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# Wind-Tunnel Studies of the Effects of Simulated Damage on the Aerodynamic Characteristics of Airplanes and Missiles

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# WIND-TUNNEL STUDIES OF THE EFFECTS OF SIMULATED DAMAGE ON THE AERODYNAMIC CHARACTERISTICS OF AIRPLANES AND MISSILES

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## SUMMARY

As an aid in assessing the aerodynamic effects of battle damage that might be sustained by military airplanes or missiles, several wind-tunnel investigations have been performed at the Langley Research Center in which damage was simulated with models by the removal of all or parts of the wing and tails. Results of the investigations indicate that the loss of a major part of the vertical tail will probably result in the loss of an airplane in any speed range. The loss of major parts of the horizontal tail generally results in catastrophic instability in the subsonic range but, at low supersonic speeds, and for some planform configurations at subsonic speeds, may allow stable flight to the extent that the airplane might return to friendly territory before the pilot must eject. The results further indicate that major damage to the wing, up to the point of the complete removal of one wing panel, and major damage to the horizontal tail may be sustained without necessarily causing the loss of the airplane or pilot. The complete loss of some of the aerodynamic surfaces of various missiles may result in catastrophic instability or, in some instances, may permit an essentially ballistic flight trajectory to be maintained - the difference depending upon the location of the lost surface with respect to the missile center of gravity.

## INTRODUCTION

As an aid in assessing the aerodynamic effects of battle damage that might be sustained by military airplanes or missiles, several wind-tunnel investigations have been performed at the Langley Research Center in which damage was simulated with models by the removal of all or parts of the wing, the horizontal tail, and the vertical tail. The discussion is restricted to the effects of damage on static aerodynamic characteristics over a limited angle-of-attack and angle-of-sideslip range, and no attempt was made to simultaneously trim the models about all three axes. The investigations have a two-fold purpose: (1) to serve as an aid in determing the "kill" probability for combat evaluation; and (2) to serve as an aid in determining the extent of damage that might be sustained and still allow an airplane and/or missile to return to friendly territory or to complete a mission. Details of some investigations thus far completed may be found in references 1 to 7.

## SYMBOLS

$C_L$ lift coefficient

$C_l$ rolling-moment coefficient

$C_m$ pitching-moment coefficient

$\partial C_m/\partial C_L$ longitudinal stability parameter

$C_n$ yawing-moment coefficient

$C_{n_\beta}$ directional stability parameter

M Mach number

$\alpha$ angle of attack, deg

$\beta$ angle of sideslip, deg

$\Lambda$ wing sweep angle, deg

$\delta_a$ aileron deflection, deg

$\delta_h$ horizontal-tail deflection, deg

$\delta_r$ rudder deflection, deg

Model components:

B body

W wing

T tail

C canard

## DISCUSSION

Typical types of simulated damage employed in these investigations are shown in figures 1 to 3 for a swept-wing, a delta-wing, and a trapezoidal-wing airplane. Fairly extensive tests were made of a model of a swept-wing fighter airplane (ref. 2). Figure 4 shows the model with 52 percent of the right wing removed to simulate wing damage. Figure 5 shows the model with 44 percent of the vertical tail removed to simulate vertical-tail damage.

The effect of wing damage on the lift and longitudinal stability of the swept-wing fighter model at a Mach number of 1.57 is shown in figure 6. The results indicate a progressive decrease in the lift-curve slope as the wing is progressively removed and a slight reduction in the stability level. The airplane does remain statically stable, however, and no difficulty in trimming the pitching moment should occur if the pitch-control surface is operative.

The effect of horizontal-tail damage on the lift and longitudinal stability of the swept-wing fighter model at a Mach number of 1.57 is shown in figure 7. Only a slight decrease in lift-curve slope occurs as the horizontal-tail surface area is progressively removed. However, a measurable decrease in the longitudinal stability is indicated as the tail is removed, although the airplane remains statically stable when only two-thirds of the right horizontal-tail panel remains on the airplane. Sufficient control power is available to trim the airplane with the remaining part of the right horizontal-tail panel provided that the control is operative.

The effect of wing damage on the lateral stability of the swept-wing fighter model at a Mach number of 1.57 is shown in figure 8. As might be expected, a substantial amount of positive rolling moment is developed by the removal of parts of the right wing. The effects on the yawing moment, however, are relatively small. Because of the positive effective dihedral, the rolling moment produced by the asymmetric wing condition trims to zero roll at a sideslip angle of approximately $4^{\circ}$. Thus, for the airplane to remain flyable under these conditions, the positive effective dihedral would be necessary to trim the rolling moments, and rudder power would be necessary to provide the sideslip angle. Other tests indicate that sufficient yaw-control power is available to provide the necessary sideslip angle with a rudder deflection of about $8^{\circ}$.

The effect of damage on the directional stability parameter $C_{n_\beta}$ is shown in figure 9 for the sweep-wing fighter model at a Mach number of 1.57. These results indicate that wing damage and horizontal-tail damage have little effect on the directional stability of the airplane. However, as parts of the vertical tail are removed, the directional stability reduces drastically so that with 44 percent of the vertical area removed, the airplane is statically unstable. Of course, removal of the entire vertical tail would result in even greater instability. Conditions such as these which result in directional instability

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should have catastrophic effects upon the flyability of the airplane.

A fairly complete study of control effectiveness was performed in the investigation of a delta-wing fighter model (ref. 3). A summary of the control requirements for this fighter model at a Mach number of 1.41 and an altitude of 9.14 km is shown in figure 10. Results are shown for the rolling-moment and the yawing-moment variation with sideslip angle for conditions where 32 percent of the right wing is removed and where the entire right wing is removed. The asymmetry thus produced is indicated by the solid faired lines. The dash lines indicate the amount of aileron roll-control power available for a deflection of $20^{\circ}$ and the rudder-control power available for a rudder deflection of $20^{\circ}$. For the conditions shown, sufficient roll- and yaw-control power is available to completely offset the damage effects even when the entire right wing is removed. Results at supersonic speeds for a trapezoidal wing, twin-tail airplane with simulated wing and tail damage (ref. 4) are similar to those shown by the swept-wing and the delta-wing airplanes.

A typical variation of the longitudinal stability with Mach number for an airplane with the horizontal tail on and off is shown in figure 11. The loss of the hoirzontal tail at subsonic speeds will generally result in a catastrophic unstable condition. However, because of the rearward shift of the wing aerodynamic center with Mach number, airplanes without horizontal tails are usually statically stable at supersonic speeds. Because of this characteristic, flying in a stable condition (trim control unavailable) with the entire horizontal tail off may be possible if flight at low supersonic Mach numbers can be maintained. Some results (refs. 5 to 7) indicate that for certain delta-type planforms, and a variable-sweep planform, longitudinal stability might also be maintained even at low speeds (figs. 12 and 13). Under such conditions, trim could only be expected to occur at relatively low angles of attack or at lift conditions very nearly zero; however, the airplane may possibly be flown under these conditions for distances sufficient to return to friendly territory before the pilot must eject. Thus, the airplane may be lost, but the pilot will be saved.

The typical effect of Mach number on directional stability for conventional airplane configurations is shown in figure 14 for the vertical tail on and off. When the vertical tail is removed, directional instability generally occurs throughout the Mach number range, and destruction of the airplane is almost certain either at subsonic or supersonic speeds.

Although only limited studies of cruise missiles have been made with and without tail surfaces, the general results of these tests are similar to results for the airplane studies. An interesting example illustrated in figure 15, however, indicates a case wherein a subsonic cruise missile might continue to fly a longitudinally stable flight path even with the tail surfaces removed. Under certain conditions, such a characteristic might permit the missile to maintain an essentially ballistic trajectory and successfully complete a mission.

