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INVESTIGATION OF TURBULENT WAKE COOLING WITH BASE EJECTION AT MACH 8



W. D. Laraway

ARO, Inc.

August 1966

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INVESTIGATION OF TURBULENT WAKE COOLING
WITH BASE EJECTION AT MACH 8

2. Wake -- Cooling.
3. Base ejection.

W. D. Laraway
ARO, Inc.

1-2

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FOREWORD

The work reported herein was done at the request of the Air Force Office of Scientific Research (AFOSR), for Mithras, Inc., under Program Element 61445014, Project 9781, and Task 978102.

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), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from March 14 to May 23, 1966, under ARO Project No. VB0663, and the manuscript was submitted for publication on July 14, 1966.

This technical report has been reviewed and is approved.

Donald E. Beitsch
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ABSTRACT

Tests were conducted at Mach 8 to investigate the effect on turbulent wake temperatures of base gaseous injection into the near wake of a 20-deg cone-cylinder model. Helium and nitrogen were employed at varying mass flow rates with both supersonic and subsonic ejection velocities. Pitot pressure, cone static surface pressure, total temperature, and helium concentration measurements were made in the region from one to five model diameters downstream of the model base. All data were taken at model zero angle of attack and free-stream Reynolds number of 3.48×10^6 per foot. Selected results are presented to illustrate the types of data obtained. These results show that helium was the more efficient wake coolant and that supersonic ejection was more efficient than subsonic ejection.

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NOMENCLATURE

A	Orifice throat area, in. ²
C	Orifice coefficient
c	Helium concentration, percent
D	Diameter of model base, 4.0 in.
K	Mass flow constant, $\sqrt{0.525^\circ\text{R}/\text{sec}}$ for nitrogen, $\sqrt{0.211^\circ\text{R}/\text{sec}}$ for helium
M_∞	Free-stream Mach number
$\dot{m}$	Mass flow, lb _m /sec
p	Pressure, psia
p'_o	Stagnation pressure downstream of a normal shock, psia
Re_∞	Free-stream Reynolds number, per foot
r	Radial distance from model centerline, in.
T	Temperature, °R
x	Distance downstream from model base, in.

SUBSCRIPTS

1	Conditions at ejection gas metering orifice
2	Conditions at ejection gas model orifice
c	Conditions on cone probe surface
o	Free-stream stagnation conditions
t	Wake total conditions
α	Indicated by ionization gage

SECTION I INTRODUCTION

The purpose of these tests was to study the effects of gaseous injection upon the properties of the near wake of a cone-cylinder model. Injection of a gas at temperatures lower than the free-stream flow total temperature would be expected to lower the wake temperature and provide a possible means of reducing the radar cross section of a re-entering vehicle.

The tests were conducted at Mach 8 in the 50-in. hypersonic wind tunnel (Gas Dynamic Wind Tunnel, Hypersonic (B)) of the von Kármán Gas Dynamics Facility, AEDC, AFSC. The model was tested at zero angle of attack, at a free-stream Reynolds number of 3.48×10^6 per foot, and with nose trips to ensure a turbulent wake.

The model was supported by a single, swept pylon, a dummy pylon was attached to the opposite side. Helium and nitrogen were ejected from the model base at low mass flow rates; both a subsonic and a supersonic base ejector section were used. For most testing, the gases were supplied at ambient conditions (530°R) giving an ejection gas temperature range of 690 to 880°R. For one test the gas was precooled outside the tunnel, lowering the ejection gas temperature to 635°R. Pitot pressure, cone static surface pressure, total temperature, and helium concentration measurements were made in the model near wake to assess the effect of these variables upon the wake properties.

SECTION II APPARATUS

2.1 MODEL

The model used in this study was a 10-deg half-angle cone-cylinder with an interchangeable aft section and removable dummy pylon. Figs. 1, 2, and 3 show the basic model and internal geometry, the interchangeable ejector section, and the mounting structures.

The interchangeable ejector sections consisted of a supersonic configuration and a subsonic configuration. The supersonic configuration had 27 nozzles placed around the outer base with a total throat area of 0.0726 in.². The subsonic configuration was an open duct. The orifice plate used in conjunction with the subsonic configuration had 25 holes with a total throat area of 0.0791 in.². The purpose of the orifice plate is to provide a means of calculating the gas ejection temperature when using the subsonic configuration.

2.2 SURVEY PROBES

The boundary-layer and wake survey probes are shown in Figs. 4 and 5. The tip of the boundary-layer pitot pressure probe was a nominal 0.063-in. -O.D. by 0.008-in. -thick wall stainless steel tube formed to the cross section shown in Fig. 5.

The wake gas sampling probe and pitot pressure probe were 0.094-in. -O.D. by 0.016-in. -thick wall stainless steel tubes. Surface pressures were measured on a 15-deg total-angle cone probe constructed as shown in Fig. 5. The total temperature probe was double shielded.

2.3 WIND TUNNEL

Tunnel B is an axisymmetric, continuous flow, variable density wind tunnel with a 50-in. -diam test section. The tunnel operates at nominal Mach numbers of 6 and 8 at stagnation pressures from 20 to 280 psia and from 50 to 900 psia, respectively. Stagnation temperatures up to 1350°R are utilized to prevent liquefaction of the air in the test section. The tunnel and its associated equipment are shown in Fig. 6. A description of the tunnel may be found in Ref. 1.

2.4 INSTRUMENTATION

Pitot probe pressures and model plenum chamber pressure were measured with 15-psid transducers. Based upon repeated calibrations, the precision of these measurements is estimated to be ± 0.015 psia or ± 1 percent, whichever is greater. The cone static probe pressure was measured with a 5-psid transducer, with an estimated precision of ± 0.005 psia or 1 percent, whichever is greater. The precision of the thermocouple total temperature probe measurement is estimated to be ± 5 deg, from the manufacturer's specifications.

Helium concentration measurements were made with apparatus similar to that recommended in Ref. 2. Samples of wake gas were pumped from the tunnel into a manifold which contained a strain-gage transducer and an ionization-gage transducer. Since the output of this ionization gage is proportional to the sample pressure and the helium content, the ratio of the pressures indicated by the two transducers may be related to the helium content as shown in the data reduction section. Based upon calibration of this apparatus, the precision of the concentration measurements is estimated to be ± 3 percent.

Ejection gas mass flow rate was measured with a calibrated sonic orifice (0.00084-in.² throat area) with an estimated precision of ± 2 percent.

SECTION III PROCEDURE

3.1 TEST PROCEDURE

All tests were conducted with the model at zero angle of attack and at the following conditions:

$$p_o = 800 \text{ psia}$$

$$T_o = 1340^\circ\text{R}$$

$$Re_\infty = 3.48 \times 10^6 \text{ per foot}$$

$$M_\infty = 8.01$$

Prior to the wake survey tests, trips were added to the model nose, and boundary-layer pitot pressure surveys were made on the cylinder section. These surveys indicated a fully turbulent boundary layer near the model base.

