Aerodynamic Characteristics of a Series of Twin-Inlet Air-Breathing Missile Configurations

II - Two-Dimensional Inlets at Supersonic Speeds

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SUMMARY

A series of air-breathing missile configurations has been investigated to provide a data base for the design of such missiles. The model could be configured with either twin axisymmetric or two-dimensional inlets. Three circumferential inlet locations were investigated: 90°, 115°, and 135° from the top center. Two vertical wing locations, as well as wingless configurations, were used. Three tail configurations were formed by locating the tail surfaces either on the inlet fairings or on fairings on the body. The surfaces were deflect to provide pitch control. Two-dimensional inlets with extended compression surfaces, used to improve the angle-of-attack performance of the inlets for wingless configurations, were also investigated. Although the data of this report refer specifically to the two-dimensional inlet configurations, comparison of these data with those for the axisymmetric inlet configurations of NASA Technical Memorandum 84558 indicates that even though individual values and levels of the various curves may differ, where configurations are comparable, the trends are similar and conclusions formed will generally apply to the model with either inlet configuration.

The results of the investigation indicate that the pitching-moment curve, for most configurations, was nonlinear, with a large margin of longitudinal stability at high angles of attack, but with little or no margin of stability near an angle of attack of 0°. The model had marginal lateral-directional stability for most configurations; the X-tail and the inverted tri-tail resulted in lateral-directional stability for the entire range of angle of attack. The model with an inlet orientation angle of 90° could not be trimmed at the maximum angle of attack (20°) with the maximum pitch-control deflection (-20°). Only by increasing the inlet orientation angle to 135° could the model be trimmed at an angle of attack of 20° with a pitch-control deflection of -20° with either tail configuration. Of the three tail configurations, the X-tail had a more linear pitching-moment curve and greater pitch-control effectiveness. The extended two-dimensional inlet configuration without a wing, as with the other inlets, tended to have a nonlinear pitching-moment curve; with the X-tail, the curve was straightened and the configuration was stable throughout the angle-of-attack range and the model could be trimmed at an angle of attack of 20° with a pitch-control deflection of -10°.

INTRODUCTION

During the past several years, several air-breathing missile configurations have been investigated in the Langley Unitary Plan Wind Tunnel. These include one-, two-, and four-inlet configurations with various wing and tail arrangements. The results of these investigations have been reported in references 1 through 7. Although the data from these specific missile programs have contributed to an air-breathing configuration data base, a broader data base is needed to better predict the aerodynamic characteristics of candidate configurations and to better design an air-breathing configuration to meet desired aerodynamic specifications. To provide a broader data base, a series of models, which incorporates a wider range of configuration variables, has been designed and tested.

The model could be configured with axisymmetric or two-dimensional single or twin inlets. The single inlet was located at the bottom of the body, whereas the
twin inlets could be located circumferentially from $90^\circ$ to $135^\circ$ from the top center. Two vertical wing locations were available to properly locate the wing relative to the inlets at the $115^\circ$ and $135^\circ$ inlet orientation angles to provide favorable interference between the wing and inlet at positive angles of attack. Tail surfaces could be mounted on the inlet fairing and/or on fairings on the body to provide several tail configurations. The tail surfaces could be deflected to provide pitch control. The two-dimensional inlets could be configured with extended compression surfaces intended to improve the angle-of-attack performance of the inlets for the wingless configuration.

The present investigation covers tests of the twin-inlet configurations, both axisymmetric and two-dimensional inlets. The inlets were located at circumferential locations of $90^\circ$, $115^\circ$, and $135^\circ$ from the top center. The wing was located above the model center line with the inlets located in the $115^\circ$ position and at the model center line with the inlets in the $135^\circ$ position. The wing was not used with the inlets located in the $90^\circ$ position. Three tail configurations were used. A tri-tail configuration with a vertical surface at the top center of the body and a surface mounted on each of the two inlet fairings was tested at all three inlet orientation angles. With the inlets located in the $135^\circ$ position, the single vertical surface was replaced by two surfaces in the upper $45^\circ$ position to form an X-tail configuration. Also, at the inlet orientation angle of $135^\circ$ and with the two upper surfaces, the two lower surfaces were replaced by a single lower surface to form an inverted tri-tail configuration. The tests included body-inlet, body-inlet-wing, body-inlet-tail, and body-inlet-wing-tail configurations.

The supersonic tests were performed in the high Mach number test section of the Langley Unitary Plan Wind Tunnel at Mach numbers of 2.50, 2.95, 3.50, and 3.95. The inlets were operating with flow through the model to simulate ramjet operation. The subsonic tests were conducted at Mach numbers of 0.60, 0.80, and 0.95 in the 7- by 10-Foot Transonic Wind Tunnel at the David Taylor Naval Ship Research and Development Center. The internal ducts were closed and there was no flow through the model to simulate rocket boost.

Longitudinal aerodynamic characteristics, lateral-directional stability, pitch-control effectiveness, and trim characteristics were obtained.

Because a large volume of data was obtained in this investigation, the data are presented in three reports: Reference 8 covers the twin axisymmetric inlet configurations at supersonic speeds, this report covers the twin two-dimensional inlet configurations at supersonic speeds, and reference 9 covers both inlet configurations at subsonic-transonic speeds. The results of an investigation of the single-inlet configurations are presented in reference 10.

SYMBOLS

The coefficients of forces and moments are referred to both the body axis and stability axis systems, where appropriate. Aerodynamic moments are taken about a point on the model center line at a distance downstream of the model nose equal to 50 percent of the body length (fig. 1). All coefficients are based on the cross-sectional area and the diameter of the body.