The longitudinal characteristics for two surface-to-air missiles at $M = 3$ are shown in figure 16. One missile has an aft-tail control and the other has a forward (canard) control. Both missiles become catastrophically unstable if the main wing is lost. However, if only the control surface is lost, both missiles would be able to maintain a zero-lift ballistic flight path.

## CONCLUDING REMARKS

In conclusion, the results of the investigations thus far indicate that the loss of a major part of the vertical tail will result in the loss of the airplane in any speed range. The loss of major parts of the horizontal tail may result in catastrophic instability in the subsonic range but at low-supersonic speeds, and for some planform configurations at subsonic speeds, may allow stable flight to the extent that an airplane might return to friendly territory before the pilot must eject because of lack of pitch control. The results further indicate that major damage to the wing, up to the point of the complete removal of one wing and major damage to the horizontal tail may be sustained without necessarily causing the loss of the airplane or pilot. The complete loss of some of the aerodynamic surfaces of various missiles may result in catastrophic instability or, in some instances, may permit an essentially ballistic flight trajectory to be maintained - the difference depending upon the location of the lost surface with respect to the missile center of gravity.

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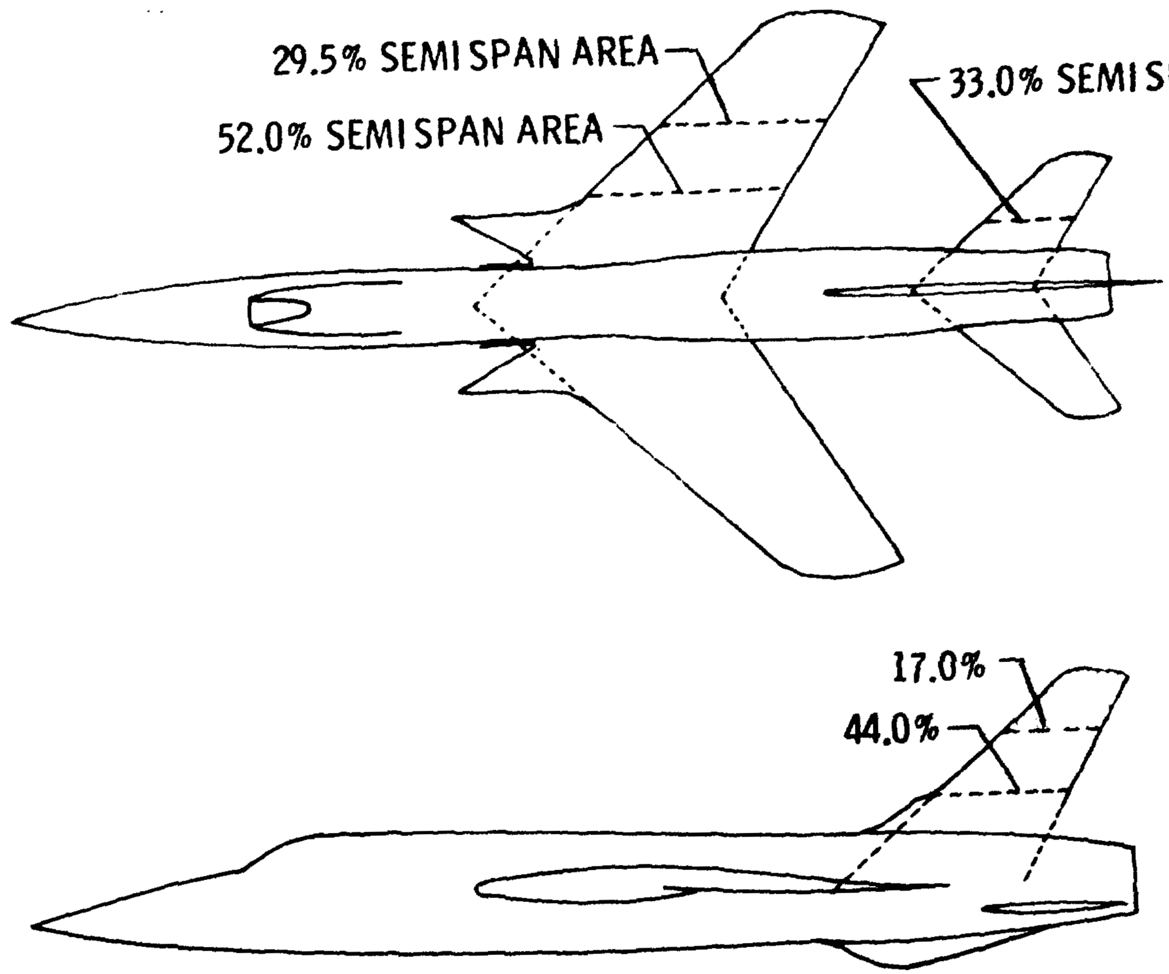


Figure 1. Swept-wing airplane.

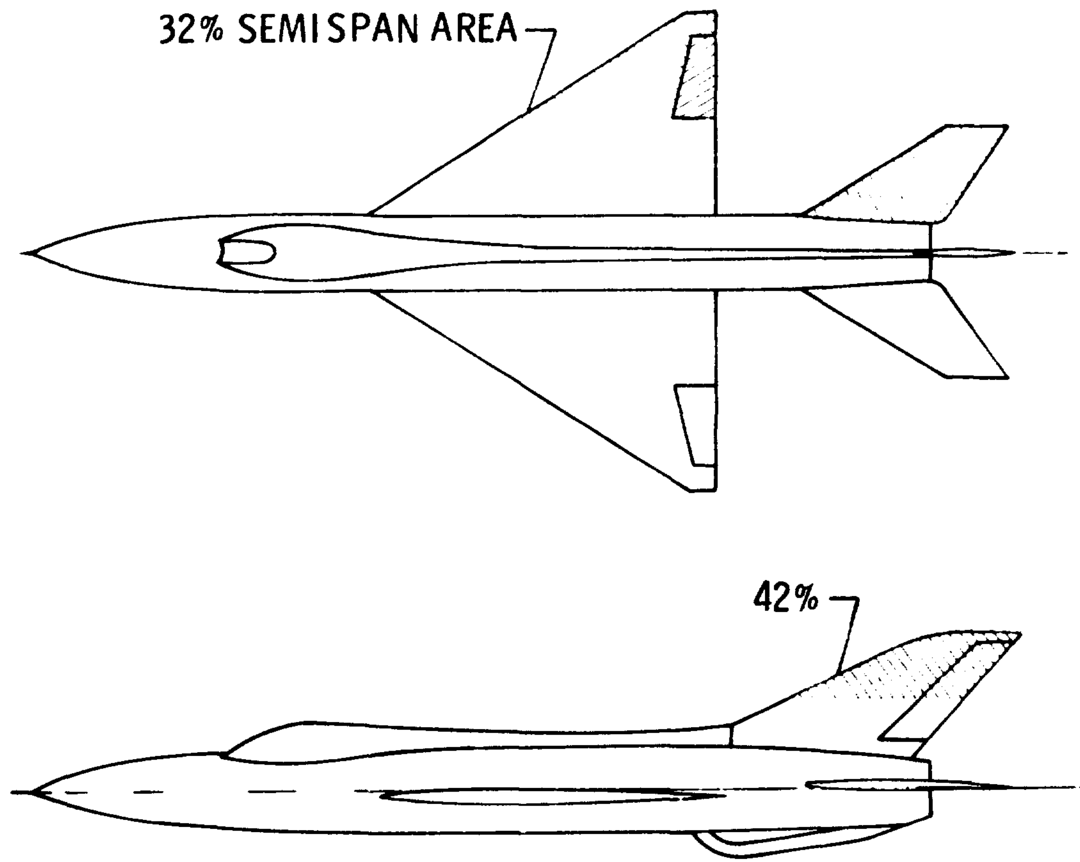


Figure 2. Delta-wing airplane.

