LONGITUDINAL AERODYNAMIC CHARACTERISTICS AT MACH 1.50 TO 4.63 OF A MISSILE MODEL EMPLOYING VARIOUS CANARDS AND A TRAILING-EDGE FLAP CONTROL

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The results are summarized in the form of various pertinent aerodynamic parameters as a function of Mach number. Although no detailed analysis of the results has been made, the summary of results is useful in demonstrating the importance of certain parameters and should be useful in providing a source of systematic experimental data for correlation with analytical techniques.
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SUMMARY

An investigation has been made in the Langley Unitary Plan wind tunnel to determine the static longitudinal stability and control characteristics of a missile configuration with cruciform delta wings and various horizontal canards. The controls consisted of three different trapezoidal canards and a wing trailing-edge flap located on the horizontal wings only. The tests were made at Mach numbers from 1.50 to 4.63, through an angle-of-attack range from about -4° to 30°, at an angle of sideslip of 0°, and at a Reynolds number of 8.20 x 10^6 per meter (2.5 x 10^6 per foot).

The results are summarized in the form of various pertinent aerodynamic parameters as a function of Mach number. Although no detailed analysis of the results has been made, the summary of results is useful in demonstrating the importance of certain parameters and should be useful in providing a source of systematic experimental data for correlation with analytical techniques.

INTRODUCTION

The National Aeronautics and Space Administration has investigated various types of controls and lifting surfaces for supersonic and hypersonic missiles to determine their effectiveness in providing maneuverability through a range of Mach numbers. (See refs. 1 to 31.) For these missile configurations, both canard controls and tail controls, either in line or interdigitated with respect to the wings, are employed to provide the maneuvering capability. Generally, the missile lifting surfaces are low-aspect-ratio wings which offer advantages such as small center-of-pressure travel, low drag penalty, and minimum space for stowage.

The present investigation was undertaken to determine the static aerodynamic stability and control characteristics of a missile configuration with cruciform delta wings swept 72.9° and various in-line horizontal canards. The controls consisted of various interchangeable trapezoidal canards and a wing trailing-edge flap on the horizontal wings
only. The configuration was identical with that of reference 14, which was tested at 
\( M = 2.01 \) only.

The present tests were conducted in the Langley Unitary Plan wind tunnel and extend the Mach number range from 1.50 to 4.63 through an angle-of-attack range from about \(-4^\circ\) to \(30^\circ\). The Reynolds number was \( 8.20 \times 10^6 \) per meter \((2.5 \times 10^6 \) per foot).

SYMBOLS

Values are given both in the International System of Units (SI) and in the U.S. Customary Units. Measurements were made in U.S. Customary Units. The force and moment coefficients are referenced to both the body and stability axes. The coordinate origin was taken on the body axis of symmetry at a point 64.35 percent of the body length from the nose.

\( A \)  
cross-sectional area of body

\( b_c \)  
canard span

\( C_A \)  
axial-force coefficient, \( \frac{\text{Axial force}}{qA} \)

\( C_{A,b} \)  
base axial-force coefficient, \( \frac{\text{Base axial force}}{qA} \)

\( C_D \)  
drag coefficient, \( \frac{\text{Drag}}{qA} \)

\( C_L \)  
lift coefficient, \( \frac{\text{Lift}}{qA} \)

\( C_m \)  
pitching-moment coefficient, \( \frac{\text{Pitching moment}}{qAl} \)

\( C_{m,\alpha} \)  
longitudinal stability parameter measured near zero angle of attack

\( C_{m,\delta,c} \)  
pitch-control effectiveness of canards measured between control deflections of \( 0^\circ \) and \( 20^\circ \) at zero angle of attack, per degree

\( C_{m,\delta,f} \)  
pitch-control effectiveness of wing trailing-edge flap measured between control deflections of \( 0^\circ \) and \(-20^\circ \) at zero angle of attack, per degree
\( C_N \)  
normal-force coefficient, \( \frac{\text{Normal force}}{qA} \)

