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Experimental Study of Tail-Span Effects on a Canard-Controlled Missile

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An experimental investigation was conducted on a cruciform canard-controlled missile configuration to determine the effects of tail span/canard span ratio on controllability. The investigation was conducted at Mach numbers from 1.75 to 3.50. Reductions of tail span/canard span ratio produced lower static margins and higher trim angle of attack. Results show that canard controls can provide pitch and yaw control as well as roll control by proper selection of the tail span/canard span ratio.

Nomenclature§

A = reference area, $\pi d^2/4$
b_t/b_c = ratio of exposed tail span to exposed canard span (body excluded)
C_ℓ = rolling-moment coefficient, rolling moment/qAd
C_{ℓ_δ} = roll-control effectiveness of two canards at $\alpha = 0$ deg; $\Delta C_l/\Delta\delta_{\text{roll}}$, per degree of deflection
C_m = pitching-moment coefficient, pitching moment/qAd
C_{m_δ} = pitch-control effectiveness of two canards at $\alpha = 0$ deg; $\Delta C_m/\Delta\delta_{\text{pitch}}$, per degree of deflection
C_N = normal-force coefficient, normal force/qA
C_n = yawing-moment coefficient, yawing moment/qAd
C_{n_δ} = yaw-control effectiveness of two canards at $\alpha = 0$ deg; $\Delta C_n/\Delta\delta_{\text{yaw}}$, per degree of deflection
C_Y = side-force coefficient, side force/qA
d = reference body diameter, 1.67 in.
M = freestream Mach number
q = freestream dynamic pressure
α = angle of attack, deg
δ = canard deflection angle
δ_{pitch} = canards deflected to provide pitching moment (positive leading edge up), deg
δ_{roll} = canards differentially deflected to provide roll control, individual canards each deflected indicated amount; positive to provide clockwise model rotation when viewed from rear, deg
δ_{yaw} = canards deflected to provide yawing moment (positive leading edge right when viewed from rear), deg
φ = model roll angle; positive clockwise when viewed from rear ($\varphi = 0$ deg, canards in vertical and horizontal planes), deg

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§Aerodynamic coefficient data are referred to the body-axis system which is fixed in the vertical and horizontal planes regardless of model roll angle. The moment reference center is located aft of the model nose at 45.0% of the body length.

Introduction

FUTURE fighter aircraft likely will have supersonic cruise and high angle-of-attack maneuver capability. To complement these features, new missiles must be developed which are more maneuverable and have less static margin than those now in use. A missile with these features and with controllability about the pitch, yaw, and roll axes would be very attractive, especially if a single aerodynamic control system could be used.

Missile concepts that feature forward located control fins are less complicated and offer more packaging flexibility than those with aft located controls. However, previous studies have shown that concepts with forward-control surfaces can have adverse induced rolling moments (e.g., Refs. 1–3). Therefore, methods of alleviating or controlling adverse rolling moments of a canard-controlled missile are desirable.

The analytical study of Ref. 4 indicated that high angle-of-attack trim characteristics and roll-control characteristics of forward-control missile configurations could be improved by reducing tail span. Predicted and experimental aerodynamic characteristics for a canard-controlled missile with several tail spans are presented in Refs. 5–7. Results from Ref. 7 were encouraging but did not include canard pitch and yaw-control deflection data at the lowest test Mach numbers ($M < 2.50$), due to model support fouling. The model was modified to alleviate fouling and additional low Mach number data were acquired. Results for the entire test Mach number range of 1.75–3.50 are presented here.

Test Facility, Models, and Procedure

Tests were conducted in both the low and high Mach number test sections of the NASA Langley Unitary Plan Wind Tunnel. This variable-pressure continuous-flow facility is described in Ref. 8. Tests were conducted at freestream Mach numbers of 1.75, 2.00, 2.50, 3.00, and 3.50 at a constant Reynolds number per foot of 2.00×10^6. The nominal angle-of-attack range was −4–20 deg at model roll angles of 0, 26.57, and 45 deg.

Model details are shown in Fig. 1. An installation photograph of the model is shown in Fig. 2. The model had a pointed tangent-ogive nose of fineness ratio 2.25, a smooth cylindrical high-fineness-ratio body with no launch straps or hanger lugs, and cruciform canards and aft tail fins. One set of canards and four sets of interchangeable tail fins with identical root chords were tested. Ratios of tail-to-canard exposed span were 0.47, 0.75, 1.07, and 1.25. Canard deflections included pitch-, yaw-, and roll-control settings.

