33. RECENT RESULTS ON THE AERODYNAMICS OF WINGED MISSILES

By M. Leroy Spearman and William A. Corlett
NASA Langley Research Center

SUMMARY

Investigations have been made in the Langley 8-foot transonic pressure tunnel and the Langley Unitary Plan wind tunnel over a Mach number range from 0.50 to 4.63 to determine the aerodynamic characteristics of three cruciform winged missile configurations with different control arrangements - a canard control, an aft tail control, and an all-movable wing control. The results for each configuration indicated a slight forward movement of the aerodynamic center with increasing supersonic Mach number so that a compatible relationship between the aerodynamic center and the center of gravity might be maintained. For each arrangement, the pitch-control effectiveness, which, in general, decreased with increasing angle of attack at the lower Mach numbers, indicated an increase with angle of attack at the higher Mach numbers. This increase in control effectiveness at high Mach numbers, coupled with the decrease in stability level, resulted in maneuvering limits, without the onset of static instability, that are generally well in excess of the limits that might be expected for an aircraft target.

INTRODUCTION

Although a considerable amount of research has been done in the past on the aerodynamics of winged missiles, this type of research has diminished considerably over the last few years. Much of the past work (reported in refs. 1 to 17) is limited, particularly in the range of Mach numbers investigated, and, to some extent, in the configuration variables that were studied. Recently a renewed interest has been shown in the development and improvement of various types of missile systems, and it is the purpose of this paper to present a brief summary of some of the results recently obtained on several representative winged maneuverable missiles suitable primarily for surface-to-air or air-to-air use against aircraft.

The missiles considered in these investigations (fig. 1) include three cruciform configurations with different control arrangements, a fixed wing with canard control, a fixed wing with aft tail control, and a fixed tail with all-movable wing control. The pitch control is in the horizontal plane in each case. Each of the fixed-wing arrangements is in line with the controls, whereas the fixed-tail arrangement is rotated 45° with respect to the wing control. (See lower right-hand sketch.) These configurations are not a part of a systematic program but represent three completely different control arrangements that might result from considerations other than aerodynamics alone. Investigations of these missile configurations have been conducted over a Mach number range from 0.50 to 4.63 in both the Langley 8-foot transonic pressure tunnel and the Langley Unitary Plan wind tunnel.

More complete results of these investigations and a more detailed description of the configurations may be found in references 18 and 19.

SYMBOLS

The aerodynamic-coefficient data are referred to the stability-axis system.

A	maximum cross-sectional area of body, feet^2
a_n	normal acceleration, feet/second^2
d	reference diameter (maximum cross section)
C_L	lift coefficient, $\frac{\text{Lift}}{qA}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAd}$
C_{m_δ}	pitching-moment coefficient per degree of control deflection
C_{L_α}	slope of lift curve measured near $\alpha = 0$
h	altitude, feet
l	body length, feet
M	Mach number
q	dynamic pressure, pounds/feet^2
W	weight, pounds
α	angle of attack, degrees
δ_c	horizontal-canard deflection, positive when leading edge is up, degrees
δ_t	horizontal-tail deflection, positive when leading-edge is up, degrees
δ_w	horizontal-wing deflection, positive when leading edge is up, degrees
x_{ac}	location of aerodynamic center from body apex, feet
x_{cg}	location of center of gravity from body apex, feet

DISCUSSION

The basic pitch-control results for the canard-control configuration at a low and a high supersonic Mach number - 1.50 and 4.63 - are shown in figure 2. These results indicate a reasonable degree of linearity at each Mach number. The pitch-control effectiveness C_{m_δ} decreases somewhat with increasing angle of attack at the lower Mach number. This result is typical for such a condition since the canard surface tends to lose lift effectiveness at the high combined angle of attack and control deflection. At the higher Mach number, however, the pitch effectiveness tends to increase with increasing angle of attack primarily because of an increase in the local dynamic pressure on the compression side of the canard surface. The change in lift with control deflection is quite small but, typical of canard arrangements, does result in a favorable increase.

