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# CHARACTERISTICS OF A TRIANGULAR-WINGED AIRCRAFT

## II - STABILITY AND CONTROL

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The stability and control problems associated with wings of triangular plan form have recently been the subject of an intensive research investigation at the Ames Laboratory. Tests have included the measurement of effectiveness and hinge moment for a constant-chord trailing-edge control at Mach numbers up to 0.95 (reference 1), effectiveness of a similar control at a Mach number of 1.53 (reference 2), and directional characteristics at low subsonic speeds and at a Mach number of 1.53 of an aircraft using a single vertical tail and using twin vertical tails (references 2 and 3). Low-speed flight tests using a constant-chord trailing-edge control have also been made in the Langley free-flight tunnel (reference 4). Some of these results relating to static longitudinal stability and control will be presented in this report.

The wing model used in these tests had a triangular plan form and an aspect ratio of 2. The control surface investigated had a constant chord and an area equal to 20 percent of the wing area. When tested with a fuselage, the fuselage was a body of revolution with a fineness ratio of 12.5 and a frontal area equal to $5\frac{1}{4}$ percent of the wing area. The effect of Mach number on the lift-curve slope and the location of the aerodynamic center are presented in figure 1. Data are included from tests of a semispan model in the Ames 12-foot low-turbulence pressure tunnel and tests of a small-scale complete-wing model in the Ames 1- by $3\frac{1}{2}$-foot tunnel and the Ames 1- by 3-foot supersonic tunnel. The results from the various test facilities show reasonable agreement, considering the large differences in Reynolds number and minor differences of model configuration.

Slope parameters of this type may often be very misleading because they fail to show the linearity or nonlinearity of the various coefficients. Figure 2 presents lift and moment data at Mach numbers up to 0.95 and more clearly illustrates the excellent linearity of the characteristics of a triangular wing at high subsonic speeds. While these data only extend up to $M = 0.95$, data obtained at transonic speeds by the wing-flow method on a free-floating model indicate none of the erratic disturbances which are associated with a straight wing in passing through a Mach number of unity.

The influence of Mach number on the effectiveness of the constant-chord plain flap is shown in figure 3. The theoretical effectiveness

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at supersonic speeds is based on linearized theory. The experimental point at a Mach number of 1.53 was obtained from tests of an airplane model having a triangular wing of aspect ratio 2.31 with a 21.3-percent-area constant-chord control. For the theoretical calculation it was assumed that there was no carry-over of elevon lift across the fuselage. The agreement between the experimental value and the theoretical value indicates that the assumption of no-lift carry-over is valid. The effectiveness data from the wing-flow method were obtained on a sharpened flat plate using the free-floating technique (reference 5). The Reynolds number for these tests was about 1 million compared to 5.3 million for the data obtained in the Ames 12-foot low-turbulence pressure tunnel. It is not completely understood whether the lack of agreement between these data is due to the difference in airfoil section, the difference in Reynolds number, or to shortcomings of the free-floating technique. Further tests are scheduled in an attempt to determine the exact reasons for these discrepancies. Figure 4 presents elevon effectiveness for several angles of attack at five different Mach numbers, the highest being 0.95. This figure illustrates again the linearity of the data from which the slope parameters have been obtained.

The hinge-moment characteristics of the constant-chord elevons are shown in figure 5. The supersonic values are computed from linearized theory and no experimental verification is available. Note the large rapid rise in $C_{h_\delta}$ at Mach numbers approaching unity. If a constant-chord control with an unswept hinge line is to be used, the necessity for some type of power-operated irreversible control mechanism is obvious. Note also the large negative values of $C_{h_\alpha}$ which will have a profound influence on the control forces in steady flight.

These data have been used to predict the static longitudinal stability and control characteristics of a hypothetical aircraft employing the wing and fuselage previously described. This aircraft if shown in figure 6. In order to permit the reduction of the hinge-moment data, a wing area of 500 square feet has been assumed. The span is thus 31.6 feet. In order to fulfill its assumed mission, the aircraft must be capable of engaging in tactical maneuvers at a Mach number of 1.5 and an altitude of 60,000 feet with wing loadings of at least 60 pounds per square foot.

The variation with Mach number of the elevon angle and the elevon hinge moment required to balance the aircraft in level flight at an altitude of 30,000 feet is shown in figure 7. The airplane center of gravity has been assumed at 32 percent of the M.A.C. Note in particular that, due to the large negative value of $C_{h_\alpha}$, the

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variation of stick force with speed is neutrally stable over most of the speed range. Note also that despite the large distance between the center of gravity and the aerodynamic center at supersonic speeds, the elevon angle required to balance the airplane at supersonic speeds is essentially independent of the Mach number. This neutral stick-fixed stability is due to the loss in elevon effectiveness associated with increasing supersonic Mach numbers.

The variation with normal acceleration of the elevon angle and elevon hinge moment in steady turning flight at two high subsonic Mach numbers is shown in figure 8. For these computations it is assumed that the elevon is used for both balancing the aircraft and as the maneuvering control. The rapid changes in control forces at large normal accelerations is due to nonlinearity of the elevon hinge moments at these high Mach numbers.

The effect of the location of the center of gravity on the maneuverability of the aircraft at a Mach number of 1.5 is shown in figure 9. In all cases the elevator deflection has been limited to 12° which is the critical-flow deflection angle for this Mach number.

It is apparent that if the aircraft is to produce a normal acceleration of 4g at an altitude of 60,000 feet with a wing loading of 60 pounds per square foot, the center of gravity must be at about 45 percent M.A.C. However, with the center of gravity this far aft, the aircraft will become longitudinally unstable at subsonic speeds. If the airplane center of gravity is not permitted to move aft of 32 percent M.A.C., the most aft center of gravity for stability at landing, the maximum normal acceleration which can be produced by the elevons for the above condition is only 0.2g. It is obvious that the maneuverability of the airplane would be enhanced if some auxiliary trimming device were available so that the elevon power could be reserved for maneuvering.

The effect of static margin on the theoretical increment in elevon hinge moment per g of normal acceleration is shown in figure 10 for flight at a Mach number of 1.5 at an altitude of 60,000 feet. It is seen that the control forces will become enormous unless the static margin is maintained between 5 and 12 percent. At lower supersonic speeds, the control forces are even higher due to the very rapid rise of negative $C_{h_\delta}$ with decreasing supersonic Mach numbers.

