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Supersonic Aerodynamic Trade Data for a Low-Profile Monoplanar Missile Concept

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A monoplanar missile concept has been studied which shows promise of improving the aerodynamic performance of air-launched missiles. This missile concept has a constant eccentricity elliptical cross-section body. Since current guidance and propulsion technologies influence missile nose and base shapes, an experimental investigation has been conducted at Mach number 2.50 to determine the effects of variations in these shapes on the missile aerodynamics. Results of these tests are presented.

Nomenclature‡

C_{D_0} = drag coefficient at zero lift
C_L = lift coefficient
C_m = pitching moment coefficient
C_{m_α} = longitudinal stability parameter
C_{n_β} = directional stability parameter
$c.p.$ = center-of-pressure location, percent body length
$(L/D)_{\max}$ = maximum lift-drag ratio
R_n/d = ratio of nose radius to body reference diameter (based on maximum body area)
α = angle of attack, deg

I. Introduction

THE need for advances in missile aerodynamic technology has been recognized and some areas for increased emphasis have been previously discussed.[1] One such area was monoplanar missiles configured for conformal carriage and supersonic delivery. The Air Force, as part of its Maneuvering Air-to-Air Missile Program, has investigated the aerodynamic characteristics of some specific elliptical-body configurations for possible monoplanar missile application. Results from wind-tunnel investigations on these candidate configurations, however, indicate that additional configuration refinement is required for an aerodynamically acceptable concept.[2,3]

In support of the Air Force, an experimental effort was initiated at the Langley Research Center to compare the aerodynamic characteristics of a circular-body monoplanar missile concept with an "equivalent" elliptical-body concept.[4] Results from these tests indicated that at supersonic speeds, the elliptical-shaped configuration could provide substantial increases (about 25%) in normal force, and thus, substantial increases in maneuvering or load-carrying capability. In addition, the elliptical concept possessed more longitudinal/directional stability compatibility, which is a desired characteristic for monoplanar missiles.

The current effort is to extend the supersonic aerodynamic data base of the elliptical-body configuration to include hemispherical noses and circular bases, or combinations thereof, so that practical trades between the aerodynamics, guidance, and propulsion technologies might be made. Tests were conducted in the Langley Unitary Plan wind tunnel at Mach number 2.50.

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Index categories: LV/M Aerodynamics; LV/M Configurational Design.

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‡All moments are referenced at a point 60.0% of the body length when measured from the nose.

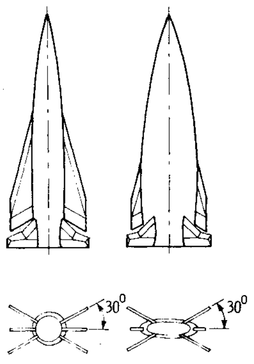
II. Model Description

The basic configurations (Fig. 1) from which the family of configurations (Fig. 2) was derived, are described in a previous paper.[4] The "equivalent" elliptical-body concept, shown in Fig. 1, essentially represents "squashing" the circular minimum-wave-drag Adams body[5] to form a 3:1 ellipse at each local body cross section while holding wing span and tail location constant.

The other concepts in the family of configurations in Fig. 2 were generated by modifying the basic forebodies to allow for two different hemispherical nose sizes. The elliptical forebody "equivalents" of these concepts had cross section eccentricities which varied from 1:1 at the nose to 3:1 at the maximum cross section area (68% body length). These "equivalent" forebodies could be fitted with two different afterbodies—one which remained at a constant 3:1 cross section eccentricity to the body case, and one which varied from 3:1 at the maximum cross section area to 1:1 at the body base. All concepts with the same nose size have identical body cross-sectional area distributions.