\( C_{N\alpha} \)  
normal-force-curve slope measured near zero angle of attack, per degree

\( d \)  
body diameter

\( l \)  
length of body

\( L/D \)  
lift-drag ratio

\( M \)  
free-stream Mach number

\( q \)  
free-stream dynamic pressure

\( r \)  
radius

\( \frac{x_{a.c.}}{l} \)  
aerodynamic-center location referenced to body length (positive rearward)

\( \alpha \)  
angle of attack of body center line, degrees

\( \delta_c \)  
canard deflection with respect to body center line, positive trailing edge down, degrees

\( \delta_f \)  
flap deflection with respect to wing-chord plane, positive trailing edge down, degrees

Model-component designations:

B  
body

\( C_1, C_2, C_3 \)  
canard surfaces (horizontal only, fig. 1)

W  
wing
MODEL

A drawing of the model with pertinent dimensions is shown in figure 1 and a photograph of the model is shown as figure 2. The geometric characteristics of the model are given in table I.

The body was composed of a modified ogive forebody and a cylindrical afterbody. The forebody, which had provisions for mounting the canard surfaces, had a rounded nose followed by a conical taper which faired into the ogive section. The ratio of overall length to diameter was 8.67.

Both the wings and the canards were flat plates with wedge-shaped leading and trailing edges. The cruciform wings had a delta planform and a leading-edge sweep of 72.9°. The area of the plain rectangular flaps, which were located on the trailing edge of the horizontal wings only, was 11.53 percent of the exposed wing area. Provisions were made for manual variation of the deflection angle of these flaps from 0° to -30° in 10° increments.

Three different canards, each having a trapezoidal planform and a common hinge line (10.54 percent of the body length), were employed for pitch control only in the plane of the horizontal wings. (See fig. 1.) Provisions were made to vary the canard deflection angles manually from 0° to 20° in 10° increments. Canard C1 had an exposed area equal to 9.58 percent of the exposed wing area and a total span that was equal to the body diameter \( \frac{b_c}{d} = 1.0 \). Canard C2 had an exposed area approximately the same as that of canard C1 (9.77 percent of the exposed wing area) but had a greater span \( \frac{b_c}{d} = 1.47 \) and consequently a higher aspect ratio. Canard C3 maintained the same aspect ratio as canard C2 but had an exposed area that was approximately 50 percent larger (15.23 percent of the exposed wing area) than that of canard C2 and a larger span \( \frac{b_c}{d} = 1.67 \).

APPARATUS AND TESTS

The tests were made in both the low and high Mach number test sections of the Langley Unitary Plan wind tunnel. The test sections are approximately 1.22 meters (4 feet) square and 2.13 meters (7 feet) long. The nozzles leading to the test section are of the asymmetric-sliding-block type; this allows continuous variation in Mach number from about 1.5 to 2.9 in the low Mach number test section and from about 2.3 to 4.7 in the high Mach number test section. For the present tests, the Mach numbers, stagnation pressures, and stagnation temperatures were as follows:
The stagnation dewpoint was maintained sufficiently low (238.7°C (-30°F)) to insure negligible condensation effects in the test section. The model was mounted on a six-component, internal, strain-gage balance which was sting supported in the tunnel. The tests were made through an angle-of-attack range from about -4° to 30° at a sideslip angle of 0° and at a Reynolds number of $8.20 \times 10^6$ per meter ($2.5 \times 10^6$ per foot). The Reynolds number based on body length was $5.42 \times 10^6$. The angles of attack have been corrected for sting and balance deflection due to aerodynamic loads and for tunnel airflow misalignment. The axial-force and drag data have been adjusted to a condition of free-stream static pressure at the model base. Typical variations of base axial-force coefficient as a function of angle of attack at the test Mach numbers are shown in figure 3 for several configurations.

