EXPERIMENTAL AERODYNAMIC CHARACTERISTICS FOR A CYLINDRICAL BODY OF REVOLUTION WITH VARIOUS NOSES AT ANGLES OF ATTACK FROM 0° TO 58° AND MACH NUMBERS FROM 0.6 TO 2.0

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The various configurations were tested at Mach numbers of 0.6, 0.9, 1.2, 1.5, and 2.0 at angles of attack from 0° to about 58°. The Reynolds numbers, based on base diameter, were 2.2X10^5, 4.3X10^5, and 6.5X10^5 at M = 0.6 and 0.9 and 3.8X10^5 at M = 1.2, 1.5, and 2.0.

The data demonstrate that the aerodynamic characteristics for a body of revolution can be significantly affected by changes in nose fineness ratio, nose bluntness, Reynolds number, Mach number, and, of course, angle of attack. Nose strakes increased the normal forces but had little effect on the side forces that developed at subsonic Mach numbers for α greater than about 25°. A grit ring around the nose had little or no effect on the aerodynamic characteristics.
NOMENCLATURE

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></td>
<td>reference area = body base area = 34.26 cm$^2$ (5.31 in.$^2$)</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>
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<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></td>
<td>pitching-moment coefficient about balance center 4d from body base,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{\text{pitching moment}}{qA_rX}$</td>
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<tr>
<td>$C_{mR}$</td>
<td></td>
<td>resultant moment coefficient, $C_m \cos \phi + C_n \sin \phi$</td>
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<tr>
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<td>CN</td>
<td>normal-force coefficient, $\frac{F_N}{qA_r}$</td>
</tr>
<tr>
<td>$C_n$</td>
<td>CYN</td>
<td>yawing-moment coefficient about balance center 4d from body base,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{\text{yawing moment}}{qA_rX}$</td>
</tr>
<tr>
<td>$C_R$</td>
<td></td>
<td>resultant force coefficient, $(C_N^2 + C_Y^2)^{1/2}$</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 = reference length = 6.60 cm (2.60 in.)</td>
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<tr>
<td>$F_A, F_N,$</td>
<td>F_Y</td>
<td>axial, normal, and side force, respectively</td>
</tr>
<tr>
<td>$\ell_N$</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>
<tr>
<td>$p_{base}$</td>
<td></td>
<td>base pressure</td>
</tr>
</tbody>
</table>

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\( q \)  
free-stream dynamic pressure

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

\( Re \)  
unit Reynolds number based on \( d \)

\( X \)  
reference length = \( d = 6.60 \text{ cm} \) (2.60 in.)

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

\( \frac{x_{acY}}{d} \)  
\( \frac{x_{acY}}{d} \) distance (in diameters) from body base to aerodynamic force center in side-force plane, \( \frac{C_n}{C_Y} + \frac{x_m}{X} \)

\( \frac{x_{acR}}{d} \)  
\( \frac{x_{acR}}{d} \) XACR/D distance (in diameters) from body base to resultant aerodynamic force center, \( \frac{C_mR}{C_R} + \frac{x_m}{X} \)

\( x_m \)  
distance from body base to balance moment reference = \( 4d = 26.42 \text{ cm} \) (10.40 in.)

\( \alpha \)  
\( \alpha \) ALPHA angle of attack, deg

\( \phi \)  
\( \phi \) PHI angle between normal force and resultant force (clockwise rotation is positive when looking along the axis from the body base to the nose), deg