The basic pitch-control results for the aft tail-control configuration at $M = 2.00$ and 4.63 are shown in figure 3. A large decrease in stability occurs at moderate angles of attack at the low Mach number. This decrease is caused primarily by the unstable moment of the body which, at low Mach numbers, increases more rapidly with increasing angle of attack than does the stabilizing moment of the wing and tail. At the higher Mach number, the tail and wing moments are more dominant and the pitching-moment variation with angle of attack is considerably improved. The effectiveness of the tail in producing pitching moment C_{m_δ} is essentially constant with angle of attack at $M = 2.00$, but some increase in effectiveness with increasing angle of attack is indicated at the higher Mach number as a result of an increase in local dynamic pressure at the tail. At either Mach number, deflection of the tail for trimming in pitch results in a loss in lift that is inherent with aft tail controls.

The basic pitch-control results for the wing-control configuration at $M = 1.47$ and 4.63 are shown in figure 4. A distinct nonlinearity occurs in the pitching moment for the lower Mach number at moderate angles of attack as a result of the tail passing through the region of the wing wake. The nonlinearity at $M = 4.63$ is much less critical.

The pitch control for this type of arrangement depends upon a relatively large lift increment from the wing in conjunction with a short moment arm. The resultant pitch-control effectiveness C_{m_δ} at $M = 1.47$ decreases with increasing angle of attack because of the decrease in wing lift at high combined angles of attack and control deflection. At $M = 4.63$ the lift increment provided by the wing is sustained at high angles of attack, again because of an increase in local dynamic pressure, and the resultant pitch effectiveness C_{m_δ} increases with increasing angle of attack.

The variation of some of the longitudinal parameters with Mach number is presented in figure 5. The coefficients are based on common reference dimensions and are thus directly comparable. The canard- and aft-tail-control configurations, which have relatively large wings, provide relatively high values of C_{L_α} whereas the wing-control configuration, with its smaller lifting surface, provides relatively low values of C_{L_α}. The pitch-control effectiveness C_{m_δ} (measured at $\alpha = 0^\circ$) decreases progressively with increasing supersonic Mach number for each configuration, with the highest values of C_{m_δ} occurring for the canard control and the lowest values occurring for the wing control.

The aerodynamic-center positions in percent body length $\left(\frac{x_{ac}}{l}\right)$ are on the order of 60 to 70 percent and indicate a slight forward movement with increasing supersonic Mach number for each configuration. This slight variation with Mach number should ease the problem of obtaining a compatible relationship between the center-of-gravity position and the aerodynamic-center position so that a desirable margin of stability might be easily maintained throughout the supersonic speed range.

The results shown in figure 6 relate the basic aerodynamic characteristics to the maneuvering capabilities of each configuration. The results show the variation of maximum trimmed values of C_L with Mach number for various positions of the center of gravity for each configuration. The results reflect the general increase in trim C_L to be expected as the center of gravity is moved rearward and the stability margin is decreased. These results are restricted to conditions of positive static stability only and are terminated when a nonlinear pitching-moment variation results in the occurrence of more than one trim point for a given control deflection.

At low Mach numbers the variation of trim C_L with center-of-gravity position is relatively small and linear because of the generally higher levels of static stability and the general decrease in C_{m_δ} with increasing angle of attack. With increasing Mach number the values of trim C_L for a given center-of-gravity position initially tend to decrease because of the decrease in C_{m_δ}. With further increase in Mach number, however, the values of trim C_L tend to increase for a given center-of-gravity position and to become more sensitive to variations in the center of gravity. The tendency toward higher available values of trim lift at higher Mach numbers results, in general, from a combination of the reduction in stability level and the increase in C_{m_δ} at high angles of attack.

The boundaries indicated by the upper limits of these curves represent the maximum values of trim lift available without the onset of static instability. Boundaries so obtained are shown in figure 7 with the lift coefficient based on a common reference area so that the results are directly comparable. These results indicate that the maximum values of C_L obtainable at the lower end of the Mach number regime are essentially the same for all three configurations. However, the variation of these lift boundaries with increasing Mach number is considerably different. In the Mach number range from about 2 to 3 the aft tail control indicates a marked superiority whereas, for Mach numbers above 3.5, the canard control shows a marked superiority. The wing control indicates the least variation with Mach number and the lowest values of trim lift throughout the Mach number range.

The four lower lines designated 40 000, 60 000, 70 000, and 90 000 feet represent the values of C_L required to sustain level flight at these altitudes for an arbitrary loading value W/A of 1000 pounds/foot^2 (based on body cross-sectional area). These values are included in order to give an indication of the excess lift available for maneuvering over and above that required for level flight. It should be pointed out that such an indication may be pessimistic since a missile may often approach a target on a climbing flight path much closer to zero lift.