The effect of the pylon model mount on wake properties was studied by measuring pitot pressure and total temperature axial centerline distributions and vertical distributions at $x/D = 1.8$, with and without the dummy pylon attached to the model.

The model with trips and the dummy pylon attached was used during the remainder of the tests. Distributions of p_t , p_c , T_t , and c were measured along the model wake centerline from x/D 's of 1 to 5, and vertical distributions were measured at $x/D = 5$ for variations of ejector section, ejection gas, and ejection gas temperatures. Table I shows the conditions of these variables under which the wake data were measured.

3.2 DATA REDUCTION

The helium concentration was derived from the equation

$$c = 131 \left(1 - \frac{p_a}{p} \right)$$

where the constant 131 was determined from ionization gage calibrations.

The pressure indicated by the ionization gage is p_a , and p is the actual pressure of the gas sample. This equation is derived in Ref. 2.

The ejection gas mass flow rate was measured with a calibrated sonic orifice, external to the tunnel, and reduced by the equation

$$\dot{m} = \frac{C_1 K p_1 A_1}{\sqrt{T_1}}$$

where the value of K was that of ideal gas.

The temperature of the ejection gas in the model plenum chamber was calculated from the equation

$$T_1 = \left[\frac{C_2 K p_2 A_2}{\dot{m}} \right]^2$$

where $\dot{m}$ is the measured ejection gas mass flow rate.

The local Mach number and static temperature data presented in Section IV were calculated from the probe data using the inviscid cone and supersonic tables of Ref. 3.

SECTION IV RESULTS AND DISCUSSION

The effect of a pylon type of model mounting on the near wake properties is shown in Fig. 7. Axial surveys along the wake centerline and radial surveys at $x/D = 1.8$ were measured with and without the dummy pylon mounted on the model. The remaining tests were accomplished with the dummy pylon attached to obtain wake symmetry along the model axis.

The curves shown in Fig. 8 are typical wake axial survey data obtained using helium gas ejection through the supersonic ejector section. Noteworthy trends indicated here are that a small quantity of gas ejection produces a large change in the total temperature profile along the model wake centerline. Also, the static temperature in the region $1 < x/D < 3$ was lowered approximately 50 percent at the largest mass flow rate. This low temperature region corresponded to an area of maximum helium concentration as verified by the helium concentration data.

The effects of ejection configuration, ejection gas, and ejection gas temperatures on the wake static temperatures are shown in Fig. 9. The

data indicate that for a given mass flow rate the supersonic ejector section was the most efficient of the configurations tested in lowering the wake centerline static temperature. The data also indicate that for a given mass flow rate of the two gases tested, helium produced from 20- to 50-percent lower static temperatures in the near wake. It should be noted, however, that because of the difference in gas heating, as it flowed through the hot model support structure, the nitrogen temperature (T_2) was significantly higher than the helium temperature. The lower portion of Fig. 9 shows that reducing the helium temperature about 100°R reduced the wake static temperatures about 50°R.

SECTION V SUMMARY OF RESULTS

Results of the tests conducted at Mach 8 to investigate the effect of base gaseous ejection on turbulent near wake temperatures can be summarized as follows:

1. Relatively small quantities of helium base ejection (0.0036 and 0.0057 lb_m/sec) produced significant cooling in the model near wake (up to 50 percent at $1 < x/D < 3$).
2. Of the two types of ejector configurations tested, the supersonic configuration was best for reducing wake static temperatures.
3. For a given mass flow rate, helium was the most efficient coolant.

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1. Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4". Arnold Engineering Development Center, July 1963.
2. Melfi, L. T., Jr. and Wood, G. M., Jr. "The Use of an Ionization Gage as a Quantitative Analyzer for Bi-Gaseous Mixtures." NASA TN D-1597, December 1962.
3. Ames Research Staff. "Equations, Tables, and Charts for Compressible Flow." NACA Report 1135, 1953.

