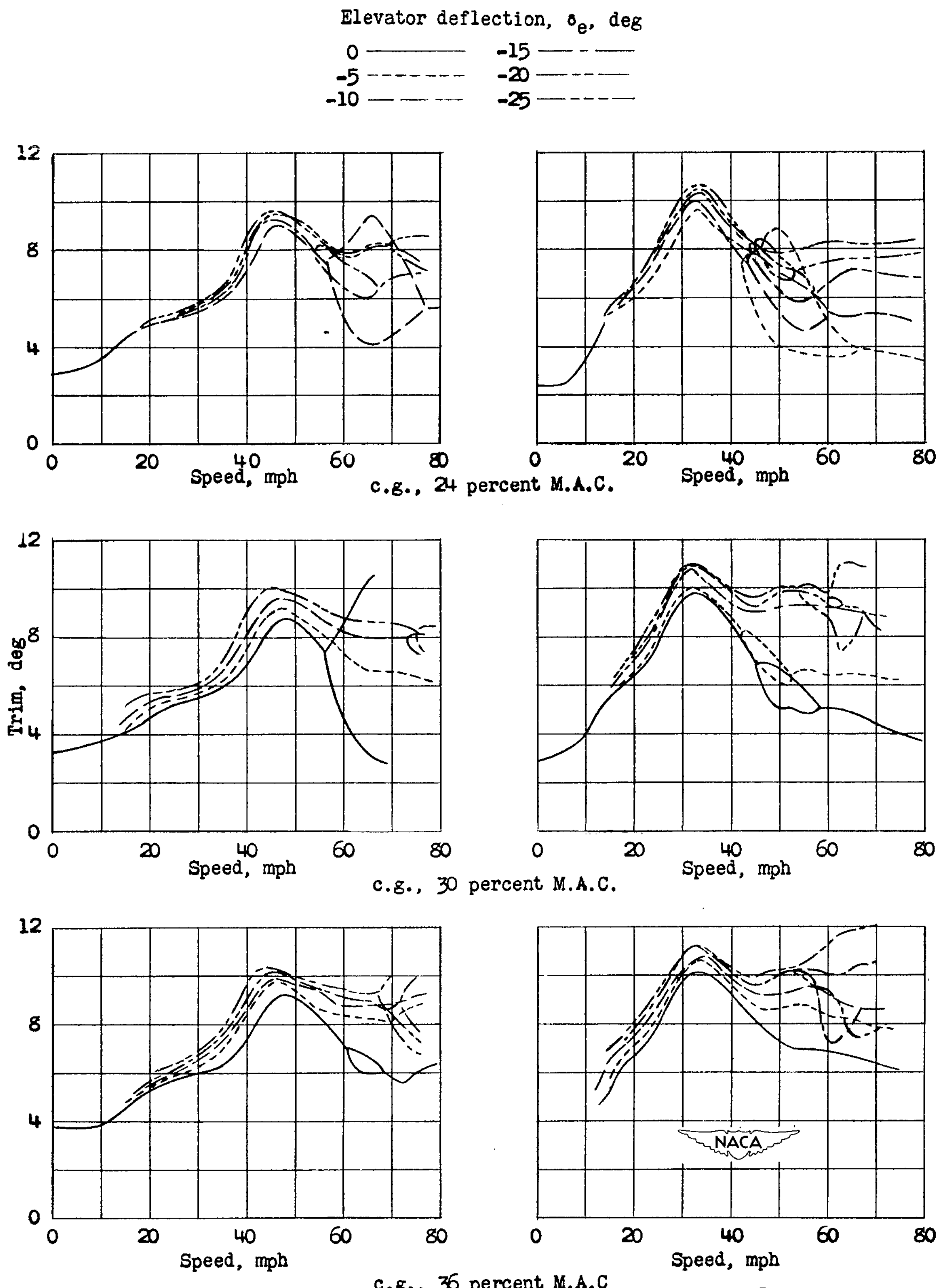


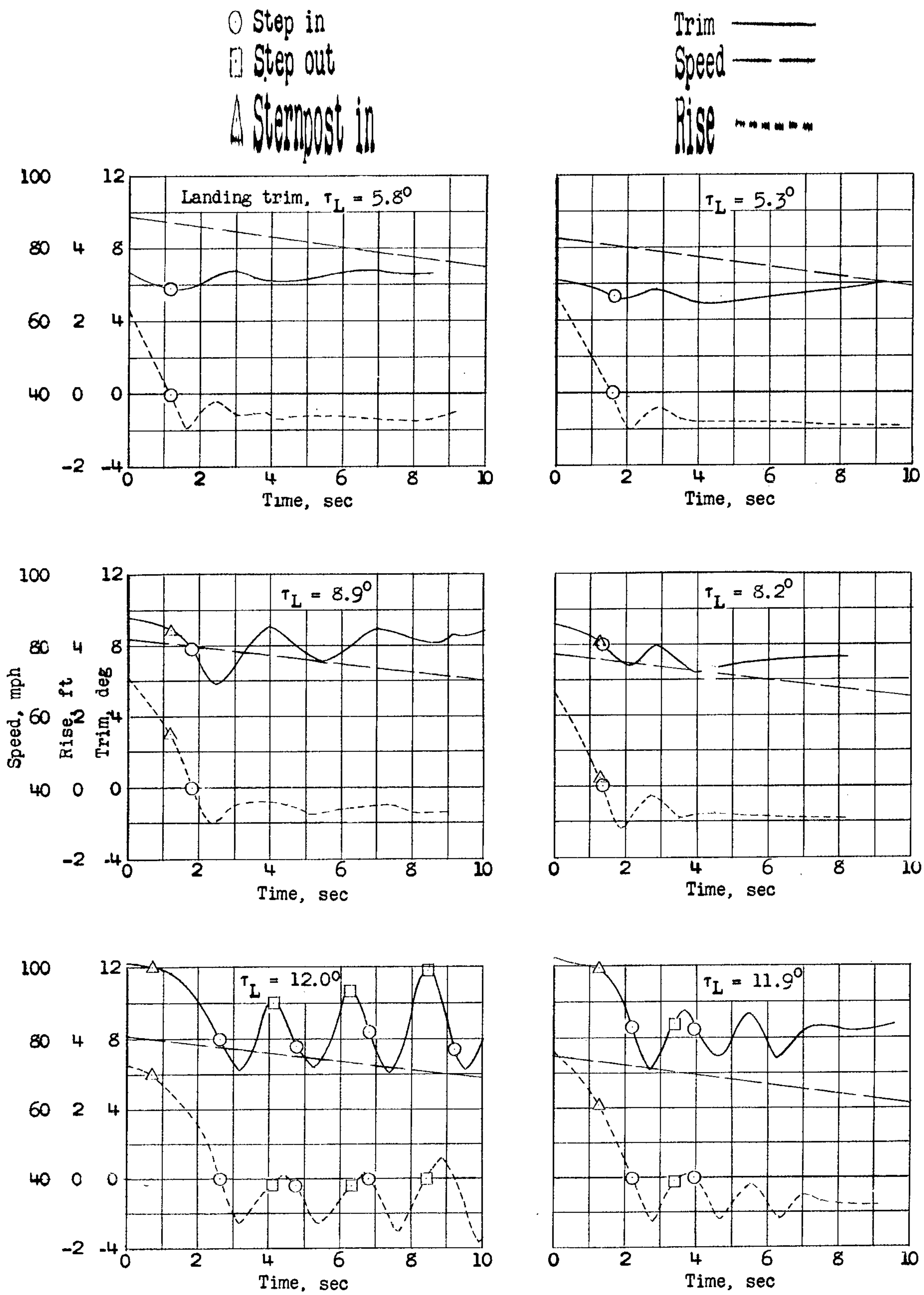
Figure 6.- Variation of aerodynamic lift