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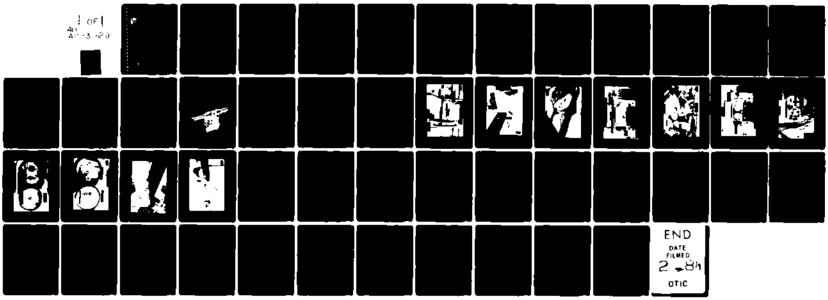

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LASER SCATTERING APPLICATIONS DEVELOPMENT TEST IN AEDC TUNNEL B AT MACH NUMBER 8

W. T. Strike and L. L. Price

ARO, Inc.

AD A093929

March 1980

Final Report for Period January 16, 1980 to February 12, 1980

Approved for public release; distribution unlimited.

ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

NOTICES

APPROVAL STATEMENT

This report has been reviewed and approved.

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FOR THE COMMANDER

John C. Hartney

JOHN C. HARTNEY, Colonel USAF
Director of Test Operations
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surface press data
Fabry-Perot interferometer
wind tunnel test

20\. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Free stream and local flow field measurements on a blunt (0.375-in. radius) nose 5-deg cone were made in Tunnel B at Mach number 8. The nonintrusive flow field measurements were made using various laser scattering optical systems to determine the free stream and local flow field particulate concentration and size distribution, the nitrogen molecule number density, and the local stream velocity using a Fabry-Perot interferometer system. The 5-deg cone pressure distributions were used to confirm the test section Mach number and to produce a known local flow field which could be used to demonstrate potentially → cont.

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20. ABSTRACT

cont'd useful laser scattering measuring techniques.

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I. ILLUSTRATIONS

II. TABLES

III. DATA PACKAGE FORMATS

NOMENCLATURE

ALPHA, α	Sector Angle (prebend angle was 12.0 deg), deg
C.R.	Center of Rotation, in.
DATA TYPE	Defines the type of measurement and the sampling procedure 1. Laser data consisting of 300 samples at 0.03 sec between points 2. Pressure data consisting of 40 samples at usually 1.0 sec between points
K	Weighting factor for the time constant in the pressure prediction routine, $in.^2/(lbf\text{-}sec)$
LILM	Laser internal light meter output, mv
LRPM	Laser receiver power meter output, mv
M	Free stream Mach number
OMEGA, PHI	Angular circumferential station, deg
P	Free stream static pressure, psia
PDn	Output of photomultiplier detector number "n", mv
PNN,PPN	Measured model nose local stagnation surface pressure, psia
PREF	Reference pressure, uH_g
PRMS	Root-mean-square of the curve fitted time history of the pressure with respect to the measured pressure-time history, psi
PT	Stilling chamber pressure, psia
PT2,PTS	Computed stagnation pressure downstream of a normal shock, psia
PW	Model surface pressure, psia
PWI	Initial pressure measured in the time history of the stabilizing model surface pressure, psia
PWF	Final pressure measured in the time history of the stabilizing model surface pressure, psia
RATIO	Ratio of LRPM/LILM in percent
RE	Reynolds number per ft

RHO	Free stream static density, lbm/ft^3
RN	Blunt nose cone radius (0.375 in.), in.
S	Cone surface length relative to the blunt nose stagnation point, in.
TOUT	Nitrogen concentration output
TT	Stilling chamber total temperature, ^{o}R
U	Free stream velocity, ft/sec
X	Model station measured from theoretical apex of the blunt 5 deg cone, in.

1.0 INTRODUCTION

The work reported herin was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65807F, for the Director of Technology (DOT) at AEDC. The DOT project manager was Capt. Ken Leners and the ARO, Inc. project monitor was Mr. L. L. Price. The results were obtained by ARO, Inc., AEDC Group (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in the von Karman Gas Dynamics Facility (VKF), Hypersonic Wind Tunnel (B) during the period January 16, 1980 to February 12, 1980 under ARO Project No. V41B-45.

This test program is to support the research effort entitled "Laser Scattering Applications." The research effort is concerned with the development of laser scattering applications to be used in satisfying future AEDC test requirements. One task in this research effort is the development and application of advanced laser scattering optical systems to measure flow field properties in the VKF supersonic/hypersonic wind tunnels. This experimental phase of the program will be used to provide the data needed to identify the particulate concentration and size distribution in the tunnel flow. Subsequently, this information concerning the tunnel flow particulate characteristics will determine the feasibility of making conventional laser velocimeter measurements in the VKF wind tunnels without "seeding" the flow.