The landing characteristics of the triangular-winged aircraft have been computed for wing loadings of 20, 30, and 40 pounds per square foot. The data used for these computations were all obtained at a Reynolds number of 15,000,000 and a Mach number of 0.18. The variation with landing speed of the elevator angle, control hinge moment, sinking speed,

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and angle of attack is presented in figure 11. For all of these computations the only longitudinal control is the constant-chord trailing-edge elevator, and landing is assumed to be accomplished with power off. It is observed that a push force is required to land the airplane and that the variation of elevon force with speed is unstable over most of the speed range. Note that for a landing speed of 140 miles per hour with a wing loading of 40 pounds per square foot, the sinking speed is in excess of 60 feet a second and the airplane angle of attack is greater than 20°. The lift-drag ratio for this condition is only 3.0. These values indicate the necessity of applying power if a safe landing is to be accomplished.

Recent tests of a similar wing and control have been made in the Langley free-flight tunnel. These tests indicated that the airplane was controllable up to a maximum lift coefficient of 1.0. A moderate amount of difficulty was observed in trying to fly the model at these high lifts due to the large sinking speeds. The tests did indicate, however, that slow-speed flight could be achieved despite the large angle of attack and the high drag.

Examination of the preceding data permits several interesting observations regarding the performance of a triangular-wing aircraft with a constant-chord control. In the first place, the elevator is not adequate for both trimming and maneuvering the aircraft at high altitudes with large wind loadings, and the elevon forces are such as to require an irreversible power control. Second, the sinking speed and landing attitudes of the aircraft are excessive when the flap is used as a longitudinal control. Third, the variation of aerodynamic center with Mach number, although much less than for a straight-wing configuration, is sufficient to complicate severely the problem of longitudinal control. If the center of gravity is permitted to move aft as fuel is consumed in supersonic flight so as to keep the supersonic static margin down to a reasonable figure, there must be some method of moving the center of gravity forward or the aerodynamic center aft to permit stability at low speeds for landing. A possible solution to these problems is presented in the following discussion.

Consider a second small triangular wing mounted far forward on the fuselage as shown in figure 12. For landing, permit this auxiliary wing to float freely about its 30 percent M.A.C. with its floating angle determined by the deflection of constant-chord trailing-edge flap connected to the pilot's control. This freely floating wing will not affect the aerodynamic center of the airplane but will serve as a very powerful longitudinal control. For the present analysis, this trimmer wing is considered to have an area equal to 8 percent of the wing area and a distance from the one-quarter M.A.C. of the main wing of 1.5 mean aerodynamic chord lengths.

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The trimmer configuration for which the present computations have been made has not been tested at transonic or supersonic speeds. Downwash from the trimmer may have a sizeable effect on the airplane characteristics, but for the present analysis no interference effects between the trimmer and the wing or between the fuselage and the trimmer have been considered.

The landing characteristics for this configuration with the wing flaps deflected $10^{\circ}$ are presented in figure 13. The sinking speed and ground angle for landing with the elevons is shown for comparison. For both sets of calculations, the center of gravity is at 32 percent M.A.C. Note that the floating trimmer reduces the sinking speed of the aircraft for a given contact speed by more than 25 percent and, equally important, reduces the ground angle by as much as $11^{\circ}$. The sinking speeds are still of such magnitude, however, that power will have to be applied for landing.

At a Mach number of 1.5 the trimmer is very ineffective. This results directly from the fact that, if the trimmer pivot is placed far enough forward to insure free-floating stability at the landing condition, the trimmer stability is so large at supersonic speeds that its control is ineffective in producing lift.

The fact that the floating trimmer does not affect the aerodynamic center, while locking the trimmer will move the aerodynamic center forward by 12 percent M.A.C., suggests a method of reducing the static margin at supersonic speeds without causing instability at landing. If the disposable load is so arranged that the center of gravity continually moves aft as fuel is consumed, take-off, climb, and supersonic flight can be accomplished with the trimmer locked and landing can be made with the trimmer floating.

Thus at take-off with the trimmer locked, the aerodynamic center will be at approximately 26 percent M.A.C. and the center of gravity may be at 20 percent M.A.C. As fuel is consumed, the center of gravity may be permitted to move aft to 32 percent M.A.C., resulting in a 6-percent static margin at a Mach number of 1.5. As speed is reduced for landing, the trimmer may be unlocked at a Mach number of about 1.1, permitting the landing to be made with a static margin of 6 percent with the same center-of-gravity position as at the termination of supersonic flight. With the trimmer locked, it may be used as a trimming device at high speeds and take-off, using the trailing-edge elevators on the wing as a maneuvering control. The maneuverability with this arrangement at a Mach number of 1.5 and an altitude of 60,000 feet is shown in figure 14. It is observed that with this arrangement if the center of gravity is not permitted to move aft of 32 percent M.A.C. (the center-of-gravity position for stability at landing), the elevons are capable of producing a maneuvering normal acceleration of 3.75g compared to 0.2g with the elevons alone (fig. 9). This increased maneuverability over that with the plain elevons is due not only to the increase in elevon power resulting from the use of the trimmer but also the permissible reduction in static margin resulting from the ability to control the aerodynamic center for landing by allowing the trimmer to float at low speeds. If the disposable load can be arranged close to the center of gravity, it may be feasible to take off and climb with the trimmer free floating, locking it only after supersonic flight has been attained. This should not modify in any way the flight characteristics previously presented.

In summary, it may be stated that, with the exception of the exceedingly large hinge moments, the longitudinal stability and control of triangular wings presents no severe difficulties for level flight at Mach numbers up to 1.5. Constant-chord trailing-edge elevons provide adequate control to balance the aircraft throughout the speed range; but if a large degree of maneuverability is required of a highly loaded aircraft, some auxiliary trimming device should be incorporated in the design. One possible configuration employs a trimmer wing placed far forward on the nose of the aircraft. Use of this trimmer permits landing at moderate ground angles and modest sinking speeds, and greatly enhances the maneuverability of the aircraft at large lift coefficients. The hinge-moment characteristics of a constant-chord trailing-edge elevon are such as to require an irreversible control mechanism with the boost power dictated by the hinge moments which occur near a Mach number of unity.

While the efficiency of a triangular wing at supersonic speeds is inferior to that of a highly sweptback wing, the increased structural strength, the increased maneuverability, and the greater freedom from landing problems certainly warrant careful consideration of this plan form for aircraft designed for pursuit and interception at transonic and supersonic speeds.