and pitching-moment coefficients with trim.



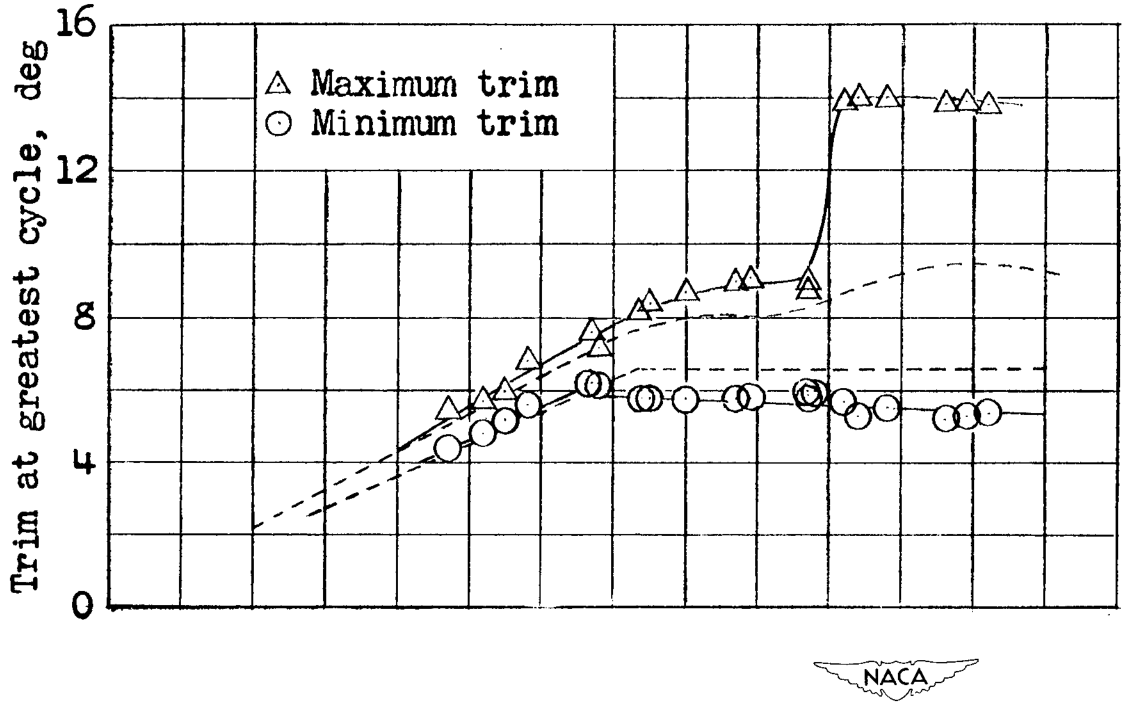
(a) Hull of $\frac{L}{b}$ = 15.