All tests were performed with boundary-layer transition grit on the body 1.20 in. aft of the nose, and 0.40 in. aft of the leading edges of the canard and tail surfaces.

Model aerodynamic forces and moments were measured with an internally mounted six-component electrical strain-

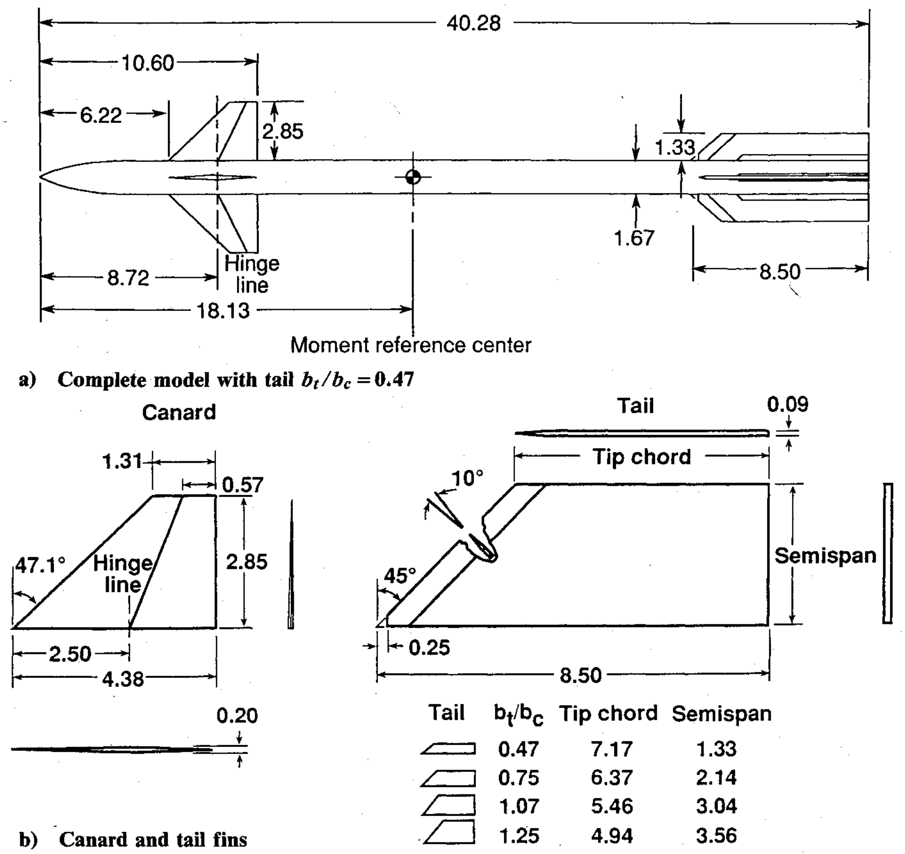

Fig. 1 Model details. All dimensions are given in inches unless otherwise indicated.

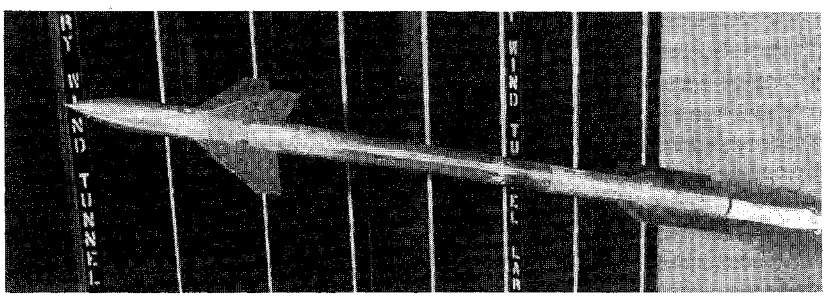

Fig. 2 Photograph of model, $b_t/b_c = 0.47$.