III. Experimental Results

Figure 3 presents the measured pitching moment and lift coefficients as a function of angle of attack for the family of circular-body configurations. The pitching moments exhibit no discernable nonlinearities due to nose bluntness, although increasingly destabilizing increments are seen as bluntness adds more and more forebody planform area ahead of the moment-reference point. Of interest is the contrasting behavior of lift and pitching moment with angle of attack for the noncircular body configurations. Figure 4, which shows Schlieren and vapor screen photographs of the pointed nose and moderately blunt nose configurations at an angle of attack of 15 deg, provides some insight into the data. It is helpful here to remember that highly elliptic bodies with their major axes presented to the crossflow tend to quickly shed, in contrast to circular bodies, a single pair of stable symmetric vortices which persist through high angles of attack. Note that fully developed vorticity begins very early on the pointed nose body (fully elliptic forebody) and is somewhat delayed on the blunt nose configuration (which initiates as a circular body), such that the development of the vortex interference lift[6] is also delayed. As nose bluntness is increased, some further degradation in overall vortex interference lift should result, but a compensatory increase due to the increased forebody planform area might be expected. The pitching moment data



MODEL GEOMETRIC CHARACTERISTICS

BODY	
LENGTH (REFERENCE)	0.7112 m
FINENESS RATIO	7.00
MAXIMUM CROSS SECTION AREA (REFERENCE)	0.008107 m^2
BASE AREA	0.00562 m^2
WING	
L.E. SWEEP	75.00 deg
T.E. SWEEP	60.00 deg
SPAN	0.2286 m
DIHEDRAL ANGLE	0 deg
TAIL	
INBOARD L.E. SWEEP	45.00 deg
OUTBOARD L.E. SWEEP	14.04 deg
T.E. SWEEP	0 deg
OUTBOARD TAPER RATIO	0.75
INBOARD TAPER RATIO	0.43
DIHEDRAL ANGLE	±30 deg
SURFACE AREA (1 FIN)	0.0048 m^2

Fig. 1 Basic study concepts.

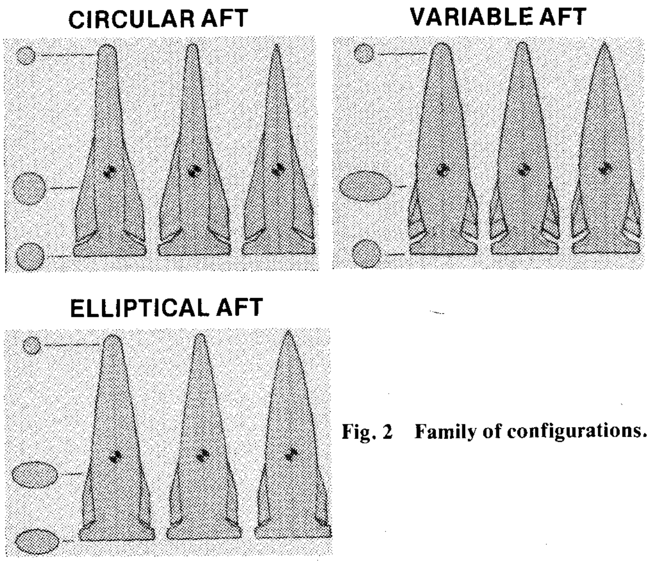


Fig. 2 Family of configurations.

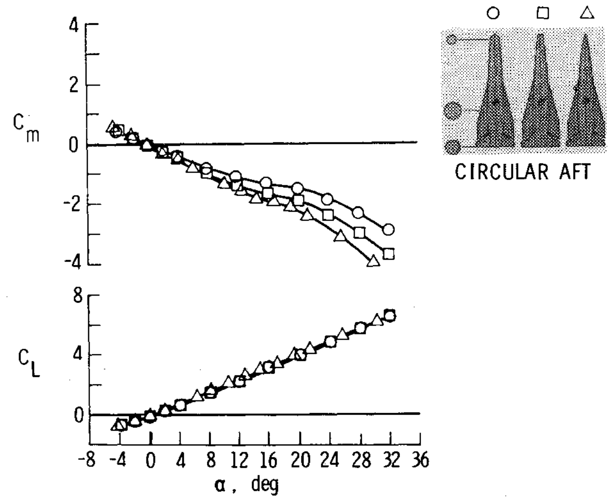


Fig. 3 Pitch-lift characteristics (circular concepts).

