Ram-Air-Spoiler Roll Stabilization Device for Forward-Control Cruciform Missiles

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A parametric experimental wind tunnel investigation has been made at supersonic Mach numbers to provide design data on a ram-air-spoiler roll control device to be used on forward control cruciform missile configurations. In addition, for roll control comparisons, conventional aileron controls on the tail fins were also tested. Results are presented indicating that the addition of ram-air-spoiler nacelles on the missile tail fins results in satisfactory roll control and only small changes in basic missile longitudinal stability. The ram-air-spoiler roll control is relatively constant over the range of vehicle attitudes and Mach numbers investigated.

Nomenclature

A = maximum cross-sectional area of model body
A_e = jet-exit slot area of one ram-air-spoiler
A_i = cross-sectional area of one ram-air-spoiler inlet
C_A = axial-force coefficient, axial force/qA
C_l = rolling moment coefficient, rolling moment/qAd
ΔC_l = incremental rolling moment coefficient due to controls
d = reference diameter
M = Mach number
P_{t_2} = total pressure behind a normal shock
P_∞ = freestream static pressure
q = freestream dynamic pressure
S_a/S_e = ratio of tail fin aileron area to total exposed planform tail fin area for one surface
t/c = tail fin thickness ratio at the root chord
X_{ac}/l = aerodynamic-center position as fraction of model length, measured from model nose
α = angle of attack, deg
ϕ = model roll angle (for $\phi = 0$ deg, the canards and tail fins are in the vertical and horizontal planes), deg

Introduction

It is well documented that missile configurations utilizing forward surfaces to provide control experience the problem of induced rolling moments at supersonic Mach numbers. The data from some of these configurations tend to indicate that the problem is associated with an interference effect of the deflected forward surface on one or more of the trailing fins. For these forward-control configurations the need is either that of reducing or eliminating the induced rolling moments or of providing an efficient system for their control.

One approach to the solution of these problems has been studied and the preliminary aerodynamic results are encouraging. This approach, which is described in Ref. 1, uses a ram-air-spoiler roll control device on a typical canard control missile configuration to compensate for the unwanted induced rolling moments.

The idea of using a ram-air-spoiler as an aerodynamic control device with low-actuator torque is not new. During 1955-1960, researchers investigated a number of roll control devices with, potentially, low-actuator torque requirements. One of the most effective of these was a jet flap or jet-freestream interaction device which used ram-air pressure for the jet working fluid. An excellent account of the preceeding ram-air-spoiler research on nonmaneuvering missiles can be found in Refs. 2-5. More recently, the feasibility of interfacing a ram-air-spoiler system with an all fluidic-logic roll control system has been investigated.[6,7]

A preliminary study[8] has indicated that the ram-air-spoiler roll control device is a feasible aerodynamic concept for providing roll stabilization on canard-controlled missiles. This paper summarizes the significant findings of a parametric experimental wind-tunnel investigation whose purpose was to expand the technology base of the preliminary study and to provide the comprehensive aerodynamic data base required to confidently assess the merits of ram-air-spoiler systems. A complete report of the investigation can be found in Ref. 9. The study included model configurations which represented the ram-air-spoiler devices operating on a typical canard-controlled missile at zero and maximum roll control as well as a comparison with conventional aileron controls, all at various missile maneuvering attitudes and Mach numbers.

Study Concept

The concept of a ram-air-spoiler roll control is illustrated in Fig. 1. The control device is located on the tail fins of a typical canard controlled missile configuration, as shown in the center of the figure. The control concept consists of an inlet located at the fin tip with a butterfly valve located in the duct. The valve, shown in the no control and control operating positions (section A-A of Fig. 1), is actuated by a jet control spindle rod through the fin. This control-valve spindle is a rod with flats at intervals corresponding to the exit slots (shown in section B-B). In the plus or minus roll control position, the butterfly valve is rotated ±90 deg, blocking the duct and forcing the air into the plenum in the fin and then through the exit slots on either the upper or lower fin surface. The flow concept illustrates the flow mechanism of the device. As the air exits perpendicular to the supersonic stream, the flow on the fin surface is separated upstream which provides effective flow turning and reaction force on the fin. The actuation requirements for such a system should be only the minimal torque required to operate a balanced butterfly valve and jet-exit control spindle.