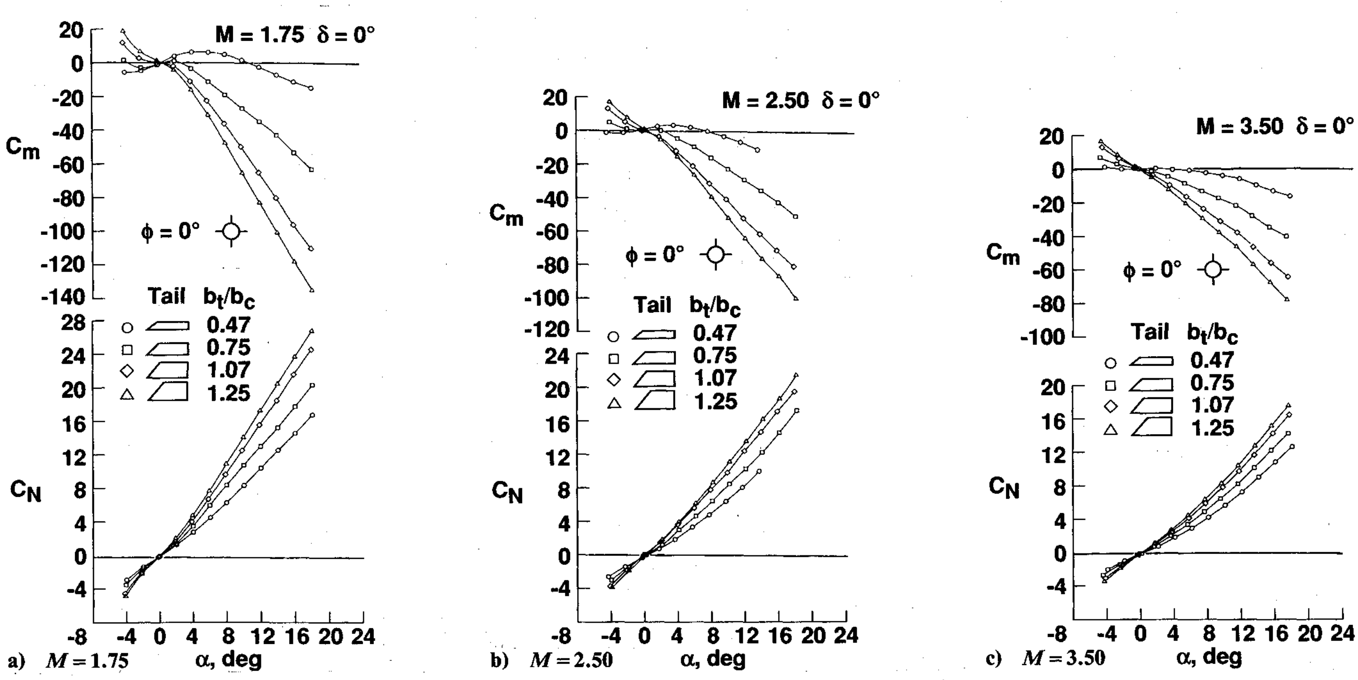

Fig. 3 Effects of tail span on longitudinal characteristics of model with zero canard deflection, $\phi = 0$ deg.

