UNCLASSIFIED

AD NUMBER
AD487548
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; AUG 1966. Other requests shall be referred to Air Force Office of Science Research, Bolling AFB, Washington, DC 20332. This document contains export-controlled technical data.**
AUTHORITY
AFOSR ltr, 1 Oct 1972

THIS PAGE IS UNCLASSIFIED

AEDC-TR-66-147

INVESTIGATION OF TURBULENT WAKE COOLING WITH BASE EJECTION AT MACH 8

W. D. Laraway

ARO, Inc.

August 1966

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

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

NOTICES

INVESTIGATION OF TURBULENT WAKE COOLING WITH BASE EJECTION AT MACH 8

2. Wakes -- Cooling.
3. Base ejection.

W. D. Laraway
ARO, Inc.

1-2

This document has been approved for public release its distribution is unlimited. Per TAB 72-19, 1 Oct., 1972. DtD

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

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
Major, USAF
AF Representative, VKF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

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.

CONTENTS

ILLUSTRATIONS

TABLE

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, $\sqrt{0.525°R}$/sec for nitrogen, $\sqrt{0.211°R}$/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:

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

$$T_o = 1340°R$$

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

$$M_\infty = 8.01$$

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_α, 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

$$T_2 = \left[\frac{C_2 K p_2 A_2}{\dot{m}}\right]^2$$

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.

REFERENCES

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.

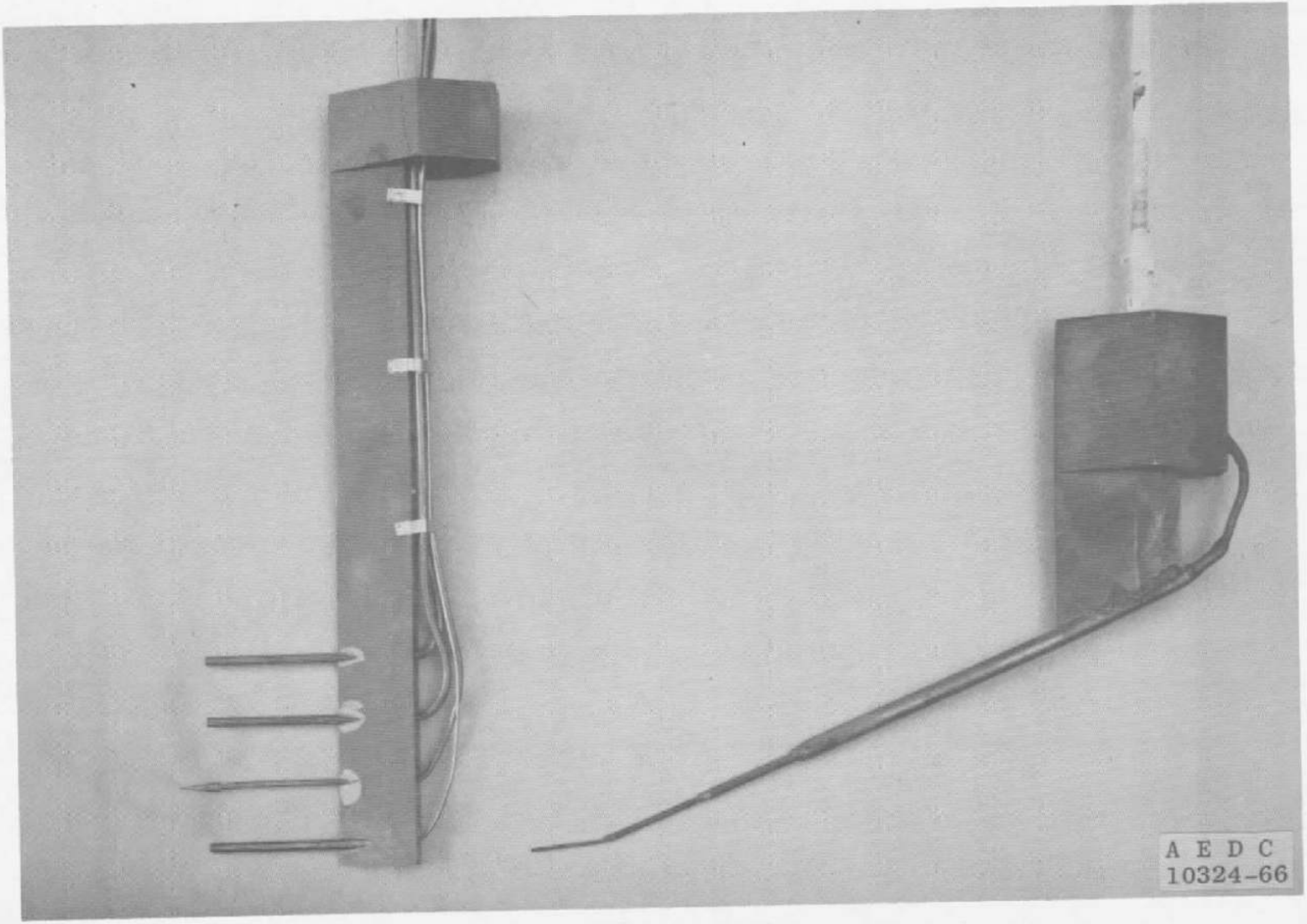
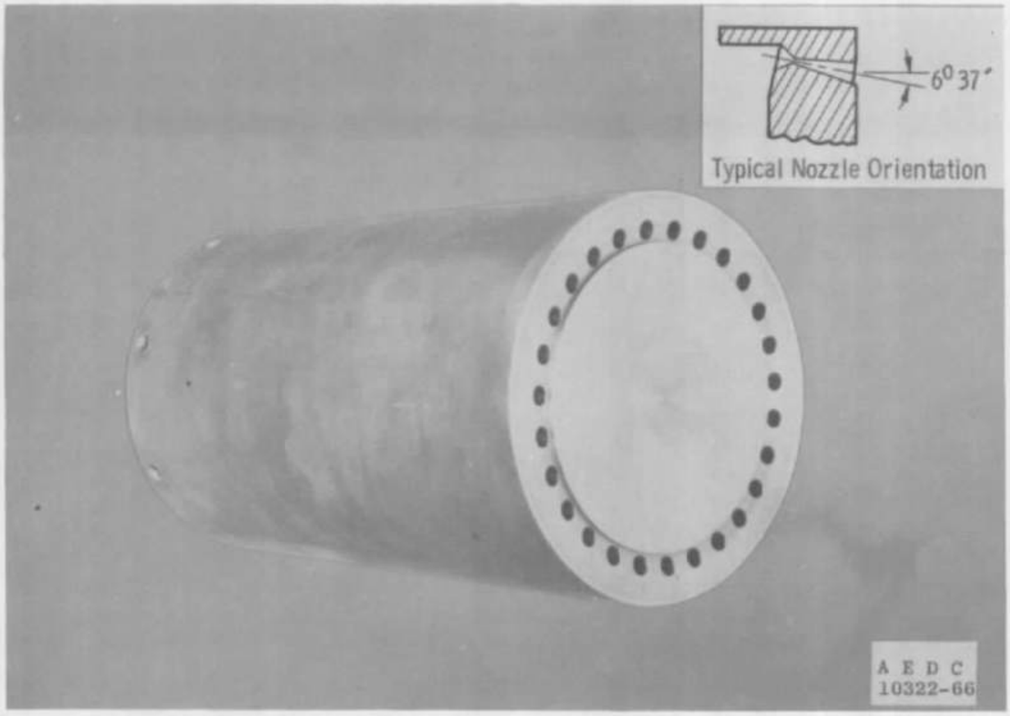
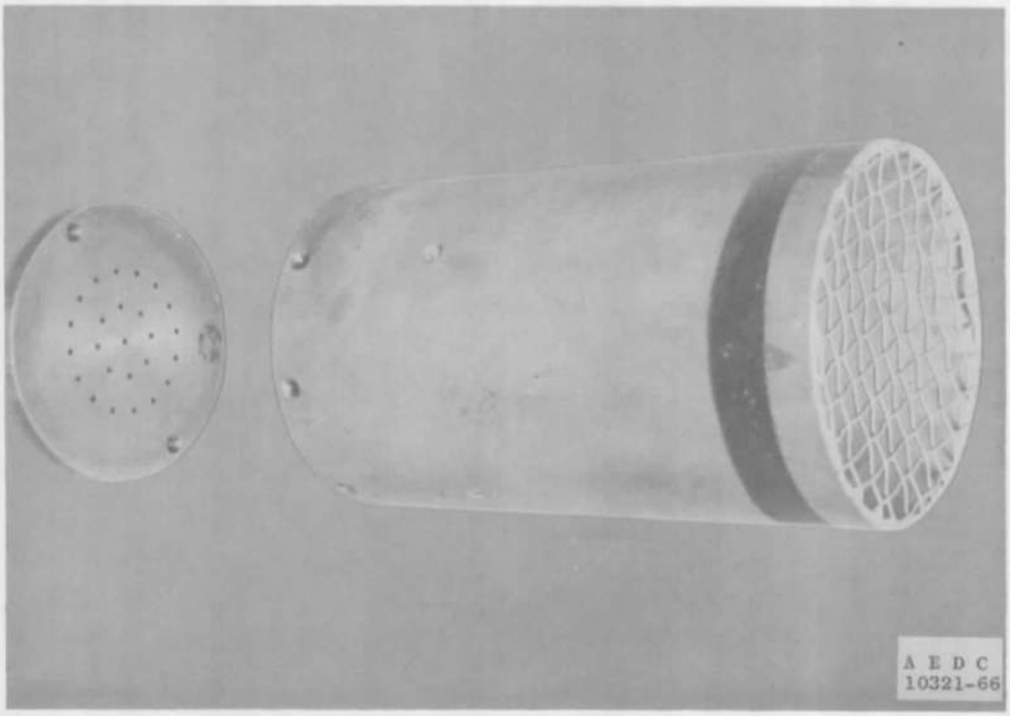


