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Control Characteristics for Wrap-Around Fins on Cruise Missile Configurations

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Selected test results of panel loads on planar and wrap-around fins are presented at $M=2.36$. The study was conducted as part of an extensive investigation of an airbreathing missile concept employing wrap-around aerodynamic surfaces. The results indicate that the fin load characteristics are nearly identical for planar and curved fins having the same projected planform; the use of planar-surface predictions for supersonic speeds in the preliminary design stages of missiles employing wrap-around fins is justified.

Nomenclature

A	= fin projected area = 39.76 cm^2
B	= body
$b/2$	= fin semispan = 5.636 cm
$\bar{c}$	= fin mean aerodynamic chord = 7.277 cm
C_A	= axial force coefficient = axial force/$q_\infty S$
C_{BM}	= fin bending moment = bending moment/$q_\infty A(b/2)$
C_{HM}	= fin hinge moment = hinge moment/$q_\infty A\bar{c}$
C_ℓ	= rolling moment coefficient = rolling moment/$q_\infty Sd$
C_m	= pitching moment coefficient = pitching moment/$q_\infty Sd$
C_n	= yawing-moment coefficient = yawing moment/$q_\infty Sd$
C_N	= normal-force coefficient = normal force/$q_\infty S$
C_{NF}	= fin normal-force coefficient = normal force/$q_\infty A$
C_Y	= side-force coefficient = side force/$q_\infty S$
d	= maximum body diameter = 8.900 cm
M	= Mach number
MRC	= moment reference center (42.05% of body length)
q_∞	= freestream dynamic pressure
R	= unit freestream Reynolds number = 1/m
S	= reference area = (maximum body cross-sectional area) 62.21 cm^2
T	= tail
W	= wing
α	= angle of attack, deg
β	= angle of sideslip, deg
δ_{pitch}	= pitch control deflection, deg (positive deflection creates negative pitching moment—leading-edge up)
δ_{roll}	= roll control deflection, deg (positive deflection creates positive rolling moment)
δ_{yaw}	= yaw control deflection, deg (positive deflection creates negative yawing moment)

Subscripts

c	= curved
p	= planar

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Introduction

THE next generation of long-range cruise missiles will, in all likelihood, be a compromise between the state-of-the-art configurations present today and component improvements that do not require costly and major changes in handling and packaging. Therefore, primary research emphasis, in the area of aerodynamic improvement to long-range cruise missiles, should be placed on those components which offer the greatest promise for increased simplicity, reliability, capability, and commonality. One of the more promising aerodynamic concepts is the idea of wrap-around surfaces for missile configurations. For tube-launched missiles, aerodynamic stabilizing surfaces need to be retracted for stowage in the launch tubes and deployed instantly after launch so as to provide aerodynamic stability and control as quickly as possible. Wrap-around fins provide this capability while leaving the maximum room for subsystems and a large nozzle exit. For many years, the military services have been conducting experimental investigations on cylindrical configurations with wrap-around fins[1-10] which are engineered for tube-launch application.

The objective of this paper is to present new test results of supersonic panel loads on wrap-around fins on cruise missile configurations. The tests were conducted in the Unitary Plan Wind Tunnel as part of the final phase of a concentrated program to determine the aerodynamic characteristics of an airbreathing missile concept having wrap-around aerodynamic surfaces.[11] The new data include curved-fin panel loads at $M=2.36$ for control deflections in pitch, roll, and yaw. Fin panel loads and flow visualization photographs are presented for configurations with wing and tail surfaces of planar and curved geometry of the same projected planform area.

Test Configurations

The baseline model (Fig. 1) consisted of a body-wing-tail configuration having a flow-through chin inlet. The body length was 105.31 cm (41.462 in.) and the maximum diameter 8.900 cm (3.504 in.). The body consisted of a nose which was a blunted ogive with a 30 deg cone frustrum, on which the chin inlet was mounted, and a cylindrical mid-section followed by a short cylindrical section of smaller diameter at the base. This short cylindrical section was recessed to

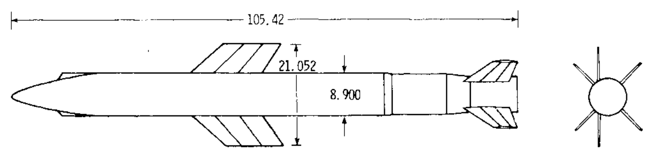


Fig. 1 Baseline test model, with fins in the x orientation. (All dimensions are in cm.)