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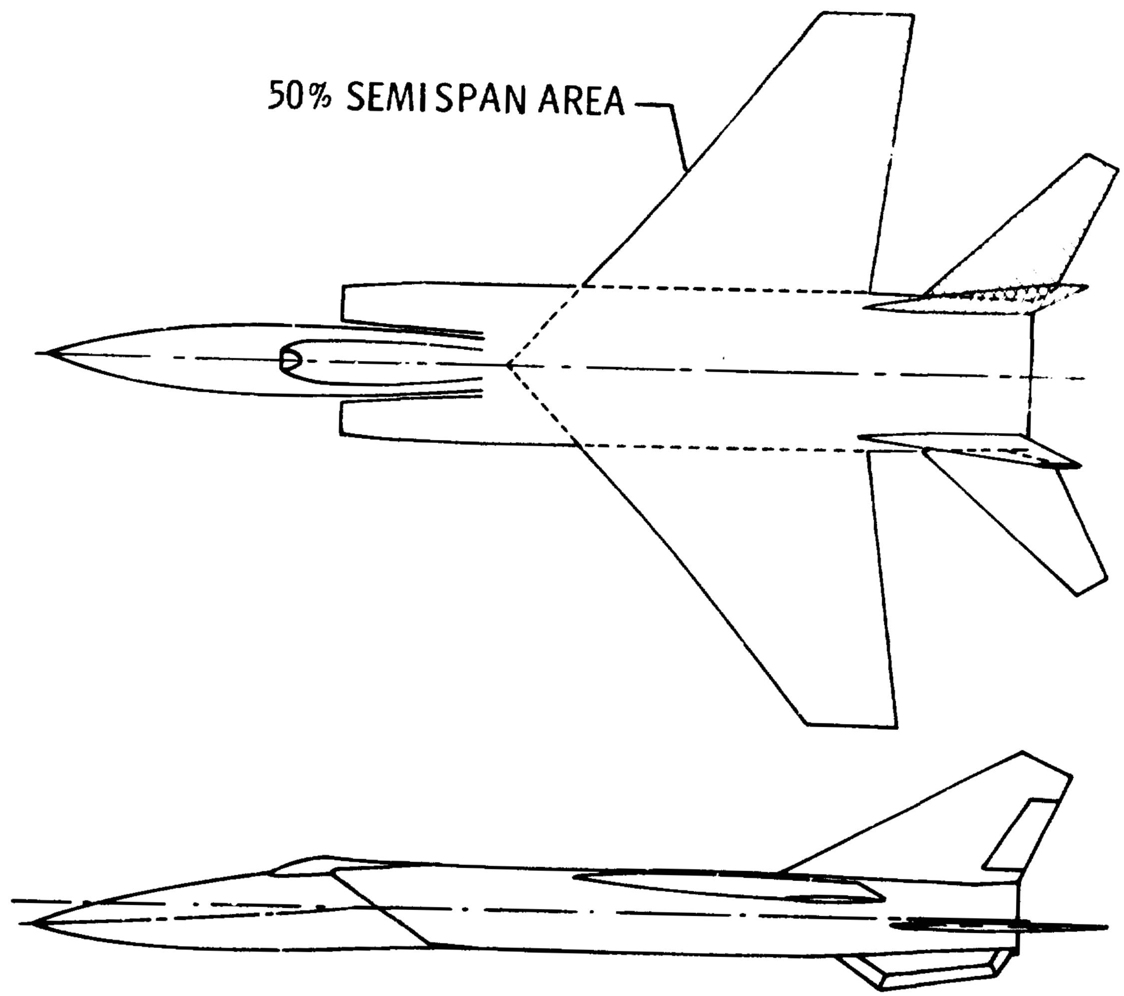


Figure 3. Trapezoidal-wing airplane.

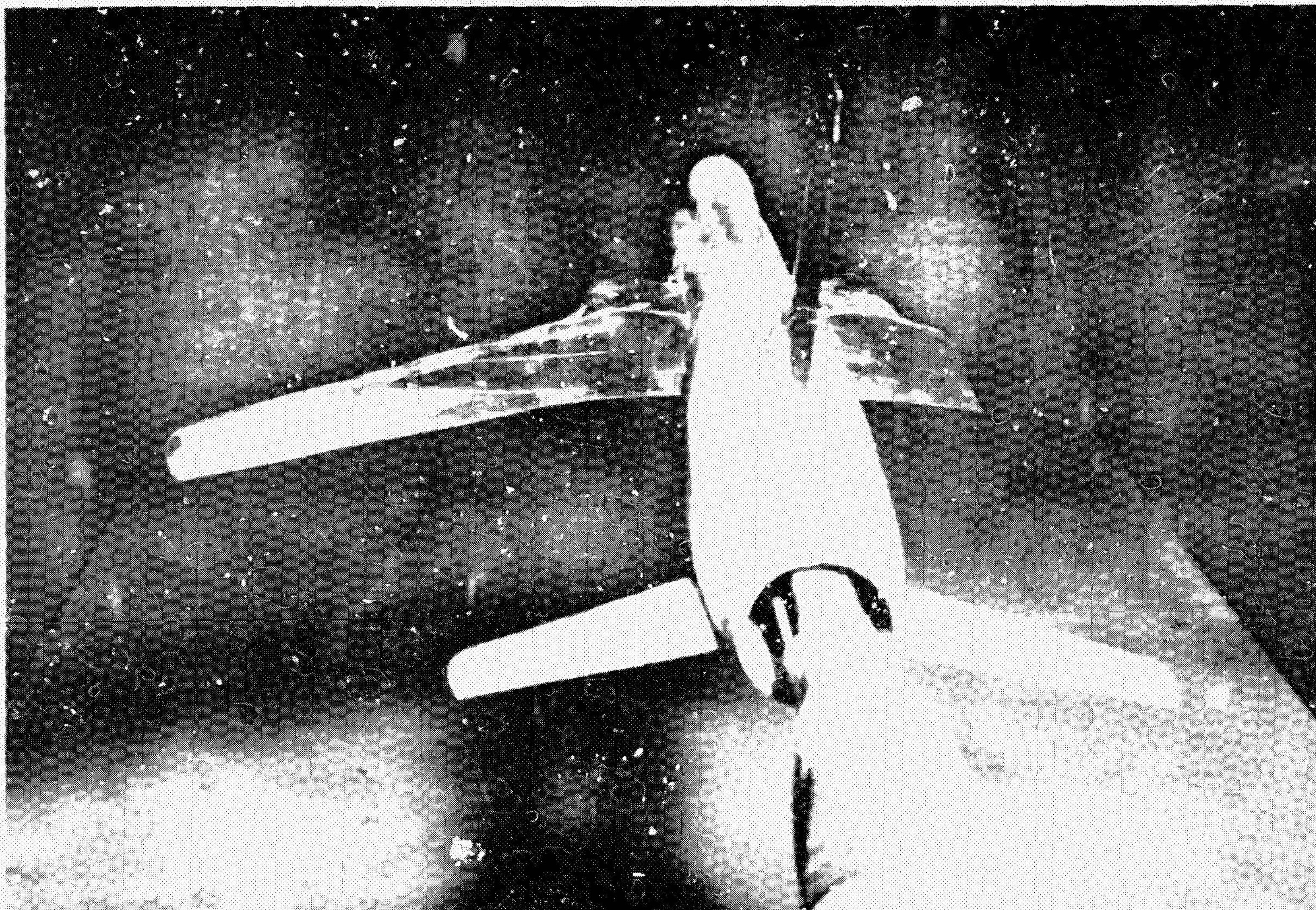

Figure 4. Swept-wing fighter model with wing damage.