Tests were made to determine the control effectiveness of the canards and the wing trailing-edge flaps separately. In addition, tests were made to evaluate the effects of the various components on the aerodynamic characteristics of the model. All tests were made with the boundary-layer transition point fixed by means of roughness strips. The leading edges of the 0.16-cm-wide ($\frac{1}{16}$-inch) transition strips were located about 3.05 cm (1.2 inches) aft of the body nose and 1.02 cm (0.4 inch) streamwise behind the leading edges of the wings and canards. All roughness strips were composed of carborundum grains having a nominal diameter of 0.030 cm (0.012 inch).

**PRESENTATION OF RESULTS**

The results of the investigation are presented in the following figures:

<table>
<thead>
<tr>
<th>M</th>
<th>Stagnation pressure</th>
<th>Stagnation temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kN/m²</td>
<td>lb/ft²</td>
</tr>
<tr>
<td>1.50</td>
<td>66.60</td>
<td>1391</td>
</tr>
<tr>
<td>1.90</td>
<td>75.94</td>
<td>1586</td>
</tr>
<tr>
<td>2.30</td>
<td>93.61</td>
<td>1955</td>
</tr>
<tr>
<td>2.96</td>
<td>129.75</td>
<td>2710</td>
</tr>
<tr>
<td>3.95</td>
<td>229.35</td>
<td>4790</td>
</tr>
<tr>
<td>4.63</td>
<td>315.05</td>
<td>6580</td>
</tr>
</tbody>
</table>

Effects of the wing and canard C₁ on the longitudinal aerodynamic characteristics of the model

Effects of the wing and canard C₂ on the longitudinal aerodynamic characteristics of the model

Figure

Effects of the wing and canard C₁ on the longitudinal aerodynamic characteristics of the model ................................................................. 4

Effects of the wing and canard C₂ on the longitudinal aerodynamic characteristics of the model ................................................................. 5
SUMMARY OF RESULTS

The longitudinal aerodynamic characteristics of the models as affected by the various components are summarized in figure 7 for the test Mach number range. The addition of canard $C_1$ to the body alone resulted in essentially a constant increase in $C_{N\alpha}$ throughout the test Mach number range. Maintaining the area of $C_1$ but increasing the aspect ratio (canard $C_2$) resulted in a further increase in $C_{N\alpha}$ except at the higher Mach numbers. Increasing the area of the canard ($C_3$) while maintaining the aspect ratio of $C_2$ led to increases in $C_{N\alpha}$ across the Mach number range. The addition of the wing to the body provided the greatest increase in $C_{N\alpha}$, as would be expected. However, when any of the canards were added to the wing-body configuration, a decrement in $C_{N\alpha}$ resulted throughout the test Mach number range. This decrease in $C_{N\alpha}$ is a result of the interference flow field imposed on the wing by the canard. A decrease in stability ($+C_{m\alpha}$) always results from addition of the canards, whereas the addition of the wing always provides a stabilizing increment ($-C_{m\alpha}$). The aerodynamic-center location as a fraction of body length is shown in figure 7(b).

For the canard-body configurations, there is little change in $C_A$ or $C_{N\alpha}$ (fig. 7(a)) with increasing Mach number as contrasted to the wing-body-canard configurations where $C_A$ and $C_{N\alpha}$ decrease with increasing Mach number.
Figures 8, 9, and 10 present the control-deflection data for canards C₁, C₂, and C₃, respectively, and for the trailing-edge flap at $\delta_f = -20^\circ$. The data indicate reasonably linear variations of pitching moment with angle of attack for each configuration. The canards and the trailing-edge flaps are effective pitch-control devices, although the effectiveness $(C_m \delta_c)$ for the canards tested is somewhat greater than for the trailing-edge flap (fig. 13). The control effectiveness of canard C₁ is less than that of canards C₂ and C₃ but remains essentially invariant with Mach number, whereas the control effectiveness for canards C₂ and C₃ and for the trailing-edge flap decreases appreciably with Mach number. (See fig. 13.)

A comparison of the wing trailing-edge flap control with the canard off (fig. 11) and with canards on (figs. 8, 9, 10, and 12) indicates little or no effect of the canards on the flap-control effectiveness.