Fig. 1 Model Photograph



a. Supersonic



b. Subsonic

Fig. 2 Ejector Section Photographs

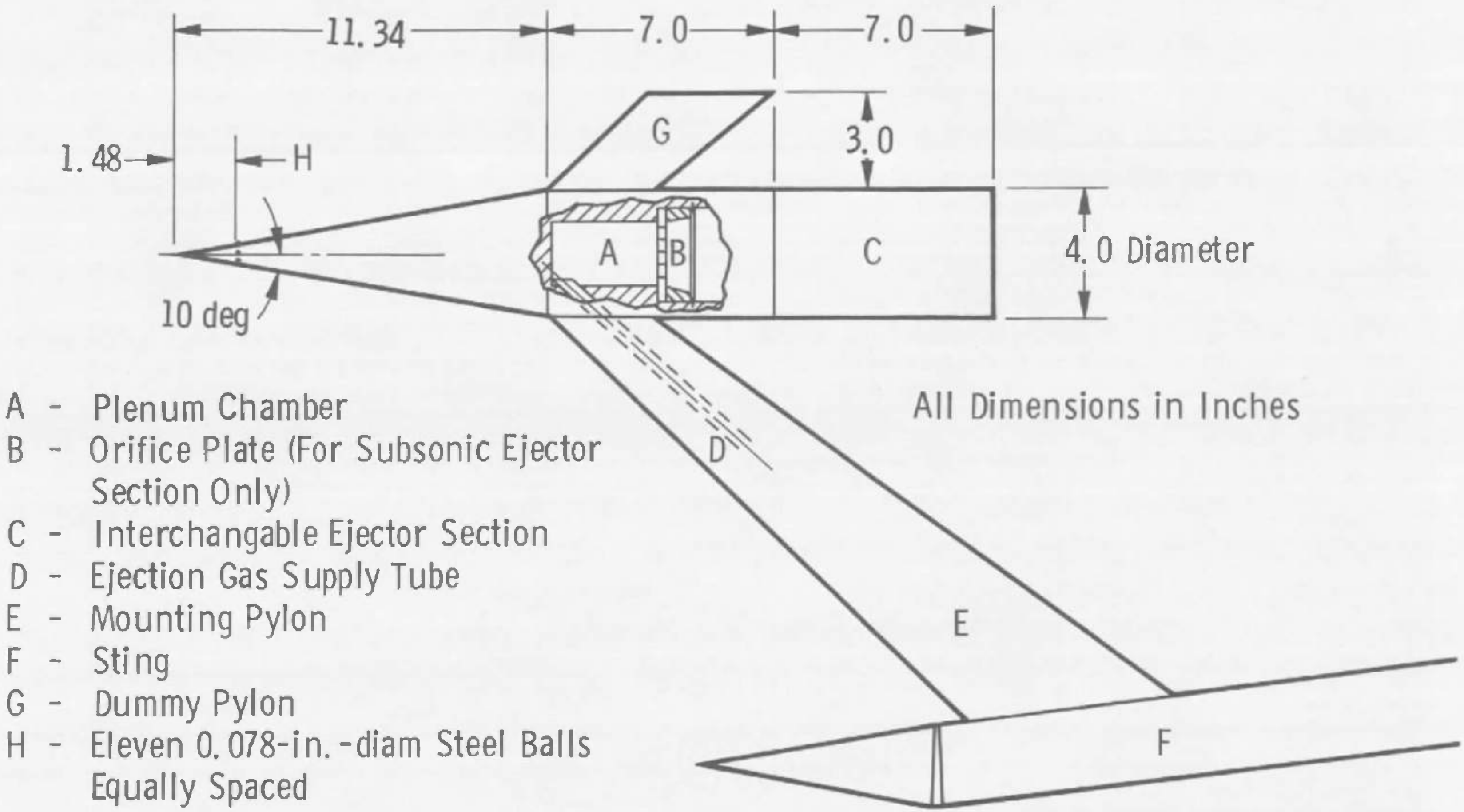


