EXPERIMENTAL AERODYNAMIC CHARACTERISTICS
FOR BODIES OF ELLIPTIC CROSS SECTION
AT ANGLES OF ATTACK FROM 0° TO 58°
AND MACH NUMBERS FROM 0.6 TO 2.0.

Leland H. Jorgensen and Edgar R. Nelson

Ames Research Center
Moffett Field, Calif. 94035

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1975
An experimental investigation was conducted in the Ames 6- by 6-Foot Wind Tunnel to measure the static aerodynamic characteristics for two bodies of elliptic cross section and for their equivalent body of revolution. The equivalent body of revolution had the same length and axial distribution of cross-sectional area as the elliptic bodies. It consisted of a tangent ogive nose of fineness ratio 3 followed by a cylinder with a fineness ratio of 7. For the first body of elliptic cross section, the ratio of the semimajor axis to semiminor axis was held constant at 2 all along the body length. For the second elliptic body the nose was unchanged, but the aftersection was changed as follows: The cross-sectional axis ratio $a/b$ was decreased from 2 to 1 over an axial distance of about 1.66 diam. Then, at this position, the $a,b$ axis system was rotated 90°, and the $a/b$ ratio was increased back to 2 over the next 2.34 diam in length. Over the last length of three body diam, this rotated $a/b$ ratio was held constant at 2.

All bodies were tested at Mach numbers of 0.6, 0.9, 1.2, 1.5, and 2.0 at angles of attack from 0° to 58°. The Reynolds numbers, based on base diameter, were $2.2 \times 10^6$, $4.3 \times 10^6$, and $6.5 \times 10^6$ at $M = 0.6$ and 0.9 and $3.8 \times 10^6$ at $M = 1.2$, 1.5, and 2.0. The elliptic bodies were tested at roll angles of 0° (flattest side of nose pitching against the flow) and 90°.

The data demonstrate that the aerodynamic characteristics can be significantly altered by changing the body cross section from circular to elliptic and by rolling the body from 0° to 90°. For example, the first elliptic body (with a constant cross-sectional axis ratio of 2) developed at zero roll about twice the normal force developed by the equivalent body of revolution. At some angles of attack greater than about 25°, side forces and yawing moments were measured in spite of the fact that the bodies were tested at zero angle of sideslip. The side-force and yawing-moment coefficients decreased with an increase in Mach number and essentially disappeared for all the bodies at Mach numbers greater than 1.2. From the standpoint of reducing undesirable side forces at high angles of attack, it is best to have the flattest side of the nose of the elliptic bodies pitching against the stream crossflow. The effect of Reynolds number was also the least significant for both elliptic bodies when the flattest side of the nose was pitched against the stream crossflow.
All forces and moments are referred to the body axis coordinate system. Because the data are computer plotted, both the conventional symbol and the plot symbol are given.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Plot symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_r$</td>
<td>CA</td>
<td>reference area = body base area = 34.26 cm² (5.31 in.²)</td>
</tr>
<tr>
<td>$a,b$</td>
<td>CA</td>
<td>semimajor and semiminor axes of elliptic cross section</td>
</tr>
<tr>
<td>$C_A$</td>
<td>CA</td>
<td>axial-force coefficient, $C_{A_{bal}} - C_{A_{base}}$</td>
</tr>
<tr>
<td>$C_{A_{bal}}$</td>
<td></td>
<td>balance axial-force coefficient, $\frac{F_A}{qA_r}$</td>
</tr>
<tr>
<td>$C_{A_{base}}$</td>
<td></td>
<td>base-pressure force coefficient, $\frac{(p - p_{base})}{q}$</td>
</tr>
<tr>
<td>$C_m$</td>
<td>CN</td>
<td>pitching-moment coefficient about balance center $4d$ from body base, $\frac{pitching moment}{qA_rX}$</td>
</tr>
<tr>
<td>$C_N$</td>
<td>CN</td>
<td>normal-force coefficient, $\frac{F_N}{qA_r}$</td>
</tr>
<tr>
<td>$C_n$</td>
<td>CYN</td>
<td>yawning-moment coefficient about balance center $4d$ from body base, $\frac{yawing moment}{qA_rX}$</td>
</tr>
<tr>
<td>$C_Y$</td>
<td>CY</td>
<td>side-force coefficient, $\frac{F_Y}{qA_r}$</td>
</tr>
<tr>
<td>$d$</td>
<td></td>
<td>body base diameter, 6.60 cm (2.60 in.)</td>
</tr>
<tr>
<td>$F_A, F_N, F_Y$</td>
<td></td>
<td>axial, normal, and side force, respectively</td>
</tr>
<tr>
<td>$l$</td>
<td></td>
<td>body length</td>
</tr>
<tr>
<td>$l_N$</td>
<td></td>
<td>nose length</td>
</tr>
<tr>
<td>$M$</td>
<td>MACH</td>
<td>free-stream Mach number</td>
</tr>
<tr>
<td>$p$</td>
<td></td>
<td>free-stream static pressure</td>
</tr>
</tbody>
</table>
$p_{base}$ base pressure