Deflection of the trailing-edge flap to trim results in a decrement in lift, but deflection of the canard to trim is such that a positive lift increment generally occurs.

Langley Research Center,
National Aeronautics and Space Administration,
REFERENCES


<table>
<thead>
<tr>
<th>Section</th>
<th>Measurement (units)</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length, cm (in.)</td>
<td>66.04 (26.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter, cm (in.)</td>
<td>7.62 (3.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-sectional area, cm² (in²)</td>
<td>45.61 (7.07)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length-diameter ratio</td>
<td></td>
<td>8.67</td>
<td></td>
</tr>
<tr>
<td>Moment-center location, percent length</td>
<td></td>
<td>64.35</td>
<td></td>
</tr>
<tr>
<td><strong>Wing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area, exposed, cm² (in²)</td>
<td>335.48 (52.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root chord, exposed, cm (in.)</td>
<td>33.02 (13.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tip chord, cm (in.)</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Span, total, cm (in.)</td>
<td>27.94 (11.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspect ratio, exposed</td>
<td>1.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leading-edge sweep, deg</td>
<td></td>
<td>72.90</td>
<td></td>
</tr>
<tr>
<td>Ratio of total span to diameter</td>
<td></td>
<td>3.67</td>
<td></td>
</tr>
<tr>
<td><strong>Trailing-edge flaps</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Span, each, cm (in.)</td>
<td>7.62 (3.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord, each, cm (in.)</td>
<td>2.54 (1.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area, both, cm² (in²)</td>
<td>38.71 (6.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposed wing area, percent</td>
<td></td>
<td>11.53</td>
<td></td>
</tr>
<tr>
<td><strong>Canards</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area, exposed, cm² (in²)</td>
<td>C₁ 32.13 (4.98)</td>
<td>C₂ 32.77 (5.08)</td>
<td>C₃ 51.10 (7.92)</td>
</tr>
<tr>
<td>Total span, cm (in.)</td>
<td>C₁ 7.62 (3.00)</td>
<td>C₂ 11.18 (4.40)</td>
<td>C₃ 12.70 (5.00)</td>
</tr>
<tr>
<td>Exposed wing area, percent</td>
<td></td>
<td>C₁ 9.58</td>
<td>C₂ 9.77</td>
</tr>
<tr>
<td>Ratio of total span to diameter</td>
<td></td>
<td>1.00</td>
<td>1.47</td>
</tr>
<tr>
<td>Hinge-line location, percent body length</td>
<td></td>
<td>C₁ 10.54</td>
<td>C₂ 10.54</td>
</tr>
</tbody>
</table>
Figure 1.- Drawing of the model. All linear dimensions are in centimeters (inches).
Figure 3.- Typical variations of base axial-force coefficient with angle of attack.
Figure 4.- Effects of the wing and canard $C_1$ on the longitudinal aerodynamic characteristics of the model.

(a) $M = 1.50$. 
Figure 4.- Continued.

(a) Concluded.
Figure 4.- Continued.

(b) $M = 1.90$. 

Figure 4.- Continued.
Figure 4—Continued.
Figure 4.- Continued.
Figure 4.- Continued.

(c) Concluded.

L/D

$\delta_c$, deg $\delta_f$, deg

- WBC $\, 0 \, 0$
- BC $\, 0 \, \text{Off}$
- WB $\, \text{Off} \, 0$
- B $\, \text{Off} \, \text{Off}$
Figure 4.- Continued.

(d) \( M = 2.96 \).

Figure 4.- Continued.
Figure 4.- Continued.
Figure 4.- Continued.

(e) $M = 3.95$.

Figure 4.- Continued.
Figure 4.- Continued.

(e) Concluded.
In $M = 4.63$.

Figure 4.- Continued.
Figure 4.- Concluded.
Figure 5.- Effects of the wing and canard $C_2$ on the longitudinal aerodynamic characteristics of the model.

(a) $M = 1.50$. 
Figure 5. - Continued.
Figure 5.- Continued.

(b) $M = 1.90$.
Figure 5.- Continued.