Fig. 3 Model Assembly Diagram

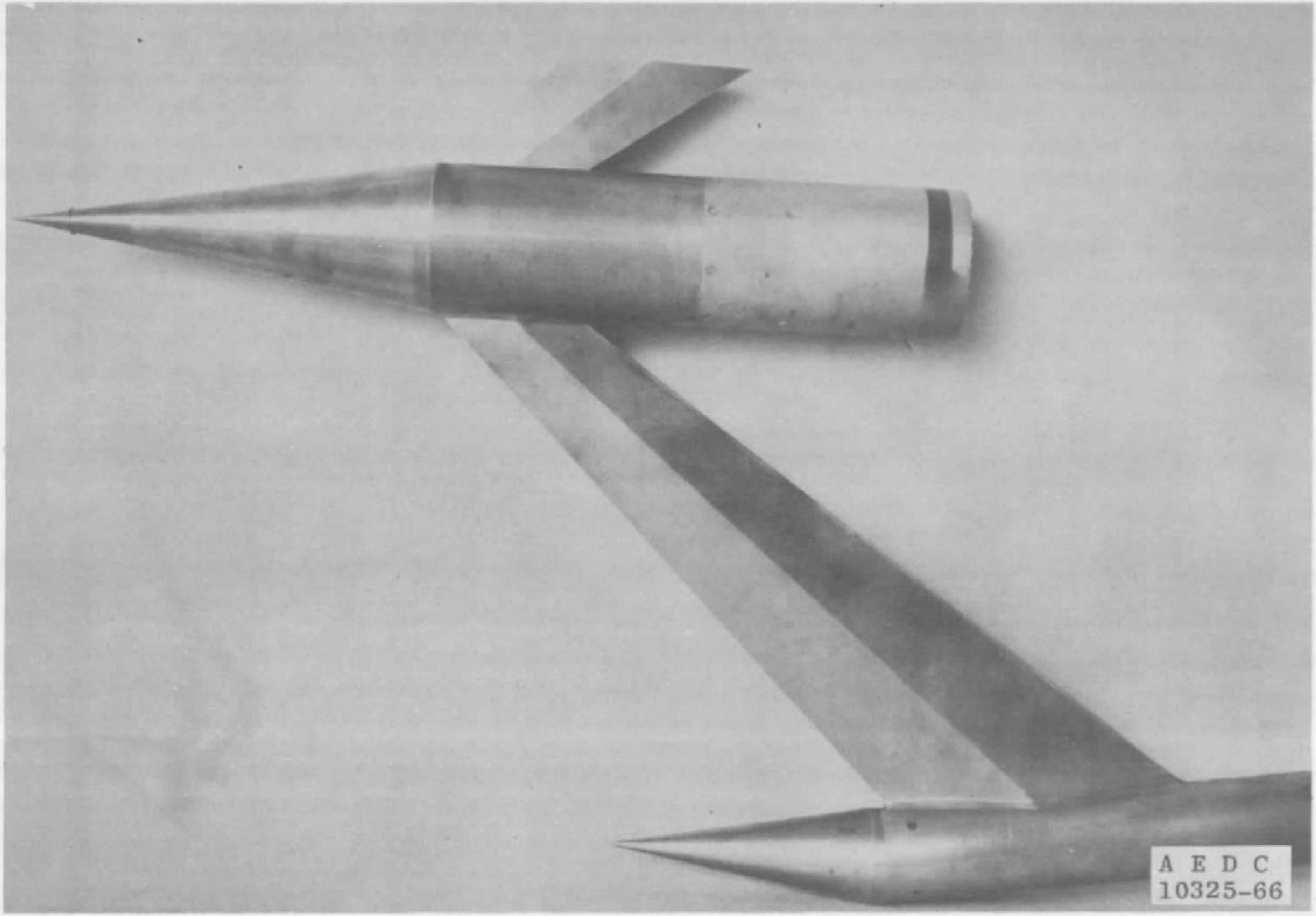


Fig. 4 Wake and Boundary-Layer Probe Photographs