$q$ free-stream dynamic pressure

$\frac{Re}{L}$ unit Reynolds number, million/m

$Re$ RE Reynolds number based on $d$

$X$ reference length $= d = 6.60$ cm (2.60 in.)

$\frac{x_{acN}}{d}$ XACN/D distance (in diam) from body base to aerodynamic force center in normal-force plane, \(\left(\frac{C_m}{C_N} + \frac{x_m}{X}\right)\)

$x_m$ distance from body base to balance moment reference $= 4d = 26.42$ cm (10.40 in.)

$\alpha$ ALPHA angle of attack, deg

$\phi$ PHI angle of bank about body longitudinal axis, deg

**Configuration Code**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Plot symbol</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_1$</td>
<td>B1</td>
<td>basic circular body (tangent ogive nose of fineness ratio 3 with cylinder aftersection of fineness ratio 7)</td>
</tr>
<tr>
<td>$B_2$</td>
<td>B2</td>
<td>body with elliptic cross section of constant $\frac{a}{b} = 2$</td>
</tr>
<tr>
<td>$B_3$</td>
<td>B3</td>
<td>body with elliptic cross section of variable $\frac{a}{b}$</td>
</tr>
<tr>
<td>$\phi = 0^\circ$</td>
<td>PHI = 0</td>
<td>body banked $0^\circ$ about longitudinal axis (see fig. 1)</td>
</tr>
<tr>
<td>$\phi = 90^\circ$</td>
<td>PHI = 90</td>
<td>body banked $90^\circ$ about longitudinal axis (see fig. 1)</td>
</tr>
</tbody>
</table>
EXPERIMENTAL AERODYNAMIC CHARACTERISTICS FOR BODIES OF ELLIPTIC CROSS SECTION AT ANGLES OF ATTACK FROM 0° TO 58° AND MACH NUMBERS FROM 0.6 TO 2.0

Leland H. Jorgensen and Edgar R. Nelson*

Ames Research Center

SUMMARY

An experimental investigation was conducted in the Ames 6- by 6-Foot Wind Tunnel to measure the static aerodynamic characteristics for two bodies of elliptic cross section and for their equivalent body of revolution. The equivalent body of revolution had the same length and axial distribution of cross-sectional area as the elliptic bodies. It consisted of a tangent ogive nose of fineness ratio 3 followed by a cylinder with a fineness ratio of 7. For the first body of elliptic cross section, the ratio of the semimajor axis to semiminor axis was held constant at 2 all along the body length. For the second elliptic body the nose was unchanged, but the aftersection was changed as follows: The cross-sectional axis ratio $a/b$ was decreased from 2 to 1 over an axial distance of about 1.66 diam. Then, at this position, the $a,b$ axis system was rotated 90°, and the $a/b$ ratio was increased back to 2 over the next 2.34 diam in length. Over the last length of three body diam, this rotated $a/b$ ratio was held constant at 2.

All bodies were tested at Mach numbers of 0.6, 0.9, 1.2, 1.5, and 2.0 at angles of attack from 0° to 58°. The Reynolds numbers, based on base diameter, were $2.2 \times 10^5$, $4.3 \times 10^5$, and $6.5 \times 10^5$ at $M = 0.6$ and 0.9 and $3.8 \times 10^5$ at $M = 1.2$, 1.5, and 2.0. The elliptic bodies were tested at roll angles of 0° (flattest side of nose pitching against the flow) and 90°.

The data demonstrate that the aerodynamic characteristics can be significantly altered by changing the body cross section from circular to elliptic and by rolling the body from 0° to 90°. For example, the first elliptic body (with a constant cross-sectional axis ratio of 2) developed at zero roll about twice the normal force developed by the equivalent body of revolution, whereas at 90° roll it developed only about half the normal force.

