<table>
<thead>
<tr>
<th>AD NUMBER</th>
<th>AD489273</th>
</tr>
</thead>
</table>

**LIMITATION CHANGES**

**TO:**
Approved for public release; distribution is unlimited.

**FROM:**
Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; SEP 1966. Other requests shall be referred to Arnold Engineering Development Center, Arnold AFB, TN.

**AUTHORITY**
AEDC ltr 12 Apr 1972
MACH NUMBER 3 TO 8 CALIBRATIONS
OF A 30-DEG CONICAL PROBE

A. D. Ray
ARO, Inc.

September 1966

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE
NOTICES

When U. S. Government drawings specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified users may obtain copies of this report from the Defense Documentation Center.

References to named commercial products in this report are not to be considered in any sense as an endorsement of the product by the United States Air Force or the Government.
MACH NUMBER 3 TO 8 CALIBRATIONS
OF A 30-DEG CONICAL PROBE

2. Probe -- Calibrate

3. Flow-angularity

A. D. Ray
ARO, Inc.

This document has been approved for public release
its distribution is unlimited.

This document is subject to special export controls
and each transmission to foreign governments or foreign
nationals may be made only with prior approval of
NASA.
FOREWORD

The work reported herein was done at the request of the Air Force Aero-Propulsion Laboratory (AFAPL), Air Force Systems Command (AFSC), for the General Electric Company, Evendale, Ohio, under Program Element 62405214, Project 3066, and Task 306603.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted from June 1 to 15, 1966, under ARO Project No. VT0604, and the manuscript was submitted for publication on August 3, 1966.

This technical report has been reviewed and is approved.

Donald E. Beitsch Leonard T. Glaser
Major, USAF Colonel, USAF
AF Representative, VKF Director of Test
Directorate of Test
ABSTRACT

An experimental evaluation of the Mach number and flow angularity measuring capabilities of a 30-deg half-angle conical probe is presented. Probe calibrations were conducted over a Mach number range from 3 to 8 and a unit Reynolds number range from 0.6 x 10^6 to 14 x 10^6 per foot. The probe sensitivity to flow angularity was essentially unaffected by Mach number and Reynolds number under the conditions investigated. Mach number sensitivity was reduced with increased Mach number.
CONTENTS

ABSTRACT ........................................ iii
NOMENCLATURE ................................... vi
I. INTRODUCTION ................................. 1
II. APPARATUS ....................................
  2.1 Models ........................................ 1
  2.2 Wind Tunnels ................................. 2
  2.3 Instrumentation .............................. 2
III. PROCEDURE ................................. 2
IV. RESULTS AND DISCUSSION ................. 3

ILLUSTRATIONS

Figure

1. Model Photograph ............................ 5
2. Model Details .................................. 6
3. Static Pressure Variation of 30-deg Cone with
   Angle of Attack
   a. Cone 1 ...................................... 7
   b. Cone 2 ...................................... 7
4. Reynolds Number Effect on $p_{\text{avg}}/p_T$ for
   30-deg Cone 1 ................................ 8
5. Effect of Angle of Attack and Mach Number on
   $p_{\text{avg}}/p_T$ for 30-deg Cone 1
   a. Angle of Attack ............................ 9
   b. Mach Number ............................... 9
6. Effect of Angle of Attack and Mach Number on
   Cone Pressure Differential for 30-deg Cone 1
   a. Angle of Attack ............................ 10
   b. Mach Number ............................... 10
7. Typical Shadowgraph .......................... 11

TABLE

I. Test Summary ................................. 12
NOMENCLATURE

M \hspace{1cm} \text{Mach number}

p \hspace{1cm} \text{Pressure, psia}

\Delta p \hspace{1cm} \text{Pressure differential (see Fig. 6), psia}

q \hspace{1cm} \text{Dynamic pressure, psia}

Re \hspace{1cm} \text{Unit Reynolds number per foot}

T \hspace{1cm} \text{Temperature, °R}

\alpha \hspace{1cm} \text{Angle of attack, deg}

SUBSCRIPTS

avg \hspace{1cm} \text{Average pressure (see Fig. 4)}

o \hspace{1cm} \text{Stagnation conditions}

T \hspace{1cm} \text{Model nose conditions}

\omega \hspace{1cm} \text{Free-stream conditions}
SECTION I
INTRODUCTION

The requirement to establish stream properties in a region of complex flow arises frequently. The ability to resolve both flow angularity and Mach number with a conical probe has been demonstrated. In order to obtain the maximum resolution of these flow properties, a probe calibration in a known flow field is required.