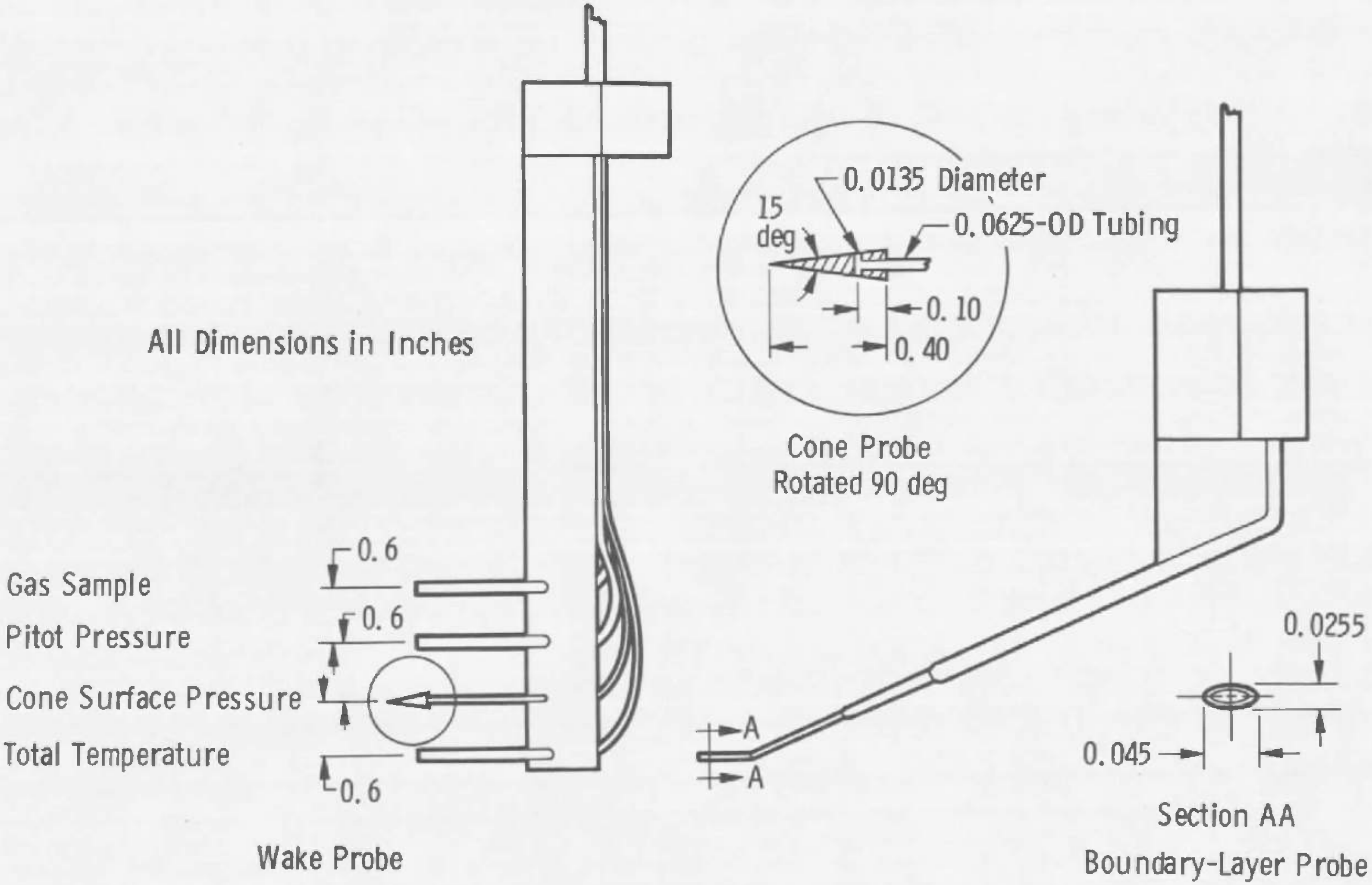
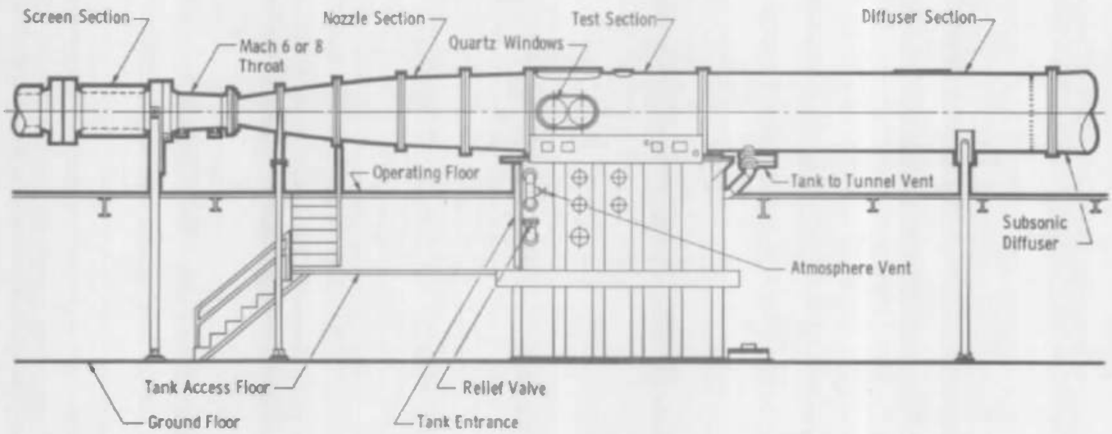
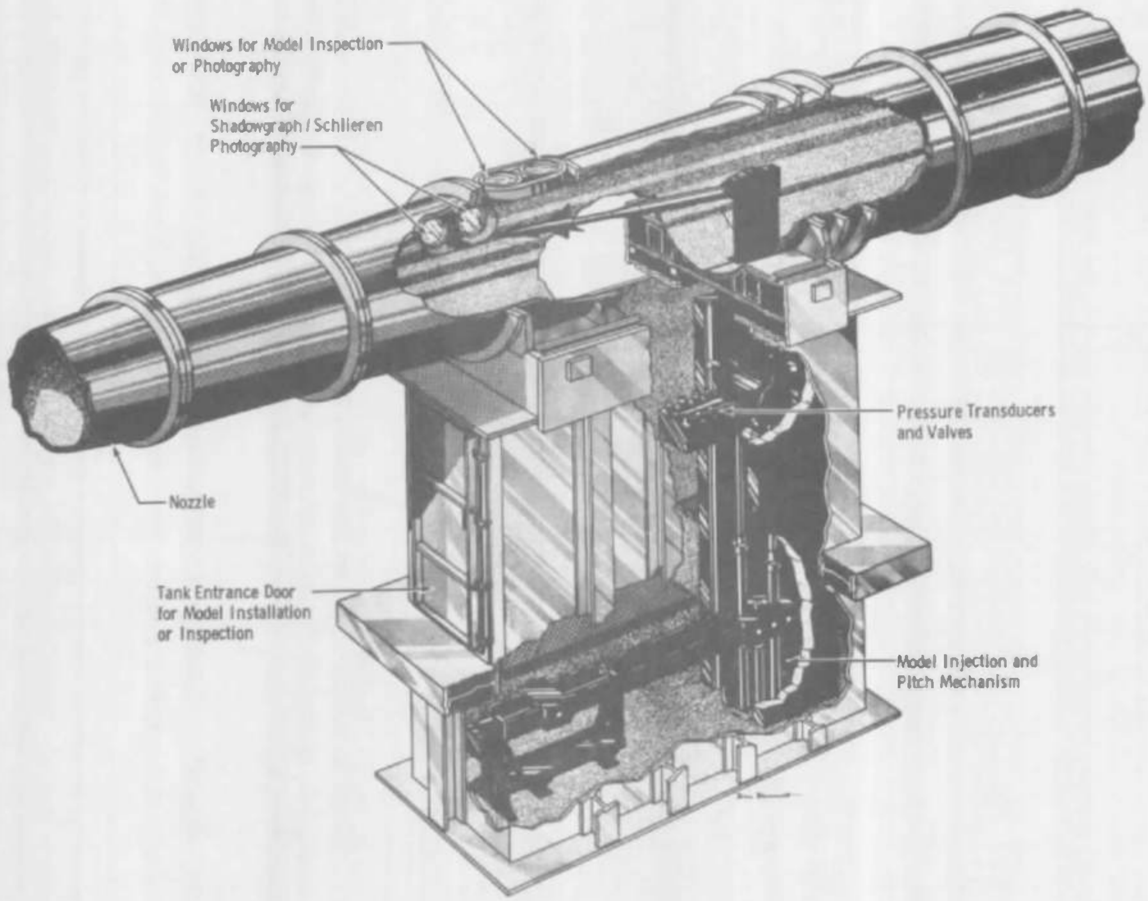