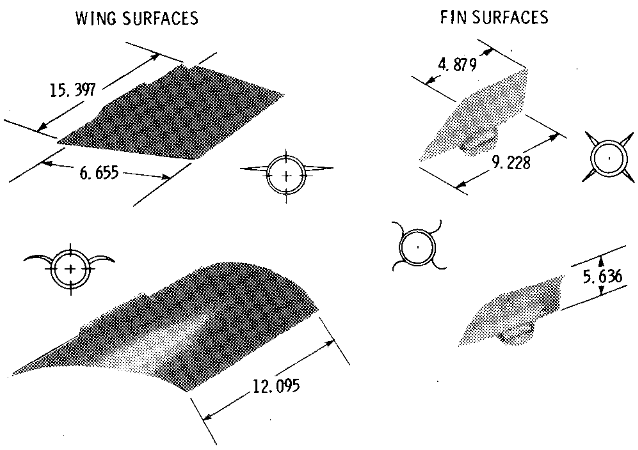
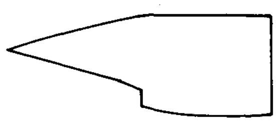
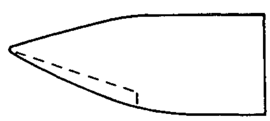


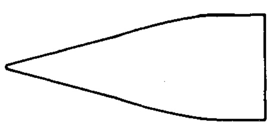
Fig. 2 Wing and fin geometry. (All dimensions are in cm.)



a) FLOW-THROUGH INLET (FORCE TESTS)



b) FAIRED-OVER INLET (TAIL LOADS)



c) SYMMETRICAL NOSE (TAIL LOADS)

Fig. 3 Nose geometry.

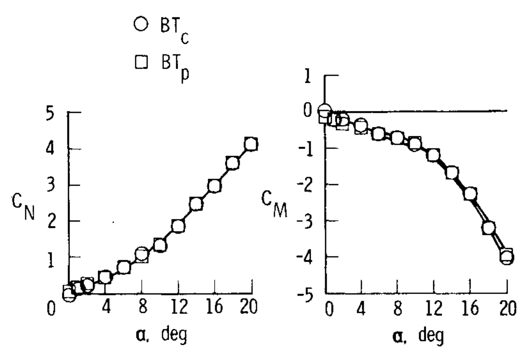


Fig. 4 Effect of curvature of tails on longitudinal characteristics. BT; $M=2.36$.

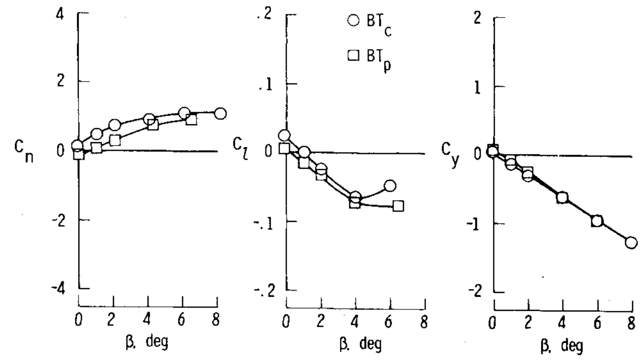


Fig. 5 Effect of curvature of tails on lateral-directional characteristics. BT; $M=2.36$; $\alpha=10$ deg.

represent the smaller diameter when the fins were extended. The body was recessed only on the lower side when the wings were extended.

The wing and fin planforms are shown in Fig. 2. Both curved and planar fins and wing surfaces were tested. The fins and wings had 5% thick modified double-wedge airfoils. The wing configuration had a 48.2 deg leading-edge sweep; the fins, 47.1 deg. The wing attachment points were located 30 deg above the horizontal plane of symmetry of the body to maximize span without requiring overlap of the wing tips in the folded position. The curved configurations had the same root and tip positions as the planar, but the mean camber plane was a cylindrical section of 90 deg in arc for the fins and 120 deg arc for the wings.

Two fins were instrumented with balances to measure hinge moments, bending moments, and normal forces. The fin balances were too large to permit testing with flow through the model. Testing was performed, therefore, either with the inlet faired over or with a solid symmetrical nose having the outline corresponding to the planview of the flow-through nose shape (Fig. 3).

