MEASUREMENTS OF THE STATIC PRESSURE DISTRIBUTIONS AND SHOCK SHAPE ON AN OBLATE SPHEROID AT MACH NUMBERS OF 3 and 6

5 JULY 1966

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND
MEASUREMENTS OF THE STATIC PRESSURE DISTRIBUTIONS AND
SHOCK SHAPE ON AN OBLATE SPHEROID AT MACH NUMBERS OF 3 AND 6

by

Lionel Pasiuk

ABSTRACT: The results of experimental measurements of the static pressure distribution and bow shock shape on an oblate spheroid are presented. This experiment was conducted at nominal Mach numbers of 3 and 6 and a free stream Reynolds number range of $2.3 \times 10^6$ to $5.8 \times 10^6$ per foot. Comparisons are made with the calculated values of several different laboratories.
Measurements of the Static Pressure Distribution and Shock Shape on an Ovulate Spheroid at Mach Numbers of 3 and 6

This report presents the results of an experimental project at the request of the Office of Naval Research. In a separate program the Office of Naval Research had found that analytical results, performed at various laboratories, gave widely different results for the pressure distribution and shock shape on a blunt body in supersonic flow. The purpose of the present experiments was to identify which analytical prediction was correct.

The experiments were carried out in Supersonic Tunnel No. 2 and the Hypersonic Tunnel at the U. S. Naval Ordnance Laboratory.

J. A. DARE
Captain, USN
Commander

K. E. ENNEHLS
By direction
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>EXPERIMENTS</td>
<td>1</td>
</tr>
<tr>
<td>Model</td>
<td>1</td>
</tr>
<tr>
<td>Test Facilities</td>
<td>2</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>2</td>
</tr>
<tr>
<td>Experimental Procedure</td>
<td>3</td>
</tr>
<tr>
<td>Possible Sources of Error</td>
<td>3</td>
</tr>
<tr>
<td>Data Reduction</td>
<td>4</td>
</tr>
<tr>
<td>Pressure</td>
<td>4</td>
</tr>
<tr>
<td>Shock Shape</td>
<td>4</td>
</tr>
<tr>
<td>RESULTS</td>
<td>4</td>
</tr>
<tr>
<td>Pressure</td>
<td>4</td>
</tr>
<tr>
<td>Shock Shape</td>
<td>5</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>5</td>
</tr>
<tr>
<td>REFERENCE</td>
<td>6</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

Figure 1  Sketch of the oblate spheroid showing pressure tap locations.
Figure 2  Photograph of the oblate spheroid model.
Figure 3  Schematic diagram of the test setup.
Figure 4  Comparison between the experimental and calculated values of the surface pressure on the oblate spheroid model at $M = 3$.
Figure 5  Comparison between the experimental and calculated values of the surface pressure on the oblate spheroid model at $M = 6$.
Figure 6  Schlieren photograph of the shock wave and model at $M = 3$.
Figure 7  Schlieren photograph of the shock wave and model at $M = 6$.
Figure 8  Comparison between the experimental and calculated values of the shock wave produced by the oblate spheroid model at $M = 3$.

TABLES

Table 1  Comparison Between Measured and Desired Model Contour
Table 2  Experimental Pressure Distribution on an Oblate Spheroid
SYMBOLS

\( a \) major axis of the oblate spheroid

\( B \) bluntness parameter of the oblate spheroid,
\( B = (a/b)^3 \)

\( b \) minor axis of the oblate spheroid

\( D \) model base diameter

\( M \) Mach number

\( P \) dimensionless pressure, \( P = p/\rho_\infty u_\infty^2 \)

\( p \) pressure

\( P_0 \) supply pressure

\( R \) coordinate normal to the flow

\( R_C \) model radius of curvature at the stagnation point

\( \text{Re}_D \) Reynolds number based on model diameter,
\( \text{Re}_D = \rho_\infty u_\infty D/\mu_\infty \)

\( r \) nondimensional coordinate normal to the flow,
\( r = R/R_C \)

\( T_o \) supply temperature

\( u_\infty \) free stream velocity

\( Z \) coordinate in the flow direction

\( Z_M \) measured \( Z \) coordinate of the model

\( z \) nondimensional coordinate in the flow direction,
\( z = Z/R_C \)

\( \mu_\infty \) absolute viscosity in the free stream

\( \rho_\infty \) density in the free stream

\( \phi \) roll angle
INTRODUCTION

Comparisons of various numerical calculations of the detached shock flow field about a series of blunt bodies were made at the Naval Weapons Laboratory under the sponsorship of the Office of Naval Research. Calculations were performed by several government and private laboratories on ellipsoids of revolution of various degrees of bluntness. Details of these methods and the results of the calculations are given in reference (1). This report contains the results of surface pressure and detailed shock wave measurements on one of these bodies and compares the experimental results with the corresponding numerical calculations.

EXPERIMENTS

Model

The model is an oblate spheroid. A sketch is given in Figure 1 and a photograph in Figure 2. To make the photograph a mirror was placed behind the model so that both its front and back may be seen. Its degree of bluntness $B$, is defined as the ratio of its major to minor axis squared,

$$B = \left(\frac{a}{b}\right)^2$$

and for this model $B = 4$. Both the maximum diameter $D$, and the radius of curvature at the stagnation point $R_c$, have values of 4 inches. The contour is given by the following equation,

$$r = 2[z(2-z)]^{1/3}$$

when the origin is taken as the stagnation point. This contour is continued in the base region.