The cone is normally instrumented with a pitot pressure orifice in the cone nose and static pressure orifices located circumferentially on the cone surface. Flow angularity is resolved from the differential pressure between diametrically opposed cone surface static orifices and Mach number from the ratio of pitot and cone static pressures.

A calibration of three conical probes has been conducted in the 12-in. supersonic and hypersonic tunnels (Gas Dynamic Wind Tunnels, Supersonic (D) and Hypersonic (E)) of the von Karman Gas Dynamics Facility (VKF) at nominal Mach numbers ranging from 3 to 8. Angles of attack from -8 to 12 deg and free-stream unit Reynolds numbers from $0.6 \times 10^6$ to $14 \times 10^6$ per foot were covered in the probe calibrations. Two of the probes were slightly blunted, 30-deg half-angle cones, and the third probe was a 10-deg half-angle cone with two interchangeable blunted noses.

SECTION II
APPARATUS

2.1 MODELS

A photograph of the test models is shown in Fig. 1, and a detailed sketch is shown in Fig. 2. Each of the two 30-deg, 0.030-in. nose radius cones (Cones 1 and 2) were instrumented with four equally spaced static orifices and a pitot pressure orifice. Two interchangeable blunted noses (0.50- and 0.15-in. nose radius) for the 10-deg cone were instrumented with a pitot and eight equally spaced static pressure orifices. The cones were oriented such that two opposing orifices were in the pitch plane.

2.2 WIND TUNNELS

Tunnels D and E are intermittent, variable density wind tunnels with flexible-plate-type nozzles and 12- by 12-in. test sections. Tunnel D operates at Mach numbers from 1.5 to 5 at a maximum stagnation pressure of 60 psia and a stagnation temperature of 540°R. Minimum stagnation pressures vary from 0.8 psia at Mach number 1.5 to 8.0 psia at Mach number 5.0. Tunnel E operates at Mach numbers from 5 to 8 at maximum stagnation pressures from 400 to 1600 psia, respectively, and stagnation temperatures up to 1400°R. Minimum stagnation pressures are one-quarter of the maximum at each Mach number. Further description of the wind tunnels may be found in the Test Facilities Handbook. ²

2.3 INSTRUMENTATION

The model pressures were measured in Tunnel D with 15- and 30-psid transducers referenced to a near vacuum. In Tunnel E, the cone static pressures were measured with 15-psid transducers and the pitot pressures with 50- and 100-psid transducers. The Tunnel E pressure measuring system utilizes a variable (near vacuum to atmospheric pressure) reference. From repeat calibrations, the estimated precision of the pressure measurements in Tunnel D was ±0.002 psia or ±1 percent, whichever was greater, and in Tunnel E was ±0.005 psia or ±2 percent, whichever was greater. The angle of attack is estimated to have been precise within 0.1 deg. A simple shadowgraph system was used in Tunnel E to photograph model flow details.

SECTION III
PROCEDURE

Data were obtained at nominal Mach numbers of 3, 4, 5, 6, 7, and 8. A Reynolds number range corresponding approximately to the maximum and minimum tunnel operating conditions was covered. A summary of the test program is given in Table I.

Variation in cone static pressure with angle of attack for the two 30-deg, half-angle cones (1 and 2) is presented in Fig. 3. To facilitate a comparison of cone data for the top and bottom orifices, the sign of the angle of attack for the top orifice was reversed. Some misalignment is indicated for Cone 1 (0- to 1-deg misalignment) and Cone 2 (2- to 3-deg misalignment) by the disagreement between the top and bottom static pressures. How much of this misalignment was attributable to model asymmetry and how much was attributable to tunnel flow angularity could not be determined from these tests.

The effect of Reynolds number at zero angle of attack on $\frac{p_{\text{avg}}}{p_T}$ for Cone 1 is shown in Fig. 4. The Reynolds number effect on $\frac{p_{\text{avg}}}{p_T}$ was approximately 6 percent at Mach number 5 where the maximum Reynolds number range was obtained.