However, on the basis of the conditions chosen for comparison, some observations can be made. For example, the results indicate that for Mach numbers below 2, level flight could not be achieved for any of these missiles for altitudes above about 60 000 feet. For higher Mach numbers, however, level flight is possible for altitudes greater than 90 000 feet.

The variation of normal acceleration a_n with Mach number was obtained for each configuration for $h = 60\ 000$ feet and $W/A = 1000$ pounds/foot^2 by ratioing the lift available to the lift required for level flight. The results (fig. 7) indicate values of a_n in the Mach number range from 2 to 4.6 that vary from about 1.5 for each configuration up to about 19 for the canard control, about 10 for the aft tail control, and about 9 for the wing control. These results are, of course, only qualitative and would vary both upward and downward for other assumed conditions. For an altitude of 90 000 feet, for example, the canard configuration is still capable of about a 4g maneuver from level flight at the highest Mach number. The maneuvering capabilities indicated are generally in excess of the limits that might be expected for an aircraft target, and, within the scope of these results, a variety of mission requirements might be satisfied.

CONCLUDING REMARKS

Investigations have recently been made in the Mach number range from 0.50 to 4.63 of three cruciform winged missile configurations with different control arrangements - a canard control, an aft tail control, and an all-movable wing control. The results for each configuration indicated a slight forward movement of the aerodynamic center with increasing supersonic Mach number so that a compatible relationship between the aerodynamic center and the center of gravity might be maintained. For each arrangement, the pitch-control effectiveness, which, in general, decreased with increasing angle of attack at the lower Mach numbers, indicated an increase with angle of attack at the higher Mach numbers. This increase in control effectiveness at high Mach numbers, coupled with the decrease in stability level, resulted in maneuvering limits, without the onset of static instability, that were generally well in excess of the limits that might be expected for an aircraft target.

REFERENCES

1. Spearman, M. Leroy: Aerodynamic Characteristics in Pitch of a Series of Cruciform-Wing Missiles With Canard Controls at a Mach Number of 2.01. NASA TN D-839, 1961.

2. Spearman, M. Leroy: Component Tests To Determine the Aerodynamic Characteristics of an All-Movable 70° Delta Canard-Type Control in the Presence of a Body at a Mach Number of 1.61. NACA RM L53I03, 1953.

3. Spearman, M. Leroy: Effect of Large Deflections of a Canard Control and Deflections of a Wing-Tip Control on the Static-Stability and Induced-Roll Characteristics of a Cruciform Canard Missile at a Mach Number of 2.01. NACA RM L53K03, 1953.

4. Spearman, M. Leroy; and Robinson, Ross B.: Aerodynamic Characteristics of a Cruciform-Wing Missile With Canard Control Surfaces and of Some Very Small Span Wing-Body Missiles at a Mach Number of 1.41. NACA RM L54B11, 1954.

5. Spearman, M. Leroy; and Driver, Cornelius: Wind-Tunnel Investigation at a Mach Number of 2.01 of the Aerodynamic Characteristics in Combined Pitch and Sideslip of Some Canard-Type Missiles Having Cruciform Wings and Canard Surfaces With 70° Delta Plan Forms. NACA RM L54F09, 1954.

6. Robinson, Ross B.: Aerodynamic Characteristics of Missile Configurations With Wings of Low Aspect Ratio for Various Combinations of Forebodies, Afterbodies, and Nose Shapes for Combined Angles of Attack and Sideslip at a Mach Number of 2.01. NACA RM L57D19, 1957.

7. Robinson, Ross B.: Wind-Tunnel Investigation at a Mach Number of 2.01 of the Aerodynamic Characteristics in Combined Angles of Attack and Sideslip of Several Hypersonic Missile Configurations With Various Canard Controls. NACA RM L58A21, 1958.

8. Katzen, Elliott D.; and Jorgensen, Leland H.: Aerodynamics of Missiles Employing Wings of Very Low Aspect Ratio. NACA RM A55L13b, 1956.

9. Foster, Gerald V.: Sideslip Characteristics at Various Angles of Attack for Several Hypersonic Missile Configurations With Canard Controls at a Mach Number of 2.01. NASA TM X-134, 1959.