### Configuration Code

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Plot Symbol</th>
<th>Component</th>
<th>Fineness Ratio</th>
</tr>
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<tr>
<td>( C_1 )</td>
<td>C1</td>
<td>circular cylinder</td>
<td>7</td>
</tr>
<tr>
<td>( N_1 )</td>
<td>N1</td>
<td>tangent ogive nose</td>
<td>3</td>
</tr>
<tr>
<td>( N_2 )</td>
<td>N2</td>
<td>tangent ogive nose</td>
<td>3.5</td>
</tr>
<tr>
<td>( N_3 )</td>
<td>N3</td>
<td>tangent ogive nose</td>
<td>5</td>
</tr>
<tr>
<td>( N_4 )</td>
<td>N4</td>
<td>tangent ogive nose with rounded tip</td>
<td>3</td>
</tr>
<tr>
<td>iv</td>
<td>iv</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| $N_5$ | N5 | tangent ogive nose with tip strakes | 3 |
| $N_6$ | N6 | tangent ogive nose with side strakes | 3 |
| $N_7$ | N7 | tangent ogive nose | 2.5 |
| $G$   | G  | transition strip around nose (0.249-cm-diam glass spheres, 0.159 cm wide, and 3.81 cm aft of nose apex) |
EXPERIMENTAL AERODYNAMIC CHARACTERISTICS FOR A CYLINDRICAL BODY OF REVOLUTION WITH VARIOUS NOSES AT ANGLES OF ATTACK FROM 0° TO 58° AND MACH NUMBERS FROM 0.6 TO 2.0

Leland H. Jorgensen and Edgar R. Nelson*

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SUMMARY

For a body of revolution, an experimental investigation was conducted in the Ames 6- by 6-Foot Wind Tunnel to determine the effect on the aerodynamic characteristics of forebody geometry, a grit ring around the nose, Reynolds number, Mach number, and angle of attack. Aerodynamic force and moment characteristics were measured for a cylindrical body (cylinder fineness ratio of 7) with tangent ogive noses of fineness ratio 2.5, 3.0, 3.5, and 5.0. In addition, the cylindrical body was tested with an ogive nose having a rounded tip and an ogive nose with two different nose strake arrangements.

The various configurations were tested at Mach numbers of 0.6, 0.9, 1.2, 1.5, and 2.0 at angles of attack from 0° to about 58°. The Reynolds numbers, based on base diameter, were 2.2\times10^5, 4.3\times10^5, and 6.5\times10^5 at M = 0.6 and 0.9 and 3.8\times10^5 at M = 1.2, 1.5, and 2.0.

The data demonstrate that the aerodynamic characteristics for a body of revolution can be significantly affected by changes in nose fineness ratio, nose bluntness, Reynolds number, Mach number, and, of course, angle of attack. Nose strakes increased the normal forces but had little effect on the side forces that developed at subsonic Mach numbers for α greater than about 25°. A grit ring around the nose had little or no effect on the aerodynamic characteristics.

INTRODUCTION

The importance of high angle-of-attack aerodynamics is increasing because of the demand for greater maneuverability of missiles and military aircraft (both manned and remotely piloted). Some recent introductory investigations in this field are reported in references 1 to 8. However, there is great need to enlarge the relatively small data base for basic bodies alone and in combination with strakes, wings, and tails at subsonic, transonic, and supersonic Mach numbers.

To help enlarge the data base for basic bodies alone, an investigation was conducted to measure the aerodynamic force and moment characteristics for a cylindrical body of revolution (cylinder fineness ratio of 7) with tangent ogive noses of fineness ratio 2.5 to 5.0. In addition, the

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cylindrical body was tested with an ogive nose having a rounded tip and an ogive nose with two different strake arrangements.

In this investigation, the cylindrical body was tested with the various noses in the Ames 6- by 6-Foot Wind Tunnel at Mach numbers of 0.6, 0.9, 1.2, 1.5, and 2.0. The Reynolds numbers, based on model base diameter, were 2.2X10^6, 4.3X10^6, and 6.5X10^6 at the subsonic Mach numbers and 3.8X10^6 at the supersonic Mach numbers. Six-component static aerodynamic force and moment coefficients were measured for angles of attack from 0° to 58°.

This report presents the basic data that show the effects on the aerodynamic characteristics of nose fineness ratio, nose tip rounding, nose strakes, Reynolds number, and Mach number over the angle-of-attack range.