At some angles of attack greater than about 25°, side forces and yawing moments were measured in spite of the fact that the bodies were tested at zero angle of sideslip. The side-force and yawing-moment coefficients decreased with an increase in Mach number and essentially disappeared for all the bodies at Mach numbers greater than 1.2.

From the standpoint of reducing undesirable side forces at high angles of attack, it was best to have the flattest side of the nose of the elliptic bodies pitching against the stream crossflow. The effect of Reynolds number was also the least significant for both elliptic bodies when the flattest side of the nose was pitched against the stream crossflow.

*Project Engineer, ARO, Inc., Moffett Field, Calif. 94035.
INTRODUCTION

High angle-of-attack aerodynamics is increasing in importance because of the demand for greater maneuverability of missiles and military aircraft. There is great need for experimental force and moment data for bodies of circular and noncircular cross section alone and with lifting surfaces at Mach numbers from subsonic to supersonic.

This report presents experimental force and moment data for bodies of elliptic cross section at angles of attack from $0^\circ$ to $58^\circ$ and at Mach numbers from 0.6 to 2.0. Data were presented for some similar bodies in 1958 (ref. 1), but the results were limited to angles of attack less than $20^\circ$ and Mach numbers from 2 to 4.

TEST FACILITY

The experimental investigation was conducted in the Ames 6- by 6-Foot Wind Tunnel, a variable pressure, continuous flow, closed return type facility. The nozzle ahead of the test section consists of an asymmetric sliding block that permits a continuous variation of Mach number from 0.6 to 2.3. The test section has a perforated floor and ceiling to remove boundary layer for transonic testing.

MODELS AND BALANCE

The dimensions of the three models tested are shown in figure 1(a), and the planform views of the models as they were oriented (in five different configurations) for the tests are shown in figure 1(b). The basic circular body $B_1$ consisted of a circular-arc tangent ogive nose of fineness ratio 3 followed by a cylindrical aftersection of fineness ratio 7. Bodies $B_2$ and $B_3$ had elliptic cross sections, and these bodies had the same length and axial distribution of cross-sectional area as $B_1$. Hence, the fineness ratio of $\ell/d = 10$ for $B_1$ was also the equivalent fineness ratio for $B_2$ and $B_3$, and all bodies had equal volumes. For $B_2$, the ratio of the semimajor to the semiminor cross-section axis, $a/b = 2$, was held constant along the body length. Bodies $B_1$ and $B_2$ were investigated in 1958 (ref. 1) for angles of attack from about $0^\circ$ to $20^\circ$ and Mach numbers from 2 to 4. Body $B_3$, which was new to the present investigation, consisted of the same nose shape as $B_2$ but had an afterbody section of variable $a/b$ over four body diameters in length and a constant $a/b = 2$ over the rear three body diameters (see fig. 1(a)).

Bodies $B_1$ and $B_2$ were constructed of stainless steel, and $B_3$ was constructed of aluminum. Photographs of $B_3$ are shown in figure 2. All models were sting mounted through the base on a six-component strain-gage "Task" balance. The balance force center was located inside each body 4 diam forward of the base.
TESTS AND DATA REDUCTION

All configuration arrangements shown in figure 1(b) were tested at angles of attack from $0^\circ$ to about $58^\circ$. Two model support setups were used — one for $\alpha = 0^\circ$ to about $27^\circ$, and the other for $\alpha = 27^\circ$ to $58^\circ$. Photographs of these setups are shown in reference 2.

The models were tested at the following Mach numbers and Reynolds numbers:

<table>
<thead>
<tr>
<th>$M$</th>
<th>$Re \times 10^6$ (m)</th>
<th>$Re \times 10^6$ (ft)</th>
<th>$Re \times 10^5$ (based on $d$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6, 0.9</td>
<td>3.28</td>
<td>1.0</td>
<td>2.3</td>
</tr>
<tr>
<td>0.6, 0.9</td>
<td>6.56</td>
<td>2.0</td>
<td>4.3</td>
</tr>
<tr>
<td>0.6, 0.9</td>
<td>9.84</td>
<td>3.0</td>
<td>6.5</td>
</tr>
<tr>
<td>1.2, 1.5, 2.0</td>
<td>5.74</td>
<td>1.75</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Six-component aerodynamic force and moment data were measured at each test condition, and all data were reduced to coefficient form and referred to the body axis coordinate system. The average base pressure from four base pressure tubes (at sides, top, and bottom of base) was used to compute the base drag, which was subtracted from the total axial-force balance measurement, so that the data presented are for forces ahead of the body base. Rolling-moment coefficients were generally negligible and are omitted from this report. Normal-force aerodynamic centers were computed from the normal-force and pitching-moment coefficients and are presented in lieu of the pitching-moment coefficients.