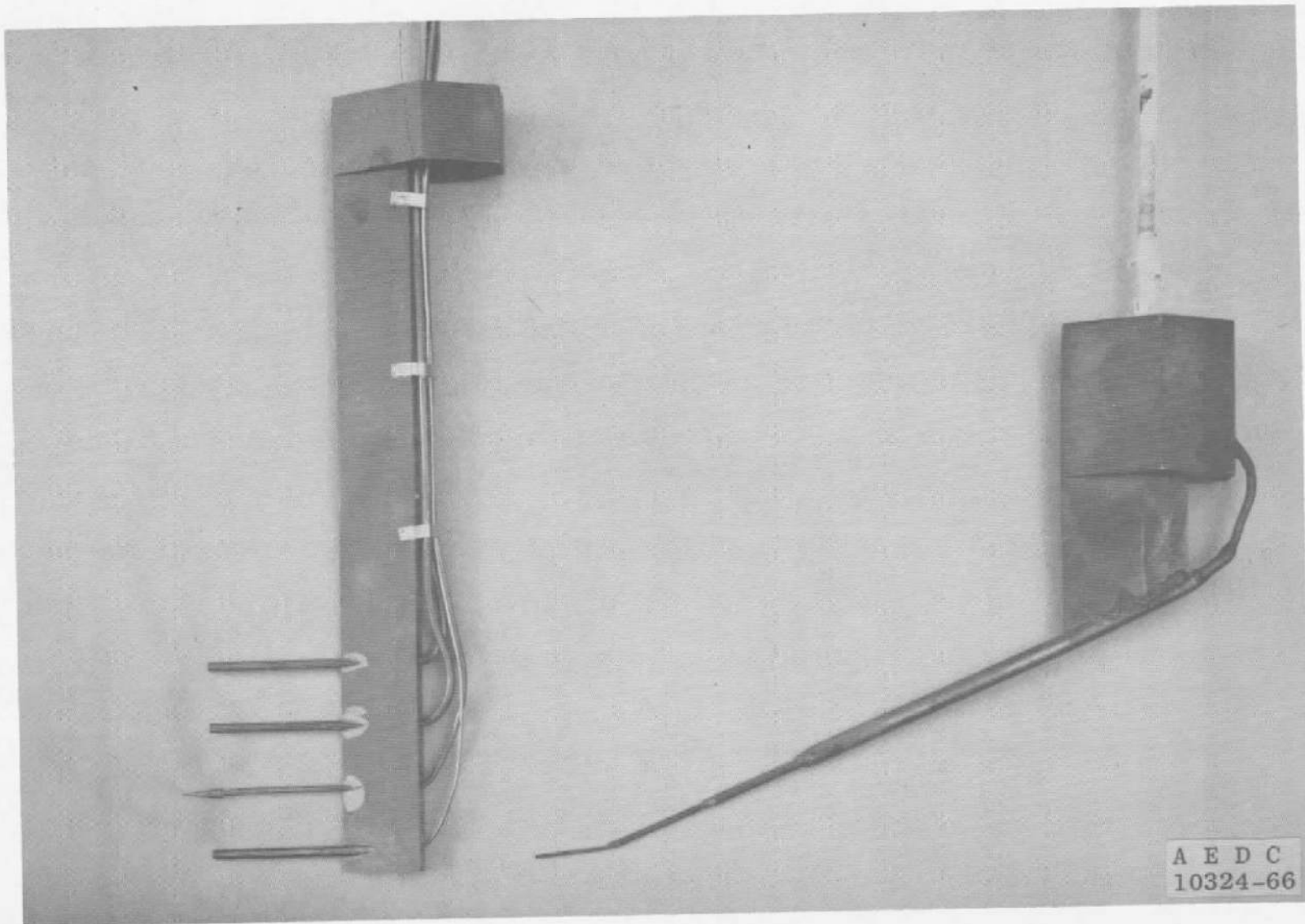
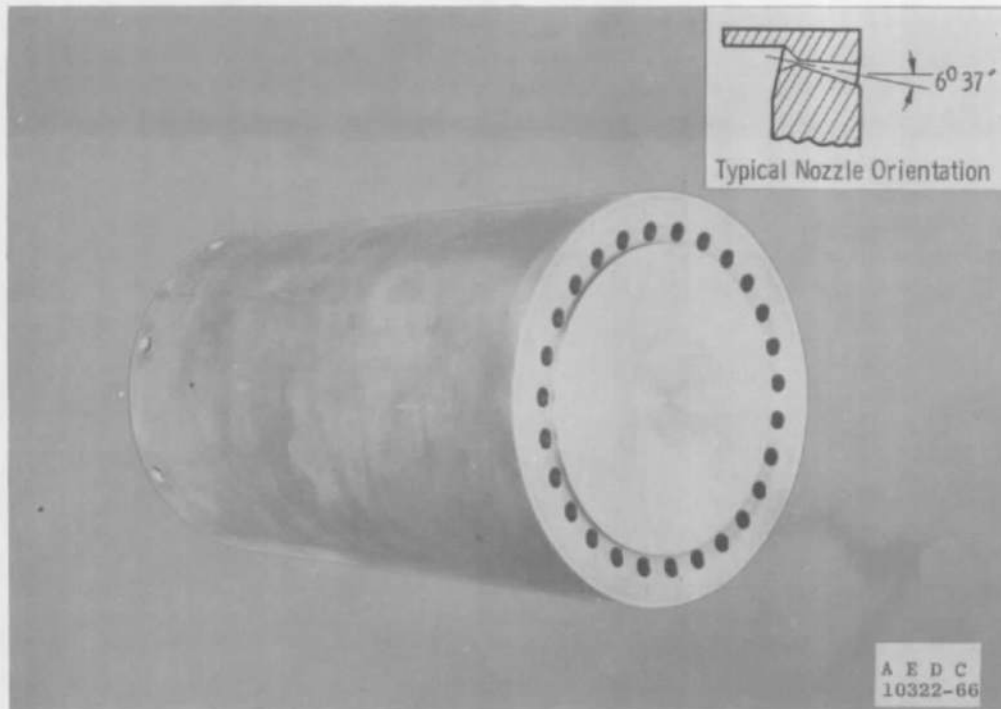
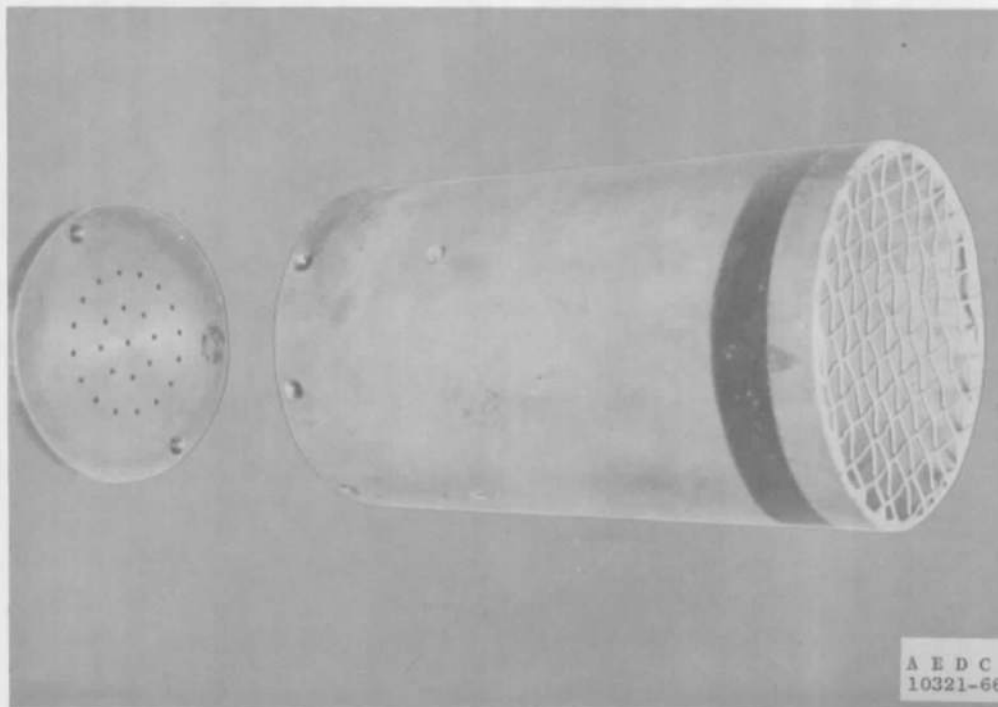