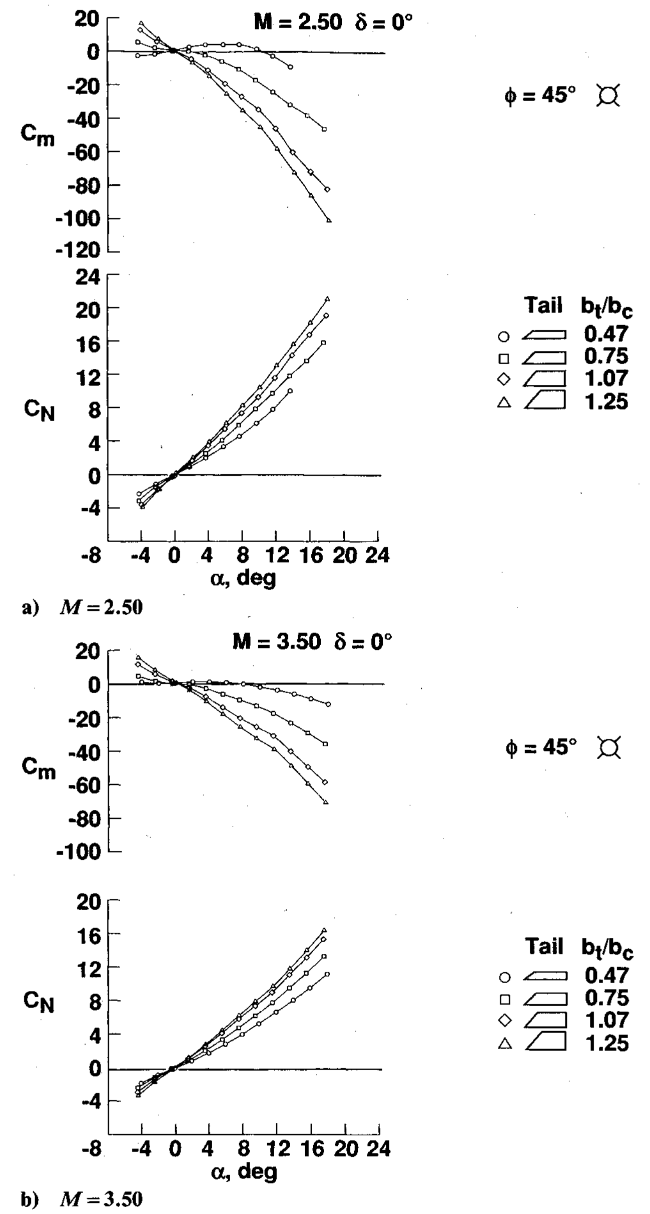

Fig. 4 Effects of tail span on longitudinal characteristics of model with zero canard deflection, $\phi = 45$ deg.

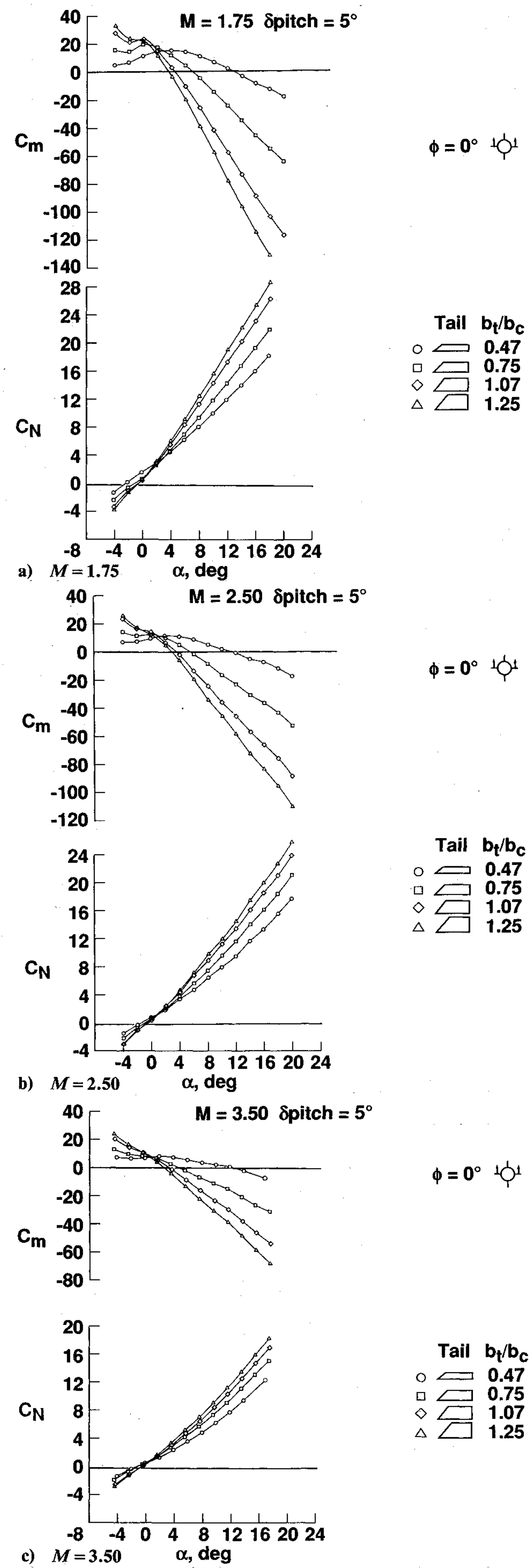

Fig. 5 Effects of tail span on longitudinal characteristics of model with canard pitch control, $\phi = 0$ deg.

gauge balance. The balance was attached to a sting that was rigidly fastened to the model support system. Model angles of attack were corrected for deflection of the balance and sting due to aerodynamic loads and for tunnel-flow angularity.

Results and Discussion

Longitudinal Characteristics

Longitudinal aerodynamic characteristics with various tail span/canard span ratios with zero canard deflection are presented in Figs. 3 and 4 at roll angles of 0 and 45 deg. Both normal-force-coefficient slope (C_{N_α}) and the stability level ($-C_{m_\alpha}$) decrease with decreasing tail span. These results confirm that reducing tail span produces less static margin and allows trim at higher angles of attack.