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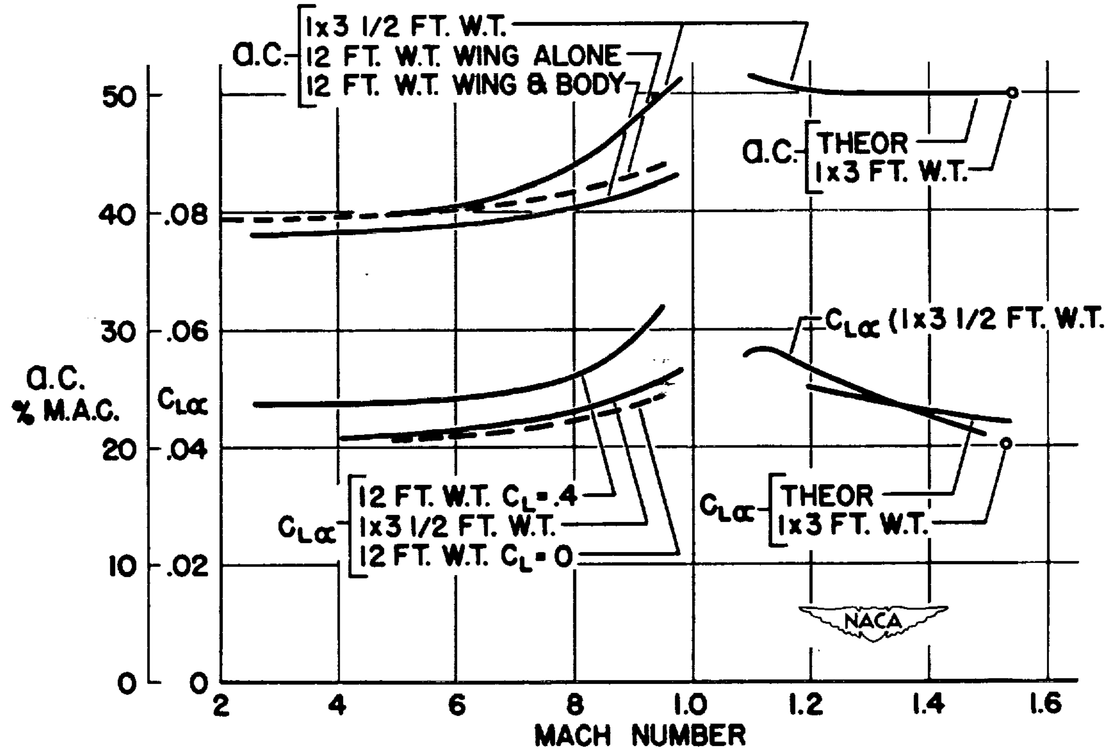


Figure 1.- The effect of Mach number on the lift-curve slope and the location of the aerodynamic center for a triangular wing of aspect ratio 2.

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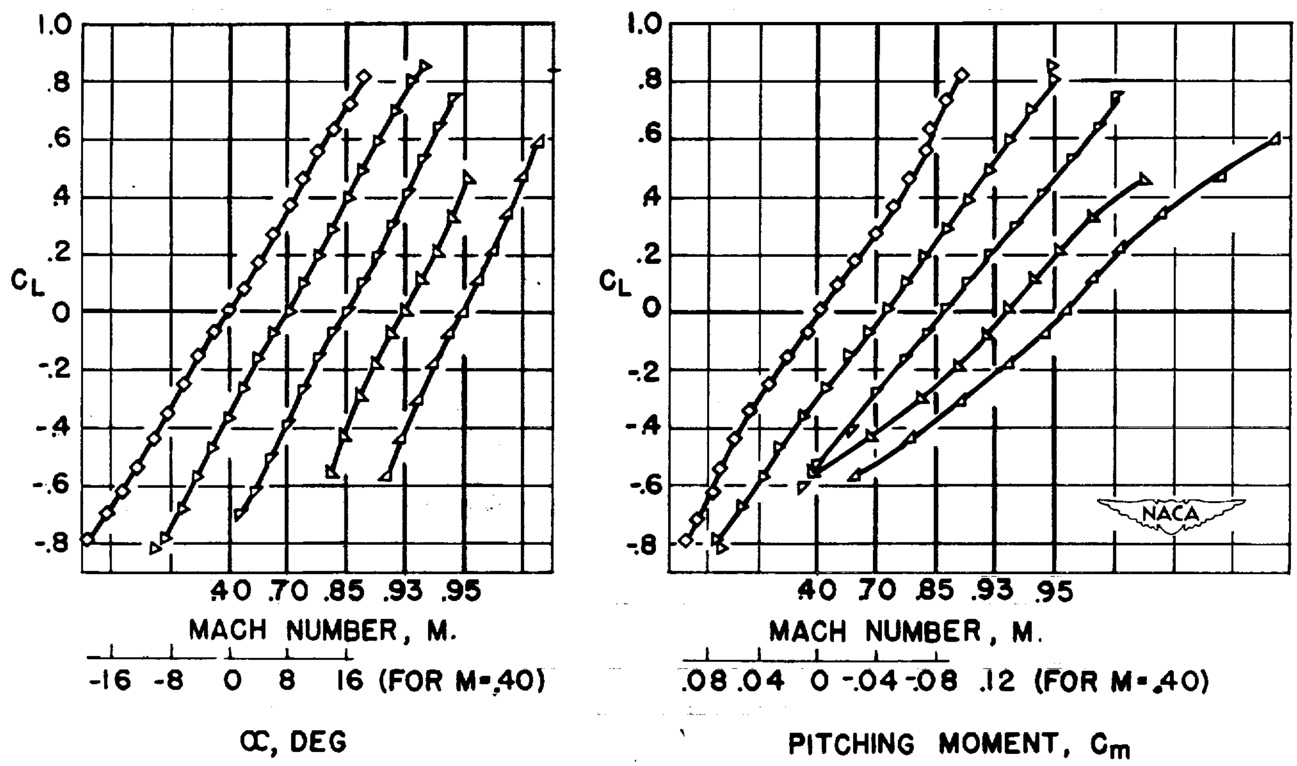


Figure 2.- The effect of Mach number on the lift and pitching-moment characteristics of a triangular wing of aspect ratio 2.