There are 24 pressure orifices on the model, each with a diameter of 0.030 inches. The location of these orifices is given in the table in Figure 1.

The model’s original surface finish was 32 microinches, and this finish remained the same through the $M = 3$ test in Supersonic Tunnel No. 2. But during the test in the Hypersonic Tunnel at $M = 6$, the surface finish became very rough on the windward half of the model and this roughness is now measured to be from 60 to 85 microinches.
Both the model and pressure tubing are made from stainless steel. The tubes are connected to the model with high temperature silver solder.

**Test Facilities**

These tests were made in Supersonic Tunnel No. 2 and the Hypersonic Tunnel of the Naval Ordnance Laboratory. The boundary layer on the model was laminar in all cases. The tunnel running conditions were as follows:

**Supersonic Tunnel No. 2:**

- Mach Number = 3.04
- Supply Pressure = 15.7 to 34.7 lb/in² abs.
- Supply Temperature = 59 to 68°F
- Reynolds Number per foot = $2.6 \times 10^6$ to $5.8 \times 10^6$
- Reynolds number based on diameter = $0.87 \times 10^6$ to $1.93 \times 10^6$

**Hypersonic Tunnel:**

- Mach Number = 5.98
- Supply Pressure = 177 to 444 lb/in² abs.
- Supply Temperature = 631 to 667°F
- Reynolds Number per foot = $2.3 \times 10^6$ to $5.5 \times 10^6$
- Reynolds Number based on diameter = $0.77 \times 10^6$ to $1.83 \times 10^6$

**Instrumentation**

Figure 3 is a schematic diagram of the pressure instrumentation setup. Each pressure tap is connected to a pressure transducer by stainless steel tubing. The transducer is mounted in a pressure switch capable of holding 48 transducers and switching each one from model to calibration pressures. The electrical signal from the transducer is recorded on magnetic tape by the DARE data readout system. This system is capable of continuously recording 100 inputs per second. At the same time two pressure taps are monitored on plotters. These two pressure taps are at the same location 180 degrees apart and are used to aerodynamically align the model.

Two brands of transducers are used. They are the CEC 312 and the Statham 130. For the pressures on the windward half of the model, 0 to 15 psia transducers are used, whereas the pressures on the leeward half were read on 0 to 5 psia transducers.
Experimental Procedure

The experimental procedure was essentially the same for both wind tunnel tests. The model was oriented in the test section so that all of the pressure taps lie in the same pitch plane. Then all pressure tube connections were made and the pressure measuring system was checked for leaks. Immediately before each data run was made, each transducer was calibrated at values of 0, 0.5, 1.0, 10.0 and 15.0 lb/in² absolute.

During each data run the following steps were followed:

1. Supply pressure and temperature were stabilized at the desired value.
2. Pressures recorded on the two plotters were observed. If the model is aligned with the flow these pressures will be equal.
3. The data were continuously recorded on magnetic tape for approximately 10 seconds giving 10 data points for each tap.
4. While the pressure data were being recorded, schlieren pictures of the flow field were photographed.

Possible Sources of Error

Measurements of the model contour were made after the tests and these measurements were not identical to the design values. Table I gives the measured and design values of the contours. As can be seen, the error in the contour becomes greater as r increases and the maximum absolute error in z is 0.007 inches. These small errors give a model that is a little more blunt. Based on a Newtonian pressure distribution, the error is less than 1.5 percent.

The sensitivity of the data readout system was better than one percent.

The transducers used were stable with time. Drift from calibration to calibration was no more than 0.5 percent for 95 percent of the transducers and none drifted more than 2.0 percent.

The gages used to read the calibration pressures are less than 0.5 percent in error.

The model was not in exact alignment with the flow. For the M = 3 and M = 6 data the percent pressure difference due to misalignment was up to 1.0 percent and 2.0 percent, respectively.
Therefore, the pressure error due to misalignment is not more
than 0.5 percent and 1.0 percent for the M = 3 and M = 6 data,
respectively.

The schlieren photographs of the shock shape were made with
70 millimeter black and white film. The expected dimensional
change of this film is less than 0.2 percent. This is well
below the measurement errors. Quantitative measurements of the
shock shape were obtained by reading the negatives on a tele-
reader. The telereader gave from 100 to 125 counts between the
shock and the body, and a measurement between two clearly defined
points could be made to within one count. The degree of scatter
of these measurements is caused by the poor definition of the
shock.

Data Reduction

Pressure

Before reducing the data the pressure calibrations of each
transducer were plotted and found to be linear in the range of
pressures encountered during the tests. Then each pressure
measurement was reduced by linear interpolation between the two
nearest calibration points.

Shock Shape

The shock shape was measured on a telereader. This
instrument projects the negative on a frosted screen through an
optical system. Superimposed over the negative's image were
vertical and horizontal cross-hairs. The negative was adjusted
so that the model was aligned with the cross-hairs and the
telereader was zeroed at the stagnation point. The z position
of the shock model was measured for various values of r and
the corresponding count readings were punched on data cards.
Then these counts were reduced to inches on the IBM 7090 computer.

RESULTS

Pressure

Table 2 contains a list of the pressure measurements for
both M = 3.04 and M = 5.98 data. The pressure data are ratioed
to $\frac{\rho_0 U_0^2}{2}$ and the model coordinates are made dimensionless with
respect to the radius of curvature at the stagnation point
(4 inches for this model).

Figure 4 is a plot of the M = 3 pressure data along with
several calculated curves. As can be seen, the curves generated
by MIT, AVCO, NASA, and NWL are in best agreement with the
experimental data. The curve labeled DOUGLAS 1 follows the experimental data for $0 \leq r \leq 0.35$, then falls slightly below. NORTHROP's calculations are in agreement for $0 \leq r \leq 0.3$.