The tests were conducted in the Langley Unitary Plan Wind Tunnel at Mach numbers from 2.00 to 4.63 for a Reynolds number of 6.6×10^6/m. The nominal range of angle of attack was from -4 to 20 deg and sideslip was from -8 to 8 deg. Vapor-screen photographs were taken at several model axial stations for angles of attack of 8, 12, and 16 deg.

Effect of Fin and Wing Curvature

Airframe Stability

The effect of fin curvature on the longitudinal and directional stability characteristics for the BT (body-tail) configuration having fins in the x position is shown in Figs. 4 and 5. The longitudinal characteristics for both planar and wrap-around surface configurations are nearly identical (Fig. 4). The corresponding lateral-directional characteristics presented in Fig. 5 show small yawing and rolling moments generated at the higher angles of attack at zero sideslip for the configuration with the curved surfaces. This effect is a result of the nonsymmetry of the curved fins with respect to the plane of the resultant angle of attack. Its understanding can be aided by visual analysis of the sketches presented in Figs. 6-8, which represent vapor-screen photographs that were taken during the test.

These figures present a comparison of the flow effects for configurations with both curved and planar tail surfaces, with and without the interference effect of a curved and a planar wing. These sketches are for a Mach number of 2.36 at 16 deg angle of attack for fins in the x orientation and model stations 108 and 75 or 57 cm.

A comparison of the curved and planar tail fins in Fig. 6 shows a noticeable asymmetry of the vortex pattern of the two visible fin surfaces. The effect of a curved or a planar wing ahead of the tails is shown in Figs. 7 and 8, respectively. Here

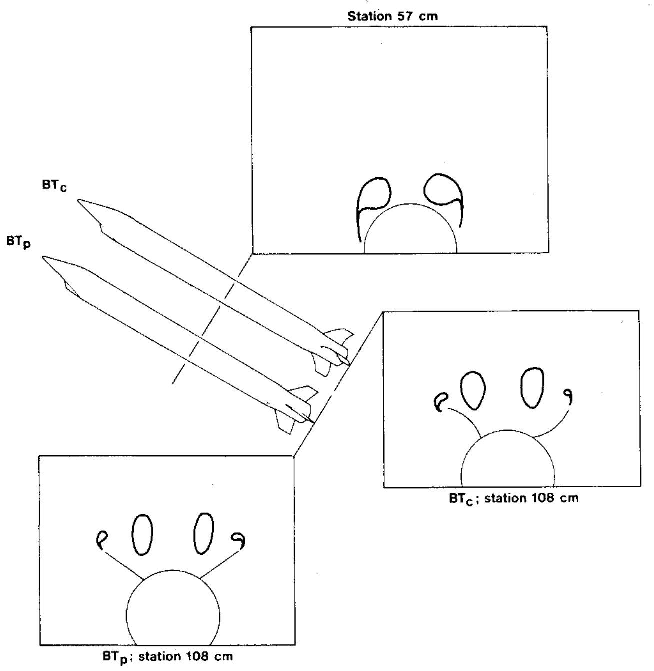


Fig. 6 Flow effects for curved and planar tail surfaces. *BT*; $M = 2.36$; $\alpha = 16$ deg.

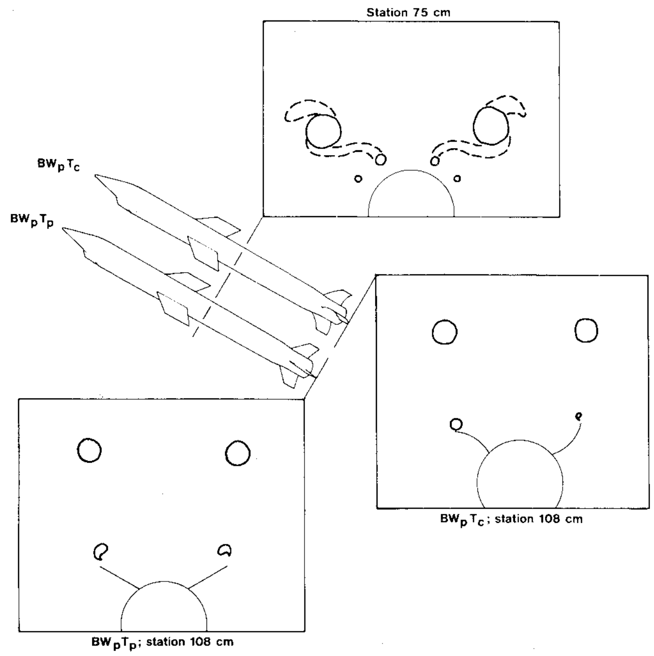


Fig. 8 Flow effects for planar wing with curved and planar tail surfaces. BW_pT; $M = 2.36$; $\alpha = 16$ deg.