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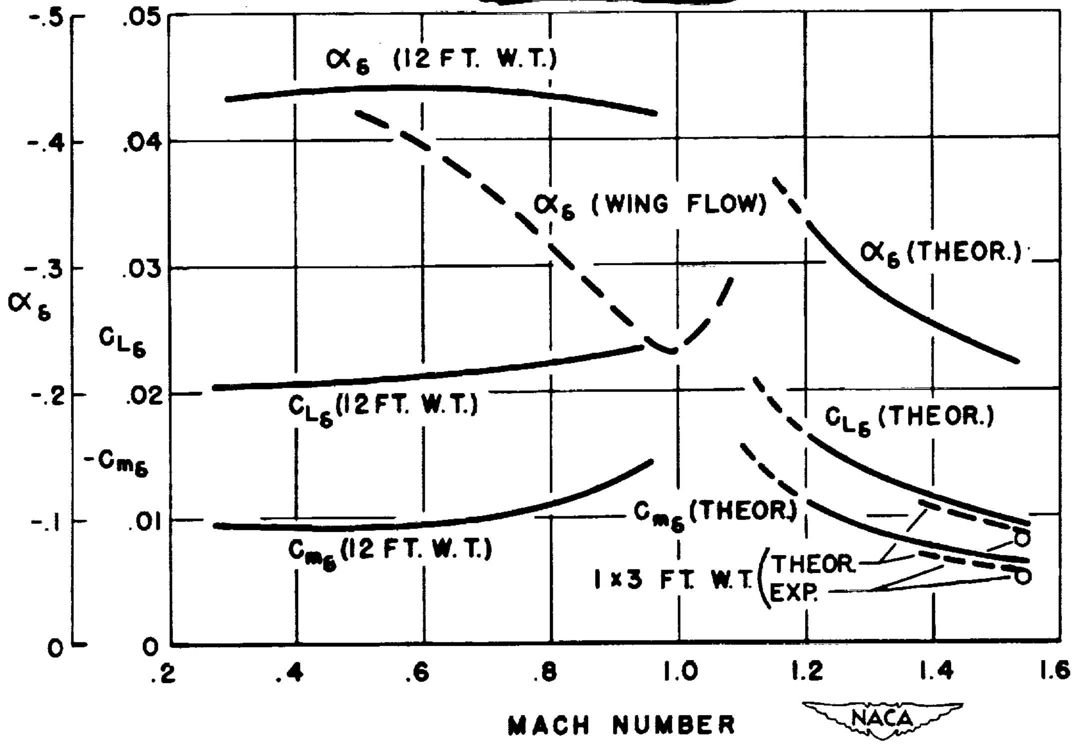


Figure 3.- The effect of Mach number on the effectiveness of a constant-chord plain flap on a triangular wing of aspect ratio 2.

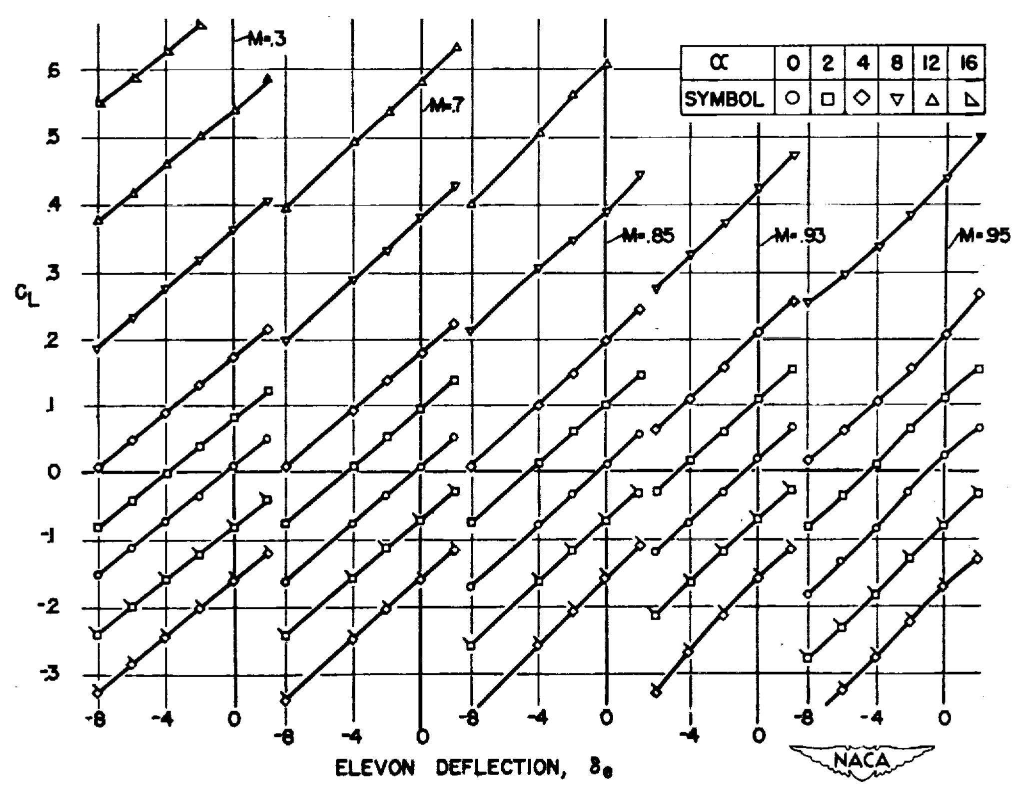


Figure 4.- The effect of Mach number on the lift effectiveness of a constant-chord plain flap on a triangular wing of aspect ratio 2.

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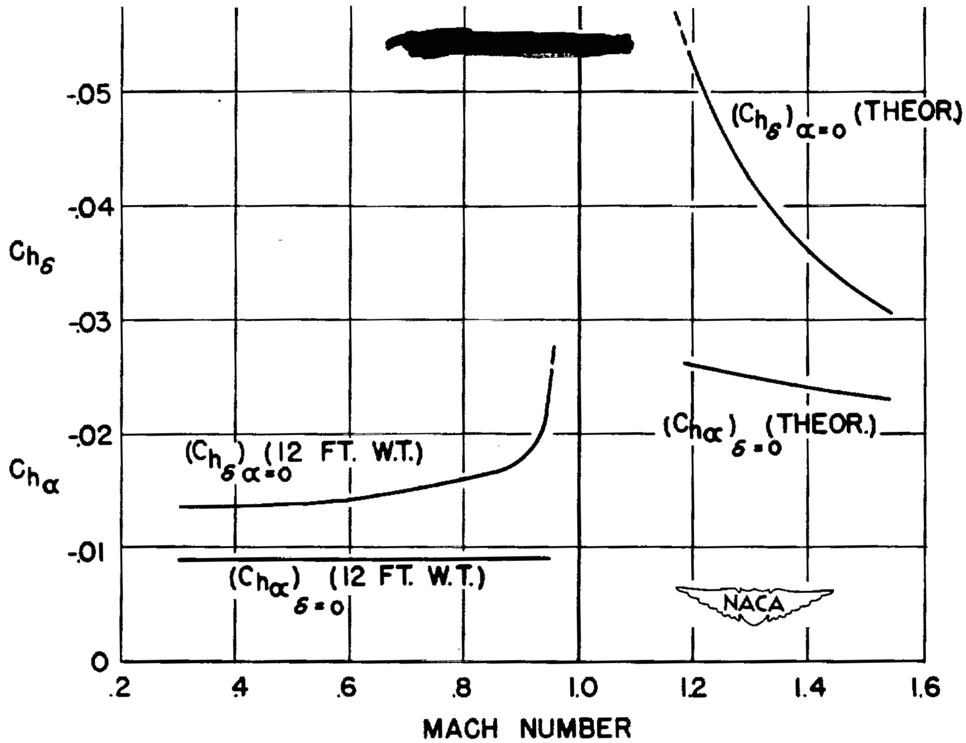