A cross-sectional area of basic body, $0.00456 \, m^2$
\( C_A \) axial-force coefficient, \( \frac{\text{Axial force}}{qA} \)

\( C_{A_i} \) internal-flow axial-force coefficient, \( \frac{\text{Internal-flow axial force}}{qA} \)

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

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

\( C_l \) rolling-moment coefficient, \( \frac{\text{Rolling moment}}{qAd} \)

\( C_{\beta} \)

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

\( C_N \) normal-force coefficient, \( \frac{\text{Normal force}}{qA} \)

\( C_r \) yawing-moment coefficient, \( \frac{\text{Yawing moment}}{qAd} \)

\( C_{\beta} \)

\( C_Y \) side-force coefficient, \( \frac{\text{Side force}}{qA} \)

\( C_{\gamma} \)

\( d \) body diameter, 0.0762 m

\( L/D \) lift-drag ratio

\( M \) free-stream Mach-number

\( M.S. \) model station

\( m/m_\infty \) inlet mass-flow ratio (ratio of inlet mass flow to mass flow at free-stream conditions through a stream tube of cross-sectional area equal to inlet projected area)

\( q \) free-stream dynamic pressure, Pa
coordinates of inlet configurations (figs. 1(c) and 1(d))

\(x, y, y_1, y_2, y_3\)

\(\alpha\) angle of attack, deg

\(\beta\) angle of sideslip, deg

\(\delta_p\) tail deflection in pitch direction, deg (positive deflection with leading edge up)

\(\phi_i\) inlet orientation angle, measured from model top center line, deg (figs. 1(a) and 1(b))

Configuration designations (various components shown in fig. 1):

B

I

I

I

I

I

T

T

T

T

W

body

body

twin circular inlets (axisymmetric inlet)

twin rectangular inlets (two-dimensional inlets)

twin rectangular inlets with inlet covers installed

twin rectangular extended inlets

twin rectangular extended inlets with inlet covers installed

tail

tri-tail, one surface at top center and one on each of the inlet fairings

X-tail, two surfaces at upper 45° positions and two surfaces at inlet fairing; used only with \(\phi_i = 135°\)

inverted tri-tail, two surfaces at upper 45° position and one surface at bottom center line

wing, located at center-line position for \(\phi_i = 135°\) and upper position for \(\phi_i = 115°\); not used in combination with \(\phi_i = 90°\)

MODEL DESCRIPTION

Details of the models are presented in figure 1 and photographs in figure 2. The body was an ogive cylinder approximately 14 diameters long. An inlet of either the axisymmetric or rectangular two-dimensional type was located on each side of the body, separated from the body by boundary-layer diverters. The ducts extended downstream of the inlets to a point where they would turn and dump into the combustor. Beyond this point, the external geometry of the inlets consisted of tapered fairings, which extended back to the model base and provided support for two lower tail surfaces. Other tail surfaces could be attached to the body by means of fairings, which provided the necessary support and represented the volume that would be required for tail control actuators.
The inlet ducts dumped into a common passage within the body. The internal flow was kept separate from the balance cavity to facilitate measurement of the internal flow and the balance-cavity axial-force and drag corrections. A rake at the exit of the duct was used to measure the flow conditions needed to compute the forces due to the internal flow.

The inlets and inlet fairings could be rotated in the circumferential direction about the model center line. The rectangular inlets each had a boundary-layer bleed slot which removed boundary layer from the compression surface and dumped it overboard. The axisymmetric inlets had no boundary-layer control. The wing used in the tests was located so that its pressure field would enhance the angle-of-attack performance of the inlets. The vertical location of the wing depended on the inlet orientation, and for inlets located on each side 90° from the top center line, the wing could not be used.

An extended inlet configuration was also investigated. This configuration consisted of the rectangular two-dimensional inlet with the compression surface extended forward to station 28.829 to enhance the angle-of-attack performance in the absence of a wing. The shorter of the two-dimensional inlet configurations was tested with and without a wing whereas the extended inlets were not tested with the wing.

The airfoil of the wing consisted of an upper surface having a wedge leading and trailing edge with a flat center section and a lower surface that was flat from leading to trailing edge. The airfoils for the tail surfaces were similar, consisting of straight-line segments, but were symmetrical (figs. 1(e) and 1(f)).

Two types of tail surfaces were used: one designed to fit on the inlet fairings and the other to fit to the body in conjunction with a fairing. When the lines of each tail surface type are projected to the body surface (fig. 1(f)), their planforms are identical. The tail arrangements available depended on the inlet orientation. At all inlet orientations, a tri-tail was used, with a surface on each inlet fairing and a top vertical surface. With the inlets located at 135° from the top center, an X-tail configuration was formed by substituting two surfaces at the upper 45° for the single vertical surface. An inverted tri-tail configuration was also formed by substituting a single vertical surface at the bottom for the tail-fairing-mounted surfaces. For pitch-control deflection, all tail surfaces except the vertical surfaces were deflected. The tail-surface deflection angle was measured in the plane normal to the tail-surface hinge line.

TESTS

The supersonic part of the investigation was conducted in the high Mach number test section of the Langley Unitary Plan Wind Tunnel at Mach numbers of 2.50, 2.95, 3.50, and 3.95. The tunnel is of the variable pressure, continuous-flow type and has two test sections, each approximately 1.2 m square and 2.1 m long. The nozzles leading to the test sections are of the asymmetric sliding-block type to allow continuous variation of Mach number. A description of the facility is given in reference 11.

A rake having eight total-pressure tubes and four static-pressure tubes was used to measure the flow conditions at the duct exit. Base pressure measurements were made with the static orifices on the model base, and balance-cavity pressures were measured with two static-pressure tubes attached to the sting and terminating near the balance. Forces and moments were measured with a six-component, sting-mounted, strain-gage balance. Separate runs were made for the internal-flow measurements, but
force data from these runs are not presented. Typical internal-flow data computed from these measurements are presented in figure 3.