Presented in Figure 5 is the data for $M = 6$. Again the NASA and NWL curves are in best agreement along with the DOUGLAS 1 and DOUGLAS 2 curves. The calculated values of NORTHROP are in good agreement in the range $0 \leq r \leq 0.325$. Here the MIT and AVCO curves fall somewhat below the experimental data.

The direct method of calculating the flow field is used by MIT, AVCO, and NWL, whereas NASA and DOUGLAS 1 use the inverse method. For a more complete description of the calculated values, see reference (1).

Shock Shape

Figures 6 and 7 are schlieren photographs of the bow wave and model at Mach numbers of 3.04 and 5.98, respectively. The $M = 3.04$ shock shape measurements are compared with the calculated values in Figure 8. The shock shapes generated by NASA, DOUGLAS 1, NWL, NORTHROP, MIT, and AVCO are in best agreement with the experimental data. For the most part, these agreements are consistent with the pressure results.

Due to the increase in the scatter of the shock measurements at $M = 5.98$, the comparisons with calculated values are not as certain as those made with the $M = 3.04$ data. It appears that the results at Mach 5.98 are very similar to those at Mach 3.04.

CONCLUSIONS

The results of experimental static pressure and shock shape measurements on an oblate spheroid have been presented. These results show that the calculations of NASA, DOUGLAS 1, and NWL are consistently in good agreement with the experimental data. Also, the predictions of NORTHROP are in good agreement with experiments from the stagnation point to $r = 0.3$. 
REFERENCE

(1) Perry, J., "A Comparison of Solutions to Some Blunt Body Problems," to be published as a report by the U. S. Naval Weapons Laboratory, Dahlgren, Virginia
TABLE 1
COMPARISON BETWEEN MEASURED AND DESIRED MODEL CONTOUR

<table>
<thead>
<tr>
<th>R (in.)</th>
<th>Measured Z_m (in.)</th>
<th>Design Z (in.)</th>
<th>Z - Z_m (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.1</td>
<td>.0010</td>
<td>.0010</td>
<td>0</td>
</tr>
<tr>
<td>.2</td>
<td>.0046</td>
<td>.0040</td>
<td>-.0006</td>
</tr>
<tr>
<td>.3</td>
<td>.0107</td>
<td>.0110</td>
<td>.0003</td>
</tr>
<tr>
<td>.4</td>
<td>.0169</td>
<td>.0200</td>
<td>.0004</td>
</tr>
<tr>
<td>.5</td>
<td>.0308</td>
<td>.0320</td>
<td>.0012</td>
</tr>
<tr>
<td>.6</td>
<td>.0449</td>
<td>.0450</td>
<td>.0011</td>
</tr>
<tr>
<td>.7</td>
<td>.0617</td>
<td>.0630</td>
<td>.0013</td>
</tr>
<tr>
<td>.8</td>
<td>.0818</td>
<td>.0840</td>
<td>.0022</td>
</tr>
<tr>
<td>.9</td>
<td>.1048</td>
<td>.1060</td>
<td>.0012</td>
</tr>
<tr>
<td>1.0</td>
<td>.1316</td>
<td>.1340</td>
<td>.0024</td>
</tr>
<tr>
<td>1.1</td>
<td>.1622</td>
<td>.1640</td>
<td>.0018</td>
</tr>
<tr>
<td>1.2</td>
<td>.1969</td>
<td>.2000</td>
<td>.0031</td>
</tr>
<tr>
<td>1.3</td>
<td>.2366</td>
<td>.2400</td>
<td>.0034</td>
</tr>
<tr>
<td>1.4</td>
<td>.2824</td>
<td>.2860</td>
<td>.0036</td>
</tr>
<tr>
<td>1.5</td>
<td>.3349</td>
<td>.3380</td>
<td>.0031</td>
</tr>
<tr>
<td>1.6</td>
<td>.3953</td>
<td>.4000</td>
<td>.0074</td>
</tr>
<tr>
<td>1.7</td>
<td></td>
<td>.4980</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>.5585</td>
<td>.5640</td>
<td>.0055</td>
</tr>
<tr>
<td>1.9</td>
<td>.6807</td>
<td>.6880</td>
<td>.0073</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td>1.0000</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 2

**EXPERIMENTAL PRESSURE DISTRIBUTION ON AN OBLATE SPHEROID**

Bluntness Parameter $B = 4$

Radius of Curvature at Stagnation Point, $R_c = 4$ inches

Maximum Diameter = 4 inches

\[
\begin{align*}
M &= 5.98 \\
P_o &= 443.6 \text{ lb/in}^2 \text{ abs.} \\
T_o &= 631^\circ F \\
R_e_D &= 1.92 \times 10^8
\end{align*}
\]

\[
\begin{align*}
M &= 3.04 \\
P_o &= 31.1 \text{ lb/in}^2 \text{ abs.} \\
T_o &= 68^\circ F \\
R_e_D &= 1.70 \times 10^8
\end{align*}
\]