The model concept used to establish the aerodynamic design parameters for such a system consists of the two configurations shown on the right-hand side of Fig. 1. The control-operating condition is simulated by a model with all four fin nacelle exits plugged, diverting the air into the plenum and out through slots on one side only of each fin

Presented as Paper 78-24 at the AIAA 16th Aerospace Sciences Meeting, Huntsville, Ala., Jan. 16-18, 1978; submitted Feb. 13, 1978; revision received May 11, 1978. This paper is declared a work of the U.S. Government and therefore is in the public domain.
Index categories: Aerodynamics; Guidance and Control.
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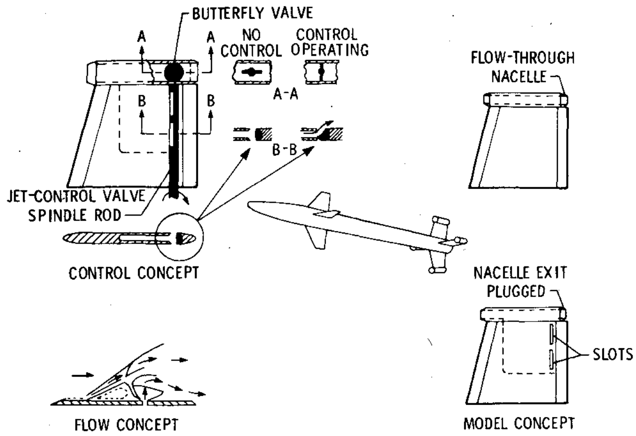


Fig. 1 Canard controlled missile with ram-air-spoiler roll control.

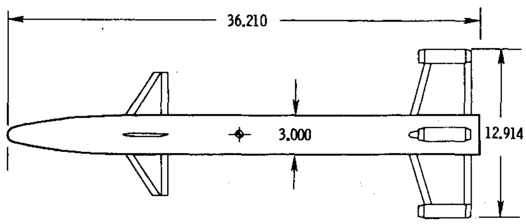


Fig. 2 Model details (in inches).

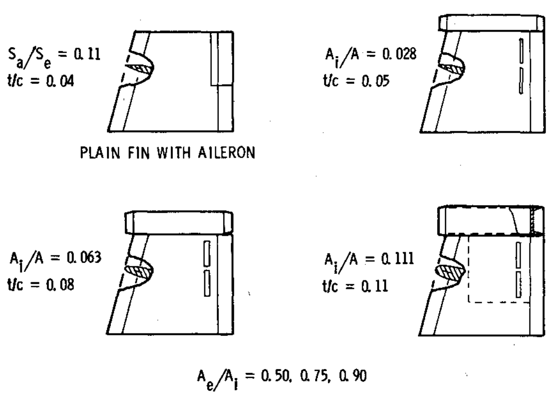


Fig. 3 Model parameters

surface to provide positive rolling moments. The model configuration representing the control in a nonoperating mode is simply a flow-through nacelle at the fin tip, as shown at the upper right of Fig. 1. In order to evaluate the ram-air-spoiler as a roll control system in the current study, a general research missile model was selected as the basic airframe. The configuration is shown in Fig. 2 with a ram-air-spoiler installed on the aft fins and overall dimensions given in inches.

The model parameters investigated in this study are illustrated in Fig. 3. The most significant parameter of this investigation is the size of the inlet for the ram-air-spoiler. As shown in Fig. 3, three inlet sizes were investigated ($A_i/A = 0.028$, 0.063, and 0.111) to provide variations in mass flow. With increases in inlet diameters, corresponding increases in respective fin thickness ratios (t/c) were necessary to make the manifold (plenum) entrance as large as possible to prevent internal flow restrictions. Several exit-to-inlet area ratios were investigated for each ram-air-spoiler tail fin configuration ($A_e/A_i = 0.50$, 0.75, and 0.90). Flow-through nacelle configurations were obtained by removing the nacelle exit plugs and substituting cover plates for slotted exit plates on the ram-air-spoiler tail fins.