Fig. 1 Model Photograph



a. Supersonic



b. Subsonic

Fig. 2 Ejector Section Photographs

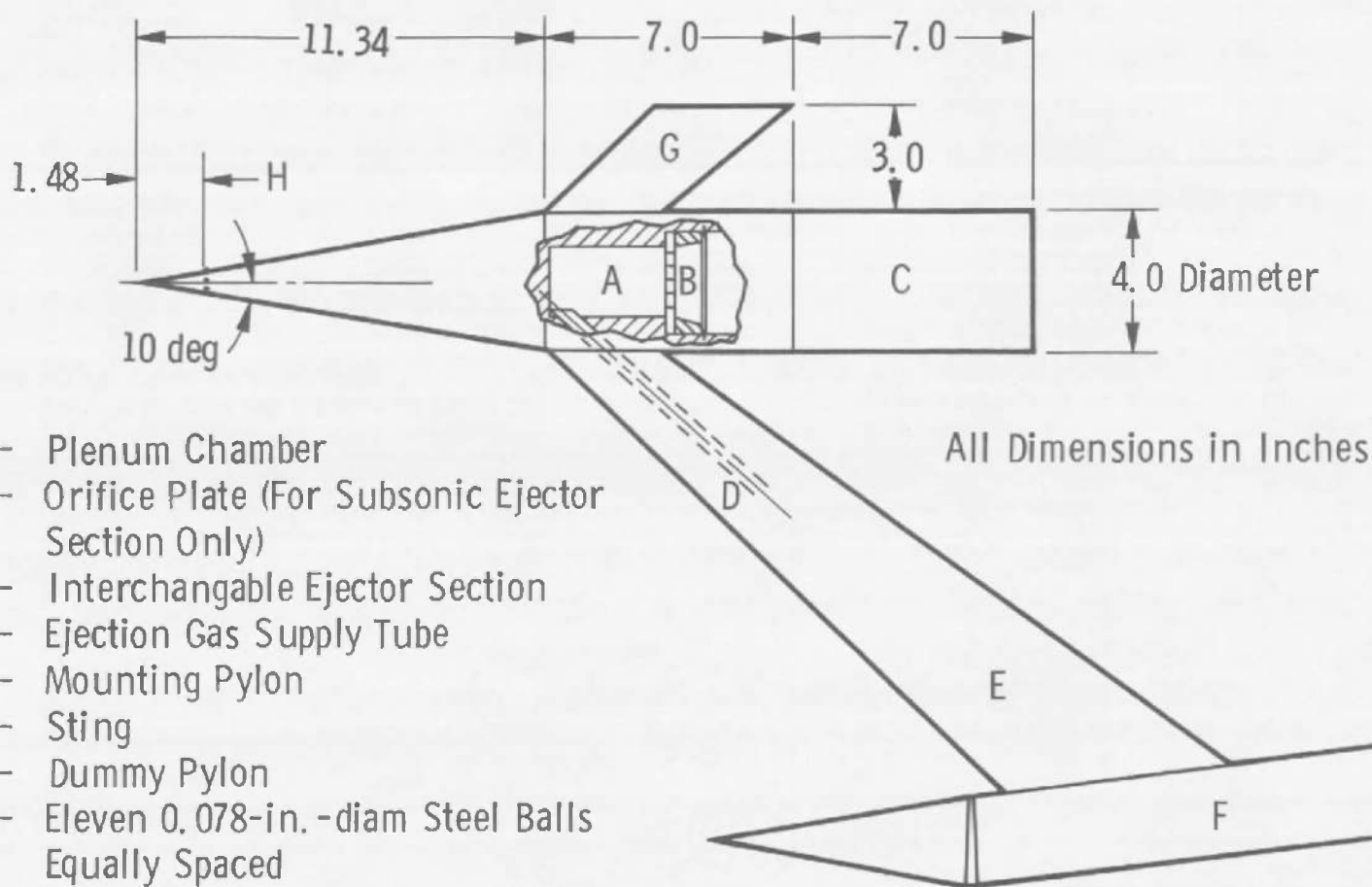


Fig. 3 Model Assembly Diagram

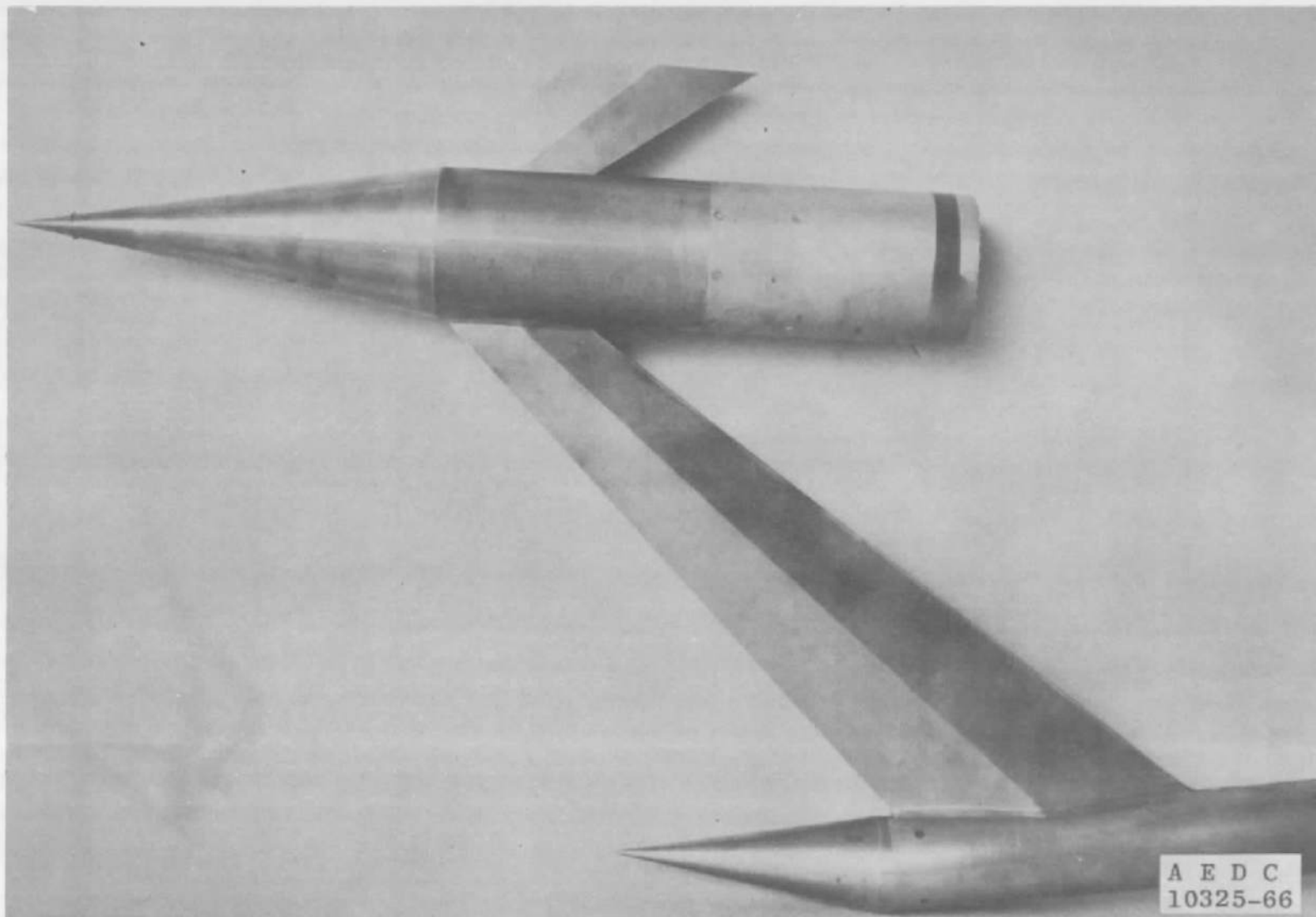