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 model components are shown in figure 1(a) and the configurations tested in figure 1(b). All test models had a combination of one of seven noses with a circular-cylinder aftersection. The cylinder (C1), 7 diameters long, was attached to the desired nose (N1 through N7). Noses N1, N2, N3, and N7 were all circular-arc tangent ogives ranging in length from 2.5 to 5 diameters. Noses N4, N5, and N6 were also circular-arc tangent ogives but with some modifications. N4 was formed by rounding the tip of a fineness-ratio 3.5 ogive to give a resulting fineness ratio of 3. N5 was a fineness-ratio 3 ogive with side strakes near the tip, and N6 was a similar ogive but with side strakes extending over the entire nose length. In figure 1(b), planform views of all configurations tested are identified by the code used throughout this report.

All model parts were constructed of stainless steel, and all models were sting mounted through the base on a six-component, strain-gage "Task" balance. The balance force center was located inside the cylindrical body 4 diameters forward of the base.

TESTS AND DATA REDUCTION

All configuration arrangements shown in figure 1(b) were tested at angles of attack from 0° to 58° on the two model-support setups shown in figure 2. One setup (fig. 2(a)) was used to test the models for α = 0° to about 27°, and the other (fig. 2(b)) was used for α = 27° to 58°.
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>2.2</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>

Several runs were made with a boundary-layer transition strip around the noses of bodies $N_1C_1$ and $N_3C_1$. This strip consisted of 0.249-cm-diam glass spheres, 0.159 cm wide and located 3.81 cm aft of the nose apex.

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 the sides, top, and bottom of the base) was used to compute the base drag, which was subtracted from the total axial-force balance measurements so that the data presented are for forces ahead of the body base. Rolling-moment coefficients were generally negligible and are omitted. 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 27) show the effects of nose fineness ratio, nose tip rounding, nose strakes, grit ring around the nose, Reynolds number, and Mach number. Each one of these effects 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, the $C_A$ data probably include some effects of support interference.

Effect of Nose Fineness Ratio

Data that show the effect of nose fineness ratio on the aerodynamic characteristics are presented in figures 3 through 7 for $M = 0.6$ to 2.0. 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, 6, and 7).

An increase in nose fineness ratio from 2.5 to 5.0 can cause significant changes in the aerodynamic characteristics. As expected, the normal-force coefficient generally increases with an increase in nose fineness ratio at all Mach numbers, and the aerodynamic force center in the normal-force plane moves forward. There are, however, some angles of attack where the changes are negligible, especially at subsonic Mach numbers.
Probably the most interesting result is the effect of nose fineness ratio on the development of side force and yawing moment with increase in angle of attack above about 25°. As shown in figures 3 and 4 for the subsonic Mach numbers of 0.6 and 0.9, the side-force and yawing-moment coefficients become rather large for the body cylinder with noses whose fineness ratios are 3.5 and 5.0 (configurations $N_2 C_1$ and $N_3 C_1$). In fact, for some angles of attack, the side forces become as large as 30 or 40 percent of the normal forces (see plots of $C_Y/C_N$ vs. $\alpha$). When the nose fineness ratio is 3.0 or less (configurations $N_1 C_1$ and $N_7 C_1$), the side-force and yawing-moment coefficients became essentially zero throughout the $\alpha$ range.

This side-force phenomenon appears to be associated primarily with subsonic flow; the side-force and yawing-moment coefficients greatly diminish at supersonic Mach numbers. They are small at $M = 1.2$ (fig. 5) and completely disappear at $M = 1.5$ (fig. 6) and $M = 2.0$ (fig. 7).

Based on the results from this investigation and from other sources (e.g., refs. 1, 2, 7, and 8), two conclusions become evident. First, the magnitudes of the maximum side-force and yawing-moment coefficients generally increase with an increase in the nose fineness ratio. Second, the magnitudes appear to decrease with an increase in Mach number.