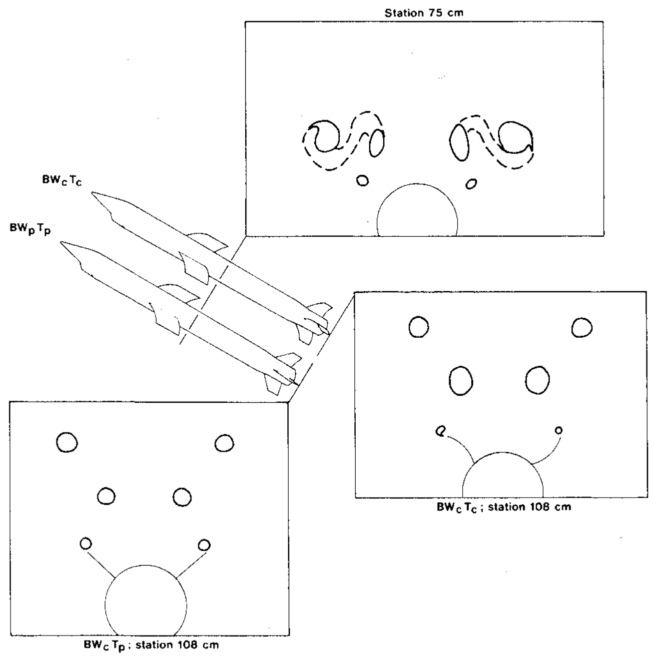


Fig. 7 Flow effects for curved wing with curved and planar tail surfaces. BW_cT; $M = 2.36$; $\alpha = 16$ deg.

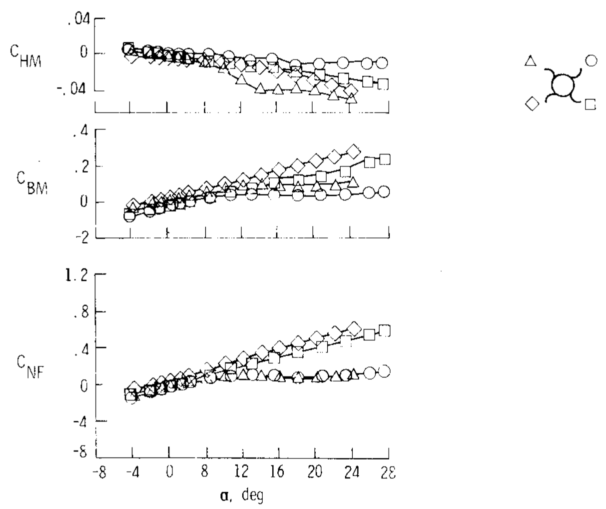


Fig. 9 Effect of fin location on fin loads. BT_c; $M = 2.36$; $\beta = 0$ deg.

there is a difference in the vortex patterns with the wrap-around wing configuration having two symmetrical pairs of vortices approaching the fins, but the planar wing having only one pair, as did the *BT* configuration (Fig. 6). However, the fin loads data presented in the following figures indicate that this additional pair of vortices had no effect on the overall loads and moments.

Fin Forces and Moments

Fin balance measurements are shown for all four positions of the curved fins for the symmetrical model nose configuration (Fig. 9). A pair of upright and inverted model runs was made to provide the results. The fin loads and moments for each of the left-hand fins are higher than the corresponding right-hand fin at the higher angles of attack, with the greatest differences in the hinge moments. This is the source of the positive rolling moment of the total configuration (Fig. 5).