<table>
<thead>
<tr>
<th>$r$</th>
<th>$P$</th>
<th>Leeward</th>
<th>$\phi=0^\circ$</th>
<th>$\phi=180^\circ$</th>
<th>$\phi=0^\circ$</th>
<th>$\phi=180^\circ$</th>
<th>$\phi=0^\circ$</th>
<th>$\phi=180^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.930</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.050</td>
<td>.928</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.100</td>
<td>.914</td>
<td>.910</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.200</td>
<td>.868</td>
<td>.874</td>
<td>.0169</td>
<td></td>
<td></td>
<td></td>
<td>.200</td>
<td>.882</td>
</tr>
<tr>
<td>0.250</td>
<td>.821</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.300</td>
<td>.764</td>
<td>.780</td>
<td>.0163</td>
<td></td>
<td></td>
<td>0.300</td>
<td>.764</td>
<td>.801</td>
</tr>
<tr>
<td>0.325</td>
<td>.720</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.325</td>
<td>.725</td>
<td></td>
</tr>
<tr>
<td>0.350</td>
<td>.675</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.350</td>
<td>.708</td>
<td>.0398</td>
</tr>
<tr>
<td>0.375</td>
<td>.626</td>
<td></td>
<td>.0167</td>
<td></td>
<td></td>
<td>0.375</td>
<td>.661</td>
<td></td>
</tr>
<tr>
<td>0.400</td>
<td>.558</td>
<td>.568</td>
<td>.0163</td>
<td></td>
<td></td>
<td>0.400</td>
<td>.558</td>
<td>.596</td>
</tr>
<tr>
<td>0.425</td>
<td>.475</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.425</td>
<td>.514</td>
<td></td>
</tr>
<tr>
<td>0.450</td>
<td>.378</td>
<td>.0164</td>
<td></td>
<td></td>
<td></td>
<td>0.450</td>
<td>.405</td>
<td>.0372</td>
</tr>
<tr>
<td>0.500</td>
<td>.043</td>
<td>.043</td>
<td></td>
<td></td>
<td></td>
<td>0.500</td>
<td>.052</td>
<td>.050</td>
</tr>
</tbody>
</table>
**FIG. 1** SKETCH OF THE OBLATE SPHEROID SHOWING PRESSURE TAP LOCATIONS

- **COORDINATES:** \( R = 2 \sqrt{2} - Z \)

- **MODEL RADIUS:** 2.00 in.
- **STING RADIUS:** 0.50 in.

**FLOW**

**PRESSURE TAP LOCATIONS**

<table>
<thead>
<tr>
<th>TAP NO.</th>
<th>R</th>
<th>Z</th>
<th>TAP NO.</th>
<th>R</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INCHES</td>
<td>INCHES</td>
<td></td>
<td>INCHES</td>
<td>INCHES</td>
</tr>
<tr>
<td>1</td>
<td>0.200</td>
<td>0.004</td>
<td>13</td>
<td>1.170</td>
<td>0.472</td>
</tr>
<tr>
<td>2</td>
<td>0.400</td>
<td>0.046</td>
<td>14</td>
<td>1.800</td>
<td>0.566</td>
</tr>
<tr>
<td>3</td>
<td>0.600</td>
<td>0.084</td>
<td>15</td>
<td>2.000</td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>1.000</td>
<td>0.134</td>
<td>16</td>
<td>1.200</td>
<td>0.400</td>
</tr>
<tr>
<td>5</td>
<td>1.200</td>
<td>0.180</td>
<td>17</td>
<td>1.800</td>
<td>1.438</td>
</tr>
<tr>
<td>6</td>
<td>1.400</td>
<td>0.226</td>
<td>18</td>
<td>1.600</td>
<td>1.600</td>
</tr>
<tr>
<td>7</td>
<td>1.500</td>
<td>0.273</td>
<td>19</td>
<td>1.400</td>
<td>1.714</td>
</tr>
<tr>
<td>8</td>
<td>1.600</td>
<td>0.320</td>
<td>20</td>
<td>1.800</td>
<td>1.800</td>
</tr>
<tr>
<td>9</td>
<td>1.600</td>
<td>0.367</td>
<td>21</td>
<td>1.200</td>
<td>1.800</td>
</tr>
<tr>
<td>10</td>
<td>1.700</td>
<td>0.414</td>
<td>22</td>
<td>0.800</td>
<td>1.916</td>
</tr>
<tr>
<td>11</td>
<td>1.700</td>
<td>0.461</td>
<td>23</td>
<td>0.600</td>
<td>1.916</td>
</tr>
<tr>
<td>12</td>
<td>1.700</td>
<td>0.508</td>
<td>24</td>
<td>0.400</td>
<td>1.916</td>
</tr>
</tbody>
</table>
NOTE:
PRESSURE TRANSUDCERS ARE MOUNTED IN A CAN THAT HOLDS 48 TRANSUDCERS. THE VALVE IS MOUNTED INSIDE THE CAN AND ALLOWS FOR SWITCHING THE TRANSUDCER FROM CALIBRATION TO MODEL PRESSURES.

DARE DATA READONT

PLOTTER

MAGNETIC TAPE

IBM 7090

FIG. 2 SCHEMATIC DIAGRAM OF THE TEST SET-UP
FIG. 4 COMPARISON BETWEEN THE EXPERIMENTAL AND CALCULATED VALUES OF THE SURFACE PRESSURE ON THE OBLATE SPHEROID MODEL AT $M = 3$. 
FIG. 5 COMPARISON BETWEEN THE EXPERIMENTAL AND CALCULATED VALUES OF THE SURFACE PRESSURE ON THE OBLATE SPHEROID MODEL AT $M = 6$. 