(b) Hull of $\frac{L}{b}$ = 6.

Figure 7.- Variation of trim with speed.



(a) Hull of $\frac{L}{b}$ = 15.   (b) Hull of $\frac{L}{b}$ = 6.



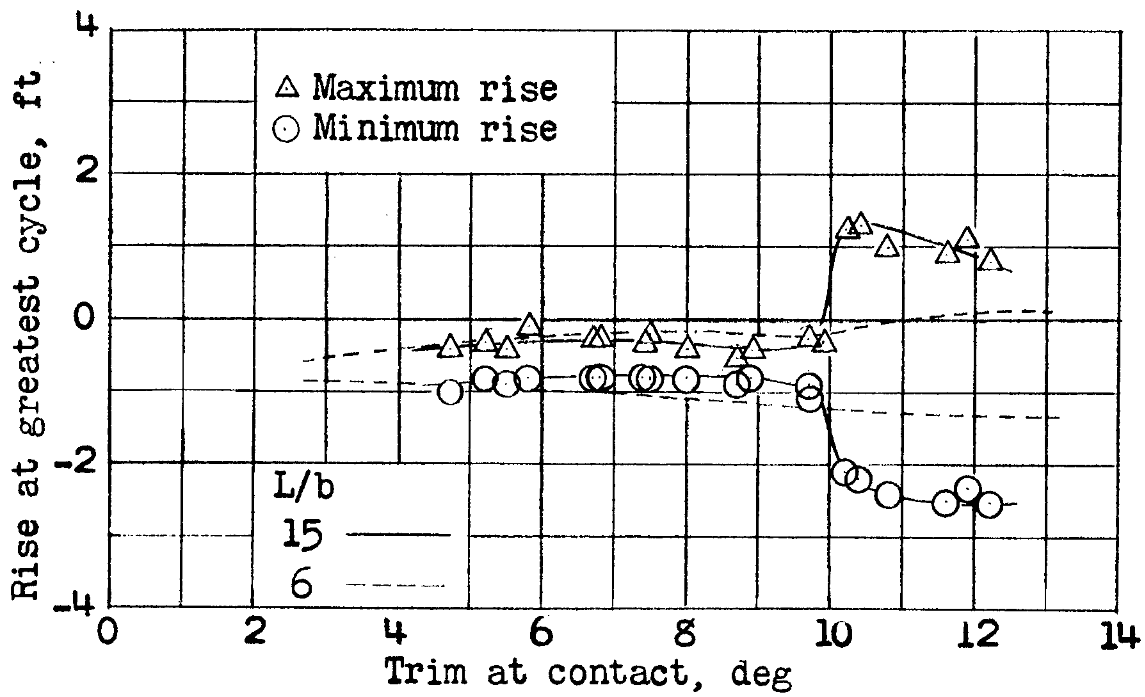


Figure 12.- Variation of maximum and minimum trim and rise with trim at contact.