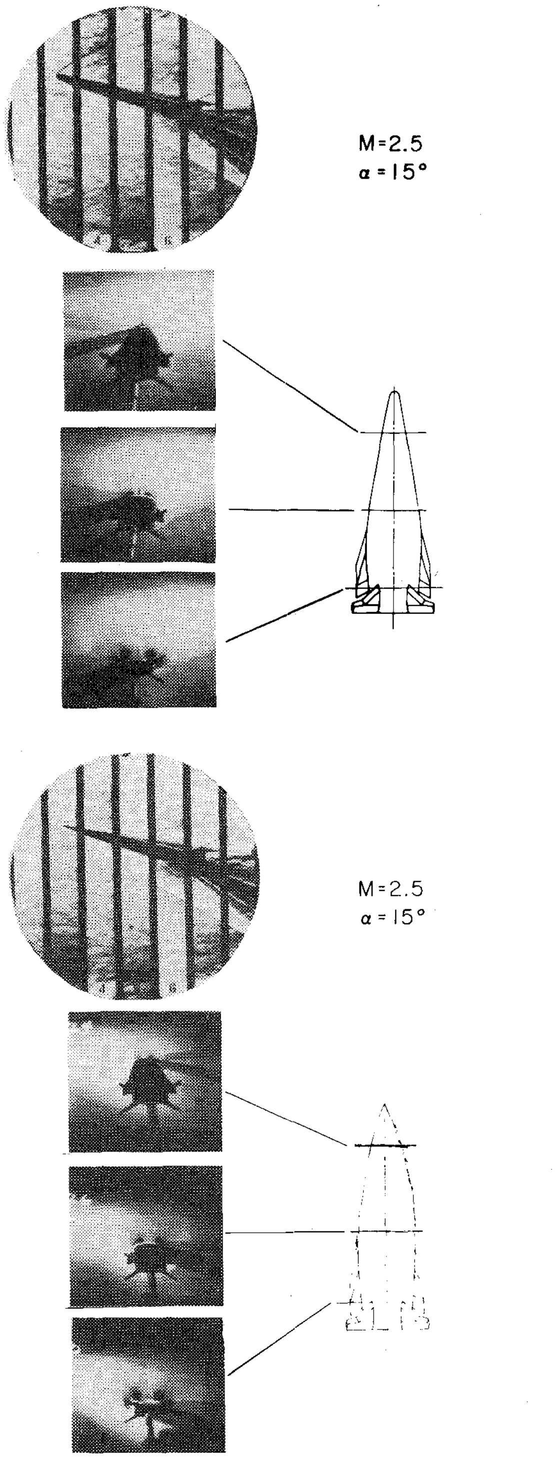


Fig. 4 Flow visualization data.

of Fig. 5 clearly support such an analysis, showing the pitch stability of the configuration with moderate bluntness to be greater than that for either the pointed forebody with early vortex development or for that of the most blunt forebody with its larger forebody planform area. To be noted, as well, is that the wider afterbody of the fully elliptic configuration with the pointed nose appears to provide for higher interference lift, particularly at high angles of attack (beyond 16 deg) than its circular-base counterpart. The somewhat decreased stability associated with this loss in lift on the afterbody for the latter at high angles supports this contention.

Figure 6 compares pitching moment and the directional-stability parameter vs lift coefficient for the entire family of configurations. Immediately apparent is the significantly greater pitching moment slopes for the all-circular body configurations which, regardless of nose bluntness, lack the destabilizing influence of vortex-induced lift experienced by elliptic forebodies. Also apparent is the sharply increased directional stability of the configurations with elliptic cross sections over those of the all-circular bodies, particularly for the pointed nose, elliptical-aft configuration at high lift coefficients. This is the effect of the airfoil-like forebody section advancing (much as an autogiro blade would) into the

