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MACH NUMBER 3 TO 8 CALIBRATIONS OF A 30-DEG CONICAL PROBE

A. D. Ray
ARO, Inc.

September 1966

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MACH NUMBER 3 TO 8 CALIBRATIONS OF A 30-DEG CONICAL PROBE

2, Probes -- Calibration

3. Flow angularity

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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
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Colonel, USAF
Director 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 0.6×10^6 to 14×10^6 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.

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NOMENCLATURE

M	Mach number
p	Pressure, psia
Δp	Pressure differential (see Fig. 6), psia
q	Dynamic pressure, psia
Re	Unit Reynolds number per foot
T	Temperature, °R
α	Angle of attack, deg

SUBSCRIPTS

avg	Average pressure (see Fig. 4)
o	Stagnation conditions
T	Model nose conditions
∞	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.[1] 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 Kármán 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 0.6×10^6 to 14×10^6 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.

---

[1]Norris, John D. "Calibration of Conical Pressure Probes for Determination of Local Flow Conditions at Mach Numbers from 3 to 6." NASA TN D-3076, November 1965.

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.

---

[2]Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, July 1963.

SECTION IV
RESULTS AND DISCUSSION

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 p_{avg}/p_T for Cone 1 is shown in Fig. 4. The Reynolds number effect on p_{avg}/p_T was approximately 6 percent at Mach number 5 where the maximum Reynolds number range was obtained.

The variation of p_{avg}/p_T with angle of attack for the maximum Reynolds number at each Mach number is shown in Fig. 5a. The pressure ratio (p_{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 $M_\infty = 4$ can be determined as a function of p_{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 p_{avg}/p_T versus M_∞ curve.

The $\Delta p/p_T$ 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 $\Delta p/p_T$ at zero angle of attack. The slopes of the $\Delta p/p_T$ versus α curves are shown in Fig. 6b as a function of Mach number. Essentially no Mach number effect on the slopes $d(\Delta p/p_T)/d\alpha$ is noted, which indicates that flow angularity can be determined independently of Mach number. No observable effects of Reynolds number on $d(\Delta p/p_T)/d\alpha$ 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.