B
FIG. 8  SCHLIEREN PHOTOGRAPH OF THE SHOCK WAVE AND MODEL AT M = 0
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A1)

Commander, Naval Ordnance Systems Command
Department of the Navy
Washington, D. C. 20360
Attn: ORD 034
Attn: ORD 03211
Attn: ORD 0351

Commander, Naval Air Systems Command
Department of the Navy
Washington, D. C. 20360
Attn: AIR 604
Attn: AIR 03C
Attn: AIR 320

Office of Naval Research
T-3
Washington, D. C. 20390
Attn: Head, Structural Mechanics Branch
Attn: Head, Fluid Dynamics Branch

Director, David Taylor Model Basin
Aerodynamics Laboratory
Washington, D. C. 20007
Attn: Library

Commander, U. S. Naval Ordnance Test Station
China Lake, California 93557
Attn: Technical Library
Attn: Code 406

Director, Naval Research Laboratory
Washington, D. C. 20390
Attn: Code 2027

Commanding Officer
Office of Naval Research
Branch Office
Box 39, Navy 100
FPO, New York, New York 09510

NASA
High Speed Flight Station
Box 273
Edwards Air Force Base, California 93523

NASA
Ames Research Center
Moffett Field, California 94035
Attn: Librarian
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A1)

No. of
Copies

NASA
Langley Research Center
Langley Station, Hampton, Virginia 23362
Attn: (Mrs.) Elizabeth R. Gilman, Librarian, Bldg. 1244
Attn: C. H. McLellan
Attn: Theoretical Aerodynamics Division

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland 11, Ohio 44135
Attn: Librarian
Attn: Chief, Propulsion Aerodynamics Division

NASA
600 Independence Ave., S. W.
Washington, D. C. 20546
Attn: Chief, Division of Research Information
Attn: Dr. H. H. Kurzweg, Director of Research

Office of the Assistant Secretary of Defense (R&D)
Room 3E1065, The Pentagon
Washington 25, D. C. 20301
Attn: Technical Library

Research and Development Board
Room 3D1041, The Pentagon
Washington 25, D. C. 20301
Attn: Library

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314

Commander, Pacific Missile Range
Point Mugu, California 93041
Attn: Technical Library

Commanding General
Aberdeen Proving Ground, Maryland 21005
Attn: Technical Information Branch
Attn: Ballistic Research Laboratories

2
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A1)

No. of Copies

Commander, Naval Weapons Laboratory
Dahlgren, Virginia 22448
Attn: Library

Director, Special Projects
Department of the Navy
Washington 25, D. C. 20360
Attn: SP-2722

Director of Intelligence
Headquarters, USAF
Washington 25, D. C. 20330
Attn: AFOIN-3B

Headquarters - Aero. Systems Division
Wright-Patterson Air Force Base
Dayton, Ohio 45433
Attn: WWAD
Attn: RRLA-Library

Commander
Air Force Ballistic Systems Division
Norton Air Force Base
San Bernardino, California 92409
Attn: BSRVA

Chief, Defense Atomic Support Agency
Washington 25, D. C. 20360
Attn: Document Library

Headquarters, Arnold Engineering Development Center
ARO, Inc.
Arnold Air Force Station, Tennessee 37389
Attn: Technical Library
Attn: AEOR
Attn: AEOIM

Commanding Officer, Harry Diamond Laboratories
Washington 25, D. C. 20438
Attn: Library, Room 211, Bldg. 92

Commanding General
U. S. Army Missile Command
Redstone Arsenal, Alabama 35808
Attn: AMSMI-RR (Mr. N. Shapiro)
Attn: AMSMI-RB (Redstone Scientific Information Center)

3
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A1)

No. of
Copies

NASA
George C. Marshall Space Flight Center
Huntsville, Alabama 35812
  Attn: Dr. E. Geissler
  Attn: Mr. T. Reed
  Attn: Mr. H. Paul
  Attn: Mr. W. Dahm
  Attn: Mr. H. A. Connell
  Attn: Mr. J. Kingsbury
  Attn: ARDAB-DA

APL/JHU (NOW 7386)
8621 Georgia Avenue
Silver Spring, Maryland 20910
  Attn: Technical Reports Group
  Attn: Mr. Richard Suess
  Attn: Dr. F. Hill
  Attn: Dr. L. L. Kronvich

Scientific & Technical Information Facility
P. O. Box 5700
Bethesda, Maryland 20014
  Attn: NASA Representative (S-AKAKL)

Commander
Air Force Flight Test Center
Edwards Air Force Base
Muroc, California 93523
  Attn: FTOTL

Air Force Office of Scientific Research
Holloman Air Force Base
Alamogordo, New Mexico 88310
  Attn: SRLTL

U. S. Army Engineer Research & Development Laboratories
Fort Belvoir, Virginia 22060
  Attn: STINFO Branch

Aerospace Research Laboratories
Wright-Patterson Air Force Base
Ohio 45433
  Attn: Thermo-Mechanics Research Laboratory (ARN)
University of Minnesota
Minneapolis 14, Minnesota 55455
Attn: Dr. E. R. G. Eckert
Attn: Heat Transfer Laboratory
Attn: Technical Library

Rensselaer Polytechnic Institute
Troy, New York 12180
Attn: Dept. of Aeronautical Engineering

Dr. James P. Hartnett
Department of Mechanical Engineering
University of Delaware
Newark, Delaware 19711

Princeton University
James Forrestal Research Center
Gas Dynamics Laboratory
Princeton, New Jersey 08540
Attn: Prof. S. Bogdonoff
Attn: Dept. of Aeronautical Engineering Library

Defense Research Laboratory
The University of Texas
P. O. Box 8029
Austin 12, Texas 78712
Attn: Assistant Director