Fig. 4 Wake and Boundary-Layer Probe Photographs

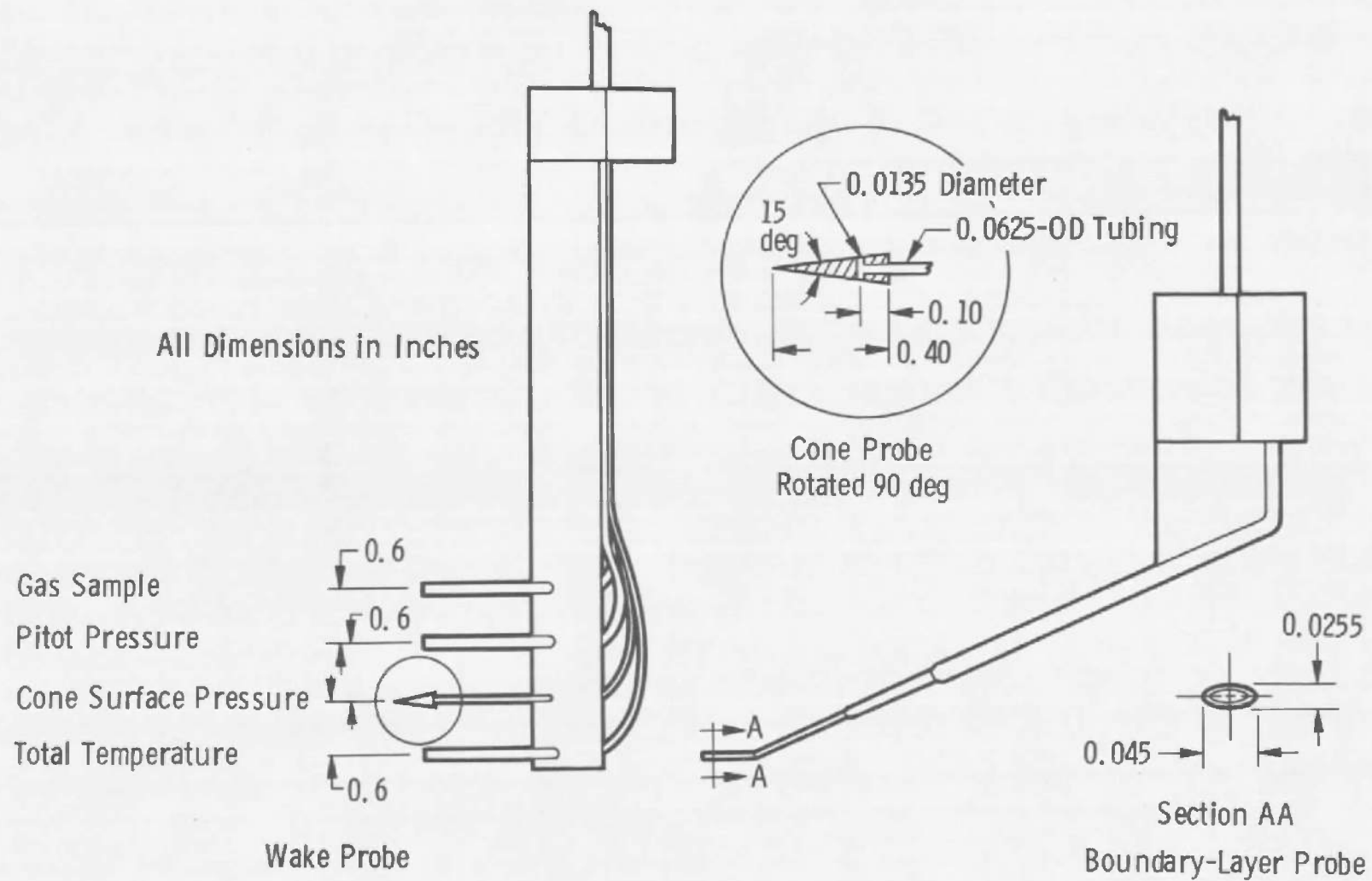
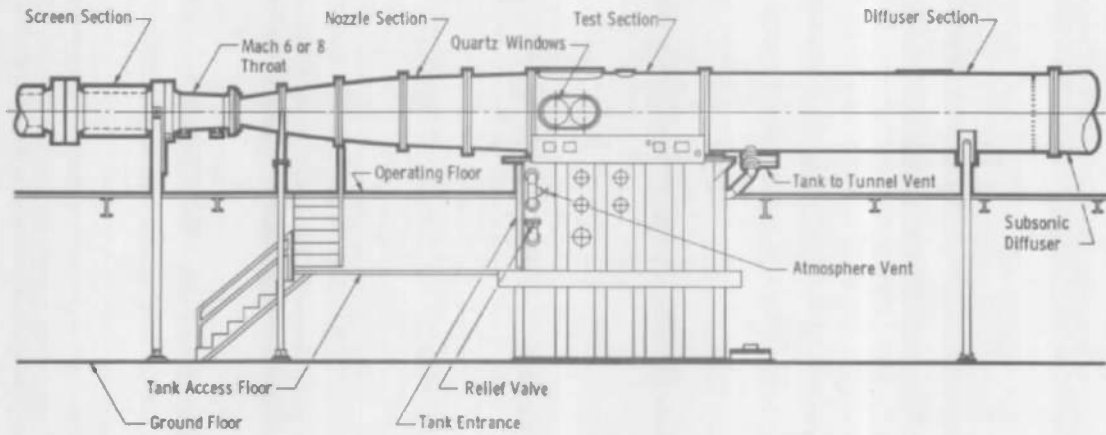
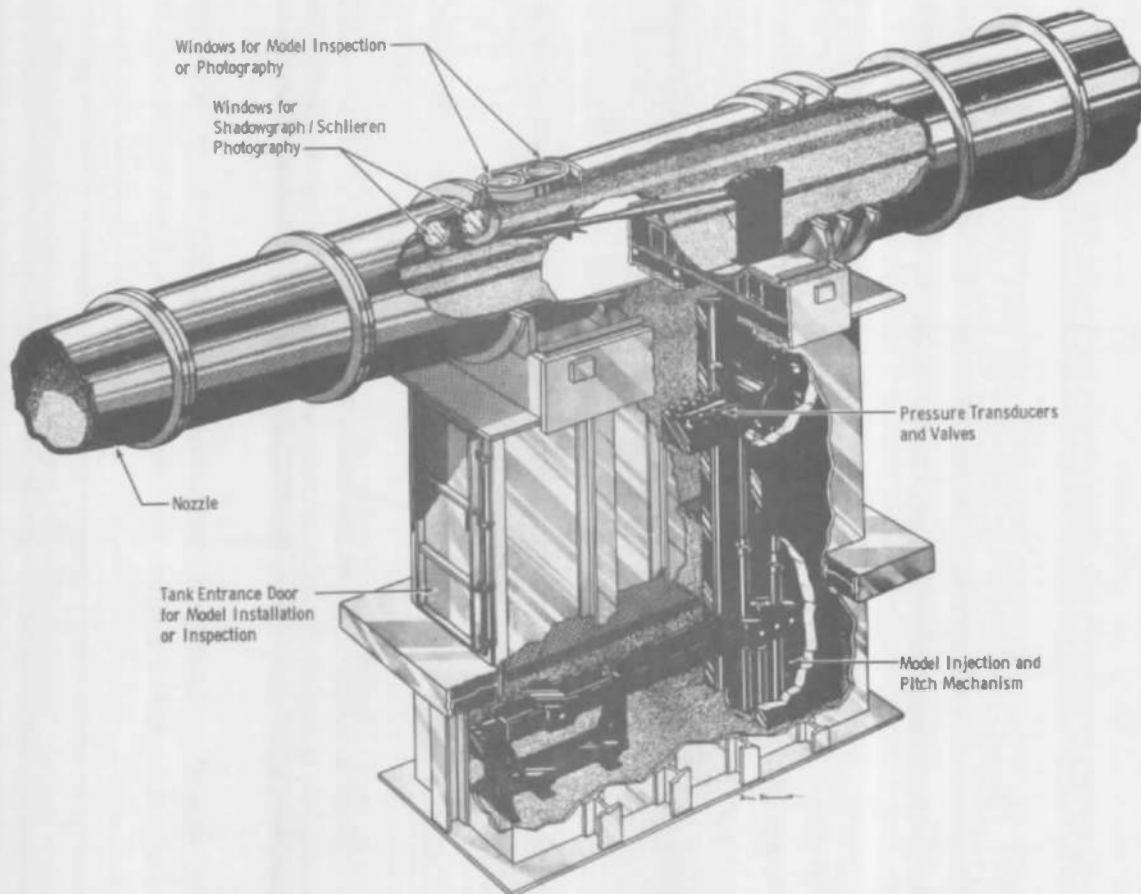