The variation of $\frac{p_{\text{avg}}}{p_T}$ with angle of attack for the maximum Reynolds number at each Mach number is shown in Fig. 5a. The pressure ratio $\frac{p_{\text{avg}}}{p_T}$ was essentially constant for each Mach number over the angle-of-attack range investigated. Using the angle-of-attack independence, the Mach number near $M_a = 4$ can be determined as a function of $\frac{p_{\text{avg}}}{p_T}$ with an uncertainty of about 15 percent because of the influence of Reynolds number (Fig. 5b). These data are observed to be in good agreement with theoretical inviscid sharp cone values at the larger Reynolds numbers. Note that Mach number determination with the probe becomes increasingly difficult as Mach number is increased because of the flattening of the $\frac{p_{\text{avg}}}{p_T}$ versus $M_a$ curve.

The $\frac{\Delta p}{p_T}$ variation with angle of attack for each Mach number (Fig. 6a) was found to be nearly linear over the angle-of-attack range investigated. A slight misalignment or flow angularity (about 1 deg) is indicated by the nonzero values of $\frac{\Delta p}{p_T}$ at zero angle of attack. The slopes of the $\frac{\Delta p}{p_T}$ versus $\alpha$ curves are shown in Fig. 6b as a function of Mach number. Essentially no Mach number effect on the slopes $\frac{d(\Delta p/p_T)}{d\alpha}$ is noted, which indicates that flow angularity can be determined independently of Mach number. No observable effects of Reynolds number on $\frac{d(\Delta p/p_T)}{d\alpha}$ were found.
A shadowgraph (Fig. 7), showing flow details at $M_\infty = 6$ and $\alpha = -3$ deg, indicates a flow disturbance on the leeward (lower) surface of the 10-deg half-angle cone. The cone static pressures in the disturbed region were erratic and thus omitted from evaluation.
Assembly Sketch

Model Support Body

10-deg Cone

30-deg Cone

1.00

2.28

3.00

0.032-diam Orifices
Equally Spaced (8)

0.020-diam Orifices
Equally Spaced (4)

Fig. 2 Model Details
Fig. 3 Static Pressure Variation of 30-deg Cone with Angle of Attack
Fig. 4 Reynolds Number Effect on $p_{avg}/p_T$ for 30-deg Cone 1

\[ p_{avg} = \frac{p_1 + p_2 + p_3 + p_4}{4} \]
Fig. 5 Effect of Angle of Attack and Mach Number on $p_{\text{avg}}/p_T$ for 30-deg Cone 1
Fig. 6 Effect of Angle of Attack and Mach Number on Cone Pressure Differential for 30-deg Cone 1
Fig. 7 Typical Shadowgraph

\[ M = 6 \]
\[ \alpha = -3 \text{ deg} \]
\[ Re_{\infty} / \text{ft} = 12 \times 10^6 \]
<table>
<thead>
<tr>
<th>Tunnel</th>
<th>$M_\infty$</th>
<th>$p_0$, psia</th>
<th>$Re_\infty/ft \times 10^{-6}$</th>
<th>$\alpha$, deg</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>3</td>
<td>10, 30, 60</td>
<td>1.7, 4.7, 9.4</td>
<td>-5 to 12</td>
<td>10-deg cone with 0.15 nose radius</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>&quot;</td>
<td>1.0, 2.8, 5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>&quot;</td>
<td>0.6, 1.8, 3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>380</td>
<td>14.0</td>
<td>-8 to 8</td>
<td>10-deg cone with 0.15 nose radius</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>210, 460, 740</td>
<td>4.0, 8.0, 12.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>340, 675, 1060</td>
<td>3.0, 6.0, 8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>410, 875, 1600</td>
<td>2.0, 4.0, 6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>210, 460, 740</td>
<td>4.0, 8.0, 12.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>410, 875, 1600</td>
<td>2.0, 4.0, 6.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Abstract**

An experimental evaluation of the Mach number and flow angularity measuring capabilities of a 30-deg half-angle conical probe is presented. Probe calibrations were conducted over a Mach number range from 3 to 8 and a unit Reynolds number range from $0.6 \times 10^6$ to $14 \times 10^6$ per foot. The probe sensitivity to flow angularity was essentially unaffected by Mach number and Reynolds number under the conditions investigated. Mach number sensitivity was reduced with increased Mach number.
conical probes
half-angles
sensitivity
Mach number
flow angularity
measuring capabilities
supersonic flow
hypersonic flow

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (corporate author) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, & 8c. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (either by the originator or by the sponsor), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U.S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through.

(4) "U.S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through.

(5) "All distribution of this report is controlled. Qualified DDC users shall request through.

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.