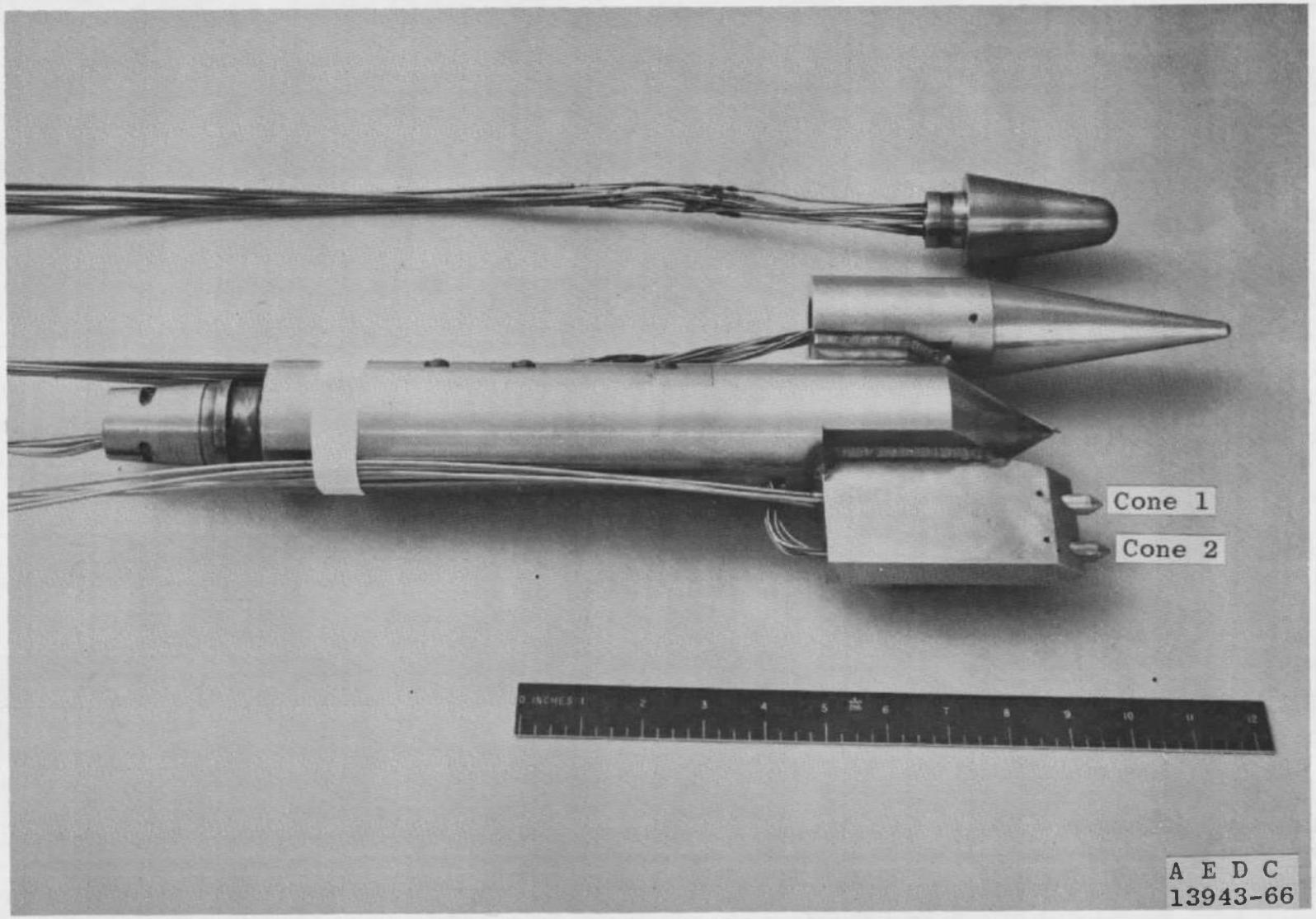


Fig. 1 