Ohio State University
Columbus 10, Ohio 43210
Attn: Security Officer
Attn: Aerodynamics Laboratory
Attn: Dr. J. Lee
Attn: Chairman, Dept. of Aero. Engineering

California Institute of Technology
Pasadena, California 91109
Attn: Guggenheim Aero. Laboratory,
Aeronautics Library
Attn: Jet Propulsion Laboratory
Attn: Dr. H. Liepmann
Attn: Dr. L. Lees
Attn: Dr. D. Coles
Attn: Dr. A. Roshko

Case Institute of Technology
Cleveland 6, Ohio 44106
Attn: G. Kuerti

1
<table>
<thead>
<tr>
<th>Institution</th>
<th>Address</th>
<th>City, State, Zip</th>
<th>Attn:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Ballistics Laboratory</td>
<td>Army Ballistic Missile Agency</td>
<td>Huntsville, AL</td>
<td>J. H. Russell</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Aero-Space Division</td>
</tr>
<tr>
<td>Applied Mechanics Reviews</td>
<td>Southwest Research Institute</td>
<td>San Antonio, TX</td>
<td>W. Kuhrt</td>
</tr>
<tr>
<td></td>
<td>8500 Culebra Road</td>
<td></td>
<td>Research Department</td>
</tr>
<tr>
<td>BUWEPs Representative</td>
<td>Aerojet-General Corporation</td>
<td>Azusa, CA</td>
<td>J. G. Lee</td>
</tr>
<tr>
<td></td>
<td>6352 N. Irwindale Avenue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Boeing Company</td>
<td>Seattle, WA</td>
<td></td>
<td>J. H. Russell</td>
</tr>
<tr>
<td></td>
<td>Attn: J. H. Russell, Aero-Space Division</td>
<td></td>
<td>Research Library</td>
</tr>
<tr>
<td>United Aircraft Corporation</td>
<td>400 Main Street</td>
<td>East Hartford, CT</td>
<td>Chief Librarian</td>
</tr>
<tr>
<td></td>
<td>East Hartford CT</td>
<td></td>
<td>Mr. W. Kuhrt</td>
</tr>
<tr>
<td></td>
<td>Attn: Mr. W. Kuhrt, Research Department</td>
<td></td>
<td>Mr. J. G. Lee</td>
</tr>
<tr>
<td>Hughes Aircraft Company</td>
<td>90230</td>
<td>Culver City, CA</td>
<td>D. J. Johnson</td>
</tr>
<tr>
<td></td>
<td>Florence Avenue at Teale Streets</td>
<td></td>
<td>R&amp;D Technical Library</td>
</tr>
<tr>
<td>McDonnell Aircraft Corporation</td>
<td>P. O. Box 516</td>
<td>St. Louis, MO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Louis, MO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lockheed Missiles and Space Company</td>
<td>P. O. Box 504</td>
<td>Sunnyvale, CA</td>
<td>Dr. L. H. Wilson</td>
</tr>
<tr>
<td></td>
<td>Sunnyvale, CA</td>
<td></td>
<td>M. Tucker</td>
</tr>
<tr>
<td>Martin Company</td>
<td>Baltimore, MD</td>
<td></td>
<td>Dr. R. Smelt</td>
</tr>
<tr>
<td></td>
<td>Attn: Library</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attn: Chief Aerodynamicist</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attn: Dr. W. Morkovin, Aerophysics Division</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CONVAIR
A Division of General Dynamics Corporation
Fort Worth, Texas 76101
Attn: Library
Attn: Theoretical Aerodynamics Group

Purdue University
School of Aeronautical & Engineering Sciences
Lafayette, Indiana 47907
Attn: R. L. Taggart, Library

University of Maryland
College Park, Maryland 20742
Attn: Director
Attn: Dr. J. Burgers
Attn: Librarian, Engr. & Physical Sciences
Attn: Librarian, Institute for Fluid Dynamics and Applied Mathematics
Attn: Prof. S. I. Pai

University of Michigan
Ann Arbor, Michigan 48104
Attn: Dr. A. Kuethe
Attn: Dr. A. Laporte
Attn: Department of Aeronautical Engineering

Stanford University
Palo Alto, California 94305

Cornell University
Graduate School of Aeronautical Engineering
Ithaca, New York 14850
Attn: Prof. W. R. Sears

The Johns Hopkins University
Charles and 34th Streets
Baltimore, Maryland 21218
Attn: Dr. F. H. Clauser

University of California
Berkeley 4, California 94720
Attn: G. Maslach
Attn: Dr. S. A. Schaaf
Attn: Dr. Holt
Attn: Institute of Engineering Research
Cornell Aeronautical Laboratory, Inc.  
4455 Genesee Street  
Buffalo 21, New York 14225  
Attn: Librarian  
Attn: Dr. Franklin Moore  
Attn: Dr. J. G. Hall  
Attn: Mr. A. Hertzberg

University of Minnesota  
Rosemount Research Laboratories  
Rosemount, Minnesota 55068  
Attn: Technical Library

Director, Air University Library  
Maxwell Air Force Base, Alabama 36112

Douglas Aircraft Company, Inc.  
Santa Monica Division  
3000 Ocean Park Boulevard  
Santa Monica, California 90405  
Attn: Chief Missiles Engineer  
Attn: Aerodynamics Section

CONVAIR  
A Division of General Dynamics Corporation  
Daingerfield, Texas 75638

CONVAIR  
Scientific Research Laboratory  
5001 Kearney Villa Road  
San Diego, California 92123  
Attn: Asst. to the Director of Scientific Research  
Attn: Dr. B. M. Leadon  
Attn: Library

