5. SOME CONFIGURATION EFFECTS ON STATIC STABILITY OF AIRPLANES AT HIGH ANGLES OF ATTACK AND LOW SPEEDS

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SUMMARY

A review has been made to examine some of the problems and possible solutions regarding stability at high angles of attack and low speeds. Pitch-up of fixed-wing configurations has been alleviated by the employment of wing leading edge and canard devices. Pitch-up for variable-sweep-wing configurations can be alleviated by a low horizontal tail, free-floating the forewing, reduction of the forewing sweep, or deflection of the forewing. The deep-stall characteristics of T-tail airplanes can be improved by increasing the ratio of tail span to nacelle span and by careful selection of nacelle position. Indications are that directional stability at high angles of attack can be improved by proper selection of fuselage cross-section shape. Directional stability for certain configurations can be improved by placing the vertical tail surfaces near the wing tips.

INTRODUCTION

The design requirements necessary for good performance at high speeds often result in undesirable low-speed stability characteristics at moderate and high angles of attack. Although many contemporary airplanes incorporate elaborate stability augmentation devices, it is still desirable to strive for good unaugmented stability characteristics.

The purpose of this paper is to review some of the problems and possible solutions regarding high angle-of-attack stability at subsonic Mach numbers. The scope of this presentation includes a discussion of the pitch-up problems of fixed-wing and variable-sweep-wing configurations, the deep-stall characteristics of T-tail airplanes, and the effects of fuselage cross-section shape and vertical tail position on directional stability.

SYMBOLS

b reference wing span

b_n nacelle span

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b_t	horizontal tail span
$\bar{c}$	wing mean geometric chord
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
$C_{m,t}$	pitching-moment coefficient provided by horizontal tail
$C_{m,.40\bar{c}}$	pitching-moment coefficient at 40 percent wing mean geometric chord
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
C_{n_β}	directional stability parameter, $\frac{\partial C_n}{\partial \beta}$
C_p	pressure coefficient, $\frac{p_{local} - p_{free\ stream}}{q_{free\ stream}}$
ΔC_p	difference in pressure coefficient between upper and lower surface of wing
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$
h_t	vertical distance from nacelle plane of symmetry to mean chord plane of horizontal tail
i_t	horizontal tail incidence (positive trailing edge down), degrees
l_n	longitudinal distance from aft end of nacelle to quarter-chord of mean geometric chord of horizontal tail
M	Mach number
p	pressure
q	dynamic pressure
S	reference wing area
S_c	exposed canard area
V	free-stream air velocity

V_C	cross-wind velocity
α	angle of attack, degrees
β	sideslip angle, degrees
Λ	leading-edge sweep of forewing or outer wing panel, degrees
δ_f	deflection of wing leading-edge flaps (positive leading edge up), degrees

FIXED-WING CONFIGURATIONS

The longitudinal stability problems which arise at low speeds for one particular high performance supersonic transport concept are illustrated in figure 1. The basic configuration, shown at the top of the figure, incorporated a warped wing with sharp leading edges and cranked wing tips. The extreme instability for the basic arrangement results from the sharp leading edges of the wing and the combined planform effects of the cranked wing tips and trailing-edge cutout.

An extensive wind-tunnel investigation was conducted in the Langley high-speed 7- by 10-foot tunnel to determine whether the longitudinal stability characteristics of this configuration could be improved. The sketch at the lower right of figure 1 indicates the modifications which were made to the configuration. An inboard portion of the wing leading edge was deflected downward and a comparatively smaller outboard segment was deflected upward. In addition, the radius of the inboard half of the wing leading edge was increased. The leading-edge modifications did not affect the maximum lift-drag ratio at low speeds. These modifications resulted in a favorable redistribution of lift over the wing and a consequent improvement in the stability characteristics. An increment in maximum lift-drag ratio of about 0.60 over that obtained for the basic configuration can be expected when the outboard flap is undeflected. However, a slight destabilizing tendency in the pitching-moment variation with lift coefficient is noted. The increased leading-edge radius of the modified configuration could be incorporated without diminishing the supersonic performance capabilities of the configuration (ref. 1). Longitudinal stability problems, however, might be encountered at other flight conditions when the wing leading edge is undeflected.