Model Photograph

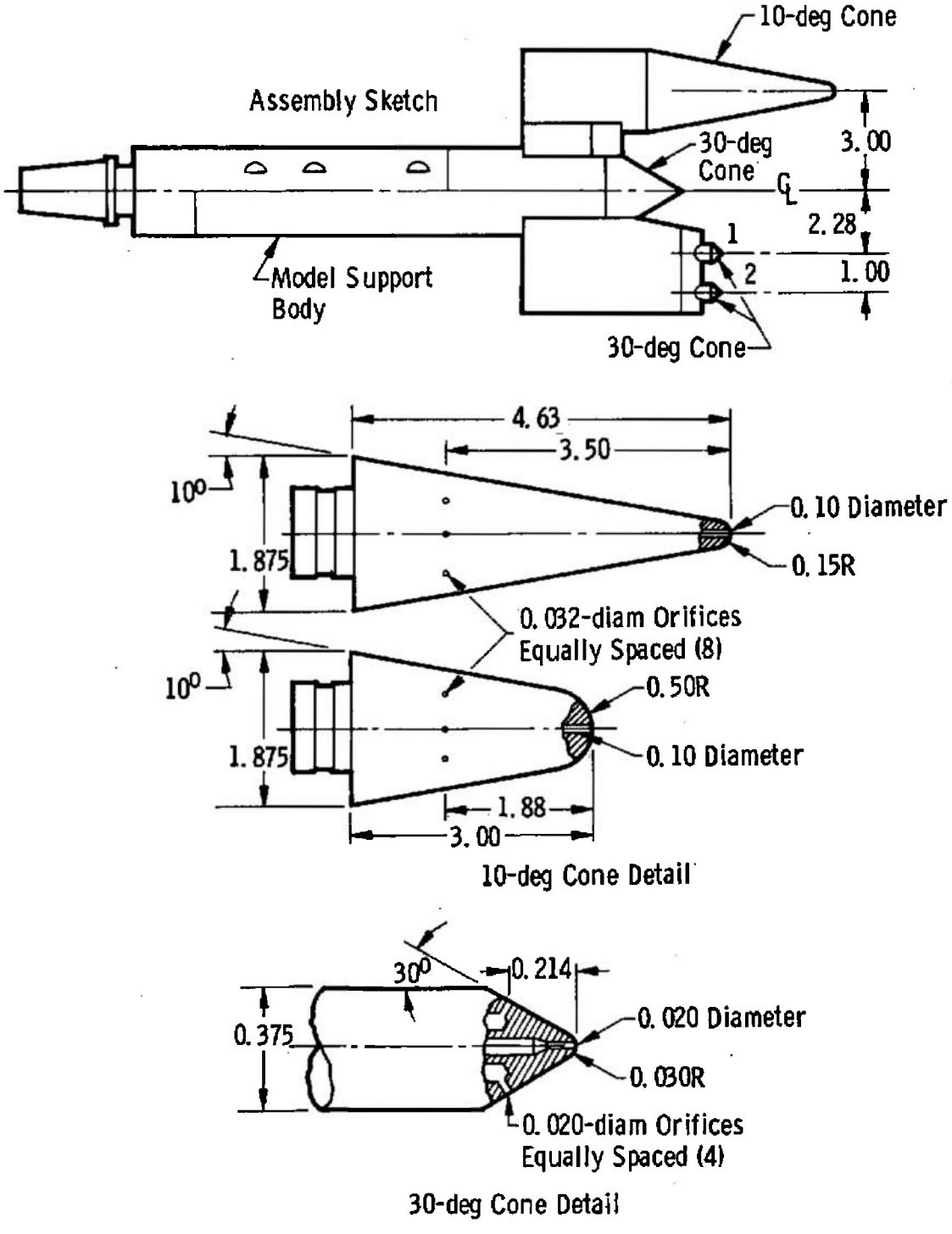