Three inlet configurations were tested: axisymmetric $I_1$, rectangular two-dimensional $I_2$, and extended two-dimensional $I_3$. Configurations having inlet orientation angles $\phi_1$ of 90°, 115°, and 135° were used. Each combination of inlet type and inlet orientation angle was tested with body-inlet, body-inlet-tail, body-inlet-wing, and body-inlet-wing-tail combinations. Exceptions were made for all inlets at $\phi_1 = 90°$ and for $I_3$ at all conditions; these inlets were not tested in conjunction with the wing. Three tail configurations were used and are shown in figure 1(g). Pitch-control deflections of 0°, -10°, and -20° were used primarily, although some configurations were also tested with a pitch-control deflection of +10°.

Tests were made at angles of attack ranging from about -5° to +20°. To obtain lateral-directional stability, runs at angles of sideslip of 0° and 3° were made. Angles of attack and sideslip have been corrected for tunnel flow angularity and for deflection of the sting and balance due to aerodynamic loads. The axial force and drag data have been adjusted to free-stream static pressure acting over the model base and the balance-chamber areas. An adjustment has been made to remove the internal drag, where the internal drag is that drag associated with the momentum and buoyancy acting in the stream direction from the free stream at exit conditions of that flow passing internally. The Reynolds number was maintained constant at $6.56 \times 10^6$ per meter. The stagnation dewpoint was maintained below 239 K to avoid condensation effects.

All tests were made with the boundary-layer transition point fixed by means of transition strips. The transition strips were located 3.05 cm aft of the body nose and 1.02 cm in a streamwise direction from the leading edge of the wings, tail surfaces, and inlets. The transition strips consisted of No. 35 sand grains individually spaced.

PRESENTATION OF RESULTS

The results of this investigation are presented in the figures as indicated in the following table:

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DISCUSSION OF RESULTS

The effects of inlet orientation angle $\phi_I$ on the longitudinal aerodynamic characteristics are presented in figures 4 and 5. At all three inlet orientation angles, the model was stable at angles of attack above about 6°. There was very little effect of $\phi_I$ on the longitudinal characteristics for $\phi_I = 90°$ and 115° ($\phi_I = 90°$ could not be tested with a wing). For both values of $\phi_I$, the slope of the pitching-moment curves changed abruptly at an angle of attack between 4° and 6°, and the longitudinal stability was less near an angle of attack of 0° than for values of angle of attack above about 6°. Increasing $\phi_I$ to 135° reduced the longitudinal stability, as well as the slope of the lift curve. At large values of angle of attack, the model was very stable; at angles of attack near 0°, the model was neutrally stable. With the wing in place ($\phi_I = 115°$ and 135°), the stability level was less. With $\phi_I = 115°$, there was near neutral stability near an angle of attack of 0°, and with $\phi_I = 135°$, the model was unstable in a range of angle of attack near 0°. As $\phi_I$ was increased, the planform area of the aft end of the body was decreased; this resulted in decreased longitudinal stability.

The effect of the various model components on the longitudinal aerodynamic characteristics is shown in figures 6 through 10. The body-inlet configurations show a trend towards little or no longitudinal stability near an angle of attack of 0° with a rather large margin of longitudinal stability at high angles of attack. Although increasing $\phi_I$ decreases the stability level, there was at least some small range of...
angle of attack at which the model was stable. Adding tail T1 increased the longitudinal stability and caused the pitching-moment curve to become more linear. At $\phi = 90^\circ$ and $115^\circ$ (figs. 6 and 7), the model was stable through the entire range of angle of attack, whereas at $\phi = 135^\circ$ (fig. 8), the model was near neutrally stable near an angle of attack of $0^\circ$. Adding the wing to the body-inlet had the effect of decreasing the longitudinal stability and causing the pitching-moment curve to become more nonlinear. Adding the wing to the body-inlet-tail also reduced the longitudinal stability, but retained some of the favorable effect of the tail. This was particularly true with the X-tail, T2 (fig. 9), which was more effective than T1.

A direct comparison of the longitudinal characteristics of the model with T1, T2, and T3 is made in figures 11 and 12. Without the wing, the model with T2 had linear pitching-moment curves, particularly near an angle of attack of $0^\circ$. With the wing, T2 provided a more linear variation of pitching-moment coefficient with angle of attack than with either T1 or T3. Near an angle of attack of $0^\circ$, the variation of pitching-moment coefficient with angle of attack was similar for T1 and T3 at positive angles of attack, the curve for T1 was located between the curves for T2 and T3, whereas at negative angles of attack, the curve for T3 was located between the curves for T1 and T2. This indicates that the windward surfaces were more effective than the leeward surfaces, and that both upper and lower surfaces (as for T2) were required for the more linear pitching-moment curves.

To consider the effect of the various model components on the lift or normal force, the pitch control and trim characteristics should be considered. Pitch-control data are presented in figures 13 through 21, and include longitudinal characteristics with pitch-control deflection $\delta$ of $0^\circ$, $-10^\circ$, and $-20^\circ$, except when limited by balance limits or model fouling. Because of the large margin of longitudinal stability, some configurations could not be trimmed at the maximum angle of attack ($\alpha = 20^\circ$). For instance, at $M = 2.95$ with $\phi = 90^\circ$ (fig. 13(b)), the inlet-body-tail model trimmed at $\alpha = 13^\circ$ with a pitch-control deflection of $-20^\circ$. At these conditions, a value of $C_N$ of 5.5 was achieved. Changing the inlet orientation angle $\phi$ to $135^\circ$ (fig. 15(b)) decreased the stability level so that the model was trimmed at $\alpha = 20^\circ$ at a pitch-control deflection of less than $-20^\circ$. Although the untrimmed $C_N$ was decreased from about 11 to 9 by the change in $\phi$, the trimmed $C_N$ increased from about 5.5 to about 7.5. Adding the wing increased the available normal force by the wing lift and by the increased trim angle of attack because of the destabilizing effect of the wing. With the wing on, at $M = 2.95$ with $\phi = 115^\circ$ (fig. 18(b)), the model was trimmed at $\alpha = 20^\circ$ with a pitch-control deflection less than $-20^\circ$, with a resulting $C_N$ of about 11. Increasing $\phi$ from 115$^\circ$ to 135$^\circ$ (fig. 19(b)) decreased the stability, and the model could be trimmed at $\alpha = 20^\circ$ with a pitch-control deflection of less than $-10^\circ$. The corresponding $C_N$, however, remained at about 11. The smaller value of $C_N$, for the reduced planform area of the configuration with $\phi = 135^\circ$ tends to be balanced by the reduced negative normal force $C_N$ due to smaller pitch-control deflection.