Therefore, the primary objective of this test program was to obtain laser-Mie scattering measurements in Tunnel B which will be used to define flow field particulate concentration and size distribution. In an attempt to fully utilize this tunnel entry and the effort expended to install the laser optical systems, the test objectives were expanded to make the following measurements and laser scattering measurement applications. Using the laser Raman scattering system, measurements were obtained for use in defining the local number density (nitrogen molecules per cu. cm.) in the free stream and downstream of the bow wave of a blunt 5-deg cone. Using this same laser scattering system, the effects of tunnel humidity on flow field measurements were examined. And finally, using a Fabry-Perot interferometer system, the feasibility of making velocity measurements based on a direct Doppler shift measurement, in place of the more conventional laser velocimeter technique requiring tunnel flow seeding, was tested. In summary, the test objectives included an evaluation of the test section flow properties and the application of various scattering measurement techniques.

These tests were conducted in Tunnel B at Mach Number 8 over the Reynolds number range of 0.5 to 3.0 million per foot. Measurements were obtained with and without the dryers in the wind tunnel circuit which produced a maximum (humidity) dew point of nominally 30°F and a minimum (humidity) frost point of -60°F. The pressure distribution on a blunt 5-deg cone (the VKF standard calibration body) was used to monitor the tunnel Mach number.

The observation volume of the laser scattering optics was positioned on the tunnel centerline in the center of the test section. With the model injected, this observation volume fell downstream of the blunt 5-deg cone bow wave, but above the model surface. The location of the observation volume relative to the model was varied by changing the vertical position of the model. At each test condition, a set of laser scattering data was recorded with the model retracted and injected into the flow. This produced test data describing the flow field properties in the free-stream flow and then in the local flow field above the blunt 5-deg cone.

This report describes the test apparatus, procedures, and data reduction of the model surface pressures and the millivolt outputs of the optical detectors.

Inquiries to obtain copies should be directed to AEDC/DOT, Arnold Air Force Station, TN 37389. A microfilm record of the test results has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel B (Fig. 1) is a closed circuit hypersonic wind tunnel with a 50-in. diam test section. Two axisymmetric contoured nozzles are available to provide Mach numbers of 6 and 8 and the tunnel may be operated continuously over a range of pressure levels from 20 to 300 psia at Mach number 6, and 50 to 900 psia at Mach number 8, with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 1,350°R) are obtained through the use of a natural gas fired combustion heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral, external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel may be found in the Test Facilities Handbook (Ref. 1).

2.2 TEST ARTICLE

The blunt 5-deg cone pressure model shown in Fig. 2 is the standard calibration body for the VKF. This cone which was designed and fabricated in the VKF is nominally 30 in. long with a 6 in. base diam and a 0.375 in. radius nose. Sixty-eight (0.063 in. I.D.) pressure taps were installed in this stainless steel model. The pressure taps are located along four longitudinal rows spaced 90-deg apart with 17 equally spaced pressure taps per row.

This calibration body was installed on a 12-deg prebend model support system as shown in Fig. 3. Variations in the sector center of rotation produces a systematic vertical displacement in the model axis relative to the tunnel axis.

2.3 LASER SCATTERING SYSTEM

To accomplish the objective of particulate size distribution and concentration measurements, an extensive optical diagnostics system was designed and installed in Tunnel B. The particular Mie scattering method employed was developed by the PWT/AT Branch. The Mie scattering instrumentation included a Spectra-Physics® argon ion laser with a beam power of approximately two watts at 514.5 nm, five detector units, and a laser receiver power meter as shown in Fig. 4. Each detector unit contained two 1P28 photomultiplier tubes as detectors of the components of scattered and polarized laser light, and each unit was situated at one of five different windows for viewing the light scattered from the flow particles as they encountered laser light in the observation volume. The laser receiver power meter measured the beam transmission through the flow. Data were recorded by the VKF computer. The pattern of scattered light signal amplitudes, polarization states, beam transmission, and detector unit viewing angles uniquely determines the size distribution and concentration, with the added potential of particulate material identification. Size specification accuracy increases with the number of detectors. All these components were mounted on platforms supported by the tunnel's two schlieren vibration-isolation support columns, which are structures independent of the tunnel and located on each side of the test section.

Components of the system located on the nonoperating side of the tunnel are shown in Fig. 5. A steel platform previously used for Tunnel C work was modified and affixed to the vibration-isolation support. The Spectra-Physics laser and three Mie scattering detector units were each mounted on one of two levels of this platform. On the tunnel operating side, two detector units and the laser power meter were mounted on an existing table, and these components are shown in Fig. 6.

A view from within the tunnel test section of the optical components located on the operating and nonoperating sides of the tunnel is shown in Figs. 7 and 8, respectively. The detector unit mounted on top of Tunnel B is shown in Fig. 9a.

Additional optical instrumentation was installed for measurement of the nitrogen molecular number density. A cooled photomultiplier tube (Fig. 9b) located above the tunnel observed Raman scattered radiation from the same observation volume through narrow bandpass and blocking filters, and these signals were recorded by hand.