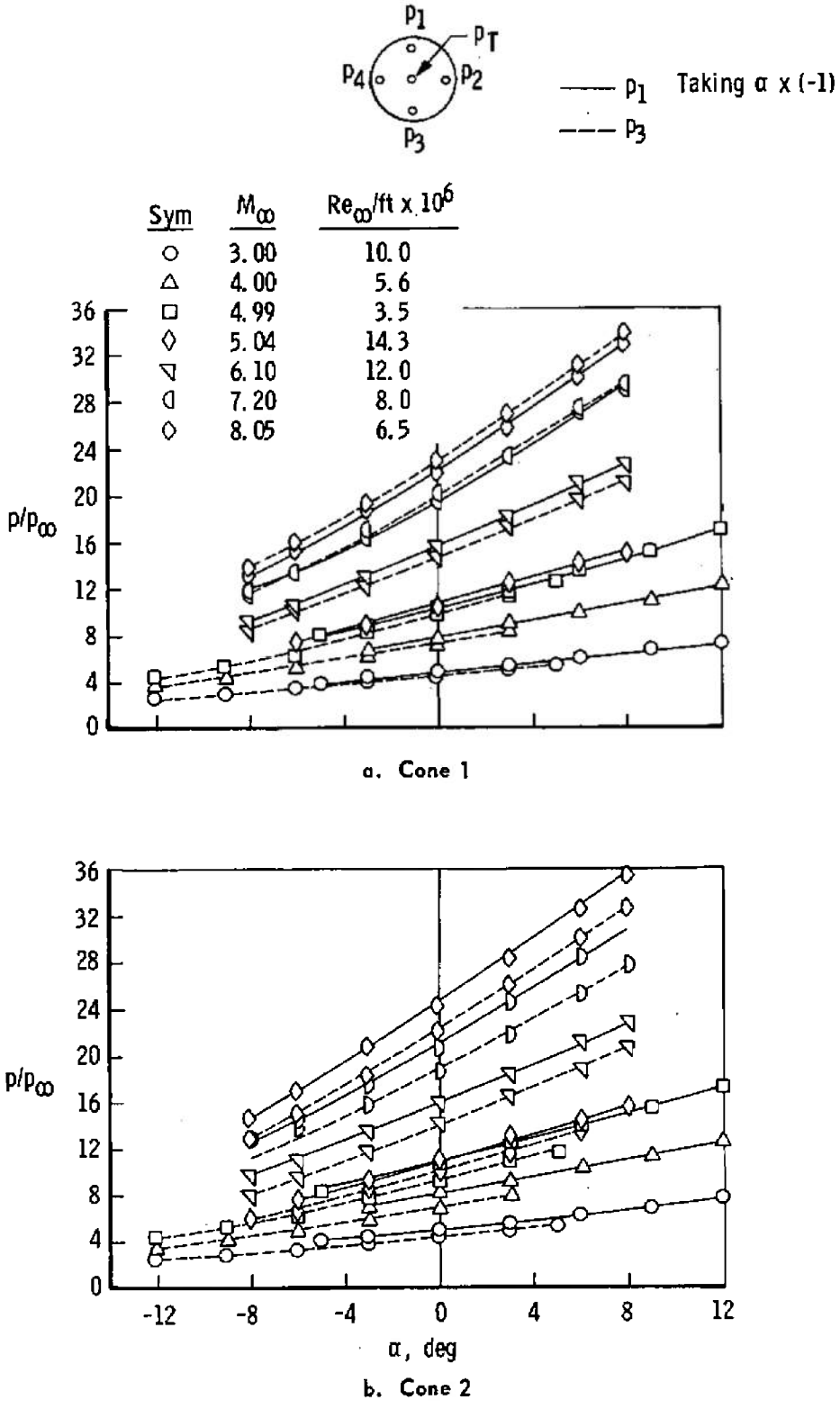