RESULTS AND DISCUSSION

Experimental results (figs. 3 through 24) show the effects of elliptic cross section with constant $a/b$ along the body length, elliptic cross section with variable $a/b$ along the body length, Reynolds number, and Mach number. Each effect is discussed briefly with the aid of plots of $C_N$, $x_{acN}/d$, $C_Y$, $C_Y/C_N$, and $C_n$ versus $\alpha$ for $\alpha = 0^\circ$ to $60^\circ$. Plots of $C_A$ versus $\alpha$ are also presented but are not discussed. Because the models were sting supported from the rear, it is likely that the $C_A$ data include effects of support interference.

Effect of Elliptic Cross Section with Constant $a/b$

In figures 3 through 7, data are presented for body $B_2$ which has an elliptic cross section with constant $a/b = 2$ along the entire length. The aerodynamic characteristics for $B_2$, oriented in roll both at $\phi = 0^\circ$ and $90^\circ$, are compared with those for $B_1$, the equivalent body of revolution. The data are for the highest test Reynolds numbers, $Re = 6.5 \times 10^5$ at $M = 0.6$ and 0.9 (figs. 3 and 4) and $Re = 3.8 \times 10^5$ at $M = 1.2, 1.5$, and 2.0 (figs. 5–7).

As expected, changes in $a/b$ and $\phi$ cause significant changes in most of the aerodynamic characteristics throughout the high $\alpha$ range. For example, values of $C_N$ are about twice as large for $B_2$ ($a/b = 2$) at $\phi = 0^\circ$ as for $B_1$ ($a/b = 1$). With $B_2$ at $\phi = 90^\circ$, however, the values of $C_N$ are roughly half those for $B_1$. At $\alpha$ less than about $30^\circ$, the aerodynamic centers ($x_{acN}/d$) are
considerably farther forward on $B_2$ at $\phi = 90^\circ$ than at $\phi = 0^\circ$, but at higher $\alpha$ they lie at about the same location.

At all Mach numbers and angles of attack, the side-force coefficients are generally quite small or negligible for $B_1$ and for $B_2$ at $\phi = 0^\circ$. For $B_2$ at $\phi = 90^\circ$ and $M$ up to 1.2, however, values of $C_Y$ become significantly large at some of the higher angles of attack. At $M = 0.6$, for example, $C_Y$ is more than twice that of $C_N$ at $\alpha = 50^\circ$. Generally, with an increase in $M$ from 0.6 to 1.2, the maximum values of $C_Y$ decrease; at $M = 1.5$ and 2.0, all values of $C_Y$ are essentially zero throughout the $\alpha$ range. This side-force phenomenon at high angles of attack appears to be associated primarily with subsonic flow.

Effect of Elliptic Cross Section with Variable $a/b$

In figures 8 through 12, data are presented for body $B_3$ which has an elliptic cross section with variable $a/b$ over part of the body length (see figs. 1 and 2). The aerodynamic characteristics for $B_3$, oriented in roll both at $\phi = 0^\circ$ and $90^\circ$, are compared with those for $B_1$, the equivalent body of revolution. As in the previous figures, the data are for the highest test Reynolds number at each Mach number.

At all Mach numbers and angles of attack, $B_3$ at $\phi = 90^\circ$ develops the greatest normal force, and the aerodynamic force center is the most rearward. With $B_3$ at $\phi = 0^\circ$, the aerodynamic center is much more forward.

Large side forces and yawing moments developed only for $B_3$ at $\phi = 90^\circ$ and at Mach numbers less than about 1.2 or 1.5. For example, at $M = 0.6$, (fig. 8), the maximum $C_Y$ is about 40 percent of $C_N$ (at $\alpha \approx 38^\circ$), whereas at $M = 1.2$ (fig. 10), the maximum $C_Y$ is only about 20 percent of $C_N$ (at $\alpha \approx 27^\circ$). At $M = 1.5$, the maximum side force is near zero. Therefore, from the standpoint of reducing undesirable side forces at high $\alpha$, it is best to have the flattest side of the nose (major axis, $a$) pitching perpendicular to the stream crossflow. This was also shown to be true for body $B_2$.