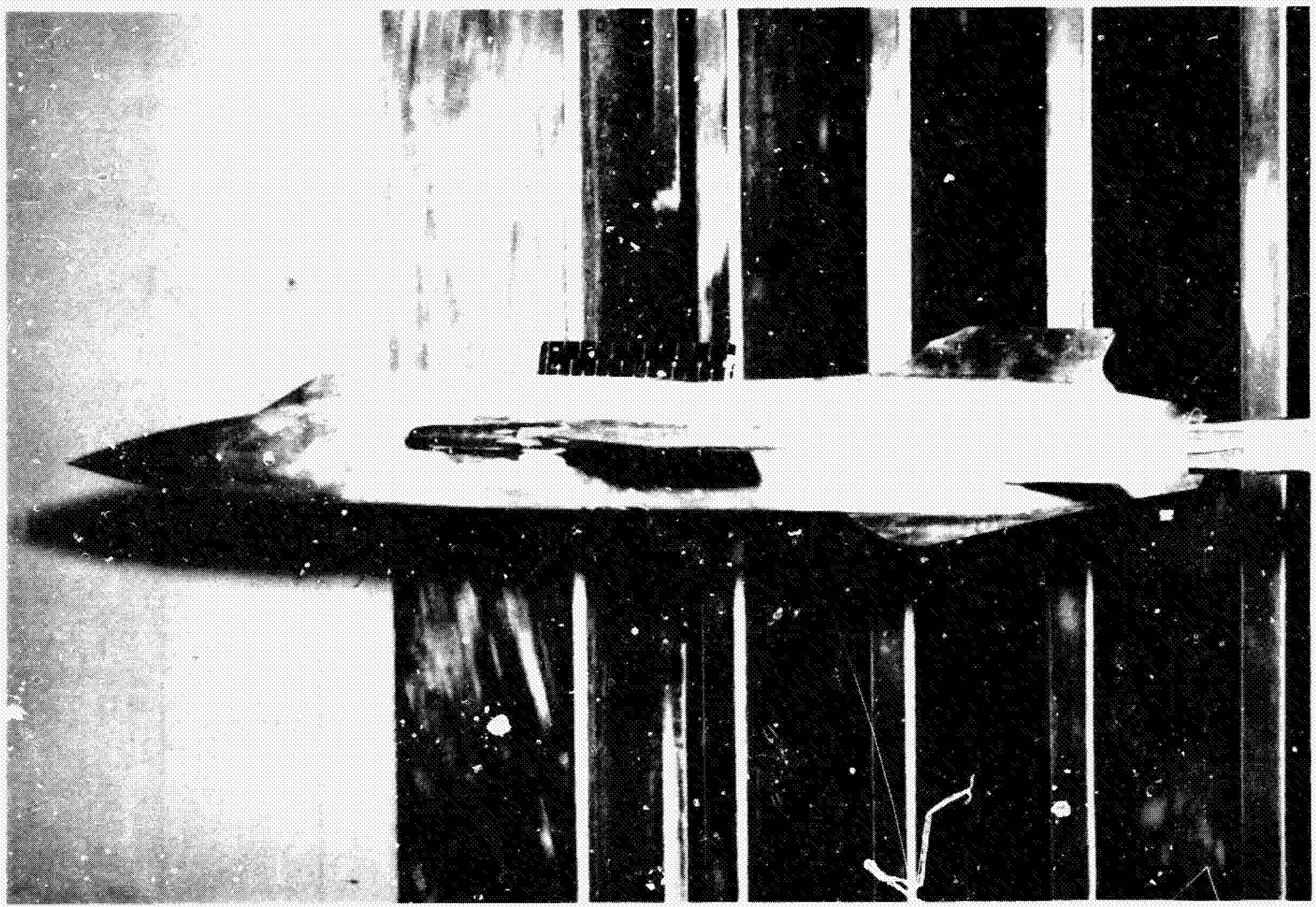

Figure 5. Swept-wing fighter model with vertical-tail damage.

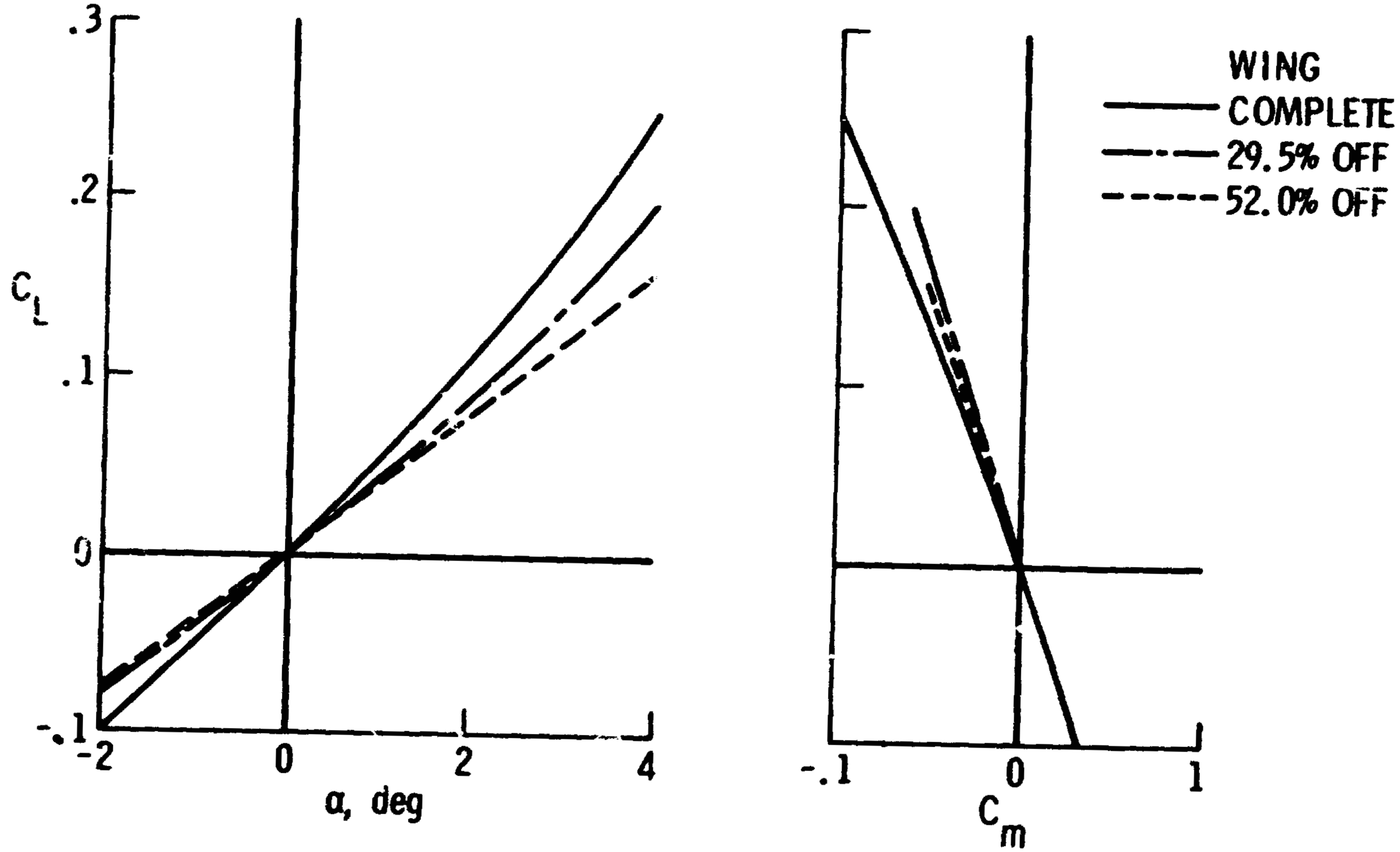


Figure 6. Effect of wing damage on longitudinal stability of swept-wing fighter model at M = 1.57. Left wing complete.