Fig. 2 Model Details



a. Cone 1

b. Cone 2

Fig. 3 Static Pressure Variation of 30-deg Cone with Angle of Attack

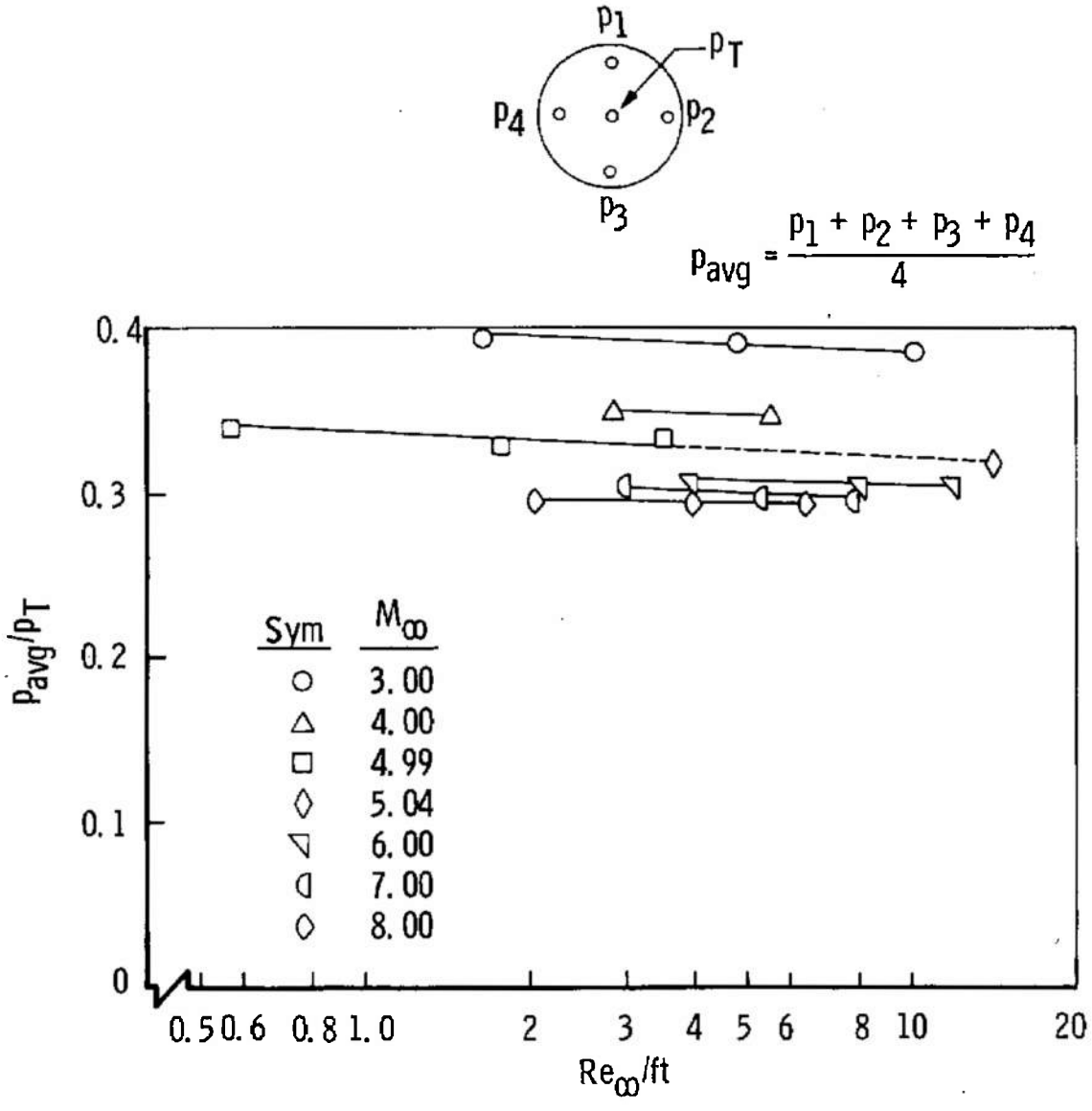
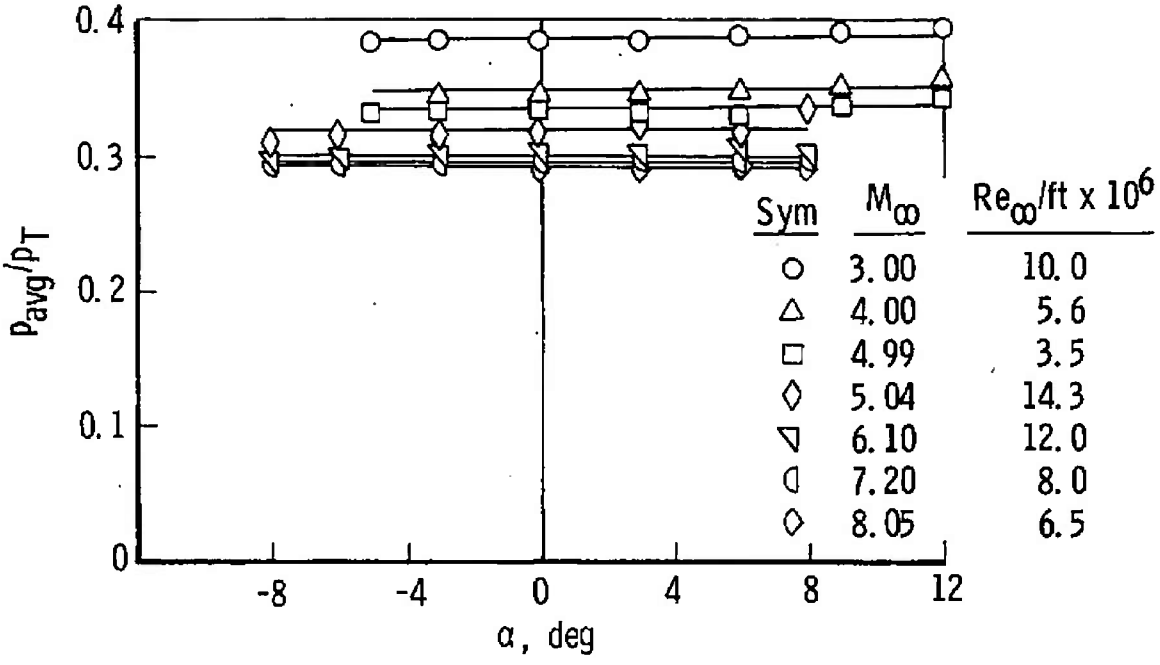
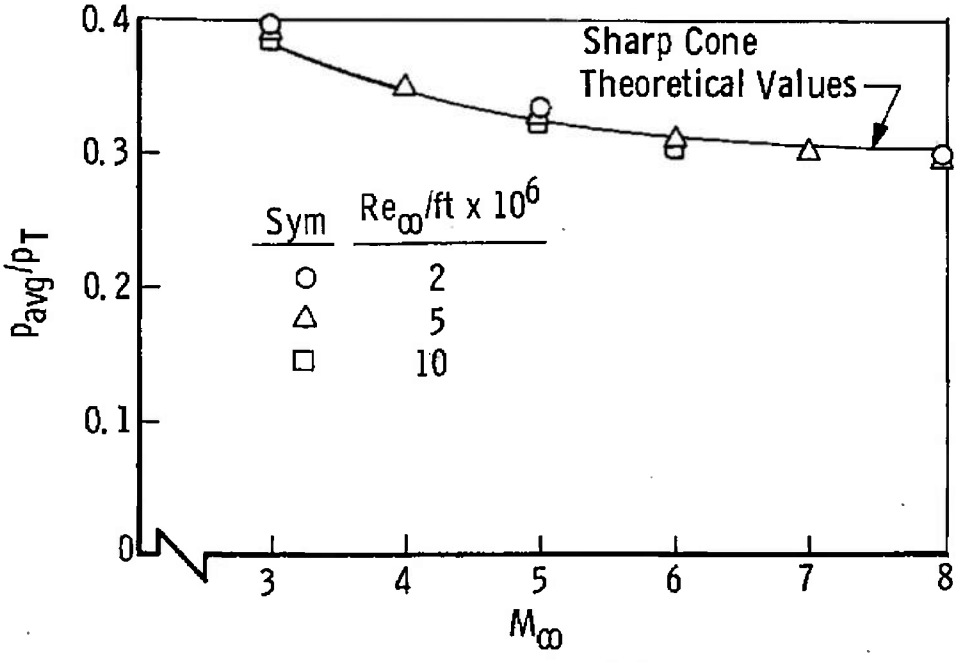