The differences between the left and right loads are difficult to relate to the flow patterns observed in the vapor-screen results. For the upper fins, the bending moment is about 25% higher for the left side, although the normal force is the same. The vortex patterns of Fig. 6 indicate a strong vortex for the left side and a very weak one for the right. These results imply that the size or strength of the vortex indicated by vapor screen is related to the fin tip load rather than the fin total load.

The loads for curved fins with pitch-control deflections, δ_p, of 5 and -10 deg are presented in Figs. 10 and 11 for the *BT* configuration having a faired-over inlet nose. The increments in C_{NF} due to δ_p are nearly constant over the angle-of-attack range, whereas, the hinge-moment increments are doubled

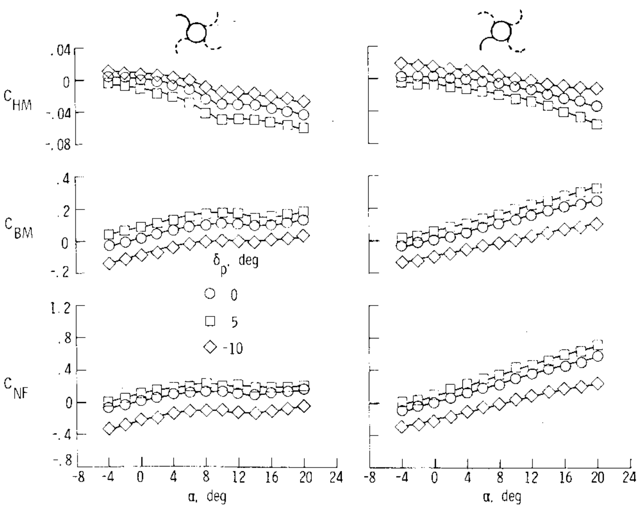


Fig. 10 Effect of pitch-control deflection on curved-fin loads. BT_c; $M=2.36$; $\beta=0$ deg.

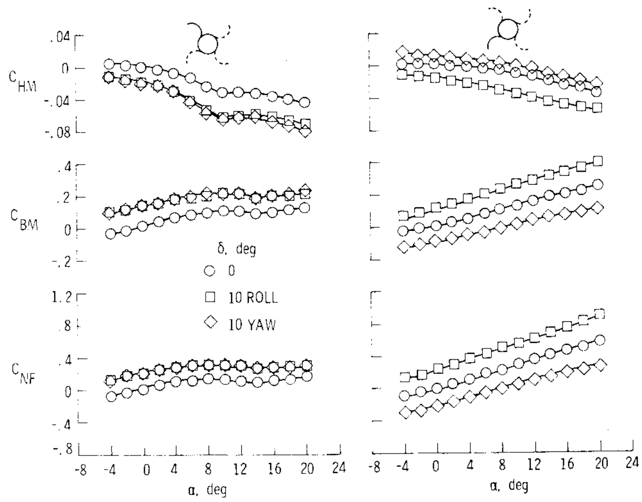


Fig. 11 Effect of roll- and yaw-control deflections on curved-fin loads. BT_c;$M=2.36$; $\beta=0$ deg.

at $\alpha=20$ deg. The effects of control deflections of 10 deg in roll and 10 deg in yaw are presented in Fig. 11.

The normal force, hinge moment, and bending moment increments due to δ_r and δ_y are relatively constant over the angle-of-attack range. All of the control deflection results are reasonably linear with angle of attack. This makes curved fins suitable for a vehicle of this type.

In Figs. 12-14, fin loads are compared for planar and curved control surfaces. The results were obtained for configurations employing the solid symmetrical nose as were those in Fig. 9. For a BT configuration, fin curvature changes hinge moment slightly at $\alpha>6$ deg (Fig. 12). For the lower fin, fin curvature slightly increases normal force and bending moment. This is apparently due to an unintentional small positive deflection of the curved fin. The results of this unintentional deflection also appear on the next two figures. The true increments (as verified by the curved-fin results of Fig. 10 or 11) like the ones for the upper fin, are actually very small.