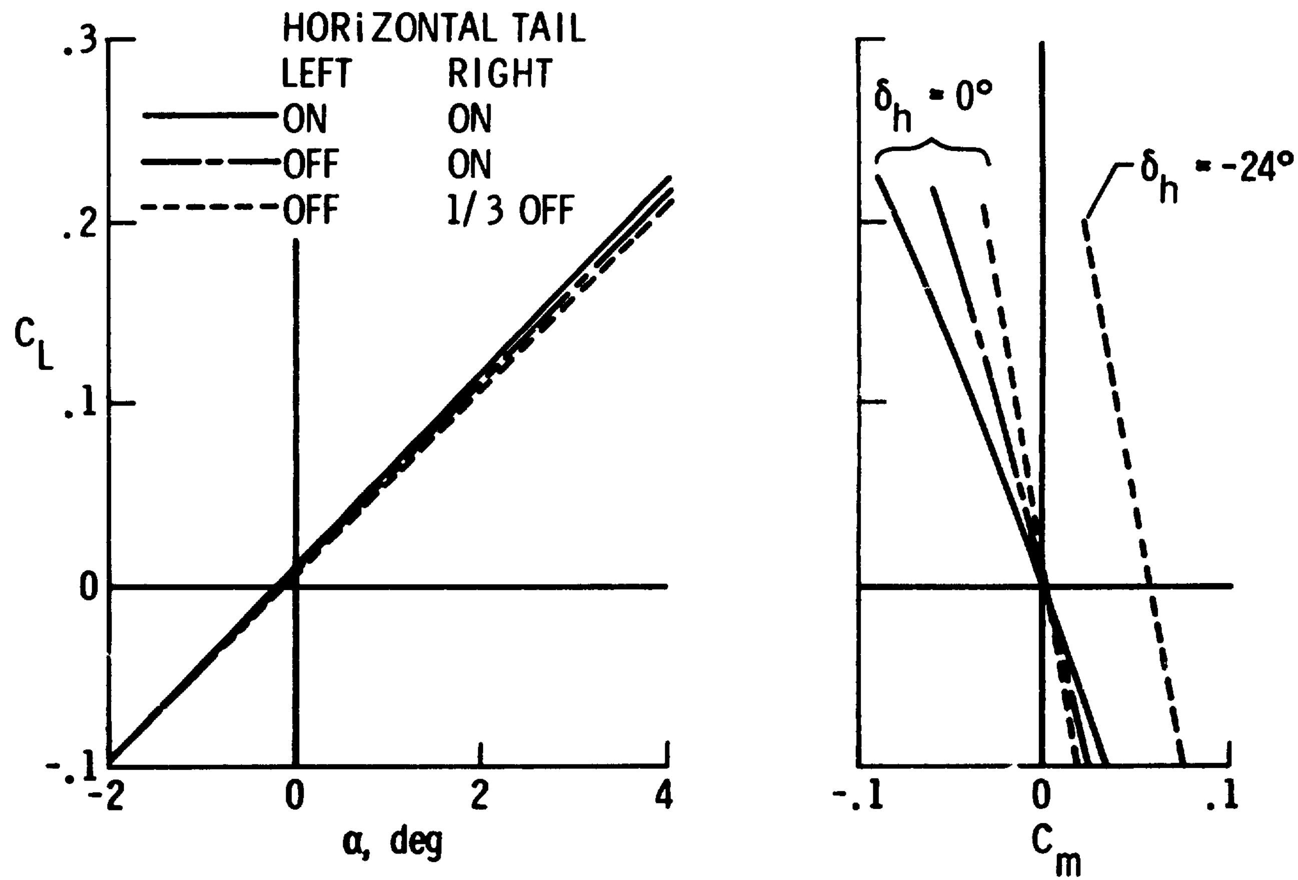


Figure 7. Effect of horizontal-tail damage on longitudinal stability of swept-wing fighter model at M = 1.57.

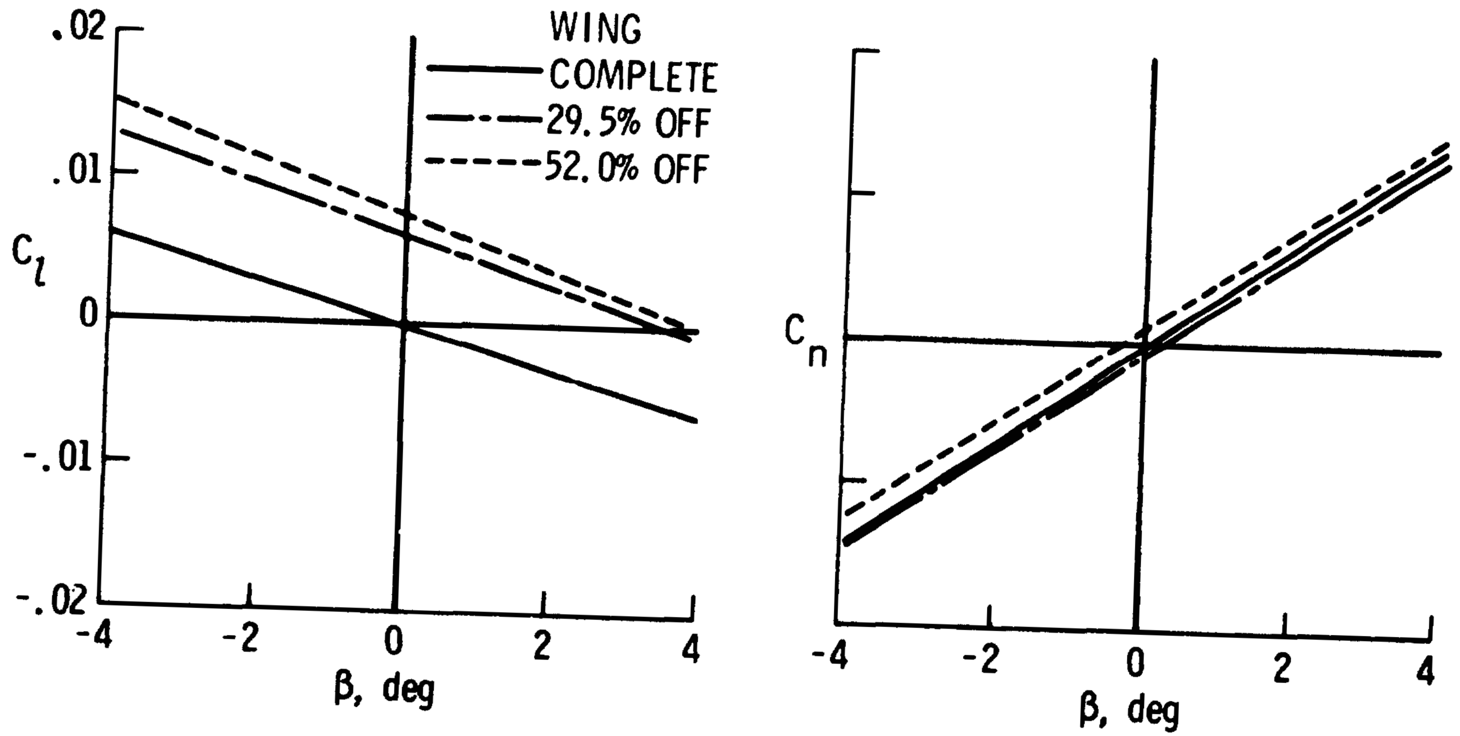


Figure 8. Effect of wing damage on lateral stability of swept-wing fighter model at M = 1.57. Left wing complete; $C_L$ = 0.05.