Figure 5.- The effect of Mach number on the hinge-moment characteristics of a constant-chord plain flap on a triangular wing of aspect ratio 2.

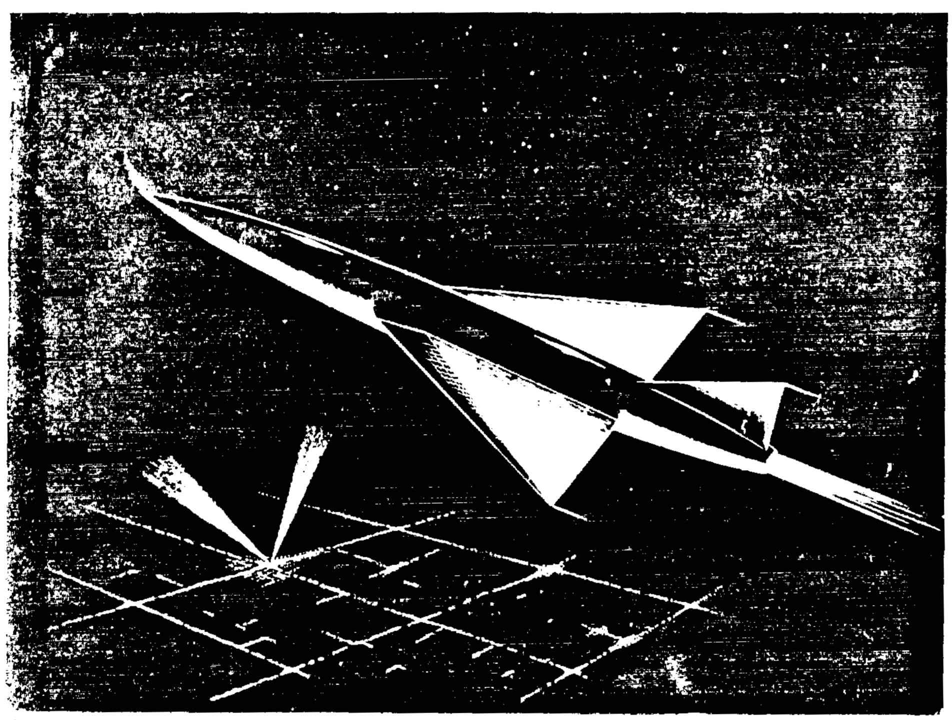

Figure 6.- Interceptor-type aircraft using a triangular wing with a constant-chord control.

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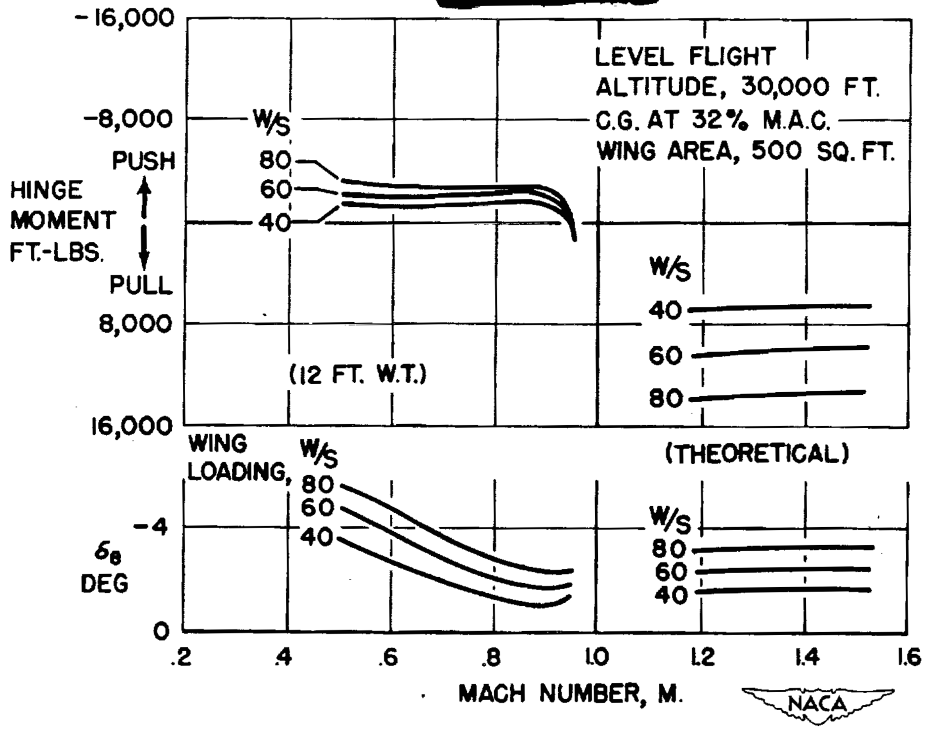


Figure 7.- The estimated variation with Mach number of the elevon angle and the elevon hinge moment required to balance a triangular-winged aircraft in level flight at an altitude of 30,000 feet.