1b) Concluded.
Figure 5.- Continued.

(c) $M = 2.30$.
Figure 5.—Continued.

(c) Concluded.
(d) $M = 2.96$.

Figure 5.- Continued.
Figure 5.— Continued.

(d) Concluded.
Figure 5: Continued.
(e) Concluded.

Figure 5.- Continued.
Figure 5. - Continued.
(f) Concluded.

Figure 5.- Concluded.
Figure 6.- Effects of the wing and canard $C_3$ on the longitudinal aerodynamic characteristics of the model.

(a) $M = 1.50$. 
Figure 6 - Continued.
(a) Concluded.
Figure 6.- Continued.

(b) $M = 1.90$. 

Figure 6.- Continued.
(b) Concluded.

Figure 6. Continued.
Figure 6.- Continued.

(c) $M = 2.30$. 

---

43
(c) Concluded.

Figure 6.—Continued.
Figure 6.- Continued.

(d) $M = 2.96$. 

$C_m$ vs $\alpha$, $\beta_c$, and $\beta_f$, $\deg$.
(d) Concluded.

Figure 6.- Continued.
Figure 6.- Continued.

(e) M = 3.95.

Figure 6.- Continued.
(e) Concluded.

Figure 6.- Continued.
Figure 6.- Continued.

$M = 4.63$. 

49
Figure 6.- Concluded.

(f) Concluded.
Figure 7.- Summary of longitudinal characteristics.
Figure 8.- Effects of deflection of the canard $C_1$ and the wing flap on the longitudinal aerodynamic characteristics of the model, configuration $WBC_1$.

(a) $M = 1.50$.  

Figure 8.- Effects of deflection of the canard $C_1$ and the wing flap on the longitudinal aerodynamic characteristics of the model, configuration $WBC_1$.  

53
Figure 8.- Concluded.

(a) Concluded.
Figure 8.- Continued.

(b) \( M = 1.50 \).
Figure 8.- Continued.

(b) Concluded.
Figure 8.- Continued.

Cm vs. a deg

CA vs. a deg

CN vs. a deg

δC, deg  δI, deg

○ 0 0

□ 10 0

□ 20 0

△ 0 -20

M = 2.30.
Figure 8. Continued.
Figure 8.- Continued.

\( \delta_e, \text{deg} \quad \delta_r, \text{deg} \)

- \( 0 \quad 0 \)
- \( 10 \quad 0 \)
- \( 20 \quad 0 \)
- \( 0 \quad -20 \)

\( C_{m}, C_{A}, C_{N} \)

\( \alpha, \text{deg} \)

(\( d \)) \( M = 2.96 \).
Figure 8.- Continued.

Idl Concluded.
(e) $M = 3.05$.

Figure 8.- Continued.
Figure 8. Continued.

Concluded.
(f) $M = 4.63$.

Figure 8.- Continued.
Figure 8. Concluded.
Figure 9.- Effects of deflection of the canard C₂ and the wing flap on the longitudinal aerodynamic characteristics of the model. Configuration WBC₂.

(a) $M = 1.50$. 

$C_m$, $C_A$, $C_N$ vs. $\alpha$, deg.
Figure 9.- Continued.
(b) $M = 1.90$.

Figure 9.- Continued.
Figure 9.- Continued.

(b) Concluded.
Figure 9.- Continued.

(c) $M = 2.30$. 

$\delta_c, \deg$ $\delta_f, \deg$

- $0 \quad 0$
- $10 \quad 0$
- $20 \quad 0$
- $0 \quad -20$

$a, \deg$

$c_m$

$c_A$

$c_N$
Figure 9.- Continued.
Figure 9.- Continued.

(d) $M = 2.96$.  

Figure 9.- Continued.
(d) Concluded.

Figure 9.- Continued.
Figure 9.- Continued.

(e) $M = 3.95$. 

$\delta_c$, deg $\delta_f$, deg
- $0$ $0$
- $10$ $0$
- $20$ $0$
- $0$ $-20$

Figure 9.- Continued.
Figure 9. - Continued.
Figure 9.- Continued.