Fig. 5 Wake and Boundary-Layer Probe Drawings



Tunnel Assembly



Tunnel Test Section
Fig. 6 Tunnel B

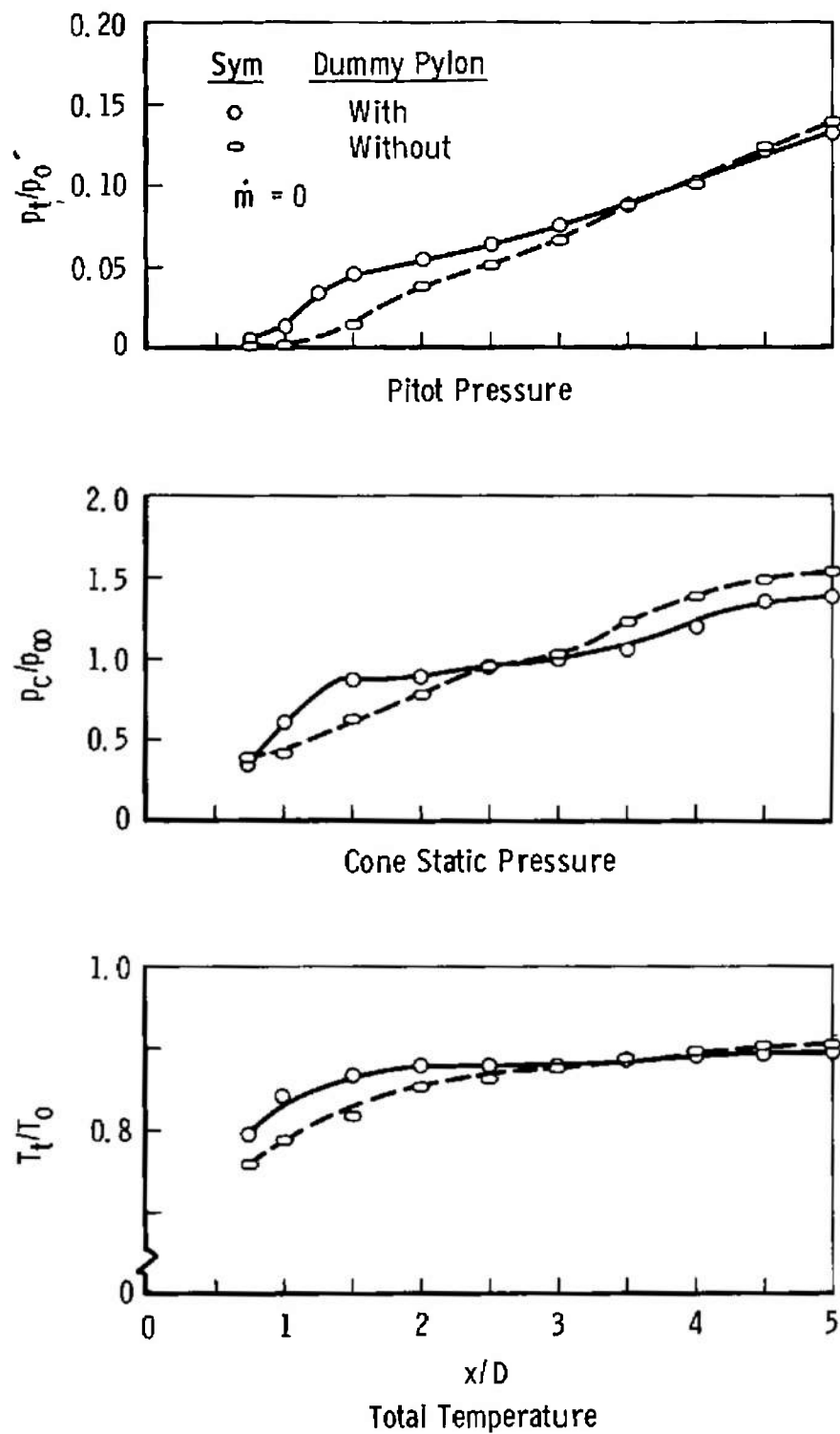
a. Axial Survey Data ($r/D = 0$)