Finally, an optical system for measuring particulate velocities was added. A Coherent Radiation argon ion laser of approximately 3 watts output of 514.5 nm was mounted alongside the Spectra-Physics laser, and a complex optical system provided a primary and a reference beam from this laser, each intersecting at the observation volume. A Fabry-Perot interferometer, associated optics, and an uncooled photomultiplier tube completed this velocity system; they were mounted on the operating side as shown in Fig. 6d.

2.4 STANDARD TEST INSTRUMENTATION

The standard measuring and recording devices, and calibration methods for all the measured parameters other than those associated with the laser scattering system are listed in Table 1. This table also contains the estimated measurement uncertainties. The corresponding information associated with the measuring, recording, and calibration techniques for the laser scattering systems will be documented by PWT/AT in their final report for ARO Project P32M-01.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

3.1.1 General

A summary of the nominal test conditions are given below.

M	PT, psia	TT °R	Min. Dew Pt	U, ft/sec	PT2, psia	RE x 10^{-6}/ft
7.99	690	1350	-59°F	3878	5.89	3.0
7.98	460	1340	-53°F	3864	3.95	2.0
7.95	232	1360	-52°F	3891	2.03	1.0
7.90	116	1345	-50°F	3868	1.04	0.5

A test log showing all configurations and variables covered in this program is presented in Table 2.

Unless specifically identified in Table 2, all data recorded with the model injected into the tunnel flow were obtained with the model center of rotation at 7.0 inches (see Fig. 3). When the column labeled "Cone in Tank" is checked, free stream laser scattering measurements were recorded. In all other cases, the model was injected into the tunnel flow and either laser data or cone surface pressure measurements were made as indicated in the test log, Table 2.

In the VKF continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

The free stream Mach number was confirmed on the basis of the pressure distribution on the VKF standard calibration body, a blunt 5-deg cone. These plotted pressure distributions are given in Fig. 10 and include the theoretical results used in confirming the free stream Mach number. The theoretical results are based on the HVSL (three-dimensional hypersonic viscous shock layer) code based on the work of Lubard and Helliwell (see Refs. 2 and 3). This version of the HVSL provides an estimate of the induced pressure distribution produced on an unyawed blunt nose cone with laminar flow in a hypersonic stream.

3.1.2 Test Procedure

Basically the first shift as indicated in Table 2 was devoted to defining the character of the flow when the tunnel dew point (humidity) was high (the order of 0 to +30°F). Cone surface pressure data were taken at each new test condition. The laser scattering data were obtained with the model in the tank to provide free stream results, and then the model was injected into the tunnel flow to obtain similar results in the local flow field over the model downstream of the model bow wave.

The final shift was devoted to obtaining similar data with the tunnel running in a very dry condition. In addition to obtaining laser scattering data with and without the model injected into tunnel flow, a set of results was obtained as the model was moved relative to the laser-optics observation volume (Runs 27 to 30 in Table 2). This sequence of tests was run in an attempt to see if laser scattering measurements could be used to detect the variations in the local static density in the flow field of the blunt cone.

Preceding and following each tunnel shift, a set of air-off laser scattering data was recorded to provide additional calibration results for the optical system.

3.1.3 Data Acquisition

The model surface pressure data were obtained by means of an pressure equilibrium technique described in Ref. 4. This required that each pressure readout be scanned 40 times in one second intervals. Based on the geometry of the pressure tubing from the model to the transducer, the nominal temperature of the air in the tubing, and the pressure-time history, the equilibrium pressure at the model surface could be defined.

The laser scattering results consisted of the millivolt output from the 10 photomultiplier detectors, the LILM, the LRPM, and the nitrogen concentration output TOUT. Except for TOUT, the outputs were scanned 300 times at equal time intervals of 0.03 seconds. All other measurements were scanned once for each data run.

3.2 DATA REDUCTION

Except for the laser scattering evaluations, all other data reduction procedures were standard. The output from the laser scattering system was converted to millivolts using the proper amplifier gains and scale factors, namely

$$\text{Millivolts} = (0.61035/\text{Gain})\text{Reading}$$

The sampled signal consisting of 300 points was summed and tabulated along with the average value. A tare value, obtained by blocking the laser beam, was obtained prior to each data point. The tare value also consisted of 300 sampled points which were summed and averaged. The tabulated results consist of the tare value, the data point, and the difference between and tare and data point.

3.3 MEASUREMENT UNCERTAINTY

In general, instrumentation calibrations and data uncertainty estimates were made using methods recognized by the National Bureau of Standards (NBS) and described in Ref. 5. Measurement uncertainty is a combination of bias and standard deviation defined as:

$$U = \pm(B + t_{95} S)$$

where B is the bias limit, S is the sample standard deviation, and t_{95} is the 95th percentile point for the two-tailed Student's "t" distribution which for degrees of freedom greater than 30 is 2.

Estimates of the data uncertainties for the standard tunnel measurements are presented in Table 1. The uncertainty estimates for the laser scattering outputs will be included in the final analysis of the results by PWT/AT.

The bias and standard deviations of the measured data were propagated through the standard data reduction in accordance with