10. Stone, David G.: Maneuver Performance of Interceptor Missiles. NACA RM L58E02, 1958.

11. Spearman, M. Leroy; and Robinson, Ross B.: Longitudinal Stability and Control Characteristics at Mach Numbers of 2.01, 4.65, and 6.8 of Two Hypersonic Missile Configurations, One Having Low-Aspect-Ratio Cruciform Wings With Trailing-Edge Flaps and One Having a Flared Afterbody and All-Movable Controls. NASA TM X-46, 1959.

12. Robinson, Ross B.; and Bernot, Peter T.: Aerodynamic Characteristics at a Mach Number of 6.8 of Two Hypersonic Missile Configurations, One With Low-Aspect-Ratio Cruciform Fins and Trailing-Edge Flaps and One With a Flared Afterbody and All-Movable Controls. NACA RM L58D24, 1958.

13. Church, James D.; and Kirkland, Ida M.: Static Aerodynamic Characteristics of Several Hypersonic Missile-and-Control Configurations at a Mach Number of 4.65. NASA TM X-187, 1960.

14. Robinson, Ross B.; and Spearman, M. Leroy: Aerodynamic Characteristics for Combined Angles of Attack and Sideslip of a Low-Aspect-Ratio Cruciform-Wing Missile Configuration Employing Various Canard and Trailing-Edge Flap Controls at a Mach Number of 2.01. NASA MEMO 10-2-58L, 1958.

15. Robinson, Ross B.; and Foster, Gerald V.: Static Longitudinal Stability and Control Characteristics at a Mach Number of 2.01 of a Hypersonic Missile Configuration Having All-Movable Wing and Tail Surfaces. NASA TM X-516, 1961.

16. Spearman, M. Leroy; and Robinson, Ross B.: Longitudinal Stability and Control Characteristics of a Winged and a Flared Hypersonic Missile Configuration With Various Nose Shapes and Flare Modifications at a Mach Number of 2.01. NASA TM X-693, 1962.

17. Corlett, William A.; and Fuller, Dennis E.: Aerodynamic Characteristics at Mach 1.60, 2.00, and 2.50 of a Cruciform Missile Configuration With In-Line Tail Controls. NASA TM X-1112, 1965.

18. Fuller, Dennis E.; and Corlett, William A.: Supersonic Aerodynamic Characteristics of a Cruciform Missile Configuration With Low-Aspect-Ratio Wings and In-Line Tail Controls. NASA TM X-1025, 1964.

19. Foster, Gerald V.; and Corlett, William A.: Aerodynamic Characteristics at Mach Numbers From 0.40 to 2.86 of a Missile Model Having All-Movable Wings and Interdigitated Tails. NASA TM X-1184, 1965.