(f) $M = 4.63$. 

Figure 9.- Continued.
Figure 9.- Concluded.
Figure 10.- Effects of deflection of the canard $C_3$ and the wing flap on the longitudinal aerodynamic characteristics of the model, Configuration WBC3.

(a) $M = 1.50$. 
Figure 10. Continued.

(a) Concluded.
Figure 10.- Continued.

(b) $M = 1.90$. 

$\delta_c$, deg $\delta_f$, deg
- $\circ$ 0 0
- $\square$ 10 0
- $\diamondsuit$ 20 0
- $\triangle$ 0 -20
Figure 10.- Continued.

(b) Concluded.
Figure 10.- Continued.

(c) \( M = 2.30 \).

\( \delta_c, \text{deg} \) \( \delta_f, \text{deg} \)

- \( 0 \quad 0 \)
- \( 10 \quad 0 \)
- \( 20 \quad 0 \)
- \( 0 \quad -20 \)
Figure 10.- Continued.
Figure 10.- Continued.

(d) $M = 2.96$.
Figure 10. Continued.

$C_L$, $C_D$, $\delta_c$, deg $\delta_f$, deg

- $\bigcirc$ $0$ $0$
- $\Box$ $10$ $0$
- $\Diamond$ $20$ $0$
- $\triangle$ $0$ $-20$
Figure 10.- Continued.

(e) $M = 3.95$. 

$C_m$, deg $\delta_f$, deg

- $0$ 0
- $10$ 0
- $20$ 0
- $0$ $-20$
Figure 10 - Continued.

\( \delta_C, \text{ deg} \) \( \delta_f, \text{ deg} \)

- \( \circ \) 0 0
- \( \square \) 10 0
- \( \diamond \) 20 0
- \( \triangle \) 0 -20

(a) Concluded.

Figure 10 - Continued.
Figure 10.- Continued.

III. $M = 4.03$.

Figure 10.- Continued.
Figure 10.- Concluded.
Figure 11.- Effects of wing-flap deflection on the longitudinal aerodynamic characteristics of the model. Canard off; WB.
Figure II. Continued.

(a) Concluded.
Figure 11. - Continued.

(b) $M = 1.90$.

Figure 11. - Continued.
Figure 1: - Continued.
(b) Concluded.

Figure II: - Continued.
(c) $M = 2.30$.

Figure 11.- Continued.
Figure 11.- Continued.

(C) Concluded.
Figure 11.- Continued.

Idt. $M = 2.96$. 

Figure 11.- Continued.
Figure 11.- Continued.

(d) Concluded.
Figure 11.- Continued.

(e) $M = 3.95$. 

Figure 11.- Continued.
Figure 11.- Continued.

(e) Concluded.
Figure 11.- Continued.

(f) $M = 4.63$. 

99
Figure 11—Concluded.
(a) $M = 1.50$.

Figure 12.- Effects of wing-flap deflection on the longitudinal aerodynamic characteristics of the model with canard $C_2$ and $\delta_c = 0^\circ$.

Configuration WBC2.
Concluded.

Figure 12.—Continued.
Figure 12.- Continued.

(b) $M = 1.90$. 

$\delta_f$, deg

- $0$
- $-10$
- $-20$
- $-30$
Figure 12.- Continued.
$\delta_f$, deg

- 0
- -10
- -20
- -30

(c) $M = 2.30$.

Figure 12.- Continued.
(c) Concluded.

Figure 12.- Continued.
Figure 12.- Continued.
Figure 12.- Continued.
(e) $M = 3.95$.

Figure 12.- Continued.
Figure 12. Continued.

\( \delta_f, \text{deg} \)

- \( \circ \) 0
- \( \square \) -10
- \( \diamond \) -20
- \( \triangle \) -30
Figure 12.- Continued.

(m) $M = 4.63$.

Figure 12.- Continued.
Figure 12.- Concluded.
Figure 13: Summary of pitch-control effectiveness.