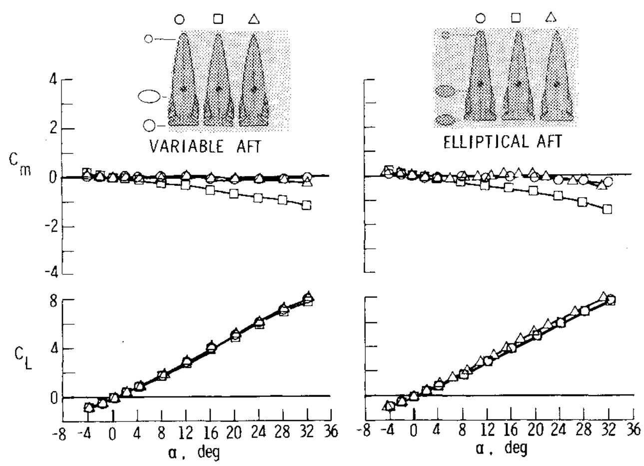


Fig. 5 Pitch-lift characteristics (noncircular concepts).

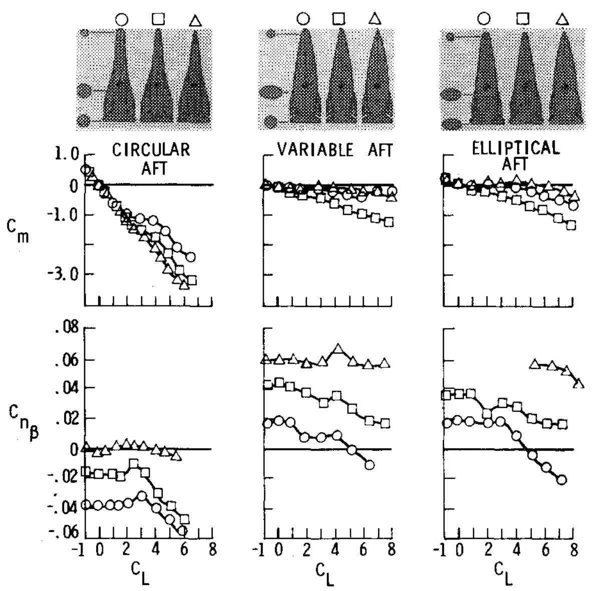


Fig. 6 Pitch and directional-stability characteristics.

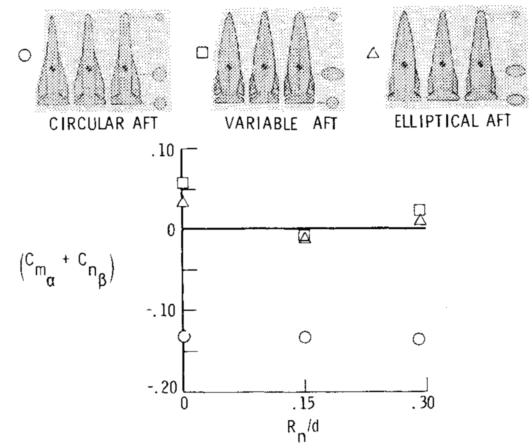


Fig. 7 Longitudinal-directional stability compatibility.

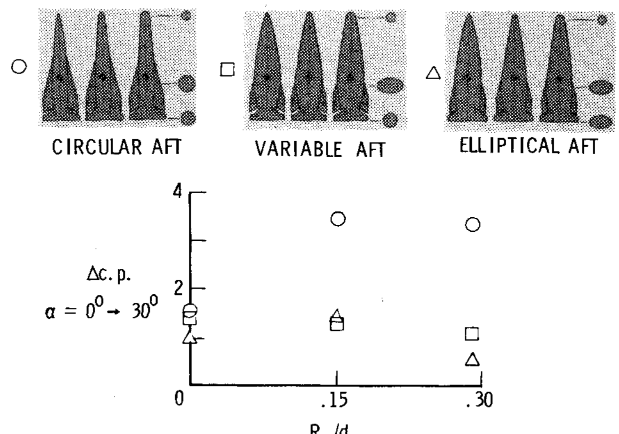


Fig. 8 Center-of-pressure variations.