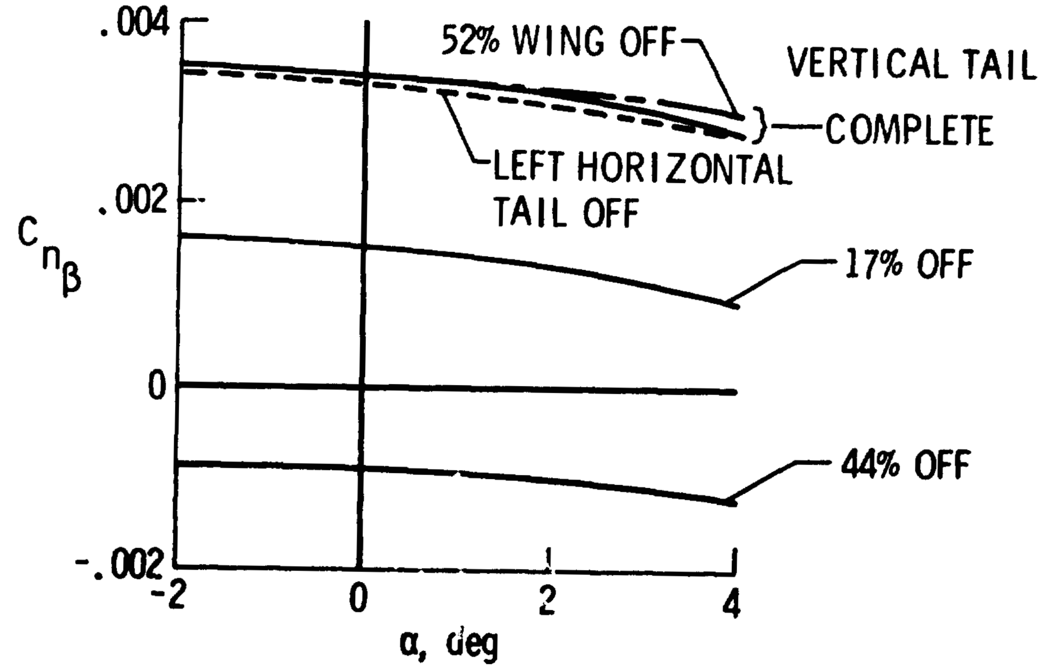


Figure 9. Effect of damage on directional stability of swept-wing fighter model at M = 1.57.

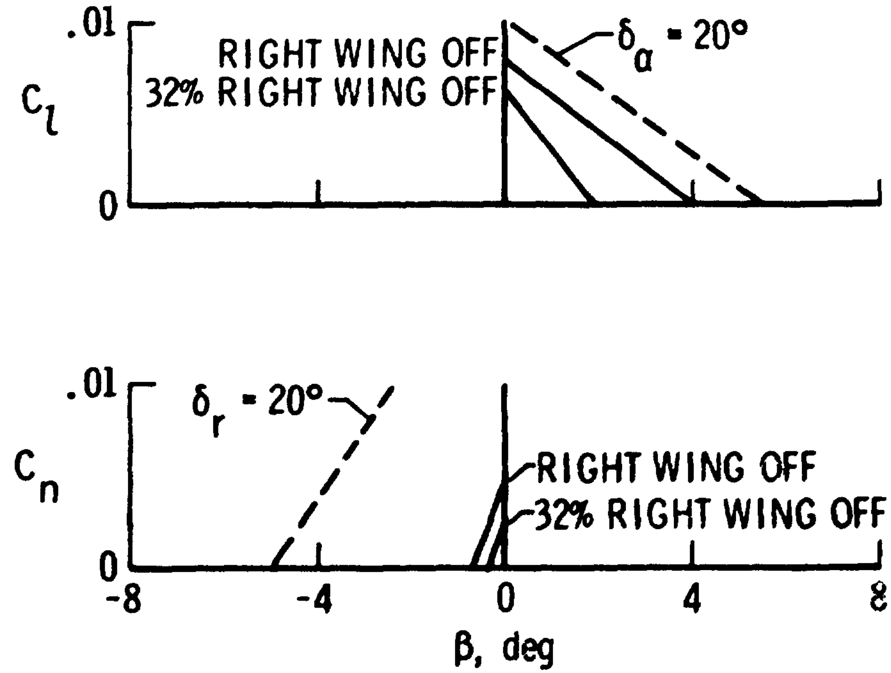


Figure 10. Summary of control requirements of delta-wing fighter model at M = 1.41. Altitude, 9.14 km.

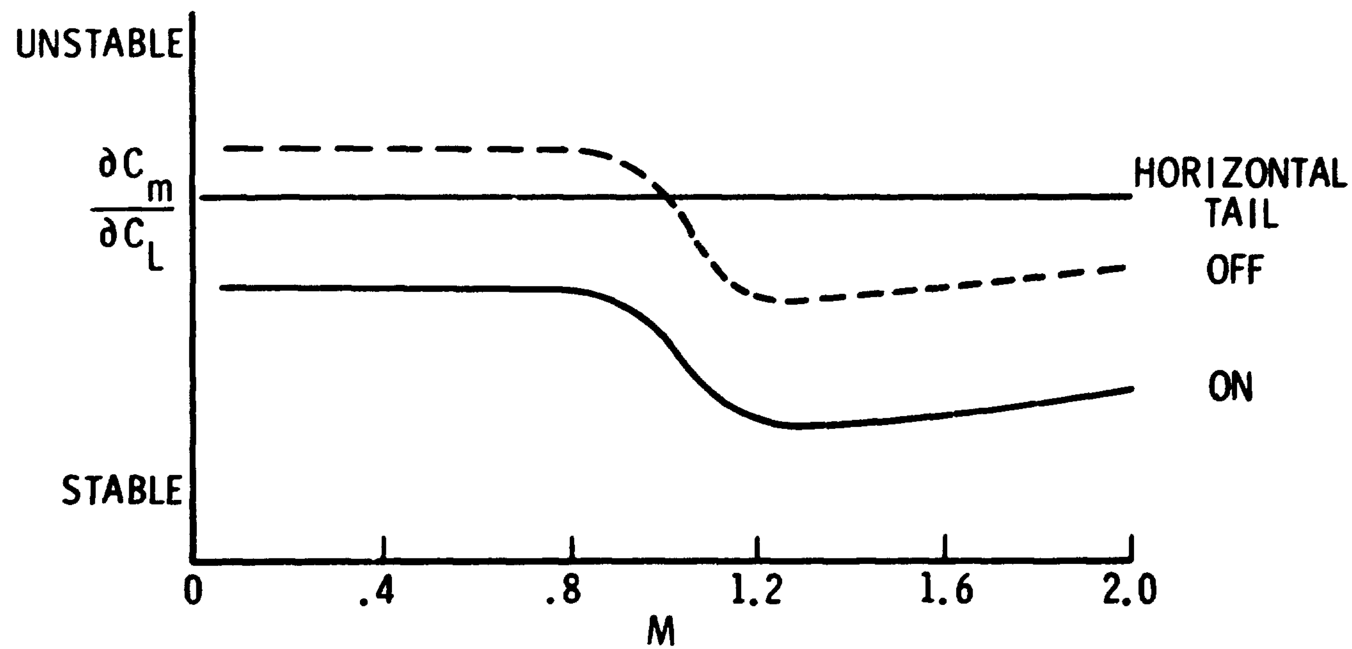


Figure 11. Effect of Mach number on longitudinal stability.