The X-tail T2 configuration (fig. 20), compared with the tri-tail T3 configuration (fig. 19), had both a greater margin of longitudinal stability and a more linear pitching-moment curve. Trim could be achieved at the maximum angle of attack ($20^\circ$) with pitch-control deflection of only about $-10^\circ$ since the pitch-control effectiveness is higher. Similarly, tail T3 provided a different level of stability and control effectiveness (fig. 21). However, with either of the three tails, for both the wing-on and wing-off configurations, the trimmed $C_N$ corresponding to the maximum angle of attack was independent of the tail configuration. Tail T3, therefore, must be considered to be the better configuration of the three configurations tested, because the pitching-moment curves are more linear.
The data for the two-dimensional extended inlet I₃ are presented in figures 31 through 42. With T₁, the pitching-moment curve displayed nonlinearity as with I₁ and I₂. With the X-tail T₂ (fig. 34), the pitching-moment curve became more linear and the model was stable throughout the range of angle of attack. With T₂, trim could be achieved at α = 20° with about -10° of pitch-control deflection, as shown in figure 38. The maximum trim normal-force coefficient was generally between that of the I₁ and I₂ configurations.

The change in both planform and lateral area of the aft end of the body which accompanies change in the inlet orientation angle would be expected to change the directional stability as well as the longitudinal stability. This effect is seen in the lateral-directional data shown in figures 22 and 23. As the inlet orientation angle φᵢ was increased, the change in directional stability was more linear with φᵢ than the variation of pitching-moment coefficient; there was a significant difference between the Cᵣᵢ for φᵢ = 90° and 115° (wing-off) data, whereas the difference in the corresponding values of Cₚ was much smaller. Since the increase in lateral area caused by increasing φᵢ is below the model center line, increasing φᵢ would be expected to decrease the lateral stability. This effect is also seen in the data of figures 22 and 23.

The effect of the various model components on the lateral-directional stability is shown in figures 24 through 28. Generally, the body-inlet alone was directionally unstable. At φᵢ = 90° and 115°, the model was laterally stable at moderate angles of attack, but at φᵢ = 135°, the body-inlet alone was unstable for the entire range of angle of attack. Adding the wing tended to decrease the directional stability and increase the lateral stability. Adding the tail to the model either with or without a wing resulted in increased directional and lateral stability, but only T₂ and T₃ resulted in a margin of lateral-directional stability for the entire angle-of-attack range.

Comparison of parts (a), (b), (c), and (d) of each data figure gives an indication of the effect of free-stream Mach number. The only effect seems to be an overall reduction of the coefficient values and a somewhat straightening of the pitching-moment curves. The trim angle of attack was generally reduced.

CONCLUDING REMARKS

A series of air-breathing missile configurations has been investigated to provide a data base for the design of such missiles. The model could be configured with either twin axisymmetric or two-dimensional inlets. Three circumferential inlet locations were investigated: 90°, 115°, and 135° from the top center. Two vertical wing locations, as well as wingless configurations, were used. Three tail configurations were formed by locating the tail surfaces on the inlet fairings or on fairings on the body. The surfaces were deflected to provide pitch control. Two-dimensional inlets with extended compression surfaces, used to improve the angle-of-attack performance of the inlets for wingless configurations, were also investigated.

Although the data of this volume refer specifically to the twin two-dimensional inlet configurations, comparison of these data with those for the axisymmetric inlet configurations of NASA Technical Memorandum 84558 indicates that even though individual values and levels of the various curves may differ, where configurations are comparable, the trends are similar and conclusions formed will generally apply to the model with either inlet configuration.
As a result of the investigation, the following general trends may be observed:

1. For most configurations, the pitching-moment curve was nonlinear, with a large margin of longitudinal stability at high angles of attack, but with little or no stability near an angle of attack of 0°.

2. The model had marginal lateral-directional stability for most configurations; the X-tail and the inverted tri-tail resulted in lateral-directional stability for the entire range of angle of attack.

3. The model with the 90° inlet orientation angle could not be trimmed at the maximum angle of attack (20°) with the maximum pitch-control deflection (-20°). Only by increasing the inlet orientation angle to 135° could the model be trimmed at an angle of attack of 20° with less than -20° pitch-control deflection with either tail configuration.

4. Of the three tail configurations, the X-tail had a more linear pitching-moment curve and greater pitch-control effectiveness.

5. The extended two-dimensional inlet configuration without a wing, as with the other inlets, tended to have a nonlinear pitching-moment curve; with the X-tail, the curve was straightened and the configuration was stable throughout the range of angle of attack and the model could be trimmed at an angle of attack of 20° with a pitch-control deflection of -10°.

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REFERENCES


(a) General arrangement of twin axisymmetric inlet I₁ configuration.

Figure 1.- Details of model. All linear dimensions are in centimeters.
Inlet and inlet fairing

Inlet centerbody coordinates

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(c) Axisymmetric inlet and inlet fairing.

Figure 1. - Continued.
Inlet and inlet fairing.

Figure 1.- Continued.
(e) Wing.

Figure 1.—Continued.
(f) Tail.

Figure 1.- Continued.
(g) Arrangement of tail configurations.

Figure 1.— Concluded.
Figure 2: Photographs of model. Photographs courtesy of David Taylor Naval Ship Research and Development Center.
(b) Bottom view of assembled model.