When large side forces and yawing moments develop, the position on the body of the resultant aerodynamic force center can shift significantly. The angle $\phi$ between the normal force and resultant force can increase, and the resultant force center can move along the longitudinal axis away from the usual normal force center. In figures 8 and 9, the aerodynamic centers are given for the cylinder with fineness ratio 3 and 5 noses ($N_1 C_1$ and $N_3 C_1$) at $M = 0.6$ and 0.9. For the configuration with the fineness ratio 5 nose ($N_3 C_1$), the resultant force is moved around the body about 17° ($\phi = -17^\circ$) from the normal force at $\alpha = 40^\circ$ and $M = 0.6$ (see fig. 8). With an increase in Mach number to $M = 0.9$, the displacement angle was less ($\phi = -12^\circ$ as shown in fig. 9). Also, at $\alpha = 40^\circ$, the aerodynamic center for the resultant force, $x_{acR}/d$, is moved forward of that for the normal force, $x_{acN}/d$ (compare values of $x_{acR}/d$ and $x_{acN}/d$ in figs. 8 and 9).

Effect of Nose Tip Rounding

In figures 10 through 14, data are presented for the body cylinder ($C_1$) with the fineness ratio 3.5 ogive nose ($N_2$) and with the fineness ratio 3.5 ogive nose whose tip was cut back by rounding to give a fineness ratio of 3 ($N_4$). Also shown for comparison are data for the cylinder ($C_1$) combined with the fineness ratio 3 sharp ogive nose ($N_1$).

Generally, the nose tip rounding has little effect on the variation of $C_N$, $x_{acN}/d$, and $C_A$ with $\alpha$. However, the tip rounding appears to significantly decrease the side-force and yawing-moment coefficients that appear at $M = 0.6$ and 0.9 for $\alpha$ greater than about 25° (compare results for $N_2 C_1$ and $N_4 C_1$ in figs. 10 and 11). Even though rounding off the tip of the fineness ratio 3.5 nose to give a fineness ratio of 3 appears to be beneficial in reducing side force and yawing moment, the beneficial effect is no greater than that obtained from merely using the fineness ratio 3 sharp ogive nose (compare results for $N_4 C_1$ and $N_1 C_1$ in figs. 10 and 11).
Effect of Nose Strakes

In figures 15 through 19, data are presented which show the effect of nose strakes on the aerodynamic characteristics. Data are compared for the cylinder ($C_1$) combined with the fineness ratio 3 ogive nose ($N_1$) and the cylinder combined with fineness ratio 3 noses having side strakes ($N_5$ and $N_6$).

As expected, the nose strakes provide additional normal force and move the aerodynamic force centers forward. The configuration with the tip strake, $N_5C_1$, develops some undesirable side force at $M = 0.6$, but generally the side forces and yawing moments are very small or zero for the other configurations ($N_1C_1$ and $N_6C_1$) which are compared with $N_5C_1$.

Effect of Grit Ring Around Nose

In figures 20 through 22, data are presented which show the effect of a ring of grit around the noses of configurations $N_1C_1$ and $N_3C_1$ at $M = 0.6$, 0.9, and 1.2. This ring consisted of 0.25-cm-diam glass spheres, 0.16 cm wide, and located 3.8 cm aft of the nose tip.

The effect of the grit ring was generally small for all conditions investigated. At $M = 0.6$, the variation of $C_Y$ ($CY$) and $C_H$ ($CYN$) with $\alpha$ was changed with the grit ring in place, but the maximum magnitudes of the side-force and yawing-moment coefficients were about the same (see fig. 20).

Effect of Reynolds Number

In figures 23 through 26, data are presented which show the effect of Reynolds number for configurations $N_1C_1$ and $N_3C_1$ at $M = 0.6$ and 0.9. The Reynolds numbers are $2.2\times10^5$, $4.3\times10^5$, and $6.5\times10^5$ based on body base diameter.

For both body configurations, there is a significant effect of Reynolds number on the variation of $C_N$ and $\chi_{acN}/d$ with $\alpha$ at $M = 0.6$. Generally, $C_N$ decreases with increasing $Re$ (see figs. 23 and 25). The effect at $M = 0.9$, however, is much smaller (see figs. 24 and 25). 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. The explanation probably can be made on the basis of crossflow theory (e.g., ref. 4). The theory tells us that, for crossflow Mach numbers ($M \sin \alpha$) less than critical (about 0.4), a change in crossflow Reynolds number ($Re \sin \alpha$) from about $2\times10^5$ to $5\times10^5$ can cause a significant decrease in crossflow drag coefficient and hence 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 $2\times10^5$ throughout all of the $\alpha$ range for $Re = 2.2\times10^5$) to supercritical (greater than about $2\times10^5$ throughout most of the $\alpha$ range for $Re = 6.5\times10^5$). For this situation, crossflow theory would predict a decrease in $C_N$ at high $\alpha$ with increase in Reynolds numbers from $2.2\times10^5$ to $6.5\times10^5$. Crossflow theory, however, would predict little or no effect at $M = 0.9$, since the crossflow Mach number would be supercritical for $\alpha$ greater than about $30^\circ$. 