Republic Aviation Corporation  
Farmingdale, New York 1735  
Attn: Technical Library

General Applied Science Laboratories, Inc.  
Merrick and Stewart Avenues  
Westbury, L. I., New York 11590  
Attn: Mr. R. W. Byrne
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A2)

Arnold Research Organization, Inc.
Tullahoma, Tennessee 37389
Attn: Technical Library
Attn: Chief, Propulsion Wind Tunnel
Attn: Dr. J. L. Potter

General Electric Company
Missile Space Division
3198 Chestnut Street
Philadelphia, Pennsylvania 19104
Attn: Larry Chasen, Mgr. Library
Attn: Mr. R. Kirby
Attn: Dr. J. Farber
Attn: Dr. G. Sutton
Attn: Dr. J. D. Stewart
Attn: Dr. S. M. Scala
Attn: Dr. H. Lew
Attn: Mr. J. Persh

Eastman Kodak Company
Navy Ordnance Division
50 West Main Street
Rochester 14, New York 14614
Attn: W. B. Forman

Library
AVCO-Everett Research Laboratory
2385 Revere Beach Parkway
Everett 49, Massachusetts 02149

Chance-Vought Corp.
Post Office Box 5907
Dallas, Texas 75222
Library 1-6310/3L-2884

National Science Foundation
1951 Constitution Avenue, N. W.
Washington 25, D. C. 20550
Attn: Engineering Sciences Division

New York University
University Heights
New York 53, New York 10453
Attn: Department of Aeronautical Engineering
New York University  
25 Waverly Place  
New York, New York 10003  
Attn: Library, Institute of Math. Sciences

NORAIR  
A Division of Northrop Corporation  
Hawthorne, California 90250  
Attn: Library

Northrop Aircraft, Inc.  
Hawthorne, California 90250  
Attn: Library

Gas Dynamics Laboratory  
Technological Institute  
Northwestern University  
Evanston, Illinois 60201  
Attn: Library

Pennsylvania State University  
University Park, Pennsylvania 16802  
Attn: Library, Dept. of Aero. Engineering

The Ramo-Wooldridge Corporation  
8820 Bellanca Avenue  
Los Angeles 45, California 90045

Gifts and Exchanges  
Fondren Library  
Rice Institute  
P. O. Box 1892  
Houston, Texas 77001

University of Southern California  
Engineering Center  
Los Angeles 7, California 90007  
Attn: Librarian

The Editor  
Battelle Technical Review  
Battelle Memorial Institute  
505 King Avenue  
Columbus, Ohio 43201

Douglas Aircraft Company, Inc.  
Long Beach, California 90801  
Attn: Library
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A2)

Fluidyne Engineering Corporation
5740 Wayzata Boulevard
Golden Valley
Minneapolis, Minnesota 55416

Grumman Aircraft Engineering Corporation
Bethpage, Long Island, New York 11714

Lockheed Missiles and Space Company
P. O. Box 551
Burbank, California 91503
   Attn: Library
   Attn: M. Laden
Marquardt Aircraft Corporation
7801 Havenhurst
Van Nuys, California 91406

Martin Company
Denver, Colorado 80201

Martin Company
Orlando, Florida 32805
   Attn: J. Mayer

Mississippi State College
Engineering and Industrial Research Station
Aerophysics Department
P. O. Box 248
State College, Mississippi 39762

Lockheed Missiles and Space Company
3251 Hanover Street
Palo Alto, California 94304
   Attn: Library

General Electric Company
Research Laboratory
Schenectady, New York 12301
   Attn: Dr. H. T. Nagamatsu
   Attn: Library

Fluid Dynamics Laboratory
Mechanical Engineering Department
Stevens Institute of Technology
Hoboken, New Jersey 07030
   Attn: Dr. R. H. Page, Director
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A2)

No. of Copies

Department of Mechanical Engineering
University of Arizona
Tucson, Arizona 85721
  Attn: Dr. E. K. Parks

Vitro Laboratories
200 Pleasant Valley Way
West Orange, New Jersey 07052

Department of Aeronautical Engineering
University of Washington
Seattle, Washington 98105
  Attn: Prof. R. E. Street
  Attn: Library

American Institute of Aeronautics & Astronautics
1290 Avenue of the Americas
New York, New York 10019
  Attn: Managing Editor
  Attn: Library

Department of Aeronautics
United States Air Force Academy
Colorado 80840

MHD Research, Inc.
Newport Beach, California 92660
  Attn: Technical Director

University of Alabama
College of Engineering
University, Alabama 35486
  Attn: Head, Dept. of Aeronautical Engineering

ARDE Associates
100 W. Century Road
Paramus, New Jersey 07652
  Attn: Mr. Edward Cooperman

Aeronautical Research Associates of Princeton
50 Washington Road
Princeton, New Jersey 08540
  Attn: Dr. C. duP. Donaldson, President

9
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A2)

No. of
Copies

Daniel Guggenheim School of Aeronautics
Georgia Institute of Technology
Atlanta, Georgia 30332
Attn: Prof. A. L. Ducoffe

University of Cincinnati
Cincinnati, Ohio 45221
Attn: Prof. R. P. Harrington, Head
Dept. of Aeronautical Engineering
Attn: Prof. Ting Yi Li, Aerospace Engineering Dept.