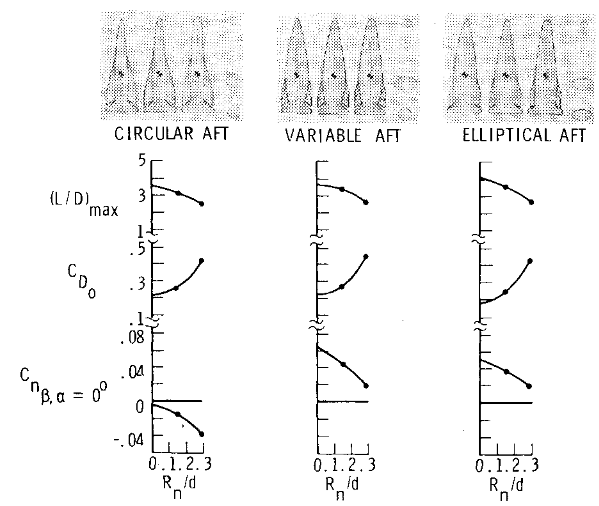


Fig. 9 Parameter summary.

subsonic crossflow, a well-documented phenomena.[7] Thus, the elliptic forebody configurations, particularly those with pointed noses, tend to exhibit significantly increased directional stability while showing decreased longitudinal stability.

In Fig. 7 is presented a parameter $(C_{m_\alpha} + C_{n_\beta})$ intended to show the compatibility in longitudinal and directional stability. Since all of the missile concepts are essentially longitudinally stable, their negative C_{m_α} contributions would tend to be countered by the positive values of C_{n_β} for the directionally stable configurations. Thus, perfect compatibility would be a resultant value of zero. The more negative values generally indicate more pitch stability than yaw stability. Likewise, the more positive values indicate more yaw than pitch stability. The further the values are from zero, the more incompatible the longitudinal and directional stability levels. The data show little sensitivity of this parameter to nose bluntness, but is is evident that elliptical concepts are far more stability compatible than the circular concepts.

Generally, a constant center of pressure (c.p.) location in maneuvering flight is desirable. Presented in Fig. 8 is the total variation in c.p. location that occurs between the angles of attack of 0 and 30 deg. Again, the data show insensitivity to nose bluntness. Although no concept exhibits large changes in c.p. location, the data show the largest variation occurring in the circular concepts, with the least variation being generally associated with concepts employing the elliptic-base afterbodies.

The remaining longitudinal parameters, as well as static directional stability, are presented as a function of nose bluntness in Fig. 9. The data show that increasing nose bluntness provides the expected increase in zero-lift drag and a corresponding decrease in maximum lift-drag ratio. The level of static directional stability is seen to be consistently reduced with increasing bluntness. Also, the highest lift-drag ratios are associated with the elliptical aft concept group.

A final point concerning the aerodynamics of these configurations can be made utilizing the flow visualization figure previously shown (Fig. 4). A characteristic of the blunt nosed configurations at angles of attack is a separated flow region beginning immediately behind the hemispherical nose which extends aft between the twin vortices nose to the body base. Note that a counterflow running downward along the inboard edge of these vortices, then toward the plane of symmetry appears to sweep the separated flow upward from the body. None of this is evident in the flow over the pointed nose configurations. This phenomena should be of interest to a designer of a cruise configuration which might employ an upper surface inlet.

IV. Concluding Remarks

The results of an experimental study at Mach number 2.50 have been presented in which a basic monoplanar missile configuration having a body of either circular or 3:1 elliptic cross section has been modified to explore the effects of nose blunting and, where appropriate, of employing a circular base. The results show that elliptical cross section concepts have more longitudinal-directional stability compatibility than the circular concepts, whether an elliptical or a circular base is employed. Center-of-pressure shift between zero angle of attack and 30 deg was small for all configurations, with that for the circular bodied configurations being largest and more variant with nose bluntness. Lift-drag ratio was highest for the elliptical aft configuration with nose bluntness providing sharp reductions in aerodynamic performance. Evidence of upper surface flow separation over the blunt nosed configurations would appear to preclude any use of an upper surface inlet.

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