The effect of Reynolds number on side-force and yawing-moment coefficients appears to be significant only for the body with the high fineness ratio nose \((N_3 C_1)\) at \(M = 0.6\) (fig. 25). At present there is no explanation for this effect.

Effect of Mach Number

In figure 27, data are presented which show the effect of Mach number on the aerodynamic characteristics for configuration \(N_3 C_1\) (the fineness ratio 5 ogive nose attached to the cylinder). For the data at \(M = 0.6\) and 0.9, the Reynolds number is \(6.5 \times 10^5\), and for the data at \(M = 1.2, 1.5,\) and 2.0, the Reynolds number is \(3.8 \times 10^5\).

At the higher angles of attack, the values of \(C_N\) increase with \(M\) from \(M = 0.6\) to 1.2 or 1.5; then there is possibly a little decrease with further increase in \(M\). This trend is generally in accord with that which would be predicted from crossflow theory (ref. 4) for bodies of revolution.

The side-force and yawing-moment plots clearly demonstrate that the side-force phenomenon at \(\alpha\) greater than about 25° is essentially associated with subsonic Mach numbers. The results show that the maximum side-force coefficient was measured at about \(\alpha = 40°\), and it was as large as about 30 percent of the normal-force coefficient at \(M = 0.6\).

CONCLUSIONS

1. An increase in nose fineness ratio caused significant changes in the aerodynamic characteristics. Normal-force coefficient generally increased, and the aerodynamic normal-force center moved forward. For noses with fineness ratios greater than 3, large side-force and yawing-moment coefficients developed at subsonic Mach numbers for angles of attack above about 25°.

2. The large side-force and yawing-moment coefficients that developed at subsonic Mach numbers greatly decreased and disappeared with increase in Mach number into the supersonic flow regime.

3. Nose-tip rounding significantly decreased the side-force and yawing moment coefficients for a body with a sharp-nosed ogive of fineness ratio 3.5. However, the beneficial decrease was no greater than that obtained by merely using a sharp-nosed ogive nose of the same fineness ratio (fineness ratio 3) as that for the resulting blunted nose.

4. Nose strakes provided some additional normal force and moved the aerodynamic force centers forward, but they had little effect on the side forces and yawing moments for the body with the fineness ratio 3 nose. Unfortunately, they were not investigated on the body with the fineness ratio 5 nose, the nose that developed the largest side forces.

5. A grit ring around the fineness ratio 5 nose failed to diminish the undesirable side forces and yawing moments associated with this configuration.
6. The normal-force, aerodynamic-center, and side-force characteristics were all significantly affected by change in Reynolds number at $M = 0.6$. The effect of Reynolds number, however, decreased with increase in Mach number to $M = 0.9$.

Ames Research Center  
National Aeronautics and Space Administration  
Moffett Field, Calif. 94035, September 20, 1974

REFERENCES


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

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

Figure 1.— Concluded.
(a) Test model ($N_1 C_1$ with grit nose ring) on support setup for $\alpha = 0^\circ$ to about $27^\circ$.

Figure 2. -- Typical model-support setups in the Ames 6- by 6-Foot Wind Tunnel.
(b) Test model \( N_0 C_1 \) on support setup for \( \alpha = 27^\circ \) to \( 58^\circ \).

Figure 2.— Continued.
(c) Side view of test model \(N_6C_1\) viewed through tunnel window.

Figure 2.—Concluded.
Figure 3.— Effect of nose fineness ratio; $M = 0.6, Re = 6.5 \times 10^5$. 