Variable-geometry canard devices have been envisioned as a method which might be utilized to reduce pitch nonlinearities and increase the trimmed lift coefficient at landing and take-off attitudes. The pitching-moment characteristics for the basic configuration have been repeated in figure 2. Pitching-moment results are also shown for the basic configuration with two variable-sweep-canard arrangements which form part of the main wing when in the retracted position. These pitch data have been adjusted to the same level of stability at low angles of attack. This adjustment required a 4-percent forward shift in center of gravity for the small canard arrangement and an 8-percent shift for the large canard arrangement. For this configuration, a forward shift in center of gravity would result in a trim drag penalty at the cruise Mach number. These data indicate that longitudinal stability at the higher angles of attack can be improved considerably by sweeping a relatively small portion of the wing forward and deflecting a portion of the forewing. Additional improvements in the pitch characteristics of the canard configurations might be expected by incorporating the additional wing leading-edge modifications shown in figure 1. From a comparison of figures 1 and 2 at landing and take-off attitudes, the nose-up moments of the canard configurations are substantially higher than those indicated for the modified configuration shown in figure 1. The positive moments would allow a trailing-edge-down control deflection and a consequent improvement in the trimmed lift. In addition, flap deflections on the canard surface would provide additional nose-up moments for trimming which would enable an increase in the deflection of the high-lift devices. The unfavorable forward shift in aerodynamic center resulting from sweeping the canard forward might be diminished by utilizing an extended trailing-edge-flap arrangement. Extending the flaps would reduce the trailing-edge cutout and have a favorable effect on the linearity of the pitch curve.

VARIABLE-SWEEP-WING CONFIGURATIONS

One of the problems which has faced the designer of supersonic airplanes is the incompatibility between the wing geometry requirements for high-speed and low-speed flight. For variable-sweep-wing airplanes, the large highly swept area ahead of the movable wing is essential to minimize aerodynamic-center travel with wing sweep. This area generally results in a loss in longitudinal stability in the intermediate to high range of angle of attack for the low-sweep conditions. In order to better understand this aerodynamic behavior, pressure distributions for an outboard-pivot-variable-sweep-wing—fuselage combination have been determined and compared with static pitching-moment results. The results of this study are shown in figure 3. The variations of pressure coefficients over the wing, at two different angles of attack, have been superimposed on tuft sketches. From this figure at an angle of attack of about 6°, in the linear range of pitch data, the pressure distributions indicate typical potential angle-of-attack loading with no tip separation. At an angle of attack of about 16°, after the loss in stability occurs, the tuft sketch at the right of the figure illustrates the strong leading-edge vortex system on the highly swept inboard portion of the wing. The influence of this vortex system is reflected in the pressure distributions shown at the right. The center of pressure on the inboard section moved aft slightly; however, the loading ahead of the moment center was substantially increased. As the vortex system moves spanwise across the wing, high angularities are induced on the outboard panel at low speeds. The induced angularities on the movable wing panel result in separation on the outer panel, as indicated by the flattening of the chordwise pressure distributions. Although the center of pressure on the outer sections moves aft slightly with increasing angle of attack, the magnitude of the lift at the wing tip remains essentially the same. The instability noted in the pitch curve, therefore, results from the combined effects of outer panel stall and the nonlinear lift on the inboard wing panel.