MISSILE CONFIGURATIONS

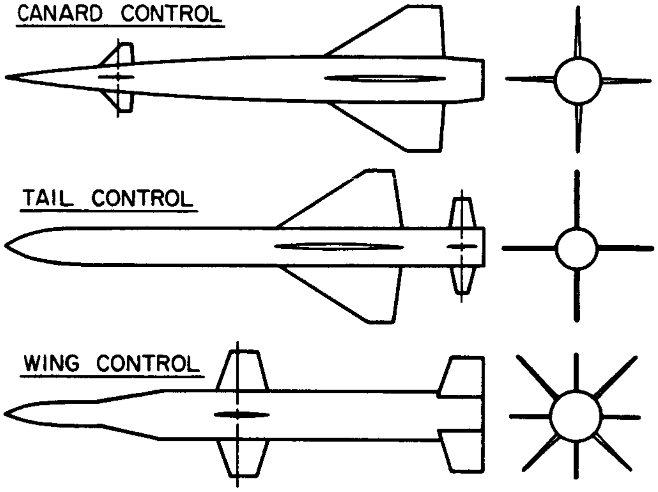

Figure 1

AERODYNAMIC CHARACTERISTICS
CANARD CONTROL

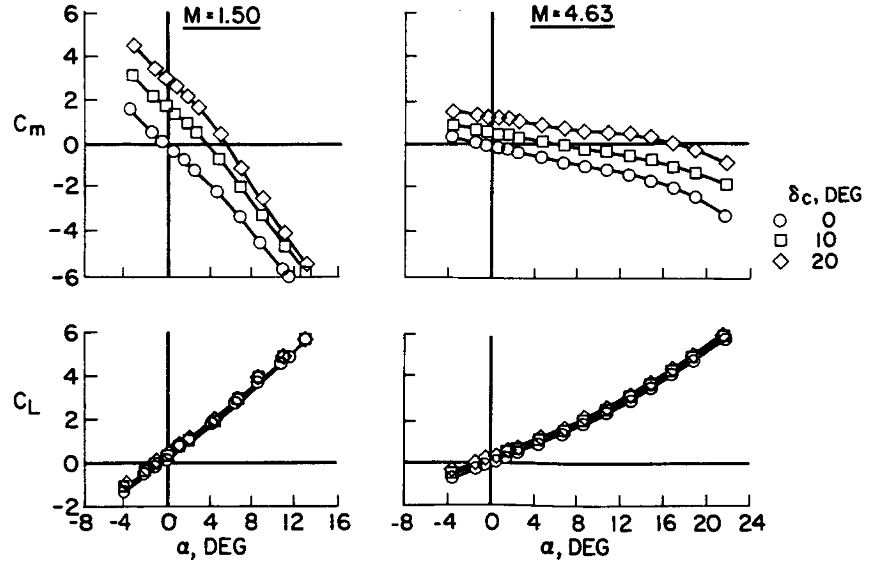

Figure 2

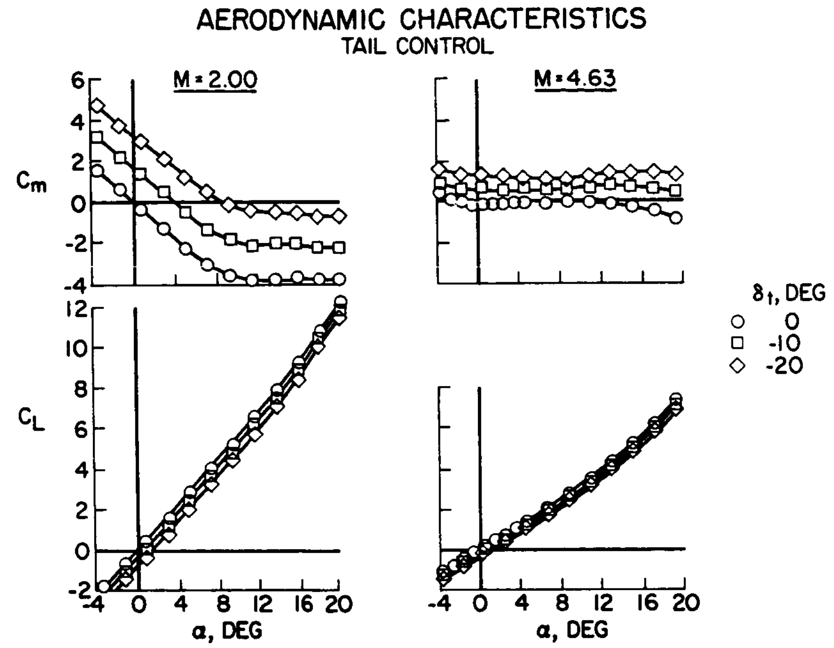

Figure 3

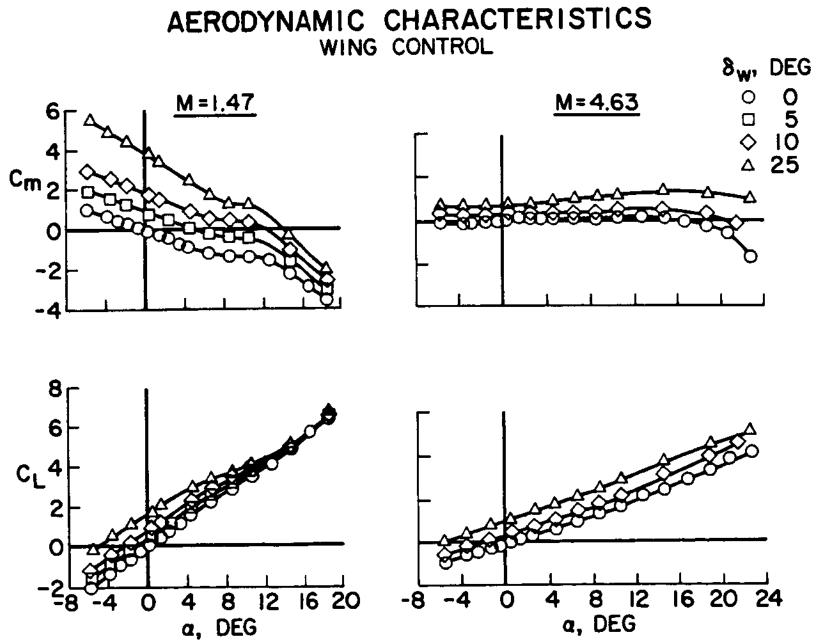

Figure 4