Fig. 4 Reynolds Number Effect on p_{avg}/p_T for 30-deg Cone 1

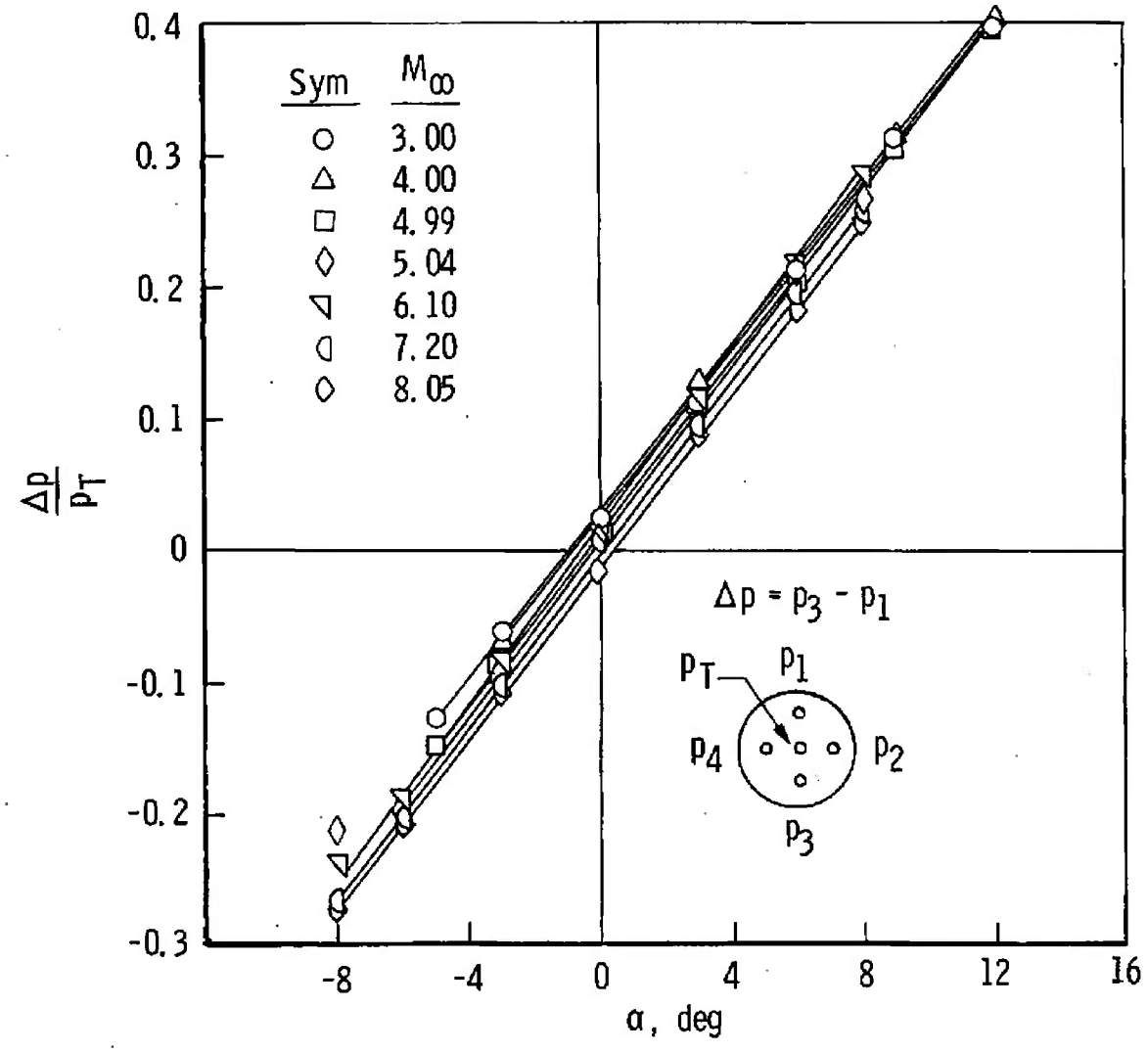


a. Angle of Attack

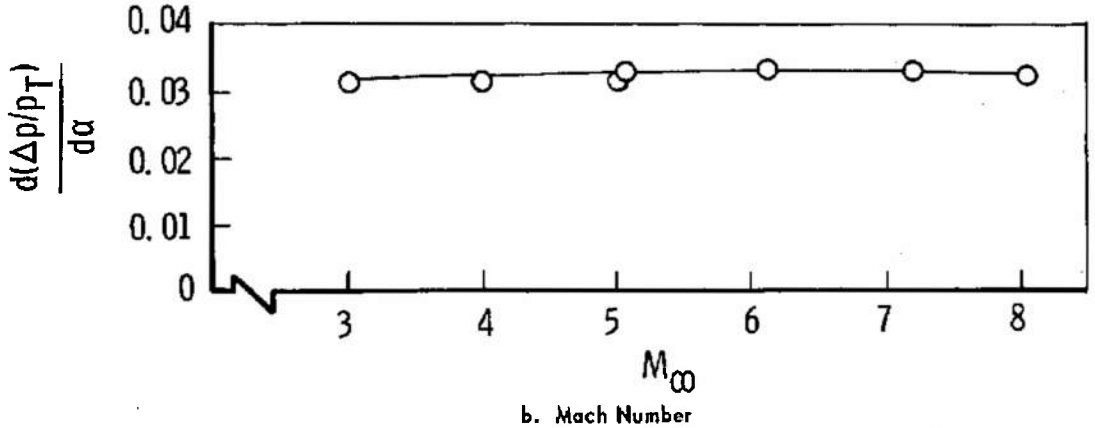


b. Mach Number

Fig. 5 Effect of Angle of Attack and Mach Number on p_{avg}/p_T for 30-deg Cone 1



a. Angle of Attack



b. Mach Number

Fig. 6 Effect of Angle of Attack and Mach Number on Cone Pressure Differential for 30-deg Cone 1