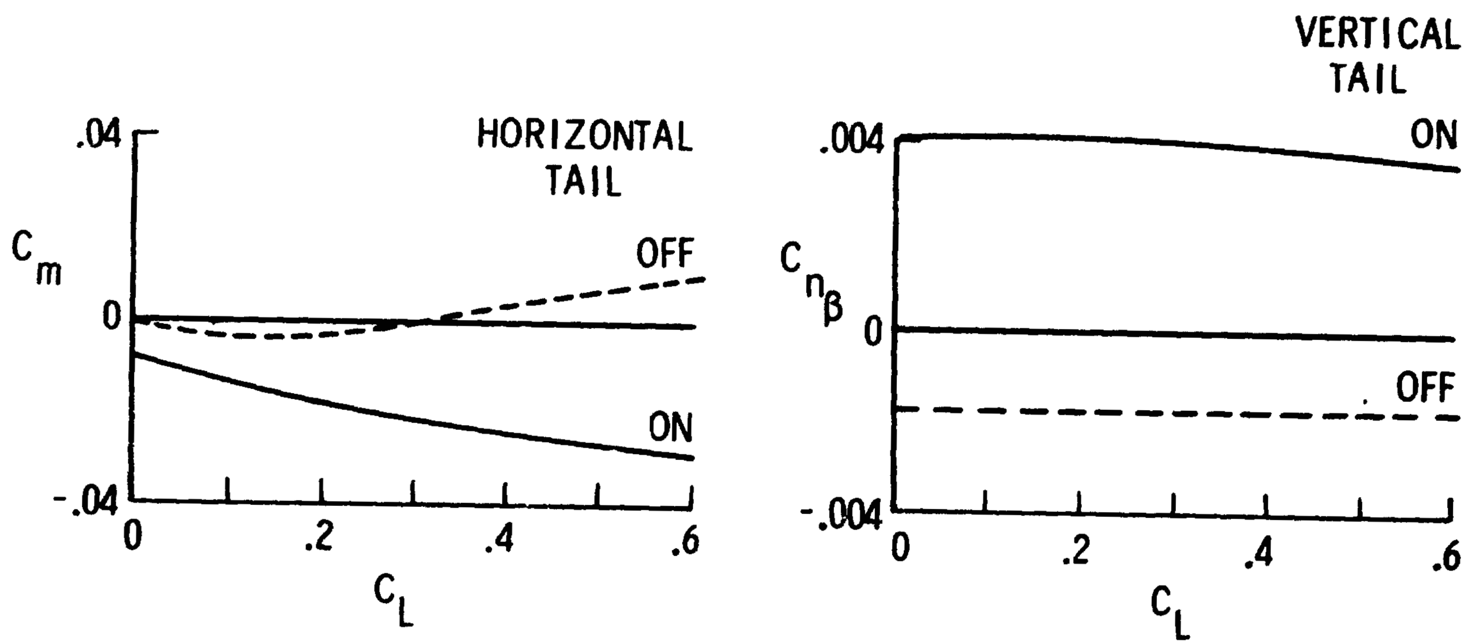




Figure 12. Effect of tails on stability characteristics of delta-wing fighter model at M = 0.60.

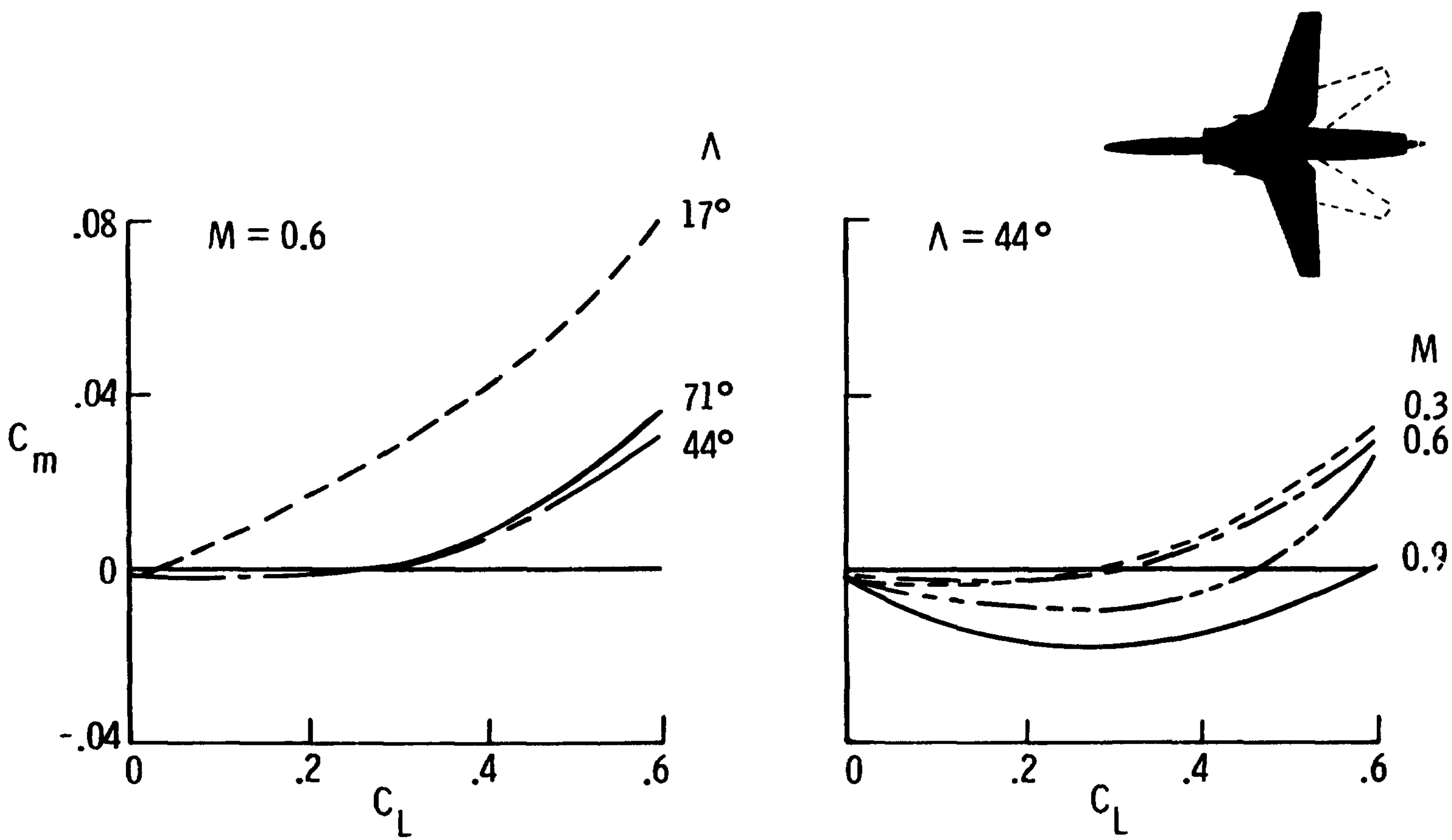


Figure 13. Effect of sweep angle and Mach number on longitudinal stability of variable-sweep fighter model at subsonic speeds. Horizontal tail off.