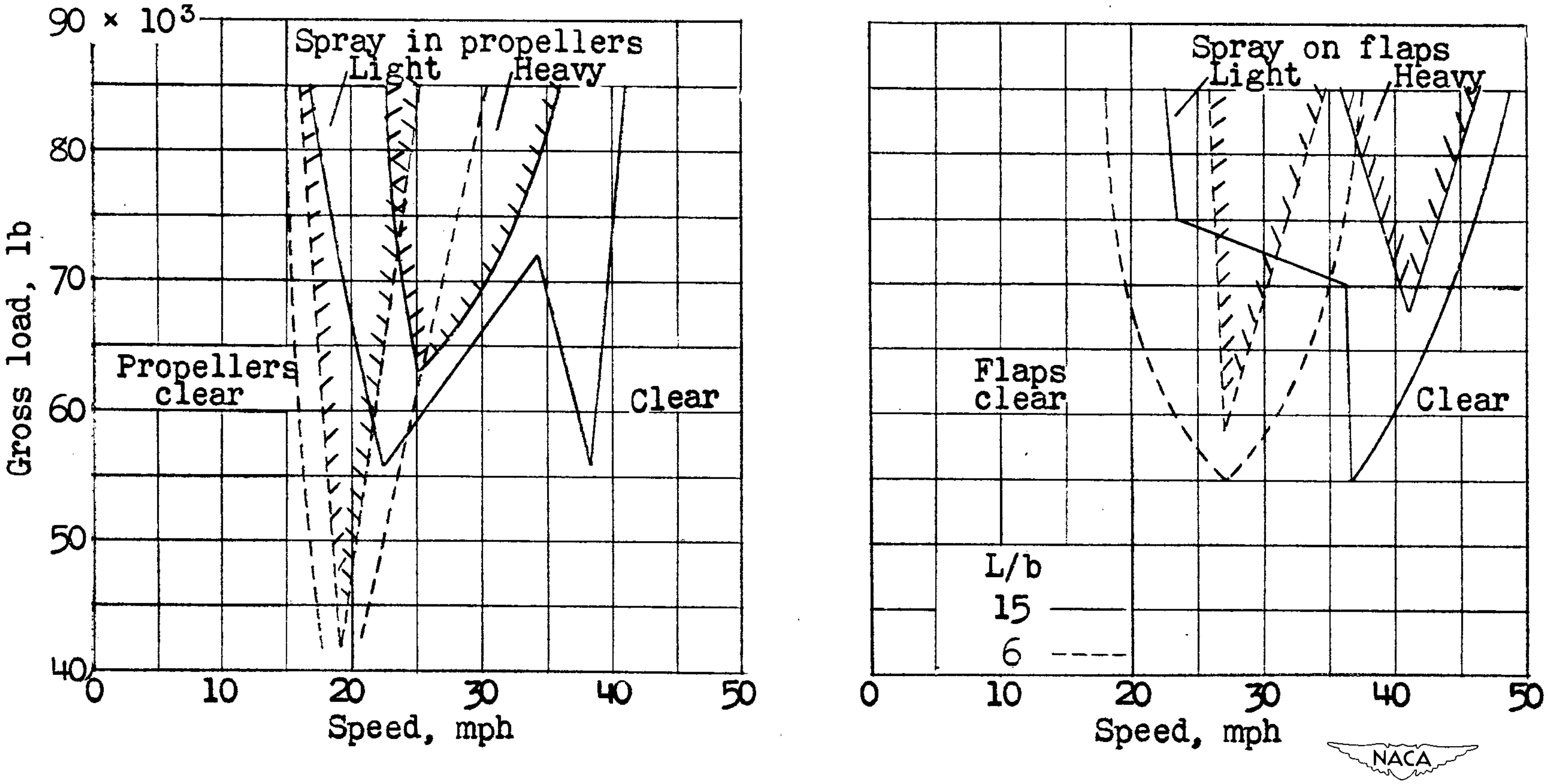
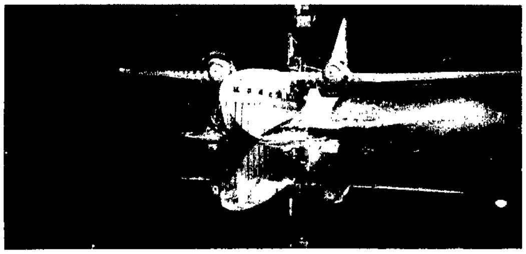
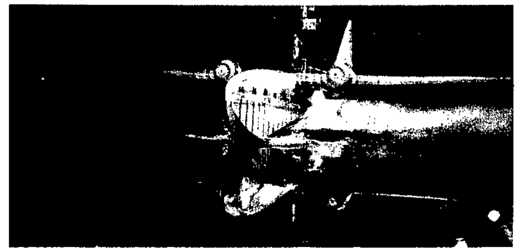


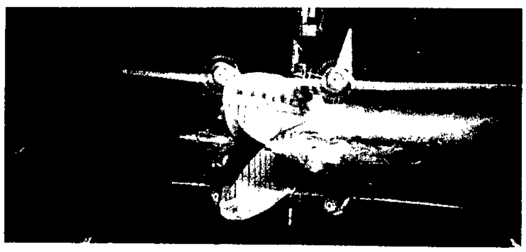
Figure 13.- Variation of range of speed for spray in propellers and on flaps with gross load.



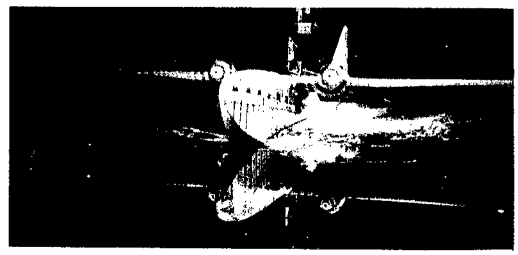
V = 23.7 mph; $\tau = 6.0^{\circ}$



V = 25.9 mph; $\tau = 6.1^{\circ}$

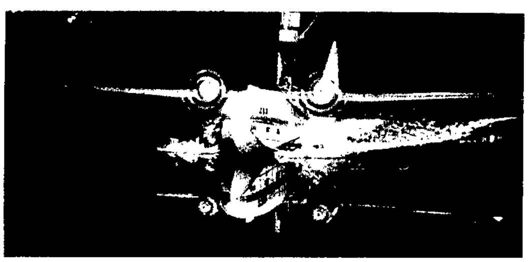


V = 30.2 mph; $\tau = 6.4^{\circ}$

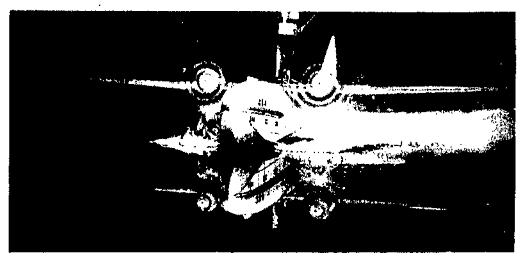


V = 32.3 mph; $\tau = 6.7^{\circ}$

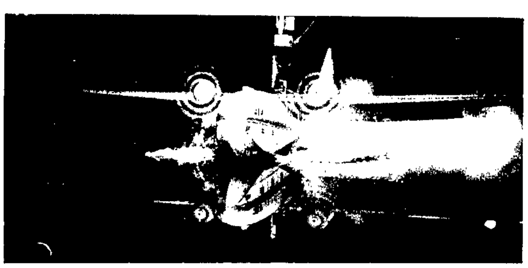
(a) Length-beam ratio of 15.