Several methods which have been shown to be successful in alleviating this pitch-up problem are illustrated in figure 4. Pitching-moment results are shown for several arrangements of a variable-sweep-wing supersonic configuration which incorporates a relatively low horizontal tail. The longitudinal stability characteristics of the basic configuration are considerably better than the pitch characteristics indicated for the variable-sweep arrangement discussed previously because of the low horizontal tail and the improved stall characteristics of the outer wing panels. These data indicate the additional improvements in pitch characteristics which might be obtained by varying the geometry of the forewing. On the left of figure 4, pitch data are shown for the outboard-pivot-variable-sweep-wing configuration, with several different forewing sweeps. These results illustrate that if a reduction in forewing sweep can be tolerated, from a performance standpoint, a stabilizing tendency can be obtained. If the cruise Mach number of the airplane dictates the employment of a highly swept forewing, the unfavorable effects of the forewing might be reduced at subsonic speeds by deflecting a portion of the fixed wing. The effect of deflecting the forewing is illustrated at the right of figure 4. The sketch indicates the portion of forewing which was deflected. The pitching-moment results indicate that deflecting the forewing 40° would tend to increase stability in the high angle-of-attack region. References 2 and 3 indicate the effects of forewing sweep and deflection on similar variable-sweep-wing supersonic transport concepts.

The adverse effects of the highly swept fixed-wing area can be diminished further by the utilization of a free-floating apex or by the incorporation of a double pivot arrangement. Figure 5 indicates the profound improvements in longitudinal stability characteristics which can be obtained by these methods. These effects are discussed in detail in references 4 and 5.

DEEP-STALL CHARACTERISTICS OF T-TAIL AIRPLANES

There has been a great deal of research on T-tail airplanes during the past several years. The purpose of the present discussion is to review the longitudinal stability problems associated with T-tail transport airplanes and to indicate the profound effect of several configuration variables. Figure 6 shows the longitudinal stability characteristics for a typical T-tail configuration with aft-mounted engines over a large angle-of-attack range. The curve for the tail-off configuration indicates a stable break after the wing stalls and a trend towards nose-down moments. Recent research has indicated that substantial improvements in the longitudinal stability characteristics of T-tail airplanes can be obtained by the employment of auxiliary horizontal tails and by careful tailoring of the wing and fuselage designs. (See refs. 6 and 7.) When the T-tail is added to this arrangement, an extreme loss in longitudinal stability is encountered which is followed by a stable trim point at an angle of attack of about 40°. Adequate control must be provided in the so-called "deep-stall" region or the airplane would remain locked in at these extremely high angles of attack. For this configuration, a horizontal tail setting of 5° provided a nose-down moment, which would enable the airplane to rotate towards the unstalled condition.

The extreme loss in longitudinal stability indicated for this configuration is associated with the loss in horizontal tail contribution when the T-tail passes through the airplane wake system. The sketch at the lower right of figure 6 illustrates the behavior of the T-tail airplane in the deep-stall region. The vector V shown in the sketch represents the relative air velocity. At these extremely high angles of attack the wing wake, reinforced by more profound nacelle-pylon wake, envelopes the horizontal tail and renders it nearly ineffective. In the deep-stall region the airplane might actually plunge downward along the flight path indicated by the dashed line even though the airplane attitude is relatively level. T-tail research has indicated that, for this particular configuration, the loss in horizontal tail contribution can be correlated closely with the relationship between the nacelle and horizontal tail positions.

The configuration sketch at the top of figure 7 indicates the pertinent dimensions of the T-tail model in terms of wing mean geometric chord $\bar{c}$ and wing span b. In addition, the configuration variables which are used in this correlation are defined in the configuration sketch. At the bottom of the figure, the loss in tail contribution, shown as the ordinate of the plot, is the ratio of the reduction in tail contribution to the maximum pitching-moment coefficient provided by the horizontal tail. The loss in tail contributions has been plotted against the ratio of nacelle distance ahead of the tail to horizontal tail height above the nacelle. The data points were obtained by varying the tail height (open symbols) and the nacelle distance (half-closed symbols) and by combined variations of the nacelle and horizontal tail arrangements (square symbols). The lines represent results for various ratios of tail span to nacelle span. The data for a ratio of tail span to nacelle span equal to 1.37 indicate that, for variations of either tail height or nacelle distance, the loss in tail contribution can be correlated with the ratio of the nacelle distance to horizontal tail height. The other data indicate that, as the ratio of tail span to nacelle span is increased, the loss in horizontal tail contribution is reduced. These results represent data for a particular configuration; however, the trends indicated should generally apply to other T-tail airplanes with aft-mounted engines.