Fig. 5 Wake and Boundary-Layer Probe Drawings

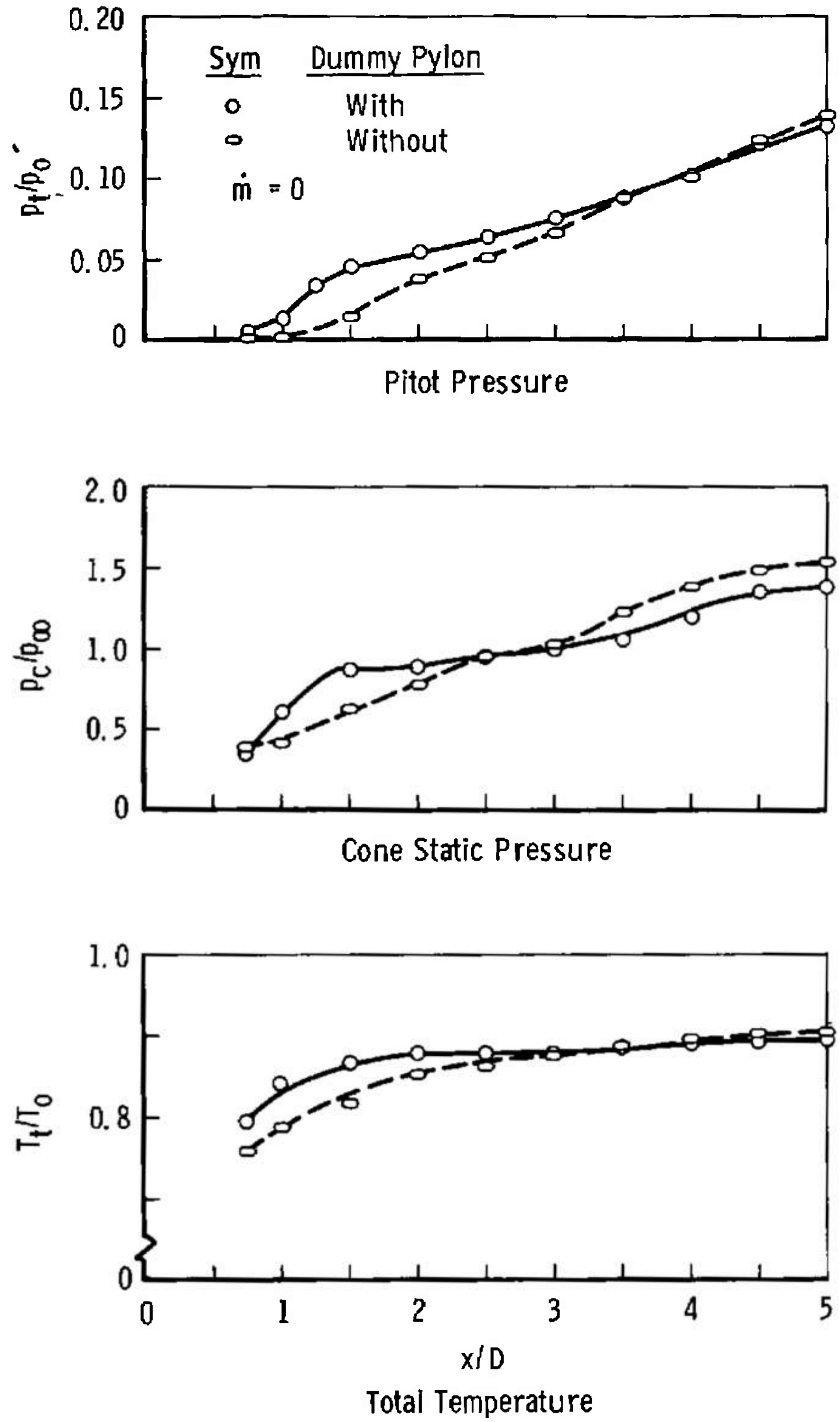


Tunnel Assembly



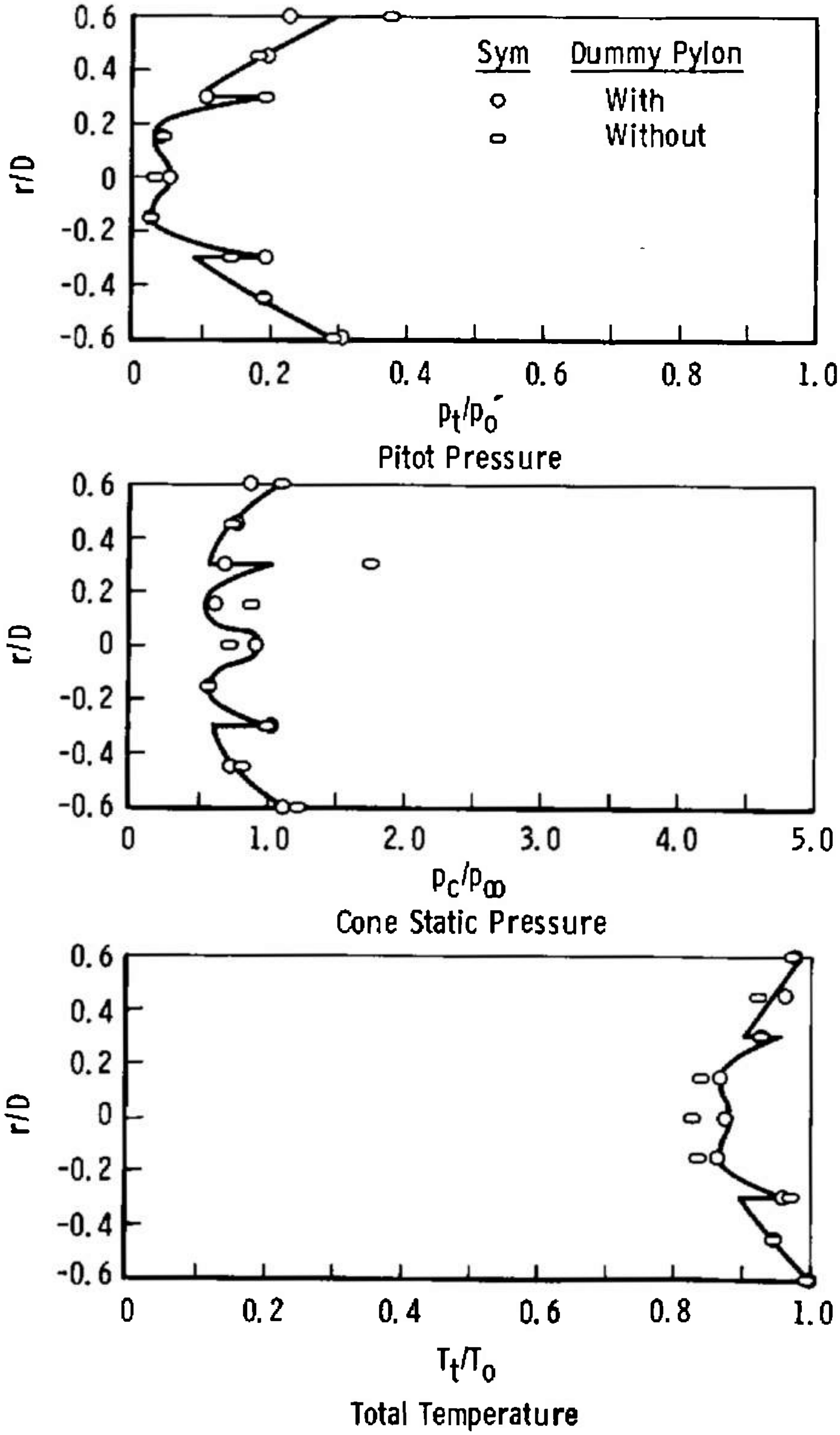
Tunnel Test Section