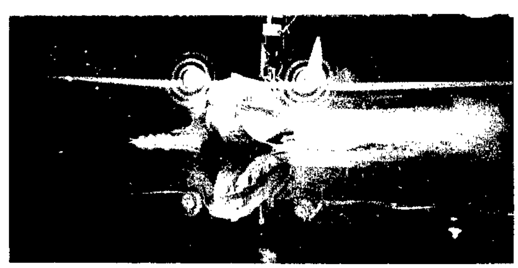
V = 17.2 mph; $\tau = 6.6^{\circ}$



V = 19.4 mph; $\tau = 7.1^{\circ}$



V = 21.6 mph; $\tau = 7.8^{\circ}$



V = 23.7 mph; $\tau = 8.0^{\circ}$

(b) Length-beam ratio of 6.

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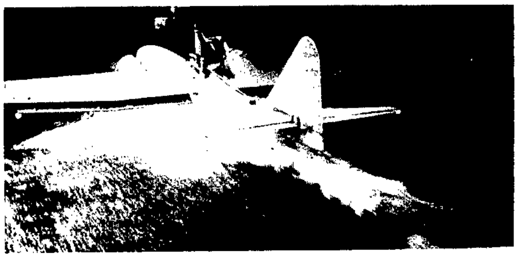
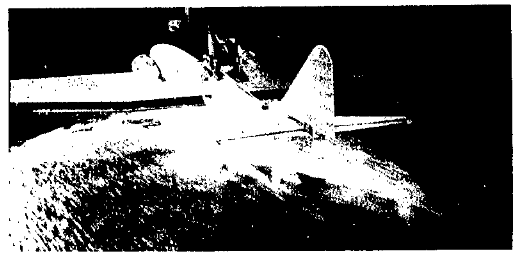
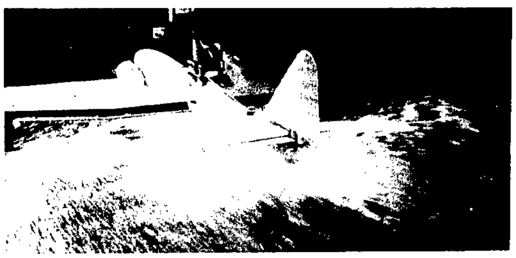
Figure 14.- Spray in propellers during take-off.



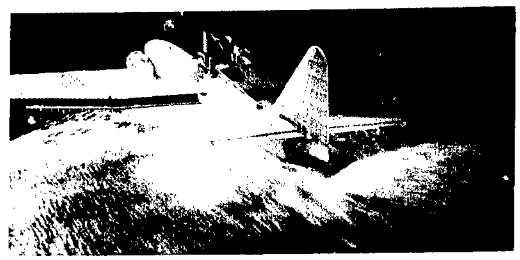
V = 38.8 mph; τ = 8.7°



V = 41.0 mph; τ = 9.4°



V = 43.1 mph; τ = 9.9°



V = 45.3 mph; τ = 10.5°

(a) Length-beam ratio of 15.

V = 25.9 mph; τ = 8.8°

V = 28.0 mph; τ = 9.1°

V = 30.2 mph; τ = 10.7°

V = 32.3 mph; τ = 10.9°

(b) Length-beam ratio of 6.

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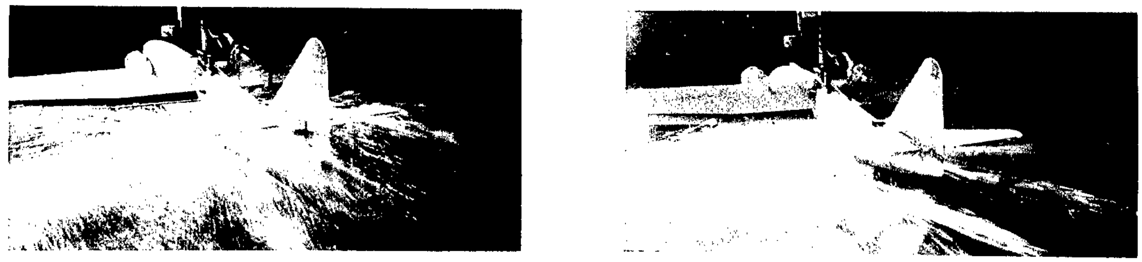
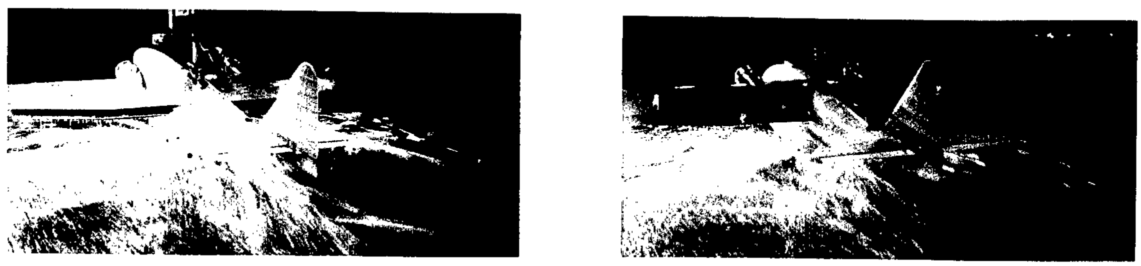
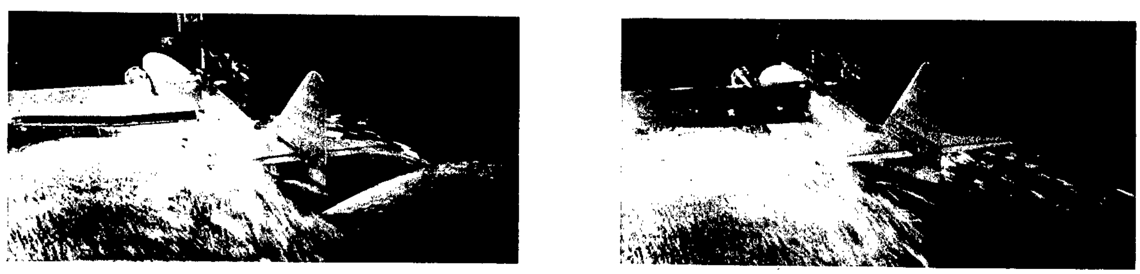
Figure 15.- Spray on flaps during take-off.