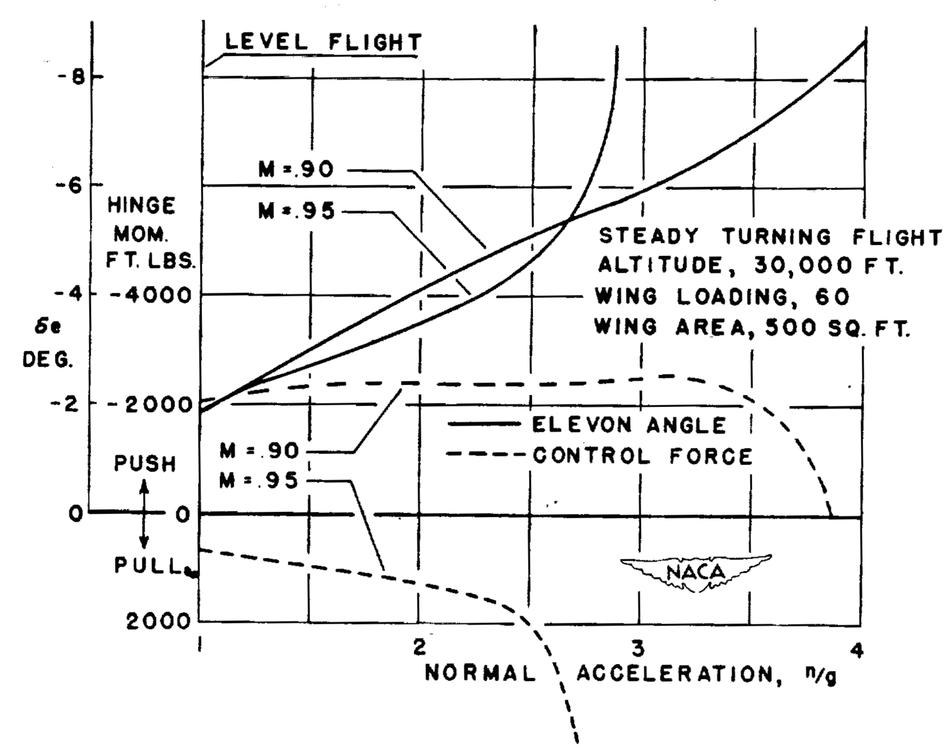


Figure 8.- The estimated variation of elevon angle and elevon hinge moment with normal acceleration for a triangular-winged aircraft in steady turning flight at an altitude of 30,000 feet.

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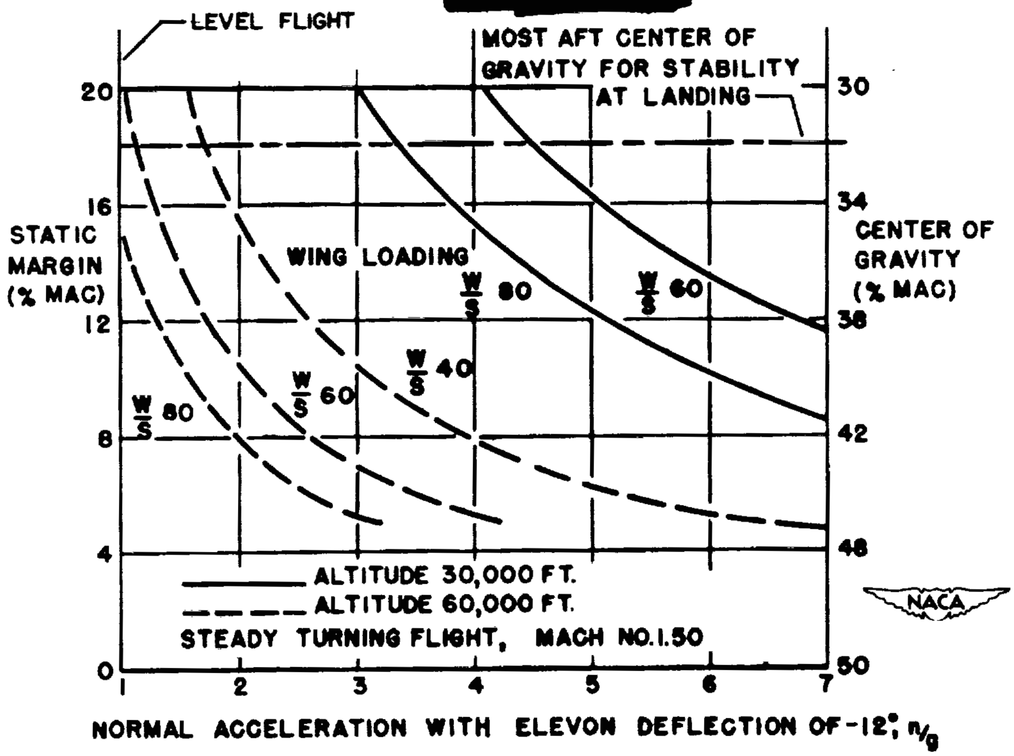


Figure 9.- The effect of static margin on the estimated maneuverability of a triangular-winged aircraft at a Mach number of 1.50.

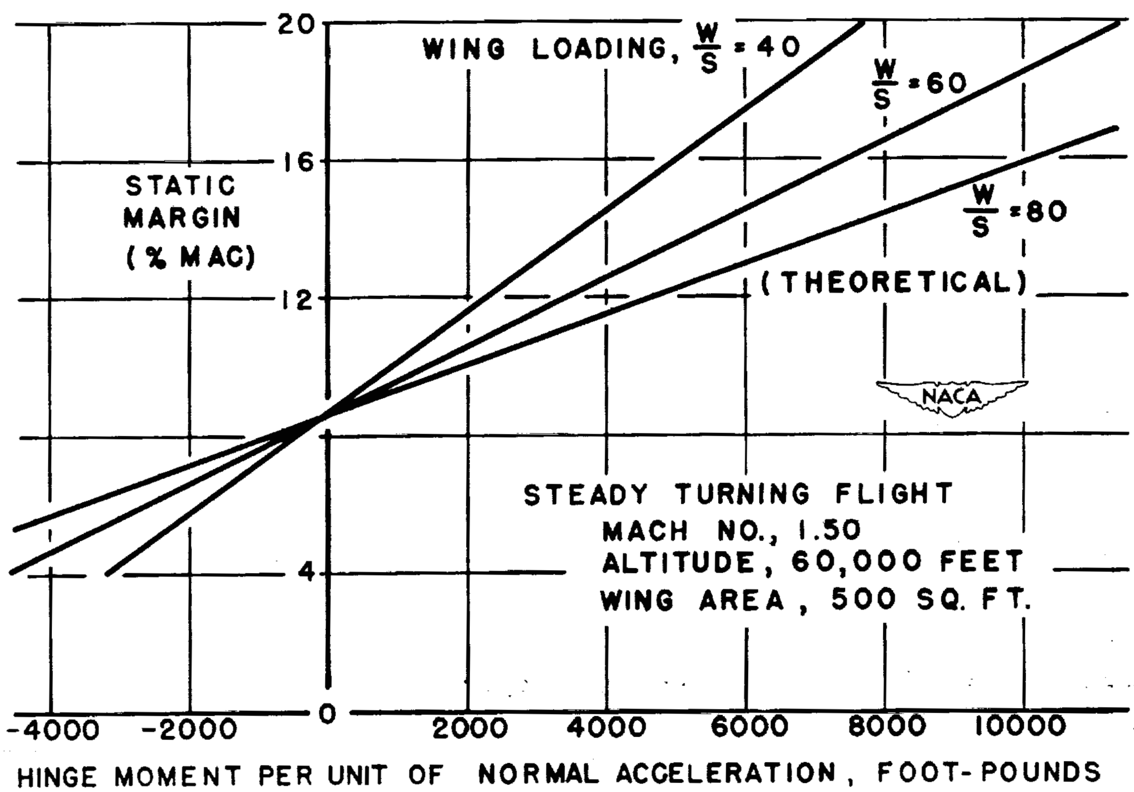


Figure 10.- The effect of static margin on the estimated elevon hinge moment per g of normal acceleration for a triangular-winged aircraft at a Mach number of 1.50.