Longitudinal characteristics with the canards deflected 5 deg for pitch control are shown in Fig. 5. A comparison of Figs. 3 and 5 shows that canard deflection increases pitching moment. However, small reductions in normal-force coefficient occur with increasing tail span because downwash produced by the canards creates a download on the tail fins that increases with tail fin size. The net effect is a favorable canard-

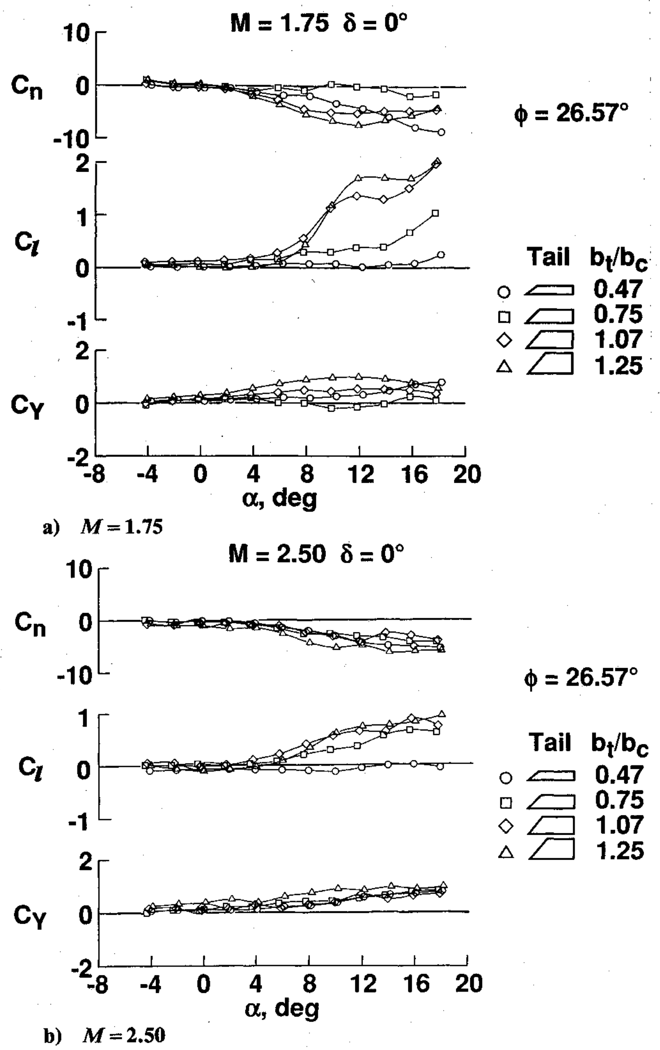

Fig. 6 Effects of tail span on lateral-directional characteristics of model at $\phi = 26.57$, zero canard deflection.