Fig. 7 Effect of Dummy Pylon on Wake Survey Data

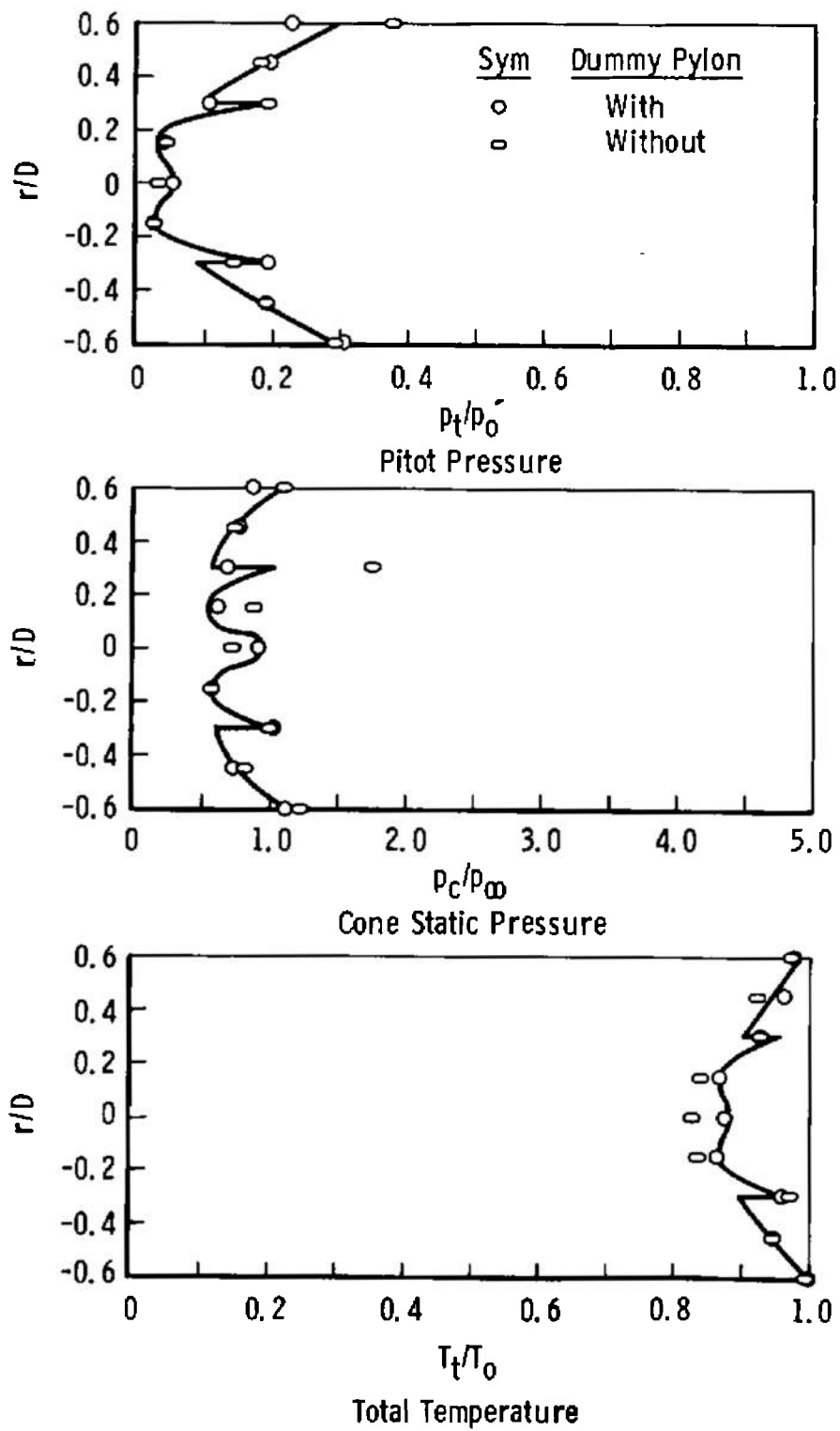
b. Radial Survey Data ($x/D = 1.8$)

Fig. 7 Concluded

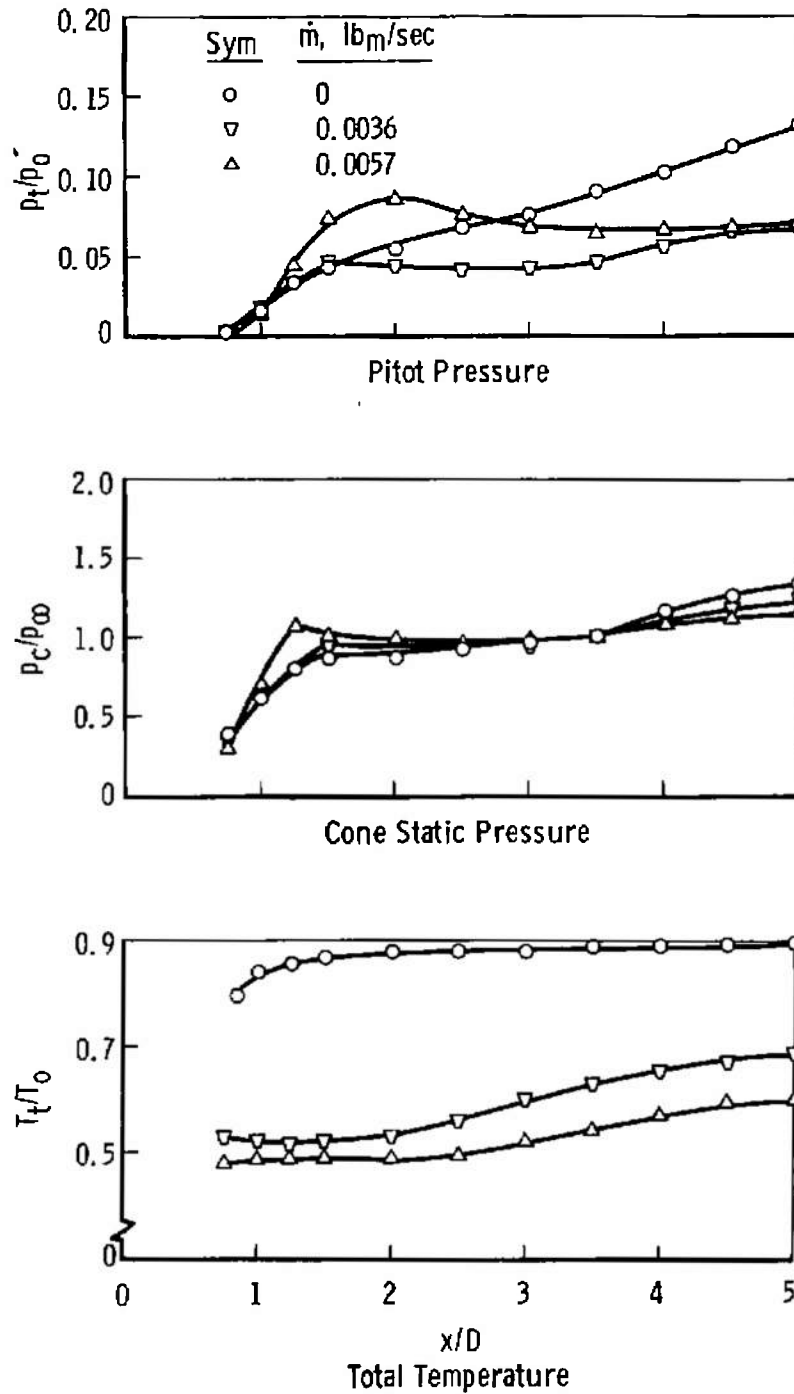


Fig. 8 Typical Wake Axial Survey Data for Helium Ejection through Supersonic Ejector Section