EFFECT OF FUSELAGE CROSS-SECTION SHAPE AND VERTICAL TAIL POSITION ON DIRECTIONAL STABILITY

Many present-day airplanes employ noncircular fuselage cross-section shapes. An interesting effect of fuselage cross-section shape on directional stability at the higher angles of attack was noted from results obtained in the Langley high-speed 7- by 10-foot tunnel. (See fig. 8.) A sketch of the complete configuration is shown at the top of the figure. The configuration employing the circular forebody exhibits a reduction in directional stability with increasing angle of attack. This effect is associated with the loss of vertical tail effectiveness caused by the adverse sidewash from the wing and forebody (ref. 8). With the noncircular forebody, there is a large increase in directional stability in the intermediate range of angle of attack and considerably higher directional stability up to the maximum angle of attack. In order to obtain a better understanding of this effect, the two forebodies were tested alone. The directional stability parameters of the two different forebodies are shown at the right of figure 8. These parameters were obtained by assuming the center-of-gravity location and reference geometry of the complete configuration. At lower angles of attack, both forebodies indicated a destabilizing effect but, at the higher angles of attack, the directional stability parameter of the noncircular forebody became positive. These results indicate that the favorable effects noted for the configuration with the noncircular forebody were largely dependent upon the direct contribution of the forebody. In the higher angle-of-attack region, a force opposed to the normal cross-flow component is developed on the noncircular forebody as a result of the asymmetric flow characteristics on the body. (See refs. 9 and 10.) The additional differences between the directional stability of the two complete configurations are associated with the wing-body interference and the forebody effect on the sidewash characteristics. Since these effects are associated with nonpotential flow, the noncircular body was tested to higher Reynolds numbers to determine whether the favorable effects would diminish. At a Reynolds number comparable to about one-half the full-scale condition for a landing supersonic transport configuration, the favorable side force was increased considerably for the modified circular forebody. It should be noted, however, that nose bluntness has a pronounced effect on the side-force variation with angle of attack. Removing the pointed nose and rounding the fore part of the remaining body resulted in a negative side force which was practically invariant with angle of attack.

Another approach to improving the directional stability at high angles of attack would, of course, be to select a vertical tail position which avoids the adverse sidewash effects. One such approach is the addition of ventral fins, which has been widely accepted. Another method which is quite compatible with the aerodynamic design of a supersonic cruise concept is the use of twin tails. In figure 9, the directional stability parameter C_{n_β} is presented for the cranked wing tip configuration with outboard vertical tails and with the vertical tail located on the after portion of the fuselage. The tail volume of the two vertical tail arrangements was nearly equal. These data show that the directional stability of the configuration having the vertical tail on the fuselage center line diminished with increasing angle of attack. The loss in directional stability for this configuration results from the unfavorable sidewash angularities generated on the vertical tail by the wing-fuselage vortex system. The outboard vertical tails, located in a favorable sidewash field, became more effective at the higher angles of attack. In addition, the outboard vertical tails were found to have a favorable effect on the longitudinal stability characteristics of the configuration.

CONCLUDING REMARKS

A review has been made to ascertain some of the problems and possible solutions regarding high angle-of-attack stability of modern aircraft at subsonic Mach numbers. Several design changes and their favorable effect on subsonic stability at high angles of attack are as follows:

1. The pitch-up of highly swept fixed-wing configurations has been alleviated by the employment of wing leading-edge and canard devices.

2. Pitch-up for variable-sweep-wing configurations can be alleviated by a low horizontal tail, reduction of the forewing sweep, a free-floating forewing, a folding forewing, or deflection of the forewing.