For roll control comparisons, a plain tail fin with aileron control was tested (Fig. 3). The aileron size was chosen to be the same fin area as would nominally be affected by the

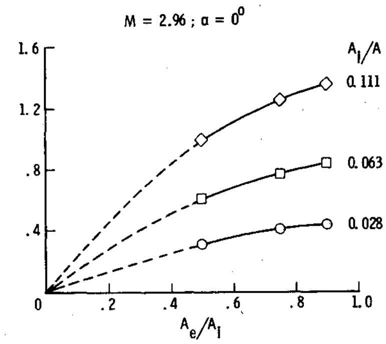


Fig. 4 Ram-air-spoiler inlet and plenum exit size effects on roll control.

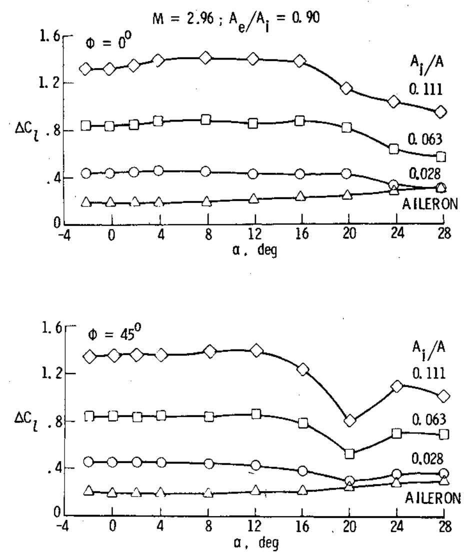


Fig. 5 Angle-of-attack effects on ram-air-spoiler roll control.

spoiler action of the ram-air-spoiler configurations ($S_a/S_e = 0.11$). The ailerons were deflected 10 deg on all four fins to provide positive rolling moments for all comparisons made in the current study.

The tests were conducted in the Langley Unitary Plan wind tunnel at Mach numbers 1.60-4.63. The nominal angle-of-attack range was -4 to 28 deg at model roll angles of 0, 22.5, and 45 deg for a Reynolds number of 6.6×10^6/m (2.0×10^6/ft).

Effects of Design Parameters on Aerodynamic Performance

The effect of inlet and plenum exit size on the roll control of the ram-air-spoiler tail fins at $M = 2.96$ for $\alpha = 0$ deg is presented in Fig. 4. The trends that are shown in this figure are typical for the other Mach numbers as well. The ram-air-spoiler tail fins are effective roll-producing devices for any of the exit-to-inlet area ratios tested. For a constant inlet size (A_i/A), the roll control increases with exit-to-inlet area ratio and obtains a maximum test value at $A_e/A_i = 0.90$. Figure 4 also indicates that for a given exit-to-inlet area ratio, the rolling moment produced by the ram-air-spoiler is generally proportional to the inlet area or the mass flow of the spoiler jet.

The effects of vehicle attitude on roll control of the ram-air-spoiler are shown in Fig. 5 for a typical Mach number of 2.96. In general, the ram-air-spoiler configurations produce significantly more rolling moment coefficient than the aileron system at 10 deg deflection. The rolling moment coefficients are essentially constant for both vehicle roll attitudes of 0 and 45 deg and over the angle-of-attack range up to 16 deg. Some gradual loss in rolling moment capability would be expected with angle of attack at the higher attitudes as inlet mass flow