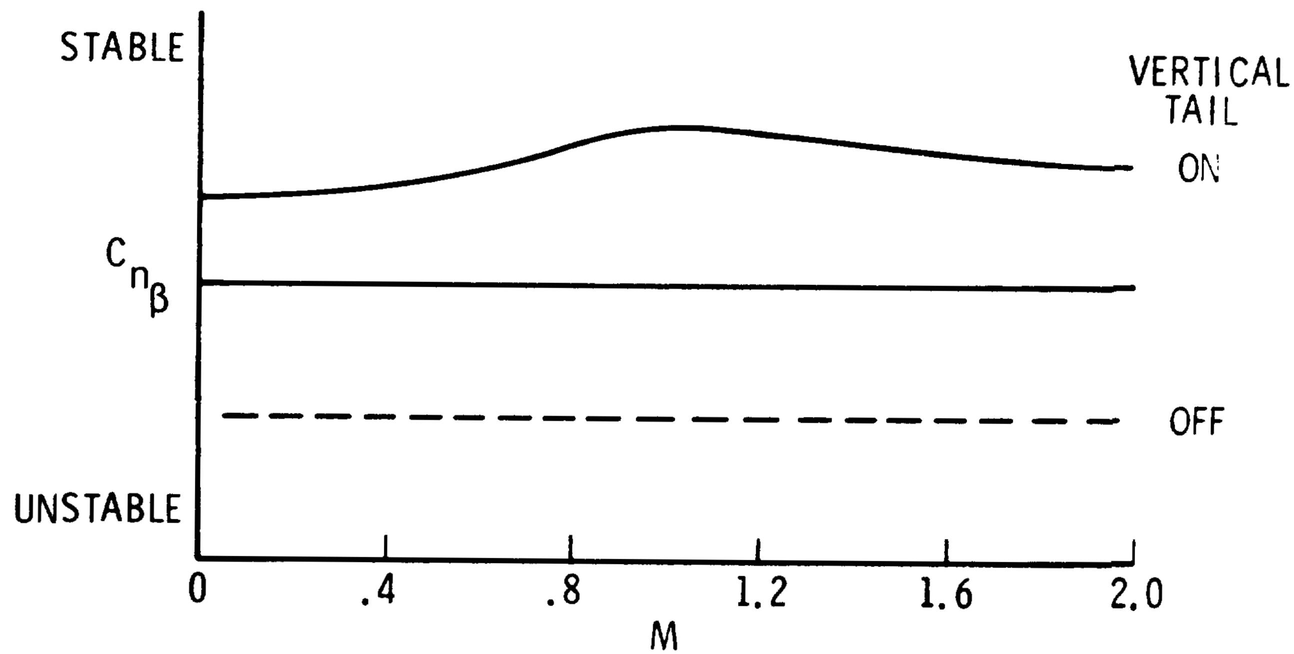


Figure 14. Effect of Mach number on directional stability.

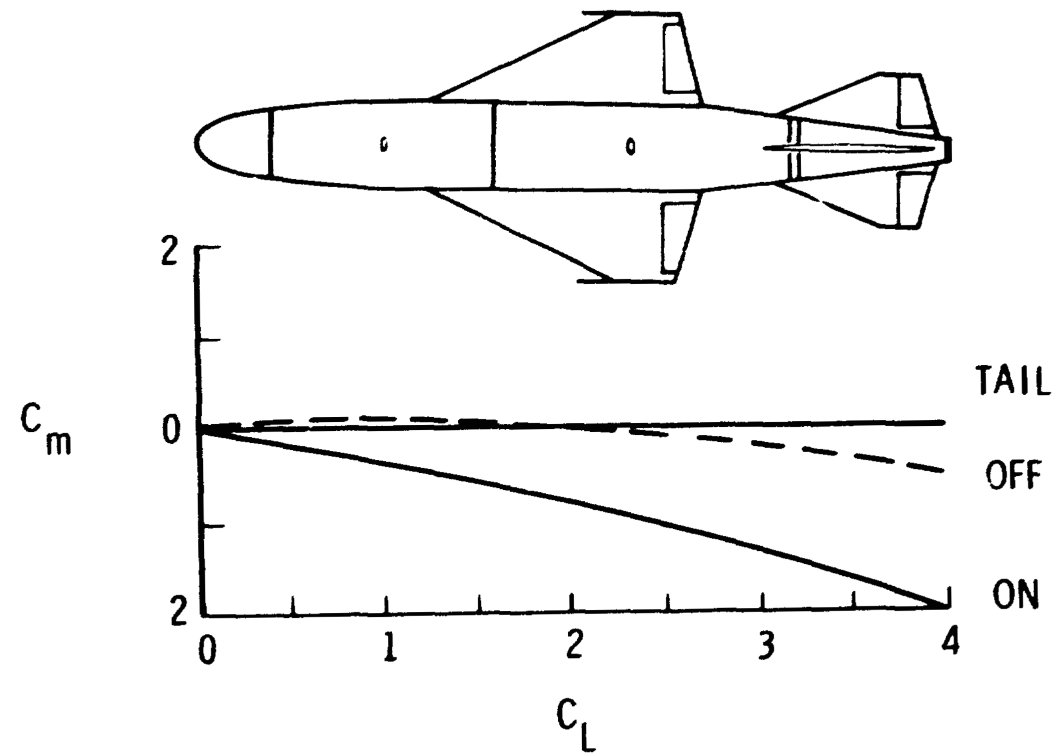


Figure 15. Effect of tail on longitudinal stability of cruise missile at M = 0.60.

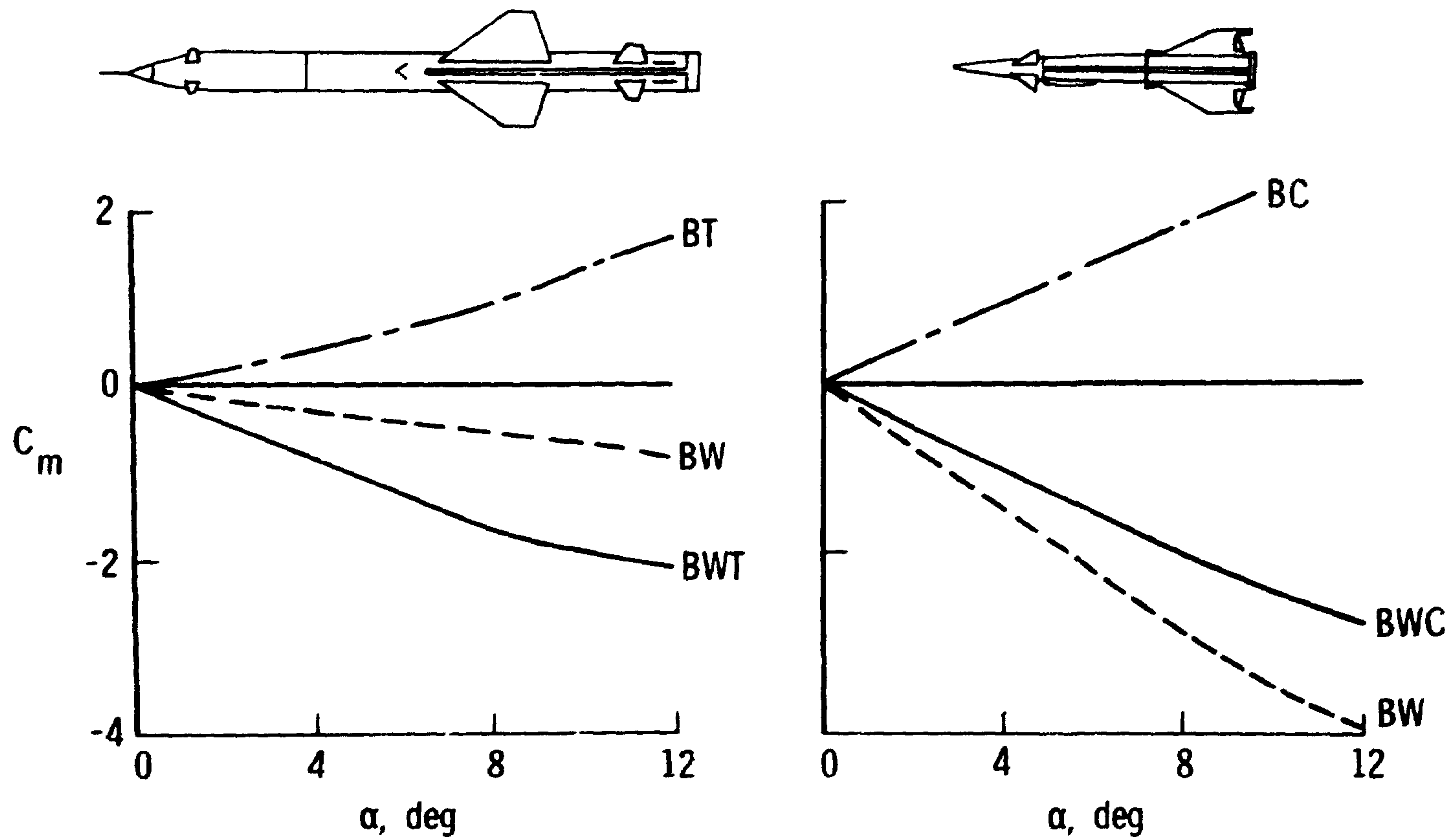




Figure 16. Effect of components on longitudinal stability of surface-to-air missiles at M = 3.