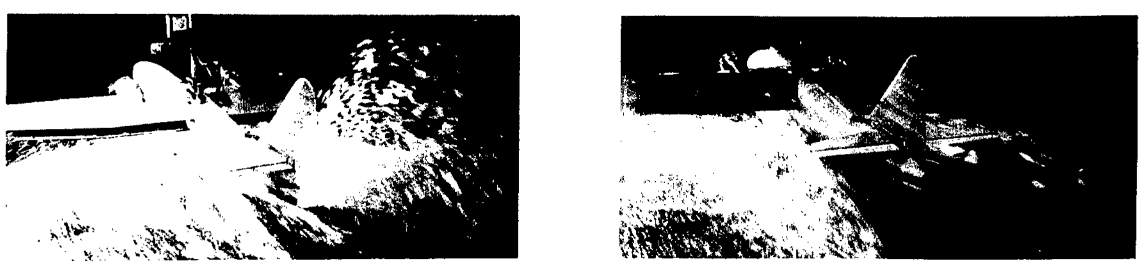
$\tau = 10.5^{\circ}$; V = 64.7 mph; $\tau = 10.8^{\circ}$



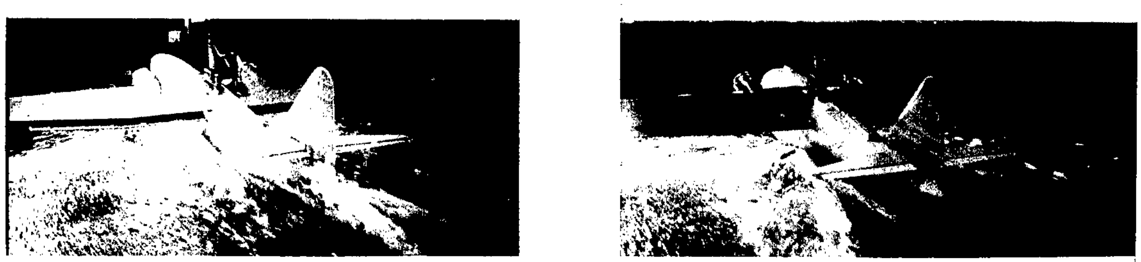
$\tau = 11.9^{\circ}$; V = 53.9 mph; $\tau = 10.9^{\circ}$



$\tau = 12.5^{\circ}$; V = 47.4 mph; $\tau = 10.9^{\circ}$



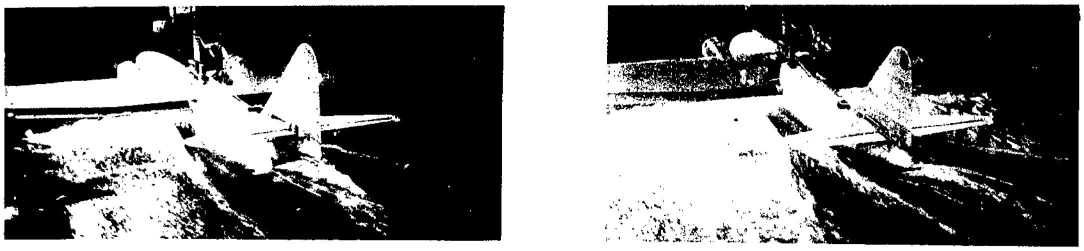
$\tau = 12.4^{\circ}$; V = 43.1 mph; $\tau = 11.9^{\circ}$