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

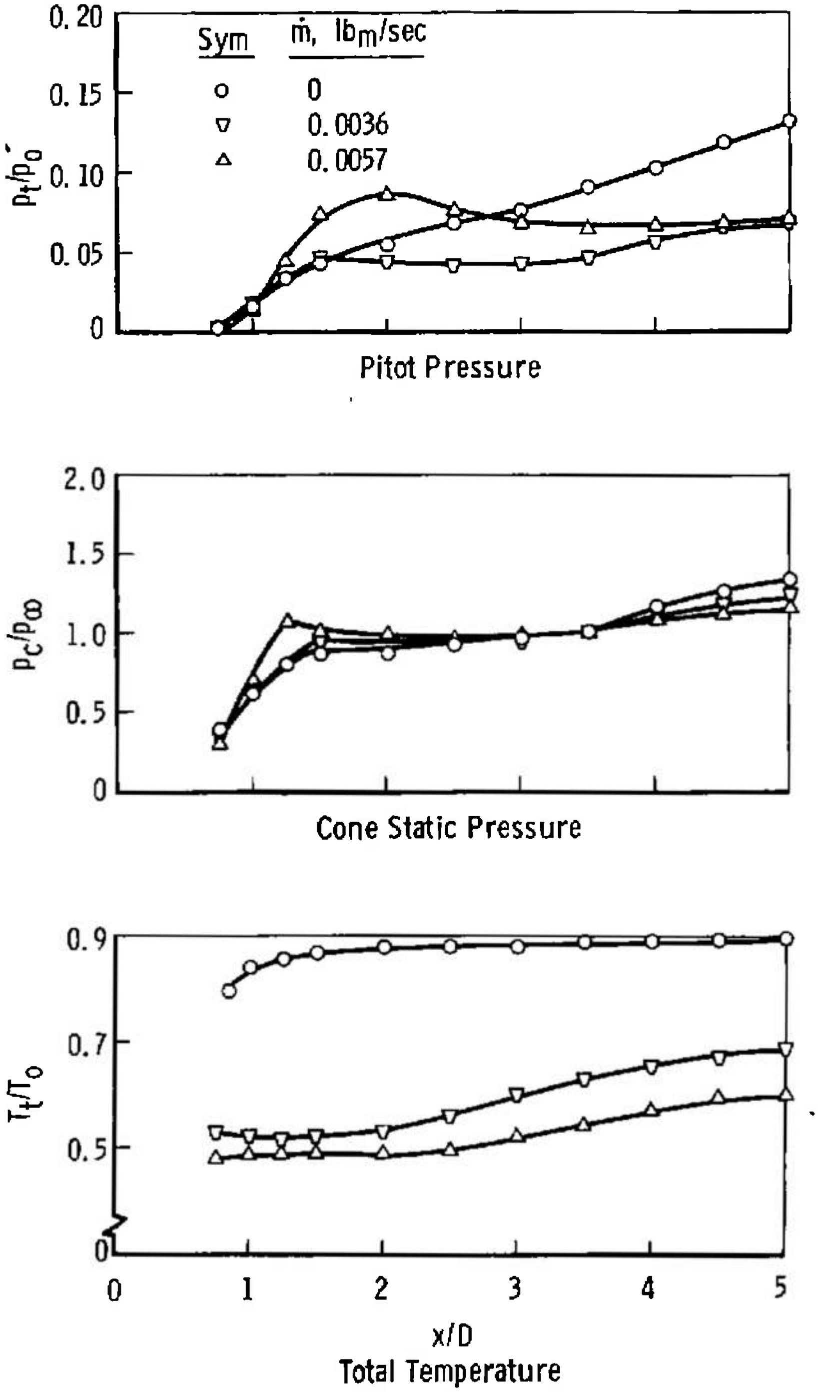


Fig. 8 Typical Wake Axial Survey Data for Helium Ejection through Supersonic Ejector Section