3. The deep-stall characteristics of T-tail airplanes can be improved by increasing the ratio of tail span to nacelle span and by careful selection of nacelle position.

4. Indications are that directional stability at high angles of attack can be improved by proper selection of fuselage cross-section shape.

5. Directional stability for certain configurations can be improved by placing the vertical tail surfaces near the wing tips.

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EFFECT OF WING MODIFICATIONS
M = 0.14

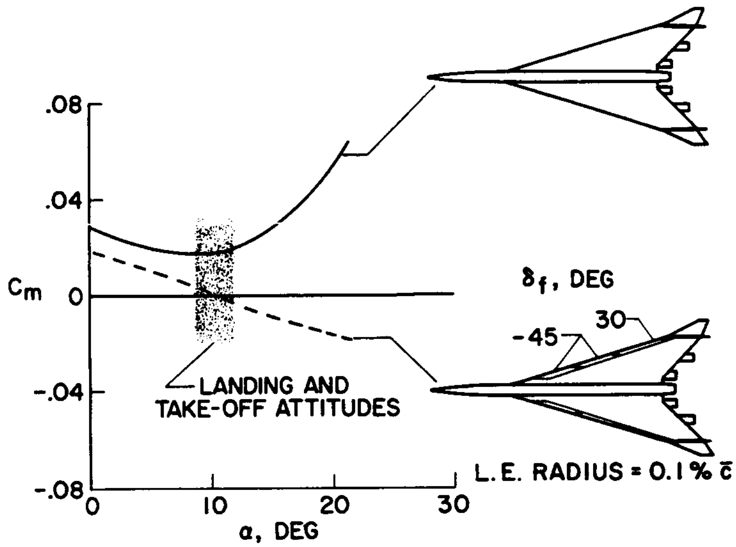

Figure 1

EFFECT OF FORWARD AUXILIARY SURFACE
M = 0.14