Effect of Reynolds Number

In figures 13 through 22, data are presented which show the effect of Reynolds number for the configurations at $M = 0.6$ and 0.9. The Reynolds numbers are $2.2 \times 10^5$, $4.3 \times 10^5$, and $6.5 \times 10^5$ based on body base diameter.

*Body ($B_1$) with circular cross section.*— For $B_1$, Reynolds number $Re$ has a significant effect on the variation of $C_N$ and $x_{acN}/d$ with $\alpha$ at $M = 0.6$ (fig. 13). At the higher angles of attack, $C_N$ generally decreases with an increase in $Re$. The effect at $M = 0.9$, however, is smaller (fig. 14). At first observation, it might be surprising that there would be this effect at $M = 0.6$ but not so much at $M = 0.9$ for such a small range of Reynolds numbers. An explanation probably can be made on the basis of crossflow theory (e.g., ref. 3 or 4). From the theory, for crossflow Mach numbers $(M \sin \alpha)$ less than critical (about 0.4), a change in crossflow Reynolds number $(Re \sin \alpha)$ from about $2 \times 10^6$ to $5 \times 10^5$ can decrease the crossflow drag coefficient significantly and hence the normal
force. In the present investigation, for $M = 0.6$ the crossflow Mach numbers were subcritical over most of the $\alpha$ range, and the crossflow Reynolds numbers ranged from subcritical (less than about $2 \times 10^5$ throughout the entire $\alpha$ range for $Re = 2.2 \times 10^5$) to supercritical (greater than about $2 \times 10^5$ throughout most of the $\alpha$ range for $Re = 6.5 \times 10^5$). For this situation, crossflow theory predicts a decrease in $C_N$ at high $\alpha$ with an increase in Reynolds number from $2.2 \times 10^5$ to $6.5 \times 10^5$. Crossflow theory, however, predicts little or no effect at $M = 0.9$, since the crossflow Mach number is supercritical (greater than about 0.4) for $\alpha > 30^\circ$.

The effect of Reynolds number on the side-force and yawing-moment coefficients also appears to be more significant at $M = 0.6$ than at $M = 0.9$. Presently, this side-force phenomenon is not well understood.

**Body ($B_2$) with elliptic cross section of constant $a/b = 2$.** For $B_2$ at $\phi = 0^\circ$, Reynolds number does not significantly affect the aerodynamic characteristics (figs. 15 and 16). However, at $M = 0.6$, there is a small decrease in $C_N$ with an increase in $Re$ from $4.3 \times 10^5$ to $6.5 \times 10^5$ over the $\alpha$ range from about $25^\circ$ to $50^\circ$ (fig. 15).

For $B_2$ at $\phi = 90^\circ$, the Reynolds number effects the aerodynamic characteristics more significantly (figs. 17 and 18). The effects on aerodynamic force center and side force are particularly significant but are not understood at present.

**Body ($B_3$) with elliptic cross section of variable $a/b$.** As for $B_2$ at $\phi = 0^\circ$, the Reynolds number does not significantly affect the aerodynamic characteristics for $B_3$ at $\phi = 0^\circ$ (figs. 19 and 20). As for $B_2$ at $\phi = 90^\circ$, there are some significant effects for $B_3$ at $\phi = 90^\circ$ (figs. 21 and 22).

Both $B_2$ and $B_3$ have the same nose shape and flow orientation at $\phi = 0^\circ$, and it is thus apparent that, from the standpoint of resisting changes in the aerodynamic characteristics due to Reynolds number, this nose shape performs best when oriented at $\phi = 0^\circ$.

### Effect of Mach Number

In Figures 23 and 24, data are presented which demonstrate the effect of Mach number on the aerodynamic characteristics for $B_1$ and $B_2$ at $\phi = 0^\circ$. For the data at $M = 0.6$ and 0.9, the Reynolds number is $6.5 \times 10^5$, and for $M = 1.2, 1.5$, and 2.0, the Reynolds number is $3.8 \times 10^5$.