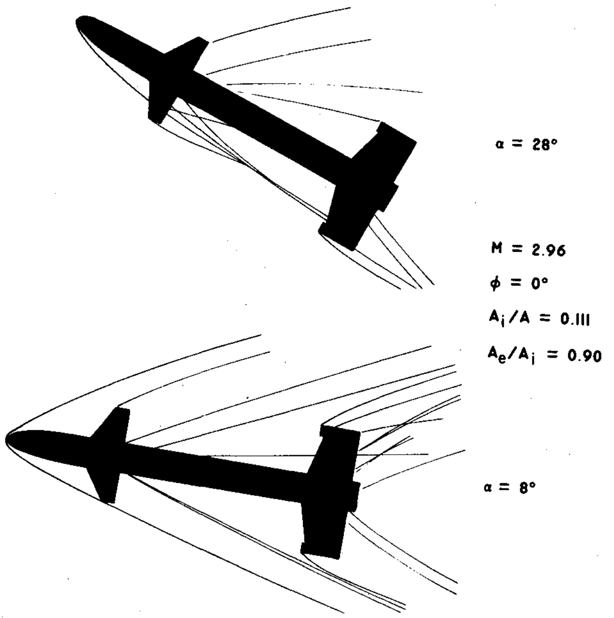


Fig. 6 Flowfield effects on ram-air-spoiler tail fins.

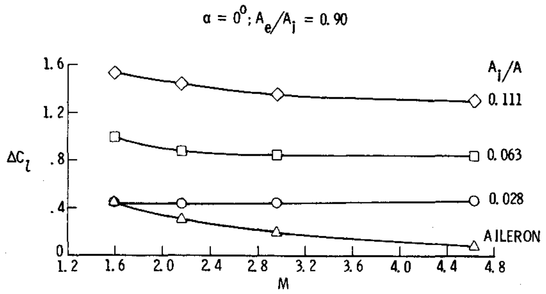


Fig. 7 Mach number effects on ram-air-spoiler roll control.

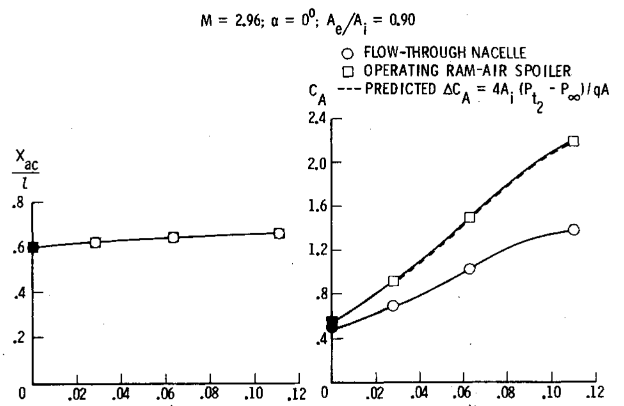
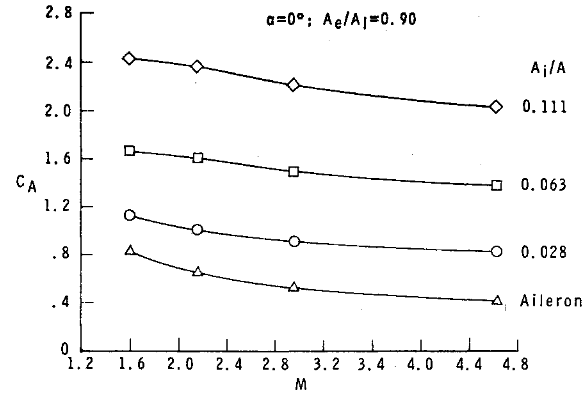


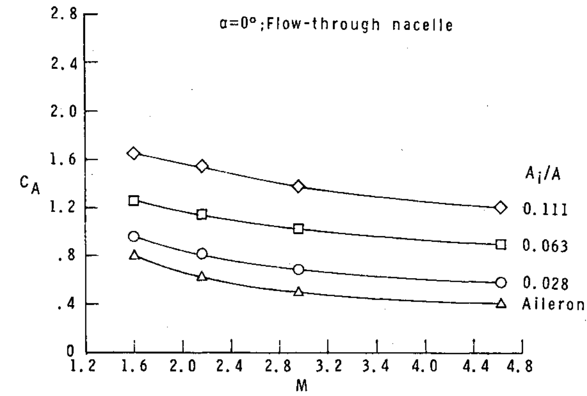
Fig. 8 Longitudinal performance effects.