Figure 2.— Concluded.
Figure 3. - Internal-flow characteristics of various configurations.

(a) Configuration $B_1I_2$: $\phi_1 = 90^\circ$. 

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(b) Configuration $B_1 I_2$, $\phi = 115^\circ$.

Figure 3.- Continued.
(c) Configuration $R_1, I_2, W_1; \quad \phi_I = 115^\circ$.

Figure 3. Continued.
Figure 3.- Continued.

(d) Configuration $B_1 I_2$; $\Phi_1 = 135^\circ$. 
(e) Configuration $B_{1}I_{2}M_{1}$, $\phi_{I} = 135^\circ$.

Figure 3.- Continued.
(f) Configuration B, $I_3$: $\phi_I = 90^\circ$.

Figure 3.- Continued.
Figure 3.—Continued.

(q) Configuration $R_1I_3$; $\phi_1 = 115^\circ$.
(b) Confinement $P_{ij}$; $\phi = 135^\circ$.

Figure 3--Concluded.
Figure 4.- Effect of inlet orientation angle $\alpha$ on longitudinal aerodynamic characteristics of contaminant $R_{ij}, F_{ij}, S_{ij}, \theta_{ij}$. 

(a) $M, \alpha$.
(a) Continued.

Figure 4.- Continued.
Figure 4.- Continued.
(b) $M = 2.95$.

Figure 4. - Continued.
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(b) Continued.

Figure 4.- Continued.
(b) Concluded.

Figure 4.—Continued.
(c) $M = 3.50$.

Figure 4.- Continued.
(c) Continued.

Figure 4.- Continued.
(c) Concluded.

Figure 4.- Continued.
Figure 4: Continued.

(d) $M = 3.95$. 
(d) Continued.

Figure 4.- Continued.
(d) Concluded.
Figure 4.- Concluded.
Figure 5.- Effect of inlet orientation angle $\phi_1$ on longitudinal aerodynamic characteristics of configuration $R, I, W, T_1$, $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 
(a) Continued.

Figure 5. - Continued.
(b) \( M = 2.95 \).

Figure 5,—Continued.
Continued.

Figure 5.- Continued.
(b) Concluded.

Figure 5.- Continued.
(c) $M = 3.50$.

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

Figure 5.—Continued.
(d) $M = 3.95$.

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

51
Figure 5.- Concluded.

(d) Concluded.
Figure 6.- Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional inlets with $\phi_I = 90^\circ$ and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 
Figure 6.- Continued.
(a) Concluded.

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

(b) $M = 2.95$. 
(h) Continued.

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

(b) Concluded.
Figure 6.—Continued.
Figure 6.-- Continued.
(c) Concluded.

Figure 6.- Continued.
(d) $M = 3.95$.

Figure 6. Continued.
(d) Continued.

Figure 6. - Continued.
Figure 6. Concluded.
Figure 7.- Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional inlets with $\Phi_I = 115^\circ$ and $\delta_p = 0^\circ$.

(a) $M = 2.50$. 
Figure 7, Continued.

(a) Continued.
(a) Concluded.

Figure 7.- Continued.
Figure 7. - Continued.

(b) \( M = 2.95 \).
(b) Continued.

Figure 7. Continued.
(b) Concluded.

Figure 7.-- Continued.
(c) $M = 3.50$.

Figure 7. - Continued.
(c) Continued,

Figure 7.- Continued.
Figure 7—Continued.

(c) Concluded.
Figure 7.- Continued.
(d) Continued.

Figure 7. - Continued.
(d) Concluded.

Figure 7. Concluded.
Figure 8.- Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional inlets with $T_1$, $\phi_I = 135^\circ$, and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 
(a) Continued.

Figure 8.- Continued.
(a) Concluded.

Figure B. - Continued.
Figure 8.- Continued.
(b) Continued.

Figure 8. - Continued.
(b) Concluded.

Figure 8.- Continued.
Figure 8.- Continued.

(c) $M = 3.50.$
(c) Continued.

Figure 8. Continued.
(c) Concluded.

Figure 8.- Continued.
Figure 8.- Continued.
(d) Continued.

Figure 8, Continued.
Figure 8.- Concluded.

(d) Concluded.
Figure 9.- Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional inlets with $T_2$, $\phi_i = 135^\circ$, and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 

89
Figure 9.— Continued.

(a) Concluded.
(b) $M = 2.95$.

Figure 9. - Continued.
Figure 9.— Continued.
Figure 9. - Continued.
Figure 9.- Continued.
Figure 9. Continued.
(d) $M = 3.95$.

Figure 9. - Continued.
(d) Continued.

Figure 9. Continued.
(4) Concluded.

Figure 9.- Concluded.
Figure 10.—Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional inlets with $T_3$, $\phi_I = 135^\circ$, and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 
Figure 10.- Continued.
(a) Concluded.

Figure 10.- Continued.
Figure 10.—Continued.
(b) Concluded.

Figure 10.- Continued.
Figure 10.- Continued.

(c) $M = 3.50$. 

Figure 10.- Continued.
(c) Concluded.

Figure 10.- Continued.
Figure 10.- Continued.

(d) $M = 3.95$. 

**Figure 10** - Continued.
(d) Continued.

Figure 10.- Continued.
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(d) Concluded.

Figure 10.— Concluded.
Figure 11.- Effect of tail configuration on longitudinal aerodynamic characteristics of configuration B₁I₂T with \( \phi_I = 135^\circ \) and \( \delta_p = 0^\circ \).
(a) Concluded.

Figure 11. - Continued.
(b) \( M = 2.95 \).

Figure 11.- Continued.
(b) Continued.

Figure 11.- Continued.
(b) Concluded.

Figure 11.- Continued.
(c) $M = 1.80$

Figure 11. - Continued.
(c) continued.

Figure 11. - Continued.
(c) Concluded.

Figure 11.- Continued.
(d) \( M = 3.95 \).