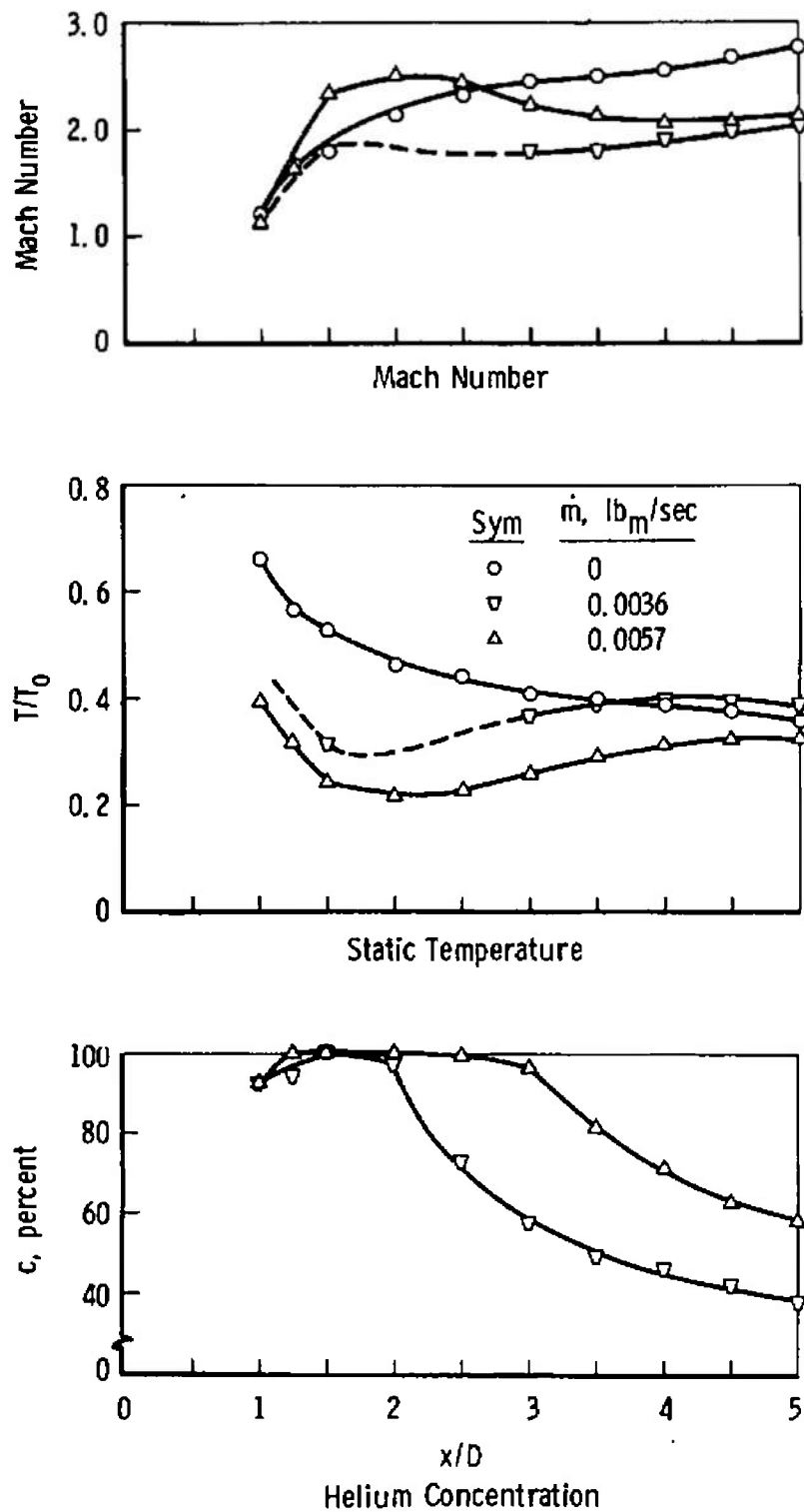


Fig. 8 Concluded

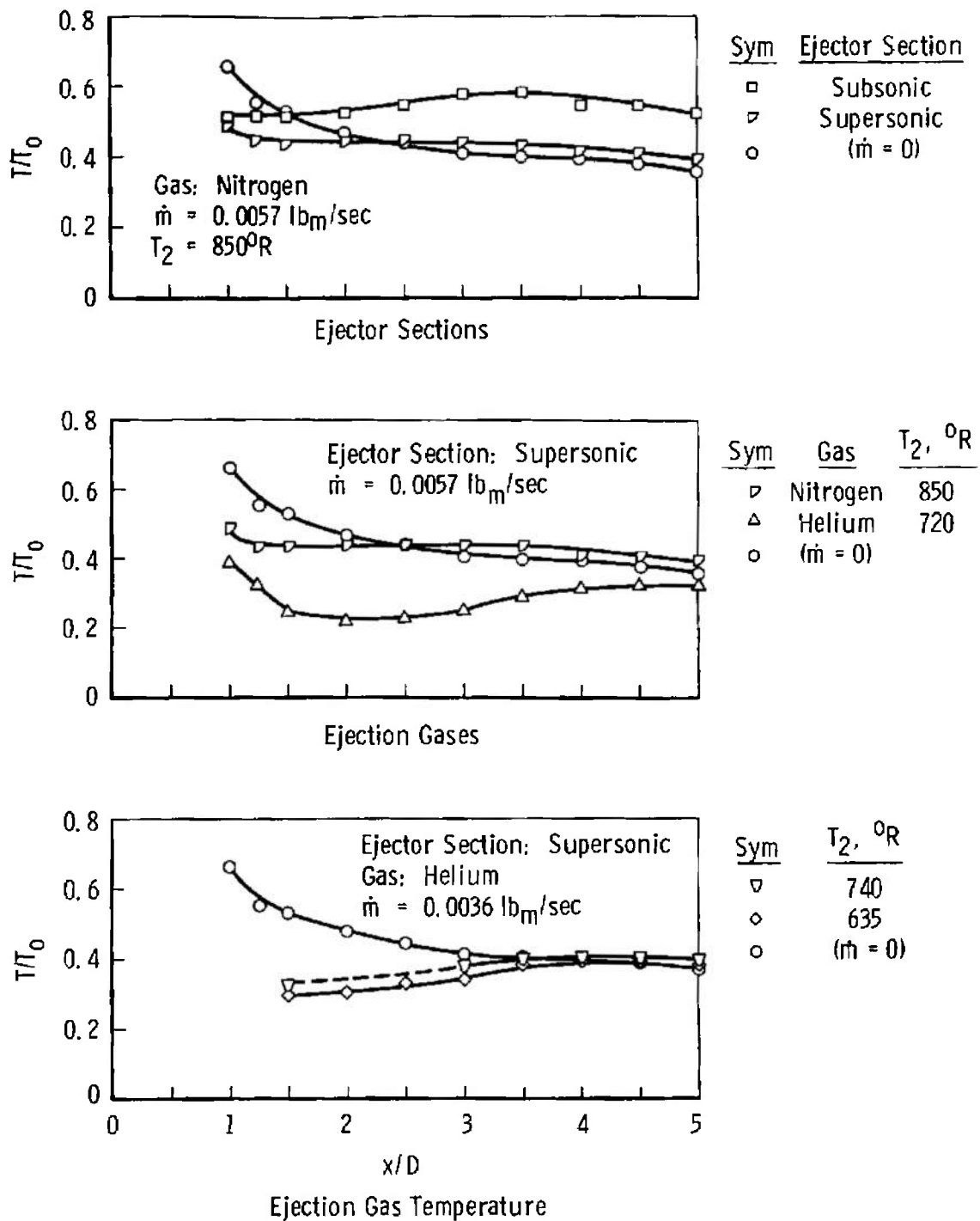


Fig. 9 Typical Effects of Test Variables on Axial Static Temperature Distributions

TABLE I
TEST CONDITIONS

Ejector Section	Ejection Gas	$\dot{m}$, lb _m /sec	T ₂ , °R
Supersonic	N ₂	0.0292	695
		0.0138	840
		0.0057	875
Subsonic	N ₂	0.0297	620
		0.0145	705
		0.0057	830
Supersonic	He	0.0056	700
		0.0035	740
		0.0035	635

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base ejection
hypersonic flow
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