(a) $\frac{x_a c_N}{d}$ and $C_N$ versus $\alpha$. 
Figure 3.— Continued.

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

Figure 3.—Concluded.
Figure 4.— Effect of nose fineness ratio; $M = 0.9$, $Re = 6.5 \times 10^5$. 

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

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<td>Cl N2 Cl N3 Cl</td>
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Figure 4.— Continued.

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

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<td>Z67/69</td>
<td>CY</td>
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</table>
(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 4.-- Concluded.
Figure 5.— Effect of nose fineness ratio; $M = 1.2, Re = 3.8 \times 10^5$. 

(a) $x_{acN}/d$ and $C_N$ versus $\alpha$. 
<table>
<thead>
<tr>
<th>SYMBOL</th>
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</table>

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

Figure 5.— Continued.
(c) $C_A$ and $C_H$ versus $\alpha$.

Figure 5.— Concluded.
Figure 6.— Effect of nose fineness ratio; $M = 1.5, Re = 3.8 \times 10^5$. 

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

Figure 6. - Continued.
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(c) \( C_A \) and \( C_n \) versus \( \alpha \).

Figure 6.— Concluded.
(a) $x_{acN}/d$ and $C_N$ versus $\alpha$.

Figure 7.-- Effect of nose fineness ratio; $M = 2.0, Re = 3.8 \times 10^5$. 
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 7.—Continued.
(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 7.— Concluded.
Figure 8. — Effect of nose fineness ratio on aerodynamic centers; $M = 0.6$, $Re = 6.5 \times 10^5$. 

(a) $\phi$ versus $\alpha$. 
(b) Aerodynamic centers versus $\alpha$ for $N_3 C_1$.

Figure 8.— Concluded.
Figure 9.— Effect of nose fineness ratio on aerodynamic centers; $M = 0.9$, $Re = 6.5 \times 10^5$. 
(b) Aerodynamic centers versus $\alpha$ for $N_3 C_1$.

Figure 9.— Concluded.
(a) $x_{acN}/d$ and $C_N$ versus $\alpha$.

Figure 10.— Effect of nose-tip rounding; $M = 0.6$, $Re = 6.5 \times 10^5$. 
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 10.—Continued.
SYMBOL CONFIGURATION DESCRIPTION
[N1 CI
[N2 CI
[N4 CI

0.50

-0.25

0.00

-0.75

-1.00

-1.25

0 10 20 30 40 50 60

ALPHA

CA

-20

-10

0

10

15

0 10 20 30 40 50 60

ALPHA

CYN

(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 10.-- Concluded.
(a) $x acN/d$ and $C_N$ versus $\alpha$.

Figure 11. – Effect of nose-tip rounding; $M = 0.9$, $Re = 6.5 \times 10^5$. 

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
Symbol & Configuration Description  \\
\hline
N1 & C1  \\
N2 & C1  \\
N4 & C1  \\
\hline
\end{tabular}
\end{table}
Figure 11.--- Continued.

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

Figure 11... Concluded.
Figure 12.— Effect of nose-tip rounding; $M = 1.2, Re = 3.8 \times 10^5$. 

(a) $\frac{x_{acN}}{d}$ and $C_N$ versus $\alpha$. 

<table>
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(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 12.—Continued.
Figure 12.— Concluded.

(c) $C_A$ and $C_n$ versus $\alpha$. 
Figure 13.-- Effect of nose-tip rounding; $M = 1.5$, $Re = 3.8 \times 10^5$.
(b) $\frac{C_y}{C_N}$ and $C_y$ versus $\alpha$.

Figure 13.—Continued.
(c) $C_A$ and $C_H$ versus $\alpha$.

Figure 13.-- Concluded.
Figure 14.— Effect of nose-tip rounding: $M = 2.0$, $Re = 3.8 \times 10^5$. (a) $x_{acN}/d$ and $C_N$ versus $\alpha$. 
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 14.-- Continued.
Figure 14. (c) $C_A$ and $C_n$ versus $\alpha$.

Figure 14. — Concluded.
Figure 15.— Effect of nose strakes; $M = 0.6$, $Re = 6.5 \times 10^5$. 