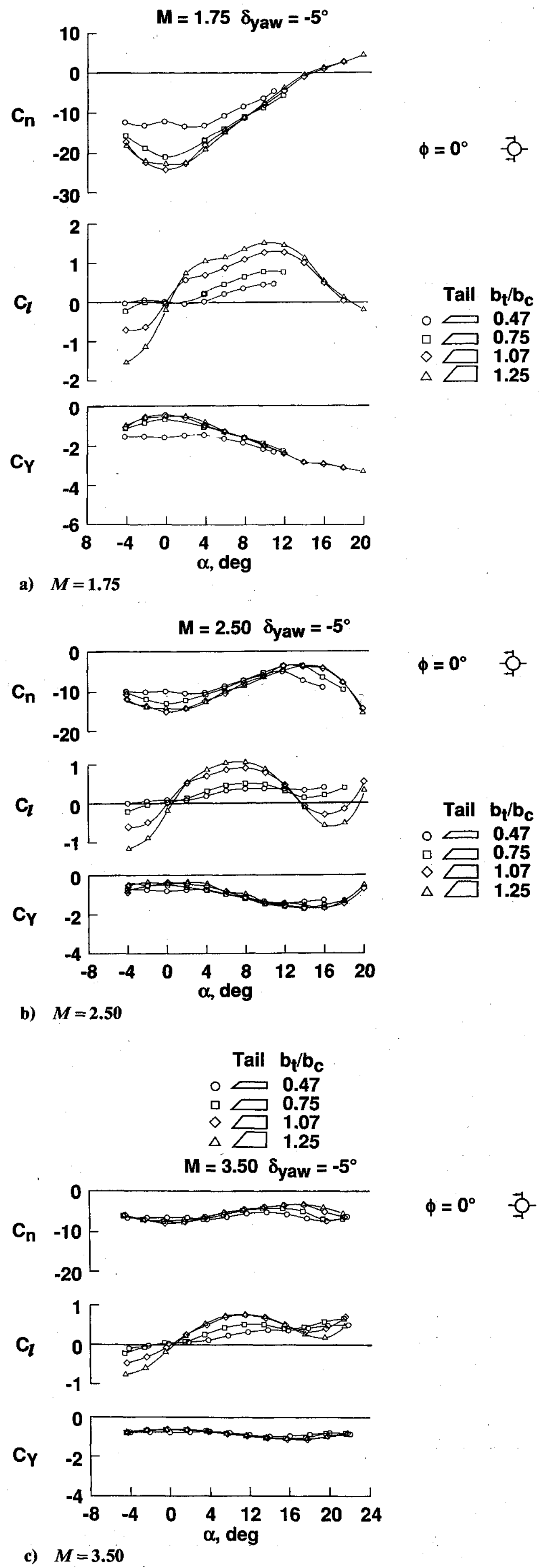

Fig. 7 Effects of tail span on lateral-directional characteristics of model with canard yaw control, $\phi = 0$ deg.

tail interference that produces a coupling moment in the pitch plane.

Lateral-Directional Characteristics

Lateral-directional aerodynamic characteristics of the models at a 26.57-deg roll angle are shown in Fig. 6. These data were acquired to determine the effects of tail fin span in nonsymmetrical flow. Tail span has little effect up to about $\alpha = 6$ deg. At the higher angles of attack, tail span has little effect on side force, moderate effect on yawing moment, and a large effect on rolling moment. The magnitude of induced rolling and yawing moment due to model roll asymmetry increases with increasing tail span.

Figure 7 shows the effects of tail span on yaw control. In general, increasing tail span at low angles of attack increases canard yaw control authority and induced rolling moment for $b_t/b_c \leq 1.07$. A small reduction in yaw-control authority occurs for $b_t/b_c > 1.07$ near $\alpha = 0$ deg.

Roll-control characteristics are presented in Figs. 8 and 9 for the model at $\phi = 0$ and 45 deg. Flow visualization studies have shown that the flowfield produced by differentially deflected canards is very complex and engulfs the tail fin region at certain model attitudes. In fact, the canard flowfield may induce tail fin rolling moments that are opposite to roll created by the canards and hence negate the desired control. Figures 8 and 9 show that increasing tail span reduces canard roll-control authority at many conditions and that roll-control reversal may occur with the larger span tails.