reduces, but sharp local losses may be produced when the forebody shock front passes over the lower inlets. Such a loss may be seen at 20 deg angle of attack when the strong forebody shocks (a coalescence of the canard and nose shocks) pass over both lower inlets at a model roll angle of 45 deg. While schlieren photographs portraying the 45 deg roll case are not available, some insight into the interference phenomena may be gained from the sketches shown in Fig. 6, which were made from available schlieren photographs of the model at $\phi=0$ deg. The designer should be aware of these shock impingement effects.

In general, the control effectiveness of any conventional aerodynamic control surface reduces as Mach number in-



a) Roll control



b) No roll control

Fig. 9 Summary of Mach number effects on total axial force coefficients.

creases in the supersonic speed range. The effect of Mach number on the roll control moment of the conventional aileron and the ram-air-spoiler is shown in Fig. 7 for $\alpha=0$ deg. As expected, the aileron shows considerable reduction in roll control with Mach number. However, the ram-air-spoiler control capability is essentially constant with Mach number.

An examination of the effects of the ram-air-spoiler on the longitudinal aerodynamic characteristics of the missile indicates little change in normal force coefficient and pitch characteristics. However, a significant increase in axial force coefficient is indicated as the size of the ram-air-spoiler is increased. Figure 8 shows typical effects of ram-air-spoiler inlet size on longitudinal stability and axial force coefficient at $\alpha=0$ deg and $M=2.96$. The solid symbols in Fig. 8 ($A_i/A=0$) indicate the plain fins with aileron controls at 0 and 10 deg. As the ram-air-spoiler inlet size increases, the wetted area and fin thickness increases. These effects tend to shift the center of pressure aft, as shown in Fig. 8. The large increase in axial force coefficient for the flow-through inlet is a direct result of fin thickness, leading-edge bluntness increase, and nacelle geometry. The axial force coefficient increment between the flow-through and operating curves is due to the ram-air momentum loss in the inlet/duct/plenum manifolds. The dashed line in Fig. 8 shows that this increment can be estimated accurately using free-stream tunnel conditions and applying the total pressure behind the normal shock to the inlet area according to the following equation.

$$\Delta C_A = 4A_i(P_{t_2} - P_\infty)/qA$$

A summary of Mach number effects on the total axial force coefficients for each ram-air-spoiler and plain tail fin configuration with and without roll control is shown in Fig. 9. The large axial force penalty associated with the ram-air-spoiler could be a serious deficiency when compared with the axial force associated with an aileron. For example, the ram-air-spoiler with $A_i/A=0.028$ produced the same roll control at $M = 1.60$ as the aileron (shown in Fig. 7), but had a 36% increase in axial force coefficient, of which 16% is attributed just to the flow-through nacelle (nonoperating) condition. For a missile system where axial force is of prime importance (longer range), the advantages of lower actuator torque requirements and better roll control at higher Mach numbers might not offset the axial force penalty of the ram-air-spoiler. However, for short-range applications, which are generally thrust dominated, axial force is usually of secondary importance compared with other control characteristics.

Summary

A parametric experimental wind tunnel investigation has been made at supersonic Mach numbers to provide design data on a ram-air-spoiler roll control device to be used on forward control cruciform missile configurations. The results indicate that the ram-air-spoiler is an effective roll control device and the roll control is generally constant with vehicle attitude and Mach number. There are only small effects on longitudinal stability, but large axial force effects associated with the increased fin thickness and ram-air momentum loss of the operating ram-air-spoiler configurations which may offset in long-range applications the potential advantages of low actuator torque requirements and better roll control at higher Mach numbers.

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