The combined effects of wing and fin curvature on fin loads are shown in Fig. 13. The primary effect occurs on the upper fin above 16 deg angle of attack. It consists of small changes in normal force and bending moment with a somewhat larger change in hinge moment. In Fig. 14, the effect of fin curvature on fin loads for a BW_pT (body, planar wing, tail)

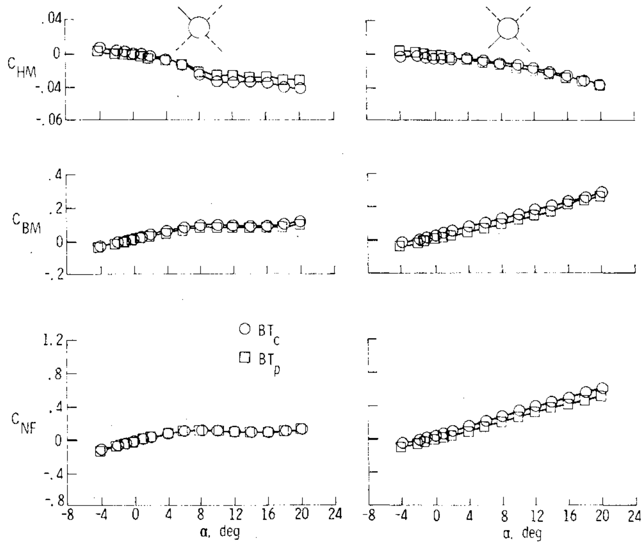


Fig. 12 Effect of fin curvature on fin loads. BT; $M=2.36$; $\beta=0$ deg.

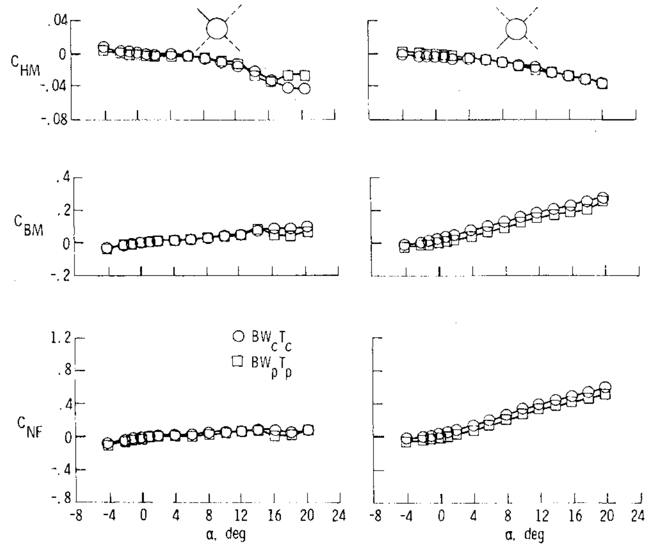


Fig. 13 Effect of combined fin and wing curvature on fin loads. BWT; $M=2.36$, $\beta=0$.

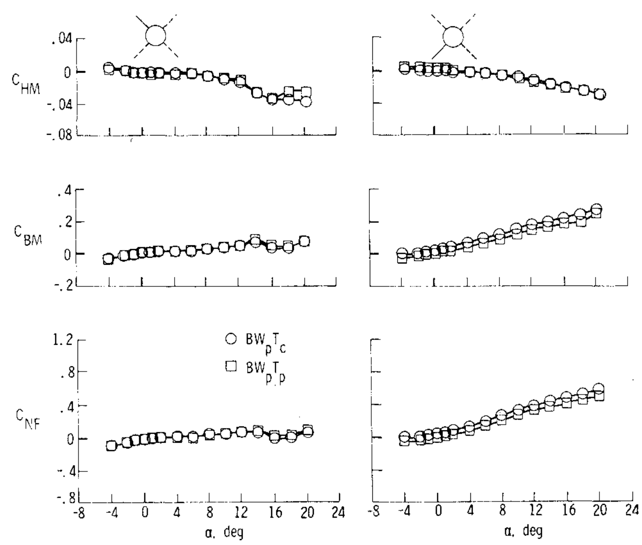


Fig. 14 Effect of tail fin curvature on fin loads. $BW_p T$; $M=2.36$; $\beta=0$.

configuration exhibits essentially the same increments as in Fig. 13 indicating that there is no effect due to curvature of the wings.

Conclusions

Results of wind-tunnel investigations made at supersonic Mach numbers to provide design data on wrap-around fins for missile configurations indicate that: 1) curved aerodynamic surfaces exhibit force and moment characteristics very similar to planar surfaces of the same projected planform; and 2) the use of planar-surface predictions for supersonic speeds in the preliminary design stages of cruise missiles employing wrap-around curved fins is justified.

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