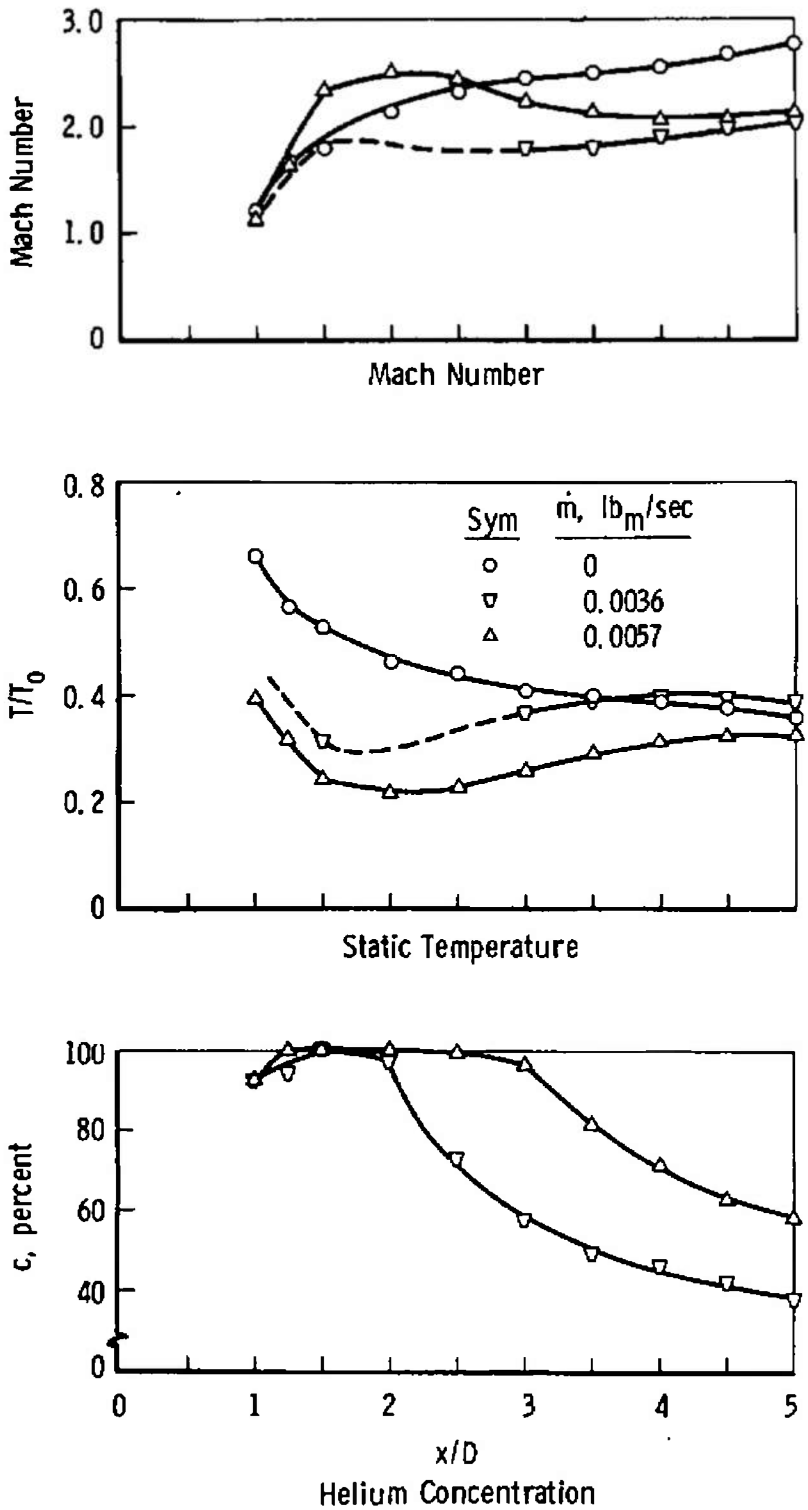


Fig. 8 Concluded

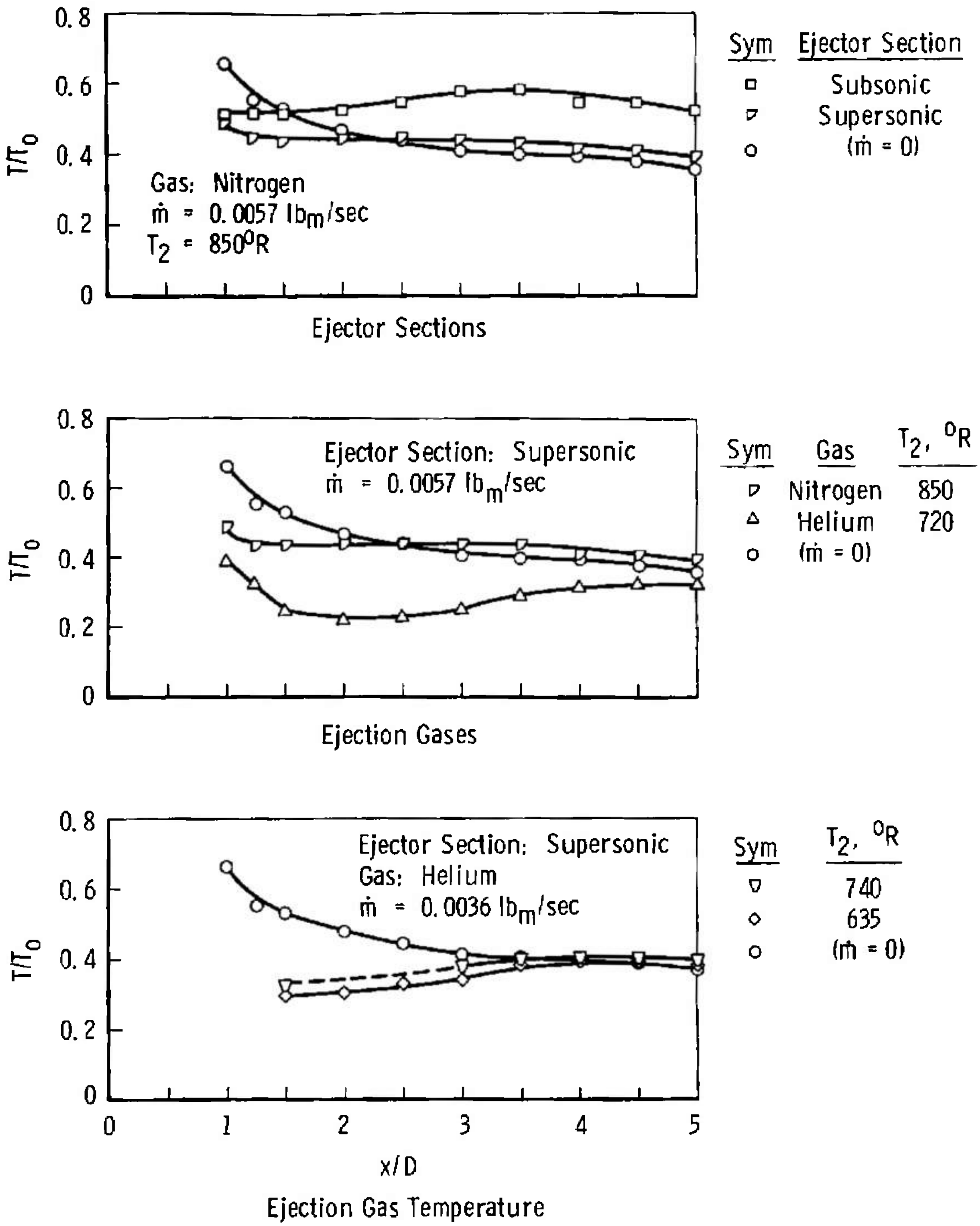


Fig. 9 Typical Effects of Test Variables on Axial Static Temperature Distributions

TABLE I
TEST CONDITIONS

Ejector Section	Ejection Gas	$\dot{m}$, lb_m/sec	T_2, °R
Supersonic	N_2	0.0292 0.0138 0.0057	695 840 875
Subsonic	N_2	0.0297 0.0145 0.0057	620 705 830
Supersonic	He	0.0056 0.0035 0.0035	700 740 635

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Arnold Engineering Development Center ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP N/A

3 REPORT TITLE

INVESTIGATION OF TURBULENT WAKE COOLING WITH BASE EJECTION AT MACH 8

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

N/A

5 AUTHOR(S) (Last name, first name, initial)

Laraway, W. D., ARO, Inc.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
August 1966	24	3

8a CONTRACT OR GRANT NO AF40(600)-1200 b PROJECT NO 9781 c Program Element 61445014 d Task 978102	9a ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-66-147 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A

10 AVAILABILITY/LIMITATION NOTICES

Qualified users may obtain copies from DDC, and transmittal to foreign governments and foreign nationals must have prior approval of AFOSR.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
N/A	Air Force Office of Scientific Research (AFOSR), Washington, D.C.

13 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.

This document has been approved for public release its distribution is unlimited. Per TAB 72-19, Dt'd 1 Oct, 72

DD FORM 1 JAN 64 1473

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
wake cooling						
base ejection						
hypersonic flow						
temperature						
helium						
nitrogen						
pressure						

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.

2*a*. 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.

2*b*. 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.

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

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

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

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

9*a*. 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.

9*b*. 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.