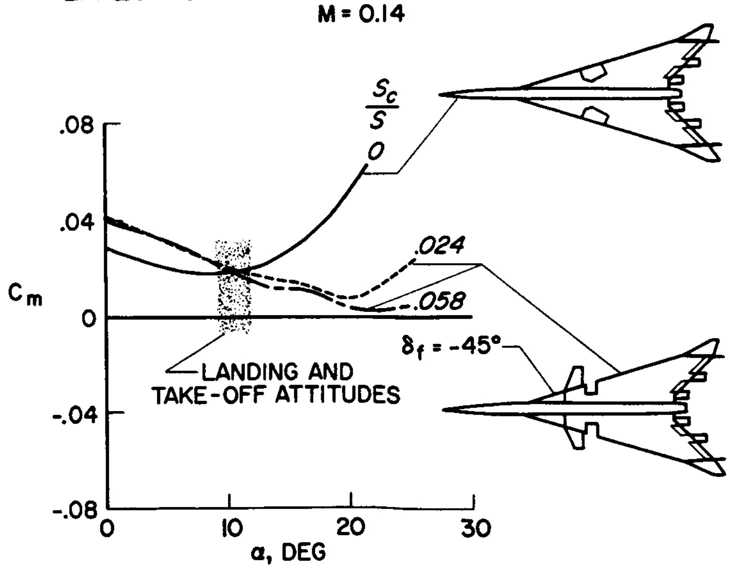

Figure 2

CORRELATION OF LOAD DISTRIBUTION WITH PITCHING MOMENT

M = 0.23

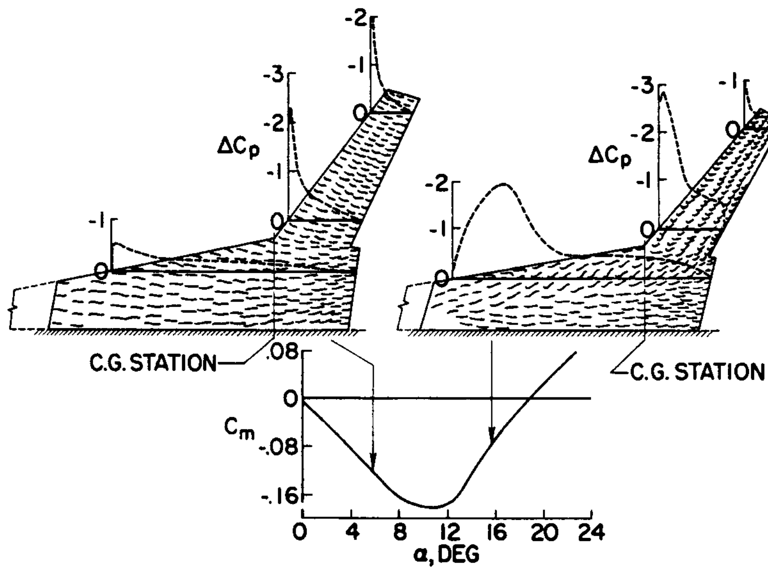

Figure 3

EFFECT OF FOREWING GEOMETRY

M = 0.10

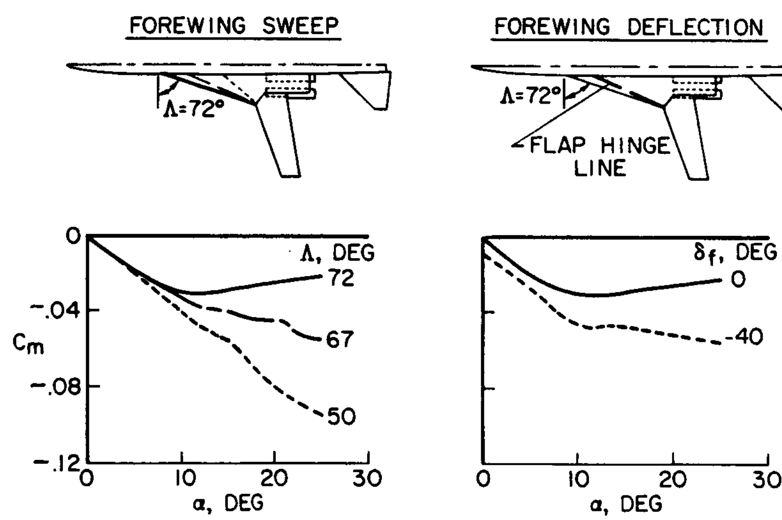

Figure 4

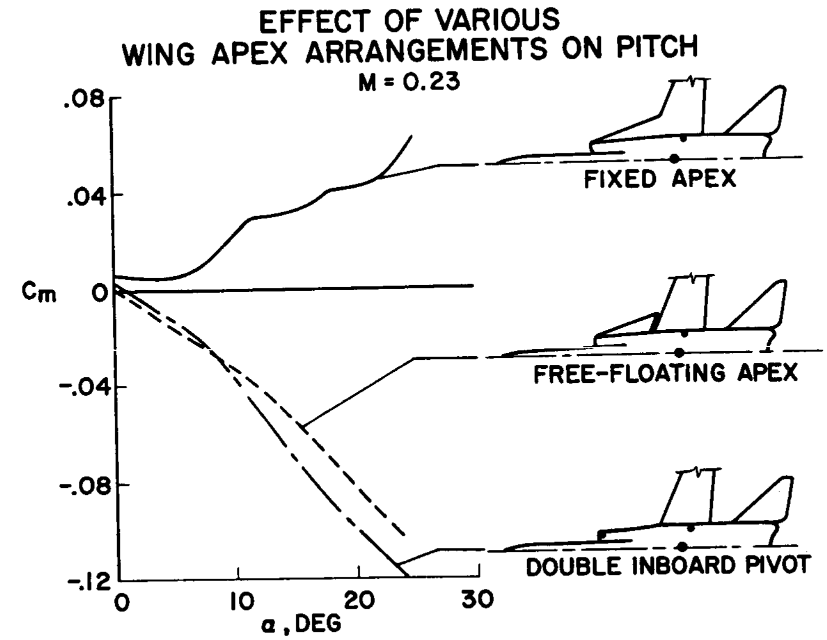

Figure 5

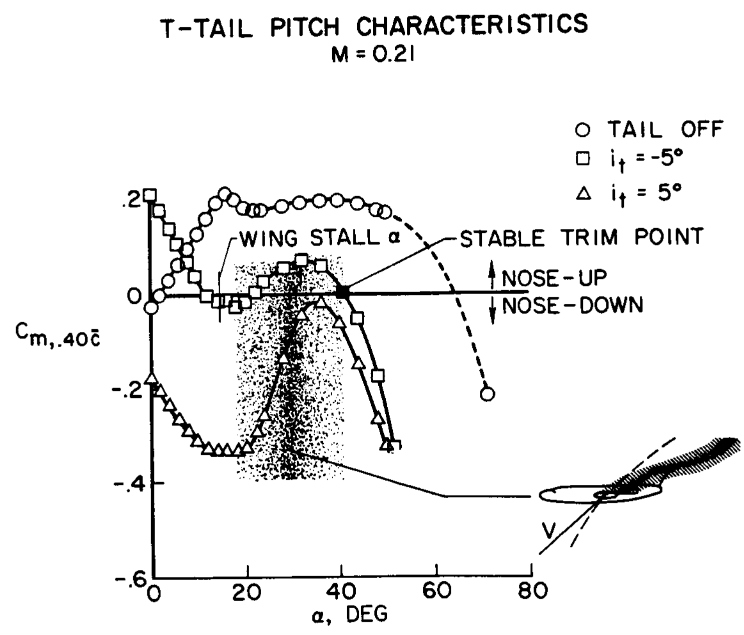