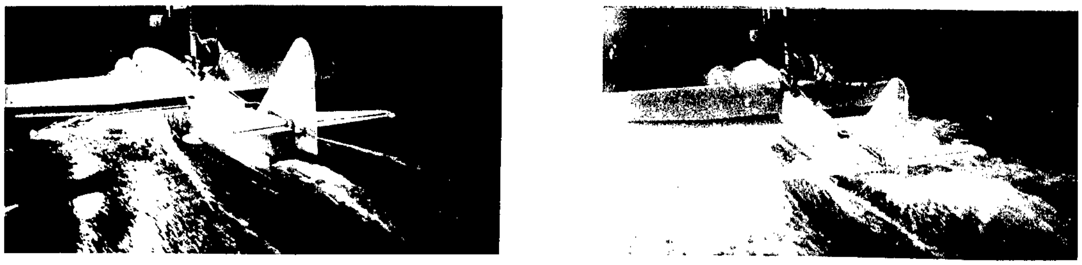
$\tau = 11.8^{\circ}$; V = 38.8 mph; $\tau = 12.5^{\circ}$

(a) Length-beam ratio of 15. (b) Length-beam ratio of 6.

Figure 16.- Spray on tail surfaces during landing.



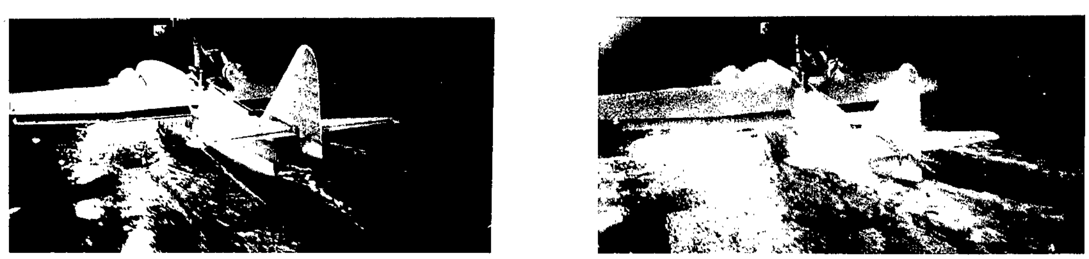
$\tau = 9.0^\circ$; V = 34.5 mph; $\tau = 13.3^\circ$



$\tau = 8.7^\circ$; V = 32.3 mph; $\tau = 13.7^\circ$

$\tau = 8.2^\circ$; V = 30.2 mph; $\tau = 12.7^\circ$

$\tau = 7.7^\circ$; V = 28.0 mph; $\tau = 11.7^\circ$



$\tau = 7.6^\circ$; V = 25.9 mph; $\tau = 11.1^\circ$

(a) Concluded. (b) Concluded.

Figure 16.- Concluded.