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

Figure 15.— Continued.
(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 15. – Concluded.
Figure 16.— Effect of nose strakes; $M = 0.9$, $Re = 6.5 \times 10^5$. 

(a) $\chi_{acN}/d$ and $C_N$ versus $\alpha$. 

Symbol Configuration Description
- NI CI
- ME CI
- NG CI
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 16.—Continued.
(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 16.— Concluded.
Figure 17.— Effect of nose strakes; $M = 1.2, Re = 3.8 \times 10^5$.

(a) $x/ac_N/d$ and $C_N$ versus $\alpha$. 
Figure 17.— Continued:

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

Figure 17.— Concluded.
(a) $x_{acN} / d$ and $C_N$ versus $\alpha$.

Figure 18. – Effect of nose strakes; $M = 1.5, Re = 3.8 \times 10^5$. 
SYMBOL CONFIGURATION DESCRIPTION

CI

(a) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 18. – Continued.
Figure 18.— Concluded.
Figure 19.-- Effect of nose strakes; $M = 2.0$, $Re = 3.8 \times 10^5$. 

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

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

Figure 19.— Concluded.
Figure 20. - Effect of grit ring around nose; $M = 0.6$, $Re = 6.5 \times 10^5$. 

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

**SYMBOL** | **CONFIGURATION DESCRIPTION**
--- | ---
$\times$ | $\times$
$\circ$ | $\circ$
$\square$ | $\square$
$\triangle$ | $\triangle$
$\diamond$ | $\diamond$
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 20. – Continued.
(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 20.—Concluded.
(a) $x_{acN}/d$ and $C_{N}$ versus $\alpha$.

Figure 21.— Effect of grit ring around nose; $M = 0.9$, $Re = 6.5 \times 10^5$. 
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 21.—Continued.
SYMBOL | CONFIGURATION DESCRIPTION
--- | ---
N | Cl
N | Cl
C | G
N | Cl
G | Cl
G

![Graph 1](c) $C_A$ and $C_H$ versus $\alpha$.

Figure 21.— Concluded.
(a) $x_{ac_N}/d$ and $C_N$ versus $\alpha$.

Figure 22. – Effect of grit ring around nose; $M = 1.2$, $Re = 3.8 \times 10^5$. 
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 22.— Continued.
Figure 22.— Concluded.
(a) $x_{acN}/d$ and $C_N$ versus $\alpha$.

Figure 23.— Effect of Reynolds number for $N_1 C_1 ; M = 0.6$. 

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Figure 23.— Continued.

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

Figure 23.— Concluded.
Figure 24. - Effect of Reynolds number for $N_1, C_1; M = 0.9$. 

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

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

Figure 24.— Continued.
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(c) $C_A$ and $C_N$ versus $\alpha$.

Figure 24.— Concluded.
(a) $x_{acN}/d$ and $C_N$ versus $\alpha$.

Figure 25.— Effect of Reynolds number for $N_3 C_1; M = 0.6$. 
SYMBOL         CONFIGURATION DESCRIPTION
            RE
\[ \begin{array}{ll}
\circ & 2.200 \\
\square & 2.288 \\
\text{...} & 2.288 \\
\end{array} \]

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

Figure 25.-- Continued.
(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 25.— Concluded.
Figure 26. – Effect of Reynolds number for $N_3 \; C_1 \; ; \; M = 0.9$. 

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

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

Figure 26.— Continued.
(c) $C_A$ and $C_N$ versus $\alpha$.

Figure 26.— Concluded.
Figure 27. — Effect of Mach number for $N_3 C_1$. 

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

Symbols: 
- $M = 0.598$, $\beta = 0.000$ 
- $M = 1.197$, $\beta = 0.000$ 
- $M = 1.499$, $\beta = 0.000$ 
- $M = 2.002$, $\beta = 0.000$
(b) $C_Y/C_N$ and $C_Y$ versus $\alpha$.

Figure 27.—Continued.
(c) $C_A$ and $C_n$ versus $\alpha$.

Figure 27.— Concluded.