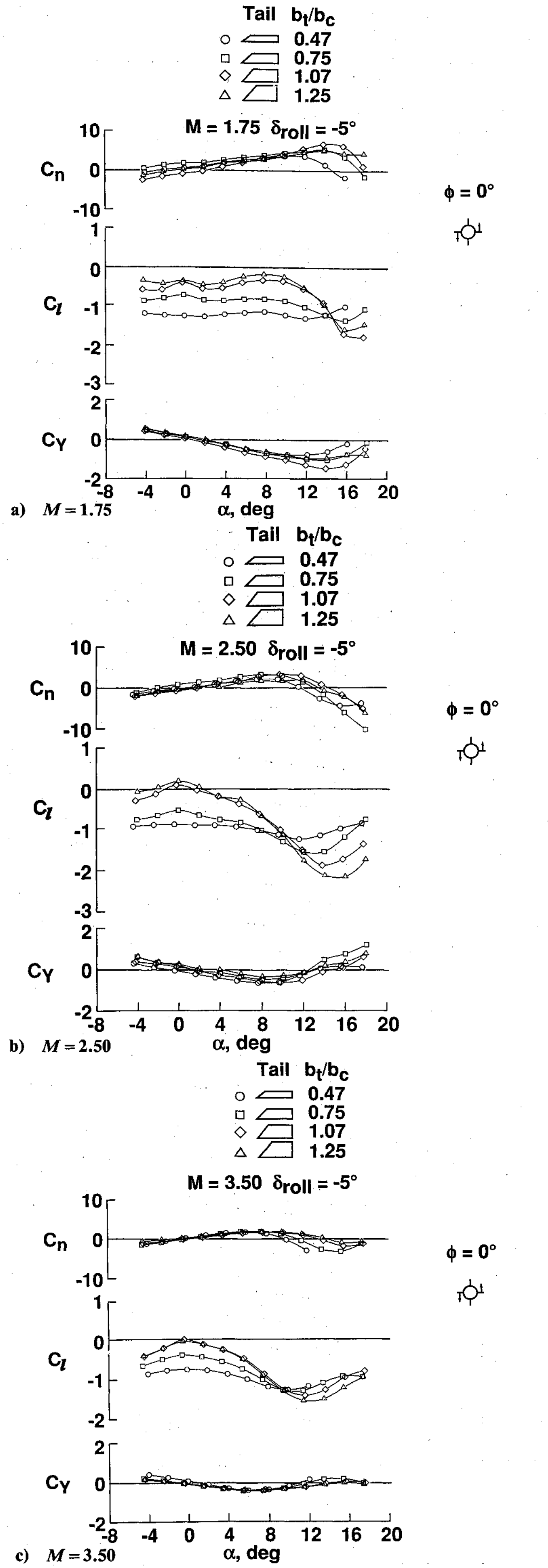

Fig. 8 Effects of tail span on lateral-directional characteristics of model with canard roll control, $\phi = 0$ deg.

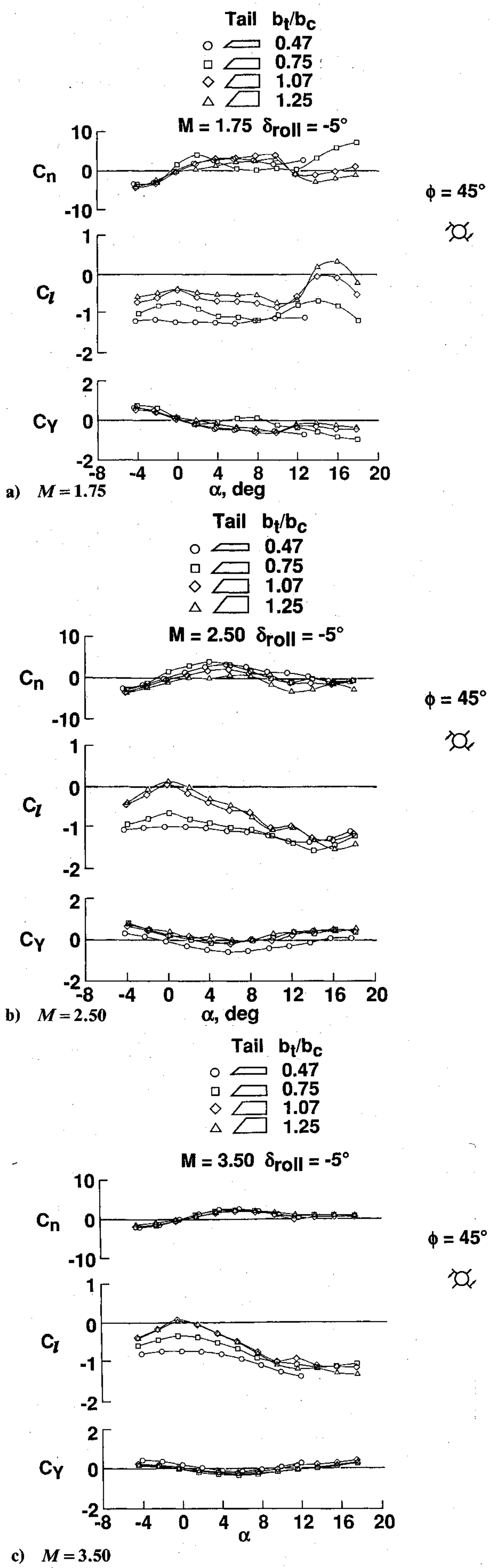

Fig. 9 Effects of tail span on lateral-directional characteristics of model with canard roll control, $\phi = 45$ deg.