Figure 11.- Continued.
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(4) Continued.

Figure 11. - Continued.
Figure 11. - Concluded.
Figure 12. Effect of tail configuration on longitudinal aerodynamic characteristics of configuration W_1, W_1^T with $\delta_1 = 10^\circ$ and $\delta_2 = 0^\circ$. 

(a) $M = 2.50$. 

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(a) Continued.

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

(a) Concluded.
(b) \( M = 2.95 \).

Figure 12, - Continued.
(b) Continued.

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

(c) Concluded.
Figure 12. - Continued.
(d) Continued.

Figure 12.—Continued.
(d) Concluded.

Figure 12. Concluded.
Figure 11. Pitch control effectiveness of configuration B₁L₁F₁ with θ₁ = 90°.
(a) Concluded.

Figure 13 - Continued.
Figure 13.- Continued.

(b) $M = 2.95$.

Figure 13.- Continued.
(b) Continued.

Figure 13. - Continued.
(c) Continued.

Figure 13. Continued.
(d) \( M = 3.95 \).

Figure 13.- Continue.
Figure 13.- Continued.
Figure 13.- Concluded.
Figure 14. Pitch-control effectiveness of configuration $B_{1}I_{2}T_{1}$ with $\phi_{1} = 115^\circ$. 

(a) $M = 2.50$. 

149
Figure 14.- Continued.
(a) Concluded.

Figure 14—Continued.
Figure 14.- Continued.

(b) $M = 2.95$.  

Figure 14.- Continued.
Figure 14.-- Continued.
(b) Concluded.

Figure 14—Continued.
(c) Continued.

Figure 14.—Continued.
(c) Concluded.

Figure 14.- Continued.
Figure 14.— Continued.

(d) $M = 3.95$.

Figure 14.— Continued.
(d) Continued.

Figure 14.—Continued.
(d) Concluded.

Figure 14.- Concluded.
Figure 15.- Pitch-control effectiveness of configuration $R_1T_2T_1$ with $\phi_I = 135^\circ$. (a) $M = 2.50$. 
Figure 15.—Continued.
(a) Concluded.

Figure 15.- Continued.
Figure 15.—Continued.

(b) $M = 2.95$. 

$\Delta\beta$, deg

0
-10
-20
Figure 15.- Continued.
Figure 15. - Continued.

(b) Concluded.
Figure 15. Continued.

(c) $M = 3.50$. 

167
(c) Continued.

Figure 15.- Continued.
(d) $M = 3.95$.

Figure 15.- Continued.
Figure 15.—Continued.

(d) Continued.
(d) Concluded.

Figure 15.- Concluded.
Figure 16. Pitch-control effectiveness of configuration $R_1T_2$ with $\phi_I = 135^\circ$. 

(a) $M = 2.50$. 

173
Figure 16.- Continued.

(a) Concluded.
(b) $M = 2.95$.

Figure 16, Continued.
(b) Continued.

Figure 16.- Continued.
(b) Concluded.

Figure 16.- Continued.
Figure 16.—Continued.
(c) Continued.

Figure 16.—Continued.
Figure 16.- Continued.
Figure 16.- Continued.
(d) Continued.

Figure 16.- Continued.
Figure 16.—Concluded.
Figure 17.- Pitch-control effectiveness of configuration $R_1T_2T_3$ with $\phi_1 = 135^\circ$. 

(a) $M = 2.50$. 

185
Figure 17.- Continued.
Figure 17.-- Continued.

(a) Concluded.
(b) \( M = 2.95 \).

Figure 17.- Continued.
Figure 17.- Continued.
(b) Concluded.

Figure 17.- Continued.
Figure 17. - Continued.

(c) $M = 3.50$. 

191
(c) Continued.

Figure 17.- Continued.
Figure 17.- Continued.

(c) Concluded.

Figure 17.- Continued.

C - 3
Figure 17.—Continued.

(d) \( M = 3.95 \).

Figure 17.—Continued.
(d) Continued.

Figure 17.- Continued.
(d) Concluded.

Figure 17.- Concluded.
Figure 18.- Pitch-control effectiveness of configuration BII with $\phi_T = 115^\circ$. $M = 2.50$. 

(a) $M = 2.50$. 

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(a) Concluded.

Figure 1R.- Continued.
Figure 18. -- Continued.

(b) $M = 2.95$.  

Figure 18.-- Continued.
Figure 18.- Continued.
Figure 18.- Continued.

(b) Concluded.
(c) $M = 3.50$.

Figure 18.—Continued.
(c) Continued.

Figure 18: Continued.
Figure 18. Continued.
(d) $M = 3.95$.

Figure 18.- Continued.
Figure 18. - Continued.

(d) Continued.
(d) Concluded.

Figure 18.- Concluded.
Figure 19. Pitch-control effectiveness of configuration $R_1T_2W_1T_1$ with $\phi_1 = 135^\circ$. 

(a) $M = 2.50$. 
Figure 19.- Continued.
(a) Concluded.

Figure 19—Continued.
(b) $M = 2.95$.

Figure 19.—Continued.
Figure 19.- Continued.
Figure 19.- Continued.

(b) Concluded.
(c) $M = 3.50$.

Figure 19.—Continued.
(c) Continued.

Figure 19.- Continued.
(c) Concluded.

Figure 19.- Continued.
(d) $M = 3.95$.

Figure 19.- Continued.
(d) Continued.

Figure 19.- Continued.
Figure 19. - Concluded.
Figure 20.- Pitch-control effectiveness of configuration $B_1 I_2 W_1 T_2$ with $\phi_1 = 135^\circ$. 

(a) $M = 2.50$. 

Figure 20.- Pitch-control effectiveness of configuration $B_1 I_2 W_1 T_2$ with $\phi_1 = 135^\circ$. 

221
(a) Continued.

Figure 20. Continued.
(b) $M = 2.95$.

Figure 20, continued.
Figure 20. Continued.
Figure 20.- Continued.