VARIATION OF LONGITUDINAL PARAMETERS WITH MACH NUMBER

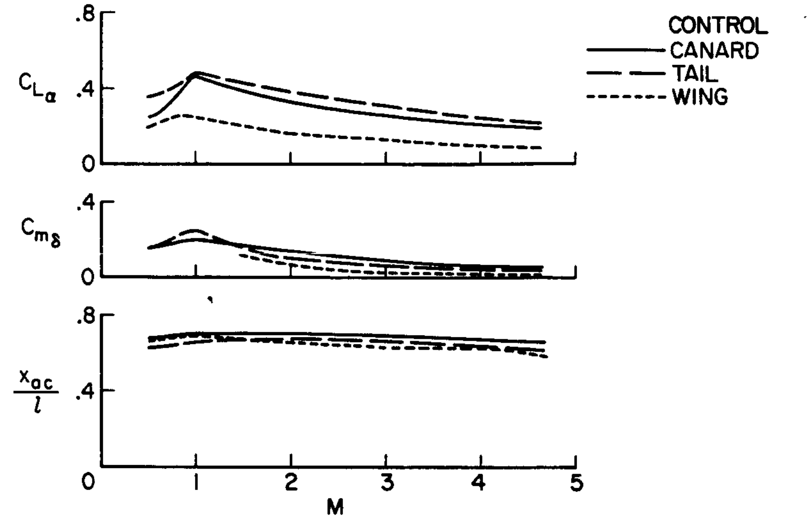

Figure 5

MAXIMUM TRIM C_L VALUES FOR VARIOUS CENTER-OF-GRAVITY POSITIONS

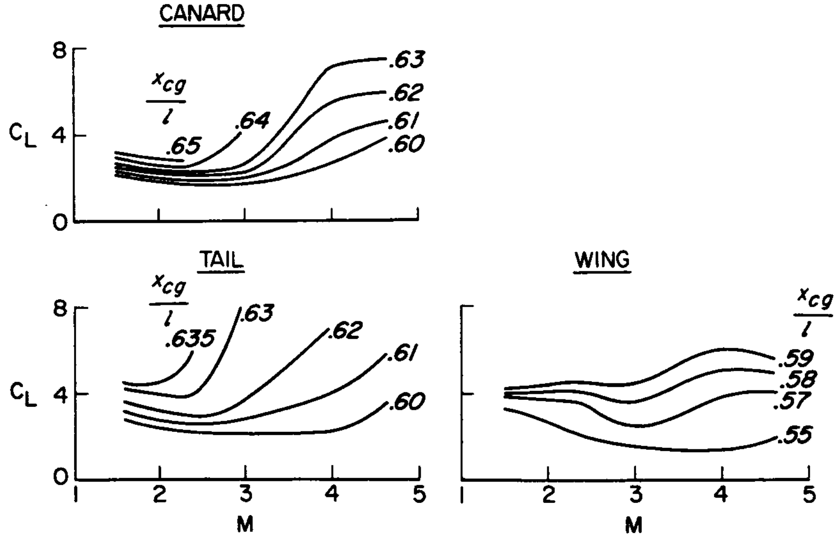

Figure 6

MAXIMUM TRIM C_L BOUNDARIES

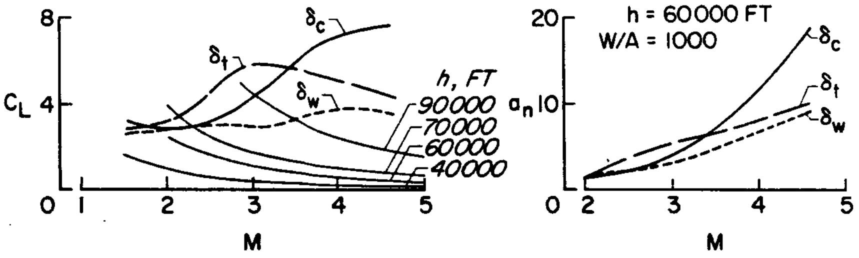

Figure 7