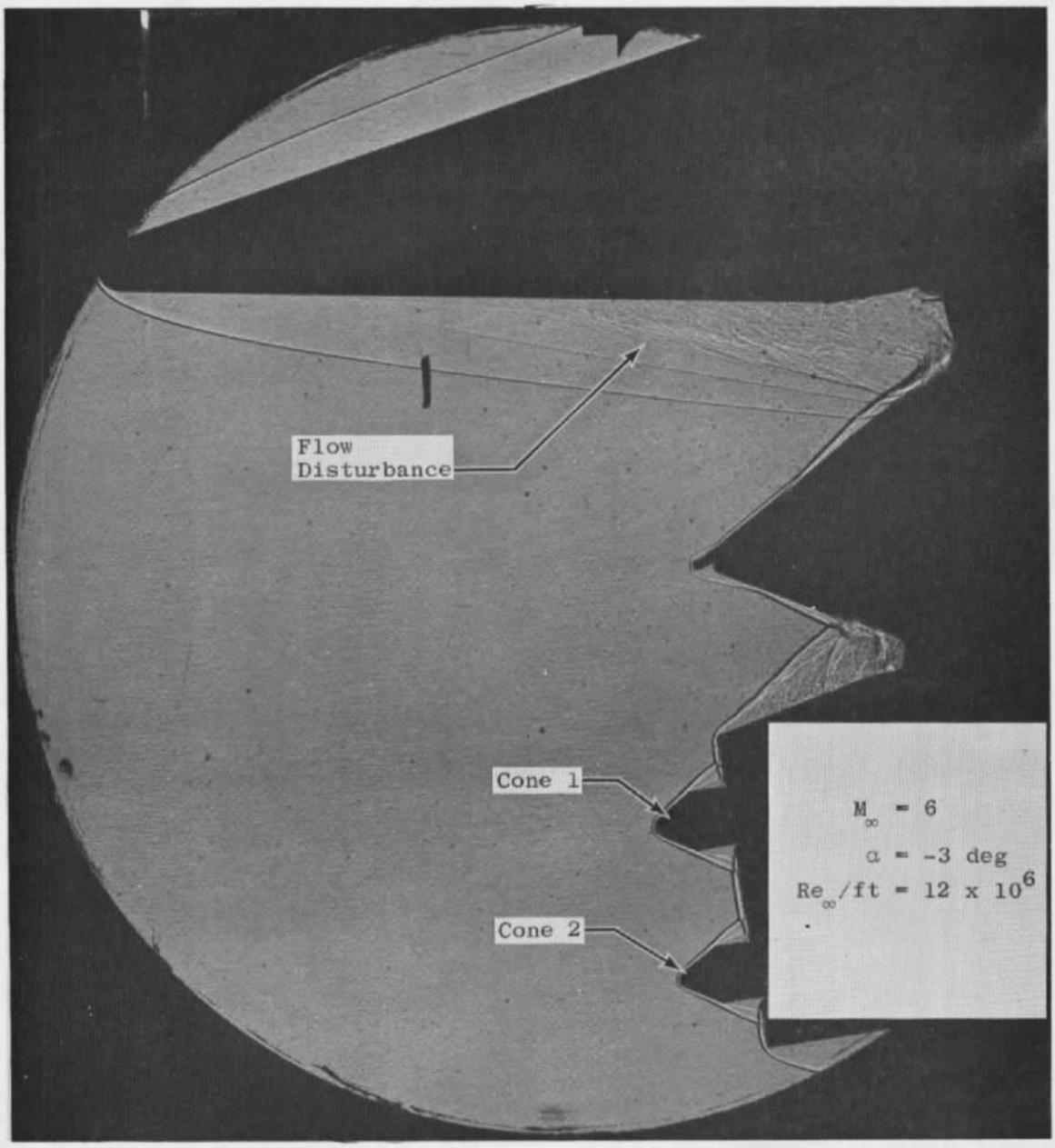


Fig. 7 Typical Shadowgraph

TABLE I
TEST SUMMARY

Tunnel	M_∞	p_o, psia	Re_∞/ft x 10^{-6}	α, deg	Remarks
D	3	10, 30, 60	1.7, 4.7, 9.4	-5 to 12	10-deg cone with 0.15 nose radius
	4	"	1.0, 2.8, 5.5		
	5	"	0.6, 1.8, 3.5		
E	5	380	14.0	-8 to 8	10-deg cone with 0.15 nose radius
	6	210, 460, 740	4.0, 8.0, 12.0		
	7	340, 675, 1060	3.0, 6.0, 8.0		
	8	410, 875, 1600	2.0, 4.0, 6.5		
	6	210, 460, 740	4.0, 8.0, 12.0		10-deg cone with 0.50 nose radius
	8	410, 875, 1600	2.0, 4.0, 6.5		

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13. ABSTRACT

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Mach number						
flow angularity						
measuring capabilities						
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