(b) Concluded.
(c) $M = 3.50$.

Figure 70, continued.
Figure 20.- Continued.

(c) Continued.
(c) Concluded.

Figure 20.- Continued.
(d) \( M = 3.95 \).

Figure 20.—Continued.
(d) Continued.

Figure 20.—Continued.
Figure 20.- Concluded.
Figure 21.- Pitch-control effectiveness of configuration $R_1I_2W_1T_3$ with $\phi_I = 135^\circ$. 

(a) $M = 2.50$. 

233
Figure 21. Continued.
Figure 21. Continued.

(a) Concluded.
Figure 21.—Continued.

(b) \( M = 2.95 \).
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Figure 21: Continued.

(b) Concluded.
(c) $M = 3.50$.

Figure 21.- Continued.
(c) Continued.

Figure 21.- Continued.
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(c) Concluded.

Figure 21. - Continued.
(d) \( M = 3.05 \).
(d) Continued.

Figure 21.—Continued.
(d) Concluded.

Figure 21.- Concluded.
Figure 22.- Effect of inlet orientation angle $\phi_T$ on lateral-directional stability of configuration $P_1I_2T_1$ with $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 
(h) $M = 2.95$.

Figure 22.—Continued.
(c) $M = 3.50$.

Figure 22.-- Continued.
(d) $M = 3.45$.

Figure 22: Concluded.
Figure 23.— Effect of inlet orientation angle $\phi$ on lateral-directional stability of configuration $B_1 I_2 W_4 T_1$ with $\delta_p = 0^\circ$.
(b) $M = 2.95$.

Figure 23.- Continued.
Figure 21 - Continued.
Figure 23.- Concluded.

(d) $M = 3.95$. 

Figure 23.- Concluded.
Figure 24.- Effect of various model components on lateral-directional stability for two-dimensional inlets with $\Phi_1 = 90^\circ$ and $\delta_p = 0^\circ$.

(a) $M = 2.50$. 
(b) $M = 2.95$.

Figure 24.- Continued.
(c) \( M = 3.50 \).

Figure 24, continued.
(d) \( M = 3.95 \).

Figure 24.—Concluded.
Figure 25. Effect of various model components on lateral-directional stability for two-dimensional inlets with $\delta_1 = 115^\circ$ and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 

(Figures not visible in the text.)
(c) $M = 3.50$.

Figure 25.—Continued.
(d) $M = 3.95$.

Figure 25.- Concluded.
Figure 26.- Effect of various model components on lateral-directional stability for two-dimensional inlets with \( T_1, \phi_1 = 135^\circ \), and \( \delta_p = 0^\circ \).
(b) \( M = 2.95 \).

Figure 26.- Continued.
(c) $M = 3.50$.

Figure 26.- Continued.
(d) $M = 3.95$.

Figure 26.- Concluded.
Figure 27. - Effect of various model components on lateral-directional stability for two-dimensional inlets with \( T_2, \phi_1 = 135^\circ, \) and \( \delta_p = 0^\circ. \)
Figure 27.- Continued.

(b) \( M = 2.95 \).
Figure 27.- Continued.
Figure 27.- Concluded.

(d) $M = 3.95$. 

268
Figure 28.— Effect of various model components on lateral-directional stability for two-dimensional inlets with $T_3$, $\Phi_1 = 135^\circ$, and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 
Figure M = 2.95.

Figure 28.—Continued.
Figure 28.- Continued.
Figure 28. - Concluded.
Figure 29.- Effect of tail configuration on lateral-directional stability for configuration B1L2T with $\phi_1 = 135^\circ$ and $\delta_p = 0^\circ$.
Figure 29. - Continued.

(b) $M = 2.95$. 

Configuration:
- $\theta_1$ 
- $\theta_2$ 
- $\theta_3$ 
- $\theta_4$ 

Figure 29.- Continued.
(c) $M = 3.50$.

Figure 29.- Continued.
(d) \( M = 3.95 \).

Figure 29.- Concluded.
Figure 30.- Effect of tail configuration on lateral-directional stability for configuration $\beta_1 I_2 W_1 T$ with $\phi_1 = 135^\circ$ and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 

Configuration

1. $\beta_1 I_2 W_1 T$
2. $\beta_1 I_2 W_1 T$
(b) $M = 2.95$.

Figure 30. - Continued.
Figure 30.- Continued.

(c) \( M = 3.50 \).

Figure 30.- Continued.
Figure 30.- Concluded.

(d) \( M = 3.95 \).
Figure 31.- Effect of inlet orientation angle $\phi_i$ on longitudinal aerodynamic characteristics of configuration $R_1I_3T_1$ with $\delta_p = 0^\circ$. (a) $M = 2.50$.,
Figure 31. - Continued.
Figure 31.- Continued.

(a) Concluded.
Figure 31. - Continued.

(b) $M = 2.95$.

Figure 31. - Continued.
(b) Continued.

Figure 31.- Continued.
Figure 31 - Continued.
Figure 31.- Continued.
Figure 31.- Continued.
Figure 31.- Continued.

(d) \( M = 3.95 \).
(d) Continued.

Figure 31.—Continued.
(d) Concluded.

Figure 31: Concluded.
Figure 32.- Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional extended inlets with $\phi_1 = 90^\circ$ and $\phi_p = 0^\circ$.

(a) $M = 2.50$. 
(a) Continued.

Figure 12. - Continued.
(b) $M = 2.95$.

Figure 32.- Continued.
(b) Continued.

Figure 32.-- Continued.
Figure 32.- Continued.
Figure 17. Continued.
Figure 32.- Continued.
(d) $M = 3.95$.

Figure 32.- Continued.
(d) Continued.

Figure 32.- Continued.
Figure 32. Concluded.
Figure 33.— Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional extended inlets with $\phi_i = 115^\circ$ and $\delta_p = 0^\circ$.

(a) $M = 2.50$. 