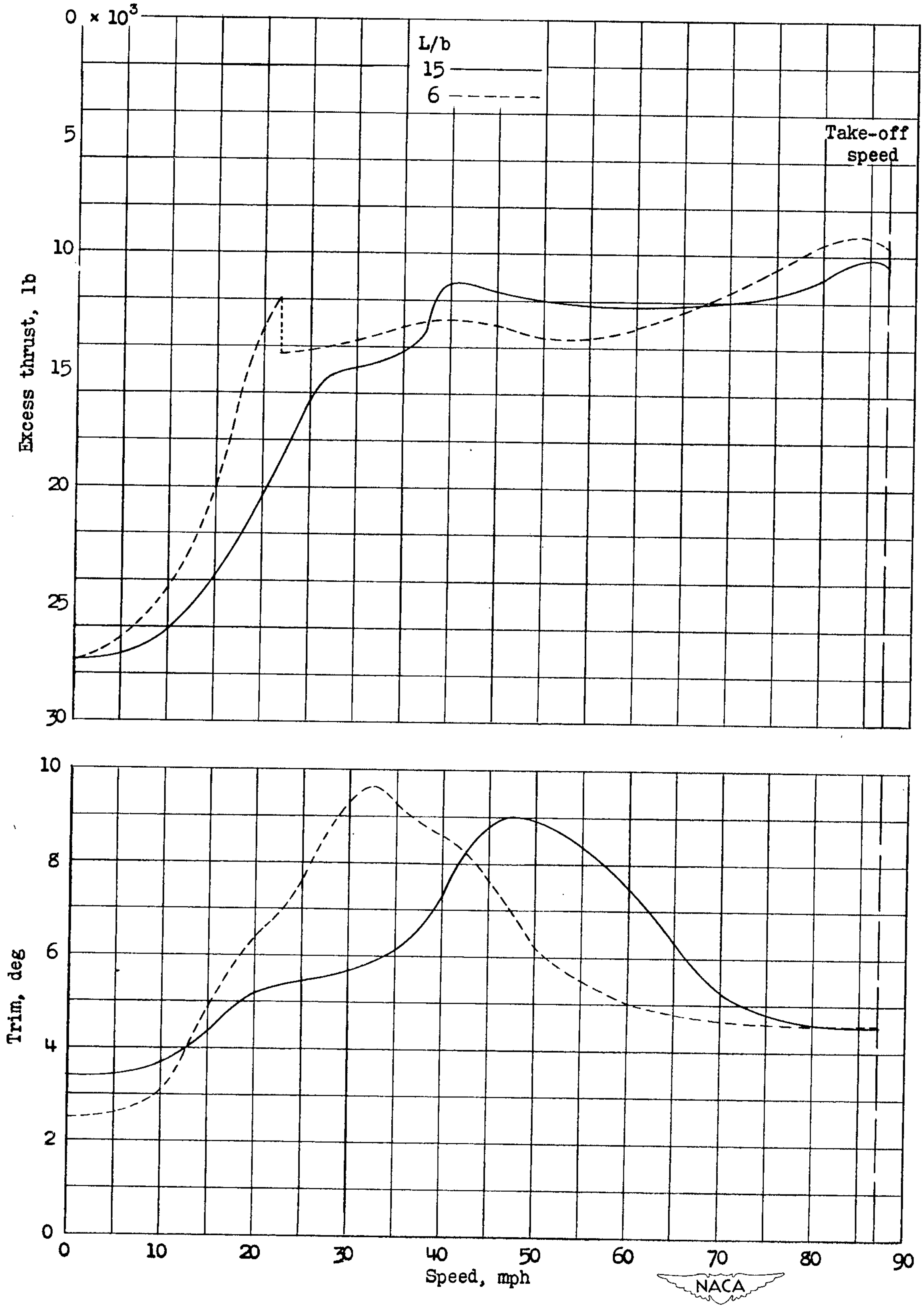


Figure 17.- Variation of excess thrust and trim with speed during take-off.

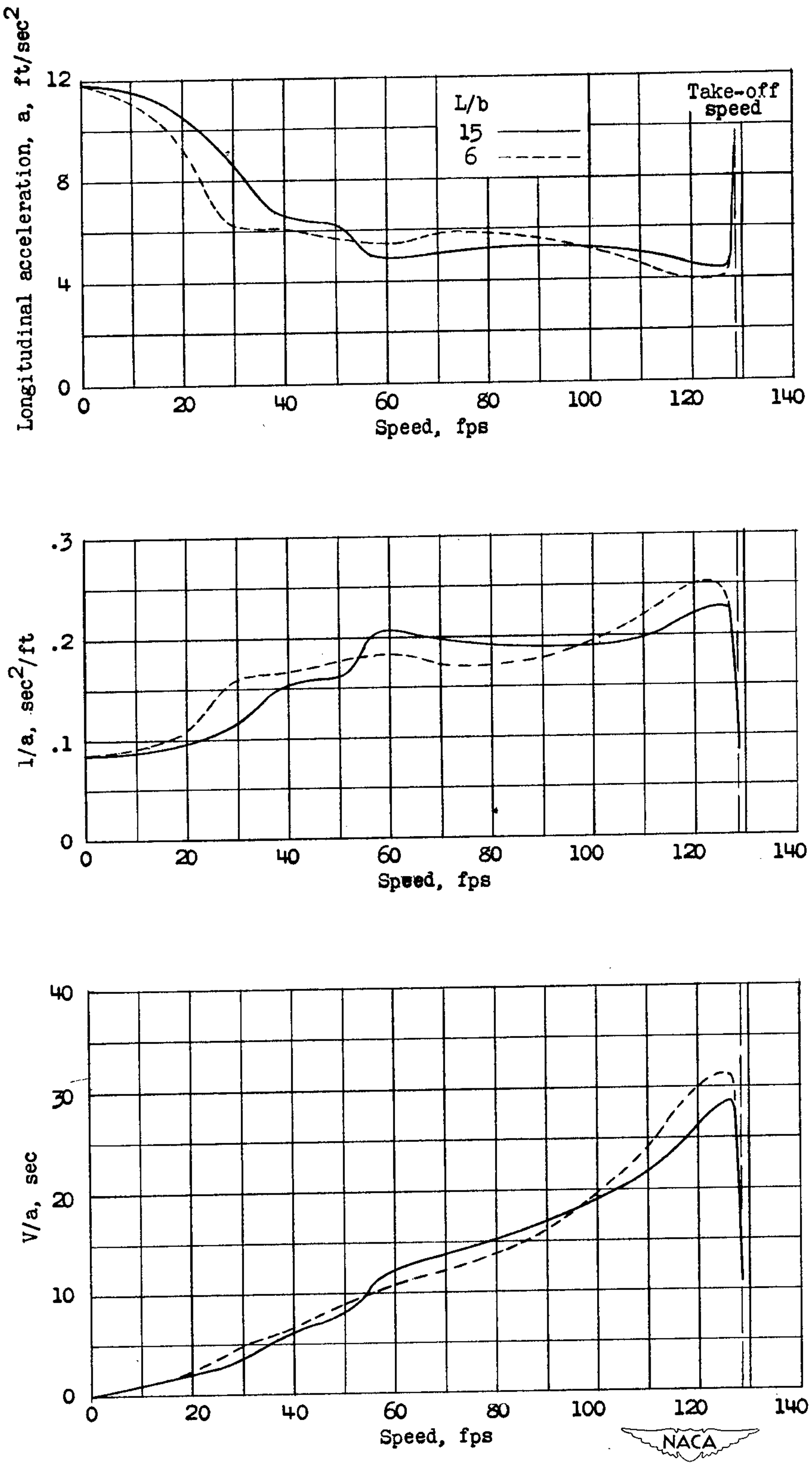


Figure 18.- Variation of longitudinal acceleration a, 1/a, and V/a with speed during take-off.