For both configurations the values of $C_N$ at the higher angles of attack ($\alpha > 40^\circ$) increase considerably from $M = 0.6$ to 1.2. Then, with a further increase in $M$ to 2.0, there is generally a small decrease or little change in $C_N$. This trend is in accord with that which would be expected from crossflow theory (ref. 3).

The side-force and yawing-moment plots show that the side-force phenomenon at $\alpha$ greater than about $25^\circ$ is essentially associated with subsonic Mach numbers. However, the values of $C_Y$ ($CY$) and $C_n$ ($CYN$) are small for these configurations at all test Mach numbers.
CONCLUSIONS

1. As expected, a change in body cross section from circular to elliptic \((a/b = 2)\) and variation in body roll angle caused significant changes in most of the aerodynamic characteristics. For example, values of normal-force coefficient for an elliptic body of \(a/b = 2\) at \(\phi = 0^\circ\) were about twice those for the equivalent circular body. At \(\phi = 90^\circ\) they were about one half.

2. At some angles of attack greater than about 25°, side forces and yawing moments were measured in spite of the fact that the bodies were tested at zero angle of sideslip. The side-force and yawing-moment coefficients generally decreased with an increase in Mach number and essentially disappeared for all the bodies at supersonic Mach numbers above 1.2.

3. At all test Mach numbers and angles of attack, the side-force coefficients were generally small or negligible for the circular body and the elliptic bodies at \(\phi = 0^\circ\). With the elliptic bodies at \(\phi = 90^\circ\), however, some values of side-force coefficient became as large as twice the values of normal-force coefficient at the same high angles of attack.

4. From the standpoint of reducing undesirable side forces at high angles of attack, it was found best to have the flattest side of the elliptic body nose pitching against the stream crossflow.

5. The effect of Reynolds number was also the least significant for the elliptic bodies when the flattest side of the nose was pitched against the stream crossflow.

6. There were significant effects of Reynolds number measured for the equivalent body of revolution, and the trends in the effects on the normal-force coefficients at high \(\alpha\) were in agreement with expectations from crossflow theory.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., 94035, September 26, 1974
REFERENCES


2. Jorgensen, Leland H.; and Nelson, Edgar R.: Experimental Aerodynamic Characteristics for a Cylindrical Body of Revolution With Various Noses at Angles of Attack from $0^\circ$ to $58^\circ$ and Mach Numbers from 0.6 to 2.0. NASA TM X-3128, 1974.


(a) Model dimensions with $d = 6.6$ cm (2.6 in.)

Figure 1.— Model dimensions and planform views of configurations tested.
(b) Planform views of configurations tested.

Figure 1.— Concluded.
(a) Planform view of $B_3$ at $\phi = 0^\circ$

Figure 2.— Photographs of aluminum body $B_3$.

(b) Three-quarter view

Figure 2.— Concluded.
(a) $x_{cN}/d$ and $CN$ versus $\alpha$

Figure 3. Effect of elliptic cross section with constant $\alpha/b; M = 0.6, Re = 6.5 \times 10^5$. 

$X_{C_N}/D$
Figure 3. — Continued.
(c) $C_A$ and $C_H$ versus $\alpha$

Figure 3.— Concluded.
(a) $x_{acN}/d$ and $C_N$ versus $\alpha$

Figure 4.— Effect of elliptic cross section with constant $a/b; M = 0.9, Re = 6.5 \times 10^5$. 
Figure 4. – Continued.
Figure 4. Concluded.

(c) $C_A$ and $C_{H}$ versus $\alpha$
Figure 5. Effect of elliptic cross section with constant $a/b$, $M = 1.2$, $Re = 3.8 \times 10^5$. 

(a) $x_a c_N$ and $c_N$ versus $\alpha$
Figure 5. – Continued.

(b) $C_y/C_N$ and $C_y$ versus $\alpha$
Figure 6.— Effect of elliptic cross section with constant \(a/b; M = 1.5, Re = 3.8 \times 10^5\).
Figure 6 – Continued.
(c) $C_A$ and $C_n$ versus $\alpha$

Figure 6.— Concluded.
Figure 7.— Effect of elliptic cross section with constant $a/b$; $M = 2.0$, $Re = 3.8 \times 10^5$. 

(a) $x_{acN} / d$ and $C_N$ versus $\alpha$
Figure 8.— Effect of elliptic cross section with variable $a/b$; $M = 0.6, Re = 6.5 \times 10^5$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
Figure 8. Continued.