Configurations:
1. $B_i_1$  
2. $B_i_2_1$  
3. $B_i_3_1$  
4. $B_i_4_1$
Figure 33. - Continued.
(a) Concluded.

Figure 33.- Continued.
(b) $M = 2.95$.

Figure 33.—Continued.
(b) Continued.

Figure 33.- Continued.
(b) Concluded.

Figure 33.- Continued.
(c) $M = 3.50$

Figure 33, continued.
Figure 33.—Continued.
Figure 33.--Continued.
Figure 33.- Continued.
(d) Continued.

Figure 33.—Continued.
Figure 33.- Concluded.

(d) Concluded.

Figure 33.- Concluded.
Figure 34.- Effect of various model components on longitudinal aerodynamic characteristics for two-dimensional extended inlets with \( \phi_1 = 135^\circ \) and \( \delta_p = 0^\circ \).

(a) \( M = 2.50 \).
Figure 34.- Continued.
(b) $M = 2.95$.

Figure 34.- Continued.
(b) Concluded.
(c) \( M = 3.50 \).

Figure 34.- Continued.
(c) Concluded.

Figure 34.- Continued.
Figure 34.— Continued.

(d) $M = 3.95$. 
(d) Continued.

Figure 34.- Continued.
Figure 34.—Concluded.
Figure 35.- Pitch-control effectiveness of configuration $B_1I_3T_1$ with $\phi_1 = 90^\circ$. 

(a) $M = 2.50$. 

329
Figure 35.- Continued.
(a) Continued.
(b) $M = 2.95$.

Figure 35.- Continued.
(b) Continued.

Figure 35.- Continued.
(b) Concluded.

Figure 35.- Continued.
Figure 35: Continuud.
Figure 35.- Continued.

(c) Continued.
Figure 35--Continued.

(c) Concluded.
Figure 35. - Continued.

(d) $M = 3.05$. 

Figure 35.- Continued.
(d) Continued.

Figure 35.- Continued.
(d) Concluded.

Figure 35.-- Concluded.
Figure 36.- Pitch-control effectiveness of configuration B₁I₃T₁ with \( \phi₁ = 115^\circ \).

(a) \( M = 2.50 \).
(a) Continued.

Figure 36.- Continued.
Figure 36.— Continued.
(b) $M = 2.95$.

Figure 36, Continued.
Figure 46. - Continued.
(b) Concluded.

Figure 36.- Continued.
(c) $M = 3.50$.

Figure 36.—Continued.
(e) Continued.

Figure 36.- Continued.
(c) Concluded.

Figure 30. - Continued.
(d) $M = 3.95$.  

Figure 36.- Continued.
Figure 36.- Concluded.
(a) $M = 2.50$.

Figure 37. - Pitch-control effectiveness of configuration $R_1I_3T_1$ with $\Phi_1 = 135^\circ$. 

353
(a) Continued.

Figure 37. - Continued.
(a) Concluded.

Figure 37.—Continued.
Figure 37. - Continued.

(b) $M = 2.95$. 
(b) Continued.

Figure 37.- Continued.
(c) $M = 3.50$.

Figure 37.- Continued.
(c) Continued.

Figure 37.- Continued.
(c) Concluded.

Figure 37.- Continued.
(d) $M = 3.95$.

Figure 37.-- Continued.
Figure 17. - Continued.
Figure 37.- Concluded.
Figure 38. Pitch-control effectiveness of configuration $R_1I_3T_2$ with $\Phi_I = 135^\circ$. 

(a) $M = 2.50$. 

$C_{L}$ vs. $C_{D}$ for various $\Phi_I$. 

$\Phi_I = 0$ and $\Phi_I = -10$.
Figure 38. Continued.
(a) Concluded.

Figure 38. – Continued.
Figure 38.- Continued.

(b) $M = 2.95$. 
(b) Continued.

Figure 38. Continued.

369
(b) Concluded.

Figure 38.- Continued.
(c) \( M = 3.50 \).

Figure 38.- Continued.
(c) Continued.

Figure 38.—Continued.
(c) Concluded.

Figure 38.- Continued.
Figure 38.- Continued.

(d) $M = 3.95$. 

Figure 38.- Continued.
(d) Continued.

Figure 39. - Continued.
(d) Concluded.

Figure 38.- Concluded.
Figure 39.- Effect of inlet orientation angle $\phi$ on lateral-directional stability of configuration $R_1 I_1 T_1$ with $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 

(a) $M = 2.50$. 

$C_{L_p}$ vs. $\alpha$ for $\phi = 0^\circ$.
(d) $M = 3.95$.

Figure 39.- Concluded.
Figure 40.- Effect of various model components on lateral-directional stability for two-dimensional extended inlets with $\phi_I = 90^\circ$ and $\delta_p = 0^\circ$.
(b) \( M = 2.95 \).

Figure 40.- Continued.
(c) $M = 3.50$.

Figure 40 - Continued.
(d) $M = 3.95$.

Figure 40. Concluded.
Figure 41. - Effect of various model components on lateral-directional stability for two-dimensional extended inlets with \( \phi_{I} = 115^\circ \) and \( \delta_{P} = 0^\circ \).
Figure 41.- Continued.

(b) $M = 2.95$. 

Figure 41.- Continued.
Figure 41.-- Continued.

(c) $M = 3.50$.

$C_{sh}$
(d) $M = 3.95$.

Figure 41.- Concluded.
Figure 42.- Effect of various model components on lateral-directional stability for two-dimensional extended inlets with $\phi_I = 135^\circ$ and $\delta_p = 0^\circ$. 

(a) $M = 2.50$. 

\[ C_{\text{fl}} \]
Figure 42.- Continued.

(b) $M = 2.95$.

Figure 42.- Continued.
(e) $M = 1.50$.

Figure 42.- Continued.
Figure 42.- Concluded.

(d) $M = 3.95$.

Figure 42.- Concluded.