Virginia Polytechnic Institute
Dept. of Aerospace Engineering
Blacksburg, Virginia 24061
Attn: Dr. R. T. Keefe
Attn: Dr. J. B. Eades, Jr.
Attn: Library

IBM Federal System Division
7220 Wisconsin Avenue
Bethesda, Maryland 20014
Attn: Dr. I. Korobkin

Superintendent
U. S. Naval Postgraduate School
Monterey, California 93940
Attn: Technical Reports Section Library

National Bureau of Standards
Washington 25, D. C. 20234
Attn: Chief, Fluid Mechanics Section

North Carolina State College
Raleigh, North Carolina 27607
Attn: Division of Engineering Research
Technical Library

Defense Research Corporation
P. O. Box No. 3587
Santa Barbara, California 93015
Attn: Dr. J. A. Laurmann

Aerojet-General Corporation
6352 North Irwindale Avenue
Box 296
Azusa, California 91702
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A2)

No. of Copies

Apollo - DDCS
General Electric Company
A&E Building, Room 204
Daytona Beach, Florida 32014
   Attn: Dave Hovis

University of Minnesota
Institute of Technology
Minneapolis, Minnesota 55455
   Attn: Prof. J. D. Akerman

Guggenheim Laboratory
Stanford University
Stanford, California 94305
   Attn: Prof. D. Bershader, Department of Aero.
       Engineering

Space Technology Laboratory, Inc.
1 Space Park
Redondo Beach, California 90278
   Attn: STL Tech. Lib. Doc. Acquisitions

University of Illinois
Department of Aeronautical and Astronautical Engineering
Urbana, Illinois 61801
   Attn: Prof. H. S. Stilwell

Armour Research Foundation
Illinois Institute of Technology
10 West 35th Street
Chicago, Illinois 60616
   Attn: Dr. L. N. Wilson

Institute of the Aeronautical Sciences
Pacific Aeronautical Library
7600 Beverly Boulevard
Los Angeles, California 90036

University of California
Department of Mathematics
Los Angeles, California 90024
   Attn: Prof. A. Robinson

Louisiana State University
Department of Aeronautical Engineering
College of Engineering
Baton Rouge, Louisiana 70803
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A2)

No. of
Copies

Mathematical Reviews
American Mathematical Society
80 Waterman Street
Providence, Rhode Island 02906

Stanford University
Department of Aeronautical Engineering
Stanford, California 94305
  Attn: Library

University of California
Aeronautical Sciences Laboratory
Richmond Field Station
1301 South 46th Street
Richmond, California 94804

University of Denver
Department of Aeronautical Engineering
Denver 10, Colorado 80210

University of Chicago
Laboratories for Applied Sciences
Museum of Science and Industry
Chicago, Illinois 60601
  Attn: Librarian

University of Colorado
Department of Aeronautical Engineering
Boulder, Colorado 80302

University of Illinois
Aeronautical Department
Champaign, Illinois 61820

University of Kentucky
Department of Aeronautical Engineering
College of Engineering
Lexington, Kentucky 40506

University of Toledo
Department of Aeronautical Engineering
Research Foundation
Toledo, Ohio 43606
AERODYNAMICS DEPARTMENT
EXTERNAL DISTRIBUTION LIST (A2)

No. of
Copies

Aerospace Corporation
P. O. Box 95085
Los Angeles, California 90045
  Attn: Advanced Propulsion & Fluid Mechanics Department
  Attn: Gas Dynamics Department

Boeing Scientific Research Laboratory
P. O. Box 3981
Seattle, Washington 98124
  Attn: Dr. A. K. Sreekanth
  Attn: G. J. Appenheimer

Vidya, Inc.
2626 Hanover
Palo Alto, California 94304
  Attn: Mr. J. R. Stalder
  Attn: Library

General Electric Company
FPD Technical Information Center F-22
Cincinnati, Ohio 45201

Northwestern University
Technological Institute
Evanston, Illinois 60201
  Attn: Department of Mechanical Engineering

Harvard University
Cambridge, Massachusetts 02138
  Attn: Prof. of Engineering Sciences & Applied Physics
  Attn: Library

University of Wisconsin
P. O. Box 2127
Madison, Wisconsin 53706
  Attn: Library

Dr. Antonio Ferri, Director
Guggenheim Aerospace Laboratories
New York University
181st St. and University Ave.
Bronx, New York 10453
Department of Aerospace & Mechanical Engineering Sciences
University of California-San Diego
La Jolla, California 92037
Attn: Dr. P. A. Libby

University of New Mexico
Albuquerque, New Mexico 87106
Attn: Dr. Theodore Sparks

Notre Dame University
Southbend, Indiana 46556
Attn: Dr. John D. Nicolaides
Department of Aerospace Engineering

Dr. John Laufer, Chairman
University of Southern California
Graduate Department of Aerospace Studies
University Park
Los Angeles, California 90007

North American Aviation, Inc.
Los Angeles Division
International Airport
Los Angeles, California 90045
Attn: Library

Mr. Walter Jaskin, Consulting Engineer
Reentry Systems Dept., Systems and Technologies
General Electric Company
P. O. Box 8555
Philadelphia, Pennsylvania 19101
# Abstract

The results of experimental measurements of the static pressure distribution and bow shock shape on an oblate spheroid are presented. This experiment was conducted at nominal Mach numbers of 3 and 6 and a free stream Reynolds number range of $2.3 \times 10^6$ to $5.8 \times 10^6$ per foot. Comparisons are made with the calculated values of several different laboratories.
1. pressure distributions
2. shock wave
3. experimental
4. supersonic flow
5. blunt body
6. ellipsoid of revolution
7. re-entry body