(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$
(c) $C_A$ and $C_n$ versus $\alpha$

Figure 8.— Concluded.
Figure 9.— Effect of elliptic cross section with variable $a/b$; $M = 0.9$, $Re = 6.5 \times 10^5$.

(a) $x_{ac}/d$ and $C_\alpha$ versus $\alpha$
Figure 9.— Continued.

(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.
Figure 9. Continued.
Figure 10.— Effect of elliptic cross section with variable $a/b$; $M = 1.2$, $Re = 3.8 \times 10^5$. 

(a) $x_{ac_N}/d$ and $C_N$ versus $\alpha$
Figure 10. – Continued.
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$
(c) $C_A$ and $C_h$ versus $\alpha$

Figure 10.— Concluded.
Figure 11. Effect of elliptic cross section with variable $a/b$; $M = 1.5$, $Re = 3.8 \times 10^5$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
(b) $C_y/C_N$ and $C_y$ versus $\alpha$

Figure 11. Continued.
Figure 11.— Concluded.

(c) $C_A$ and $C_N$ versus $x$
Figure 12.— Effect of elliptic cross section with variable $a/b$; $M = 2.0$, $Re = 3.8 \times 10^5$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
Figure 12. Continued.

(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$
Figure 13.— Effect of Reynolds number for $B_1, M = 0.6$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
Figure 13. – Continued.

(b) $C_y/C_N$ and $C_f$ versus $\alpha$.
(c) $C_A$ and $C_N$ versus $\alpha$

Figure 13. Concluded.
Figure 14.— Effect of Reynolds number for $B_1, M = 0.9$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$

Figure 14.— Continued.
Figure 1.4. – Concluded.
Figure 15.— Effect of Reynolds number for \( B_2 \); \( \phi = 0^\circ, M = 0.6 \).
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$

Figure 15.— Continued.
Figure 16. – Effect of Reynolds number for $B_2$, $\phi = 0^\circ$, $M = 0.9$.
Figure 17. Effect of Reynolds number for $B_2; \phi = 90^\circ, M = 0.6$.

(a) $\frac{x_{ac}y_d}{d}$ and $C_N$ versus $\alpha$
Figure 18.— Effect of Reynolds number for $B_2 \phi = 90^\circ, M = 0.9$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$

Figure 18.— Continued.
(c) $C_A$ and $C_n$ versus $\alpha$

Figure 18.— Concluded.
Figure 19. Effect of Reynolds number for $B_3; \phi = 0^\circ, M = 0.6$. 

(a) $x_{c_{cy}}/d$ and $C_N$ versus $\alpha$. 

(Symbol CONFIGURATION DESCRIPTION)

XACN/D  CN
SYMBOL  CONFIGURATION DESCRIPTION  RE
\( \square \)  B3  PHI=0  2.000
\( \diamond \)  B3  PHI=0  4.300
\( \triangle \)  B3  PHI=0  6.500

(b) \( C_Y/C_N \) and \( C_Y \) versus \( \alpha \)

Figure 19.— Continued.
(c) $C_A$ and $C_R$ versus $\alpha$

Figure 19.— Concluded.
Figure 20.— Effect of Reynolds number for $B_3; \phi = 0^\circ, M = 0.9$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
Figure 20—Continued.

(b) $C_y/C_N$ and $C_y$ versus $\alpha$
(c) $C_A$ and $C_n$ versus $\alpha$

Figure 20.— Concluded.
Figure 21.— Effect of Reynolds number for $B_3; \phi = 90^\circ, M = 0.6$. 

(a) $x_{acN/d}$ and $C_N$ versus $\alpha$
(c) $C_A$ and $C_n$ versus $\alpha$

Figure 21. Concluded.
Figure 22.— Effect of Reynolds number for $B_3$; $\phi = 90^\circ$, $M = 0.9$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$

Figure 22.— Continued.
Figure 23—Effect of Mach number for $B_1$.

(a) $\frac{x_{acN}}{d}$ and $C_N$ versus $\alpha$
(c) $C_A$ and $C_n$ versus $\alpha$

Figure 23.— Concluded.
(a) $x_{acN}/d$ and $C_N$ versus $\alpha$

Figure 24.— Effect of Mach number for $B_2, \phi = 0^\circ$. 
"The aeronautical and space activities of the United States shall be conducted so as to contribute ... to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."
—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546