Figure 6

CORRELATION OF NACELLE LENGTH AND TAIL HEIGHT

M = 0.21

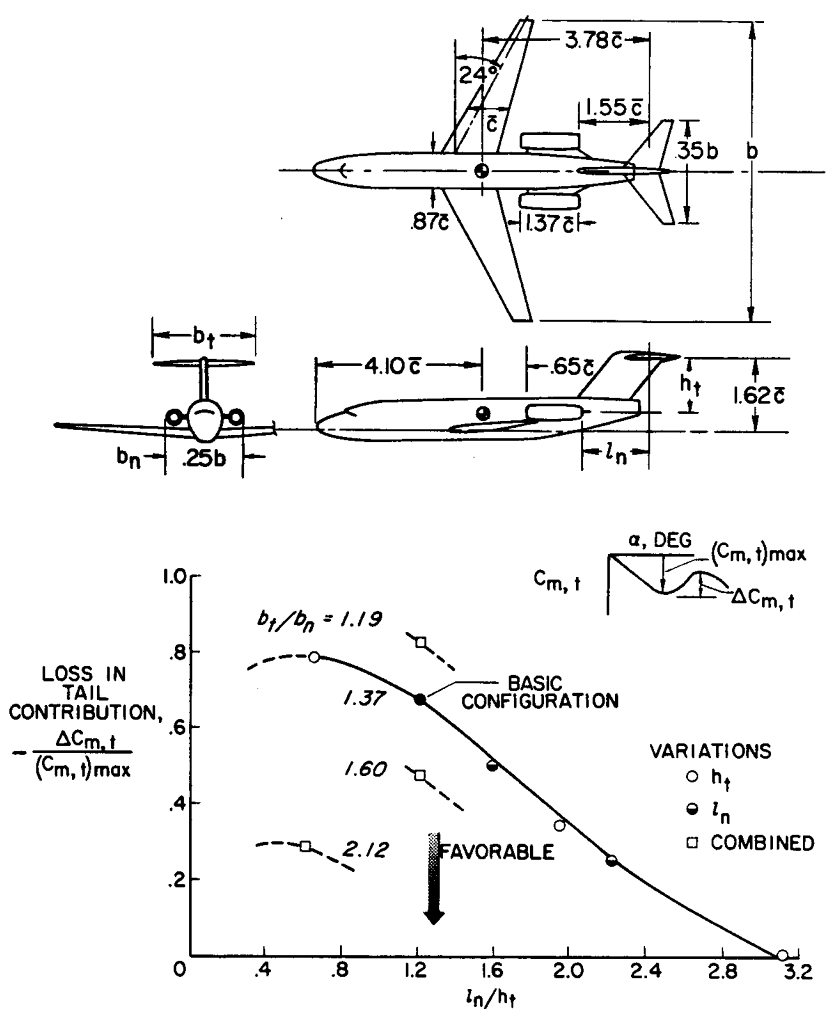

Figure 7

EFFECT OF FUSELAGE CROSS SECTION

M = 0.20

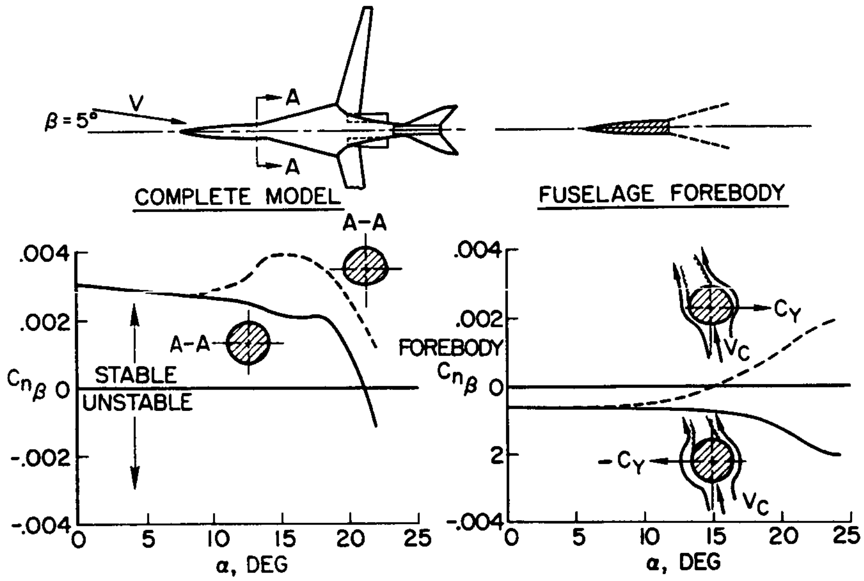

Figure 8

EFFECT OF VERTICAL-TAIL POSITION

M = 0.14

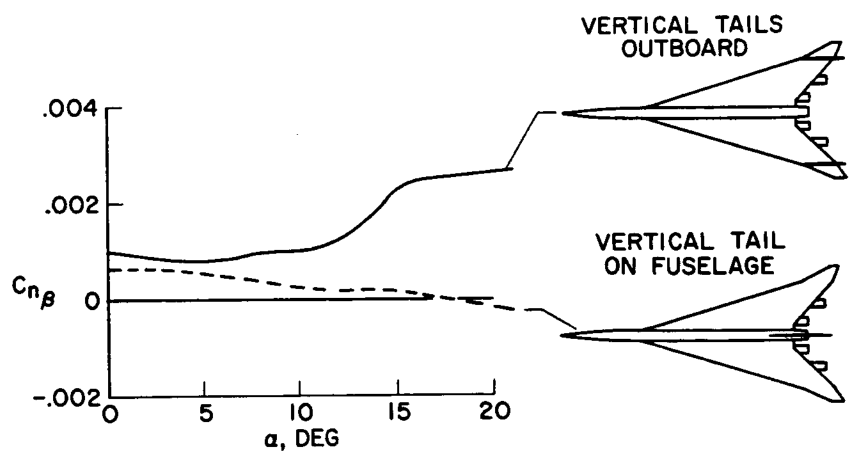

Figure 9