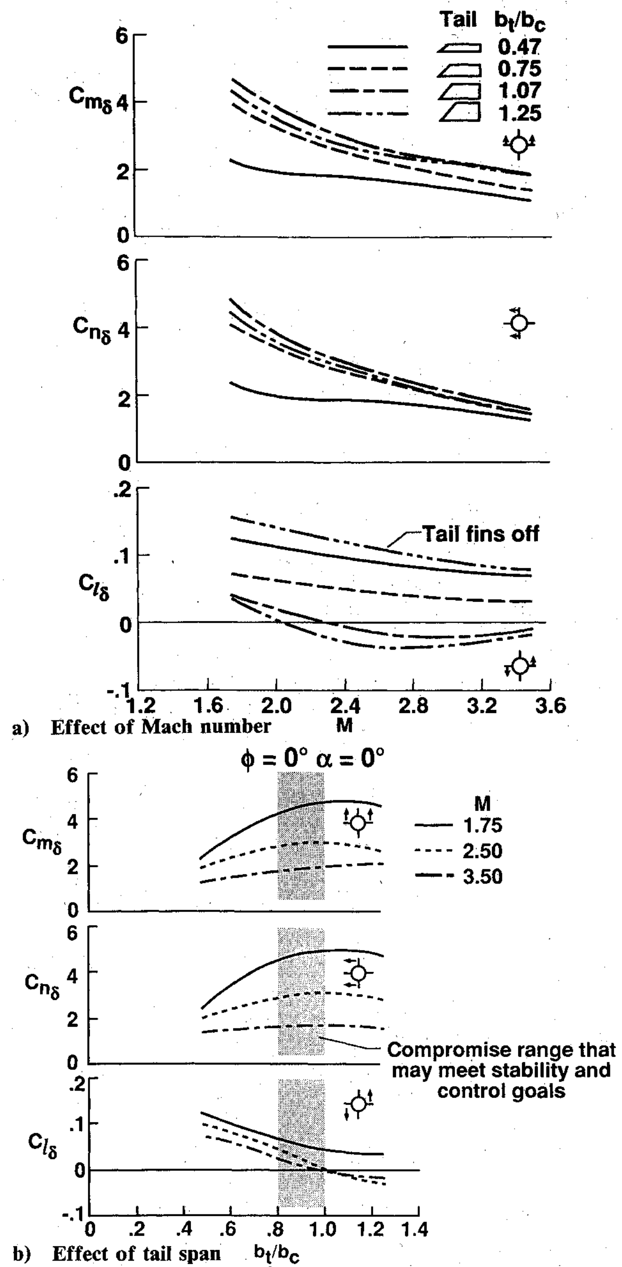

Fig. 10 Summary of canard control effectiveness of each tail configuration, $\phi = 0$ deg and $\alpha = 0$ deg.

Control Effectiveness Summary

Canard control effectiveness of each tail configuration at model ϕ and $\alpha = 0$ deg is summarized in Fig. 10. In general, C_{m_δ} and C_{n_δ} increase with increasing tail span for $b_t/b_c \leq 1.07$. For a given tail span, control effectiveness decreases with increasing Mach number. Figure 10b shows that it is possible to obtain near maximum pitch and yaw control as well as roll control by proper selection of the tail span/canard span ratio.

Concluding Remarks

An experimental investigation was conducted on a cruciform canard-controlled missile configuration to determine the effects of tail span/canard span ratio on stability and control. The investigation was conducted at Mach numbers from 1.75 to 3.50.

The significant results from the investigation are as follows.

1) Reductions of tail span/canard span ratio produced lower static margins and higher trim angles of attack.

2) A compromise range of tail span/canard span ratios is possible that gives near maximum canard pitch and yaw control as well as allowing canard roll control at zero angle of attack.

References

[1]Corlett, W. A., and Howell, D. T., "Aerodynamic Characteristics at Mach 0.60 to 4.63 of Two Cruciform Missile Models, One Having Trapezoidal Wings With Canard Controls and the Other Having Delta Wings With Tail Controls," NASA TM X-2780, July 1973.

[2]Burt, J. R., Jr., "The Effectiveness of Canards for Roll Control," U.S. Army Missile Command, Technical Rept. RD-77-8, Redstone Arsenal, AL, Nov. 1976; available from DTIC as ADA037077.

[3]Blair, A. B., Jr., "Supersonic Aerodynamic Characteristics of a Maneuvering Canard-Controlled Missile with Fixed and Free-Rolling Tail Fins," Society of Automotive Engineers, SAE Paper 90-1993, Oct. 1990.

[4]Rapp, G. H., "Performance Improvements With Sidewinder Missile Airframe Variants," AIAA Paper 79-0091, Jan. 1979.

[5]Blair, A. B., Jr., and Rapp, G. H., "Experimental and Analytical Comparison of Aerodynamic Characteristics of a Forward-Control Missile," AIAA Paper 80-0374, Jan. 1980.

[6]Allen, J. M., and Blair, A. B., Jr., "Comparison of Analytical and Experimental Supersonic Aerodynamic Characteristics of a Forward Control Missile," *Journal of Spacecraft and Rockets,* Vol. 19, No. 2, 1982, pp. 155–159.

[7]Blair, A. B., Jr., Allen, J. M., and Hernandez, G., "Effect of Tail-Fin Span on Stability and Control Characteristics of a Canard-Controlled Missile at Supersonic Mach Numbers," NASA TP-2157, June 1983.

[8]Jackson, C. M., Jr., Corlett, W. A., and Monta, W. J., "Description and Calibration of the Langley Unitary Plan Wind Tunnel," NASA TP-1905, Nov. 1981.