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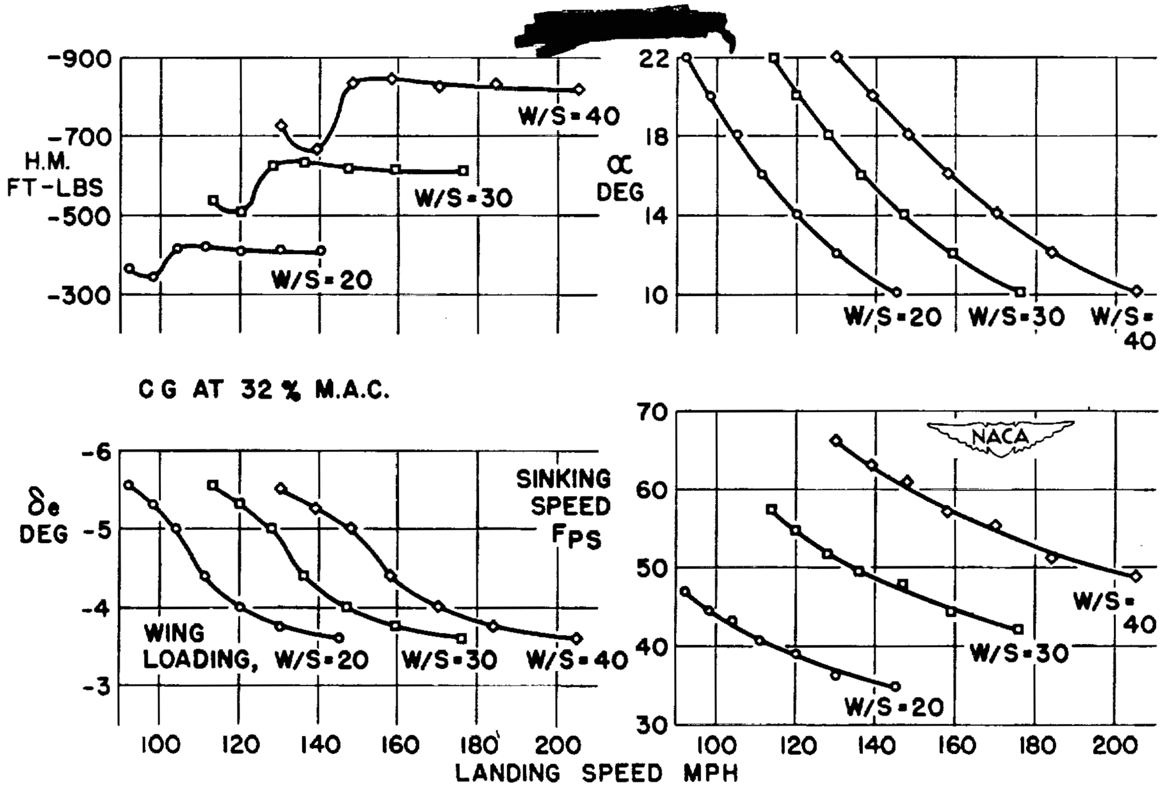


Figure 11.- The estimated landing characteristics of a triangular-winged aircraft with constant chord elevons. Center of gravity at 32 percent M.A.C.

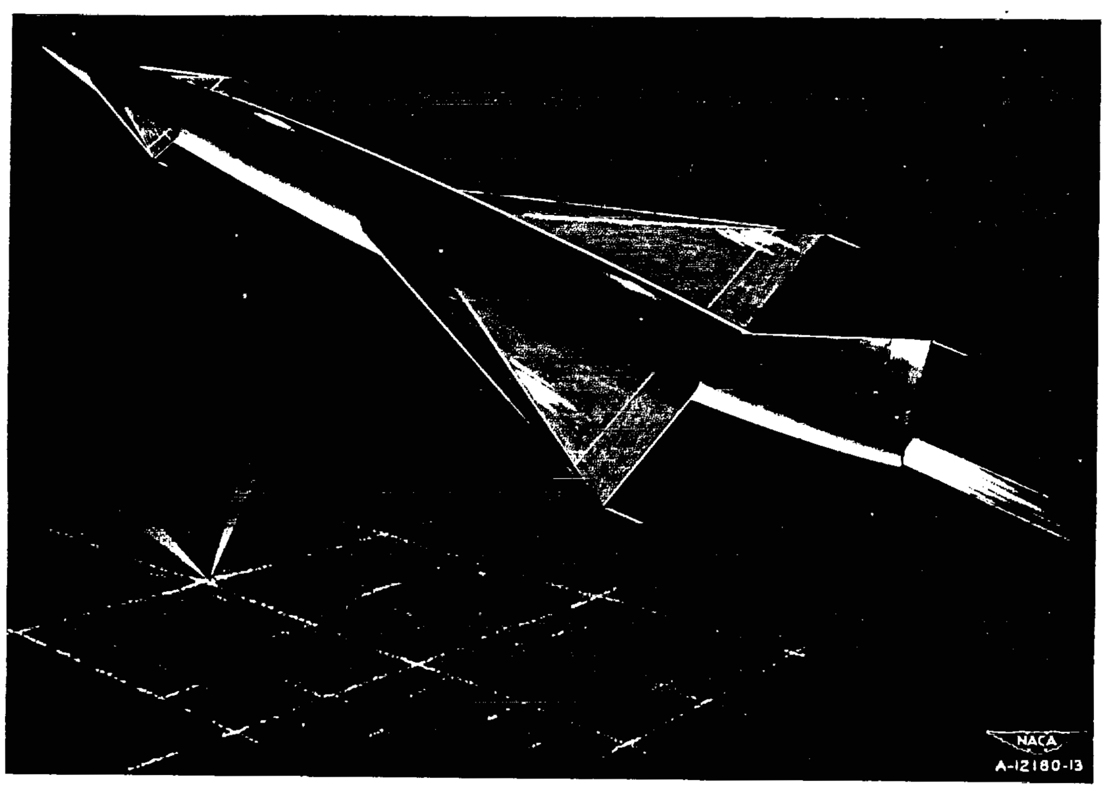


Figure 12.- Interceptor-type aircraft using a triangular wing with a constant-chord control and a trimmer wing.

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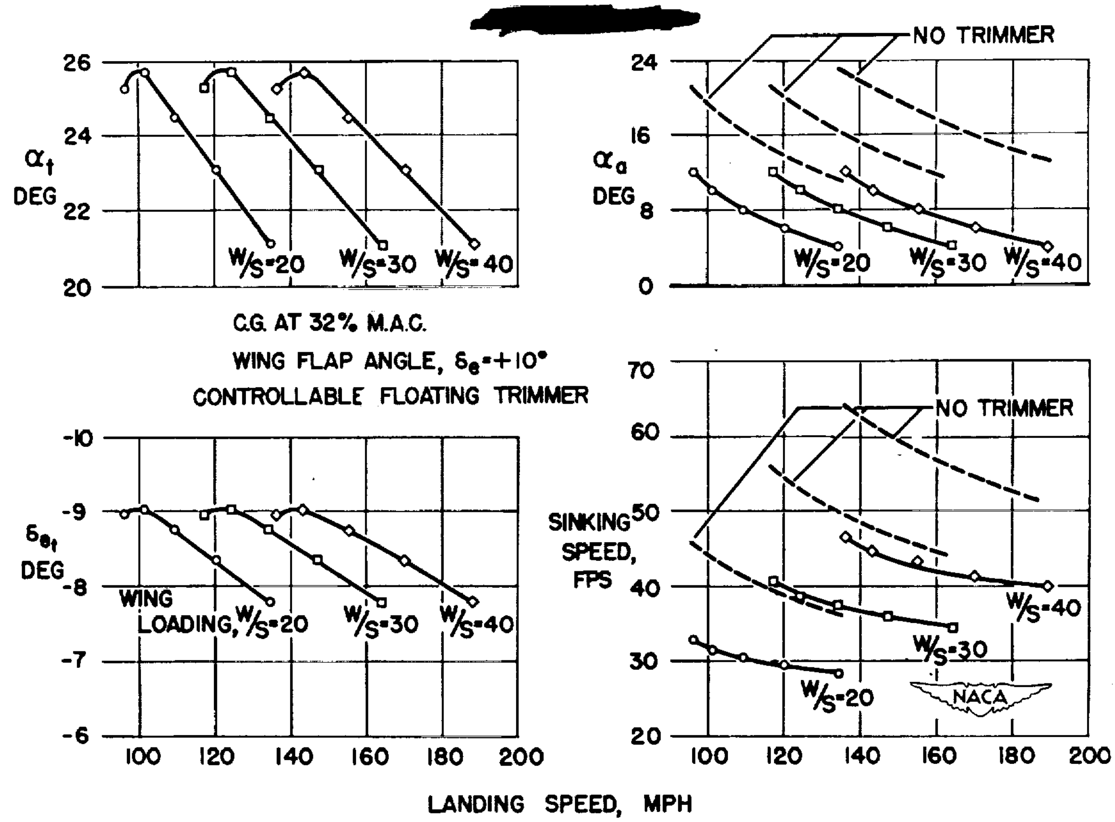


Figure 13.- The estimated landing characteristics of a triangular-winged aircraft equipped with a floating trimmer.

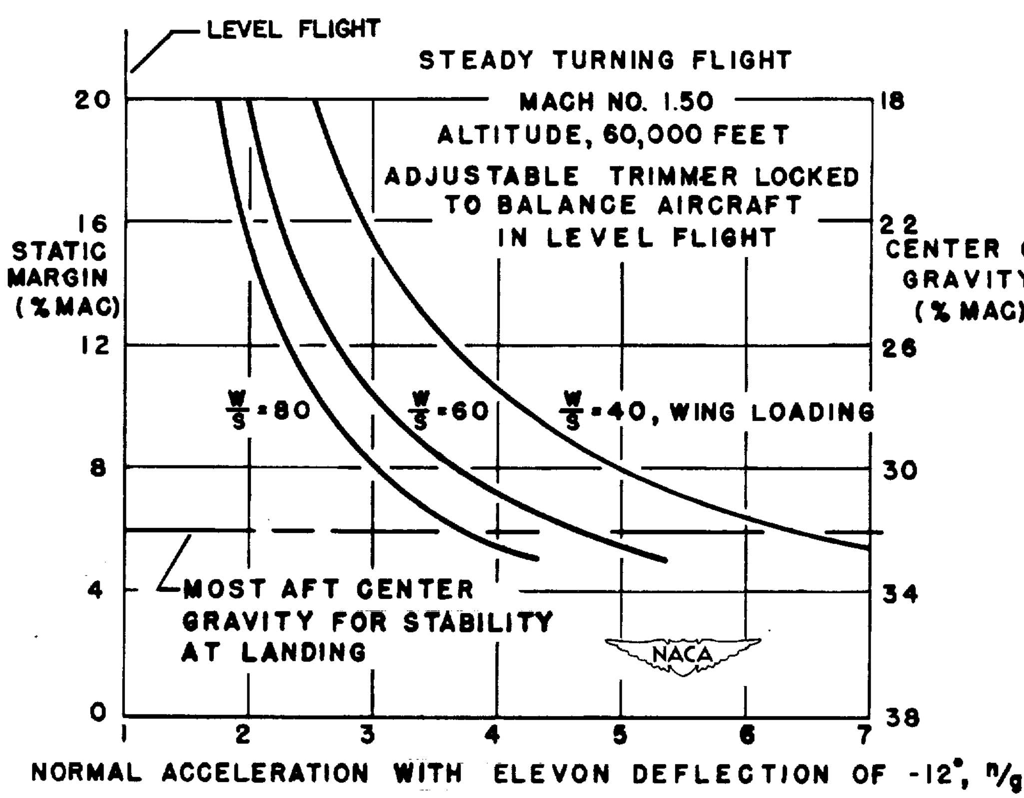


Figure 14.- The effect of static margin on the estimated maneuverability of a triangular-winged aircraft equipped with a trimmer wing. Trimmer locked to balance aircraft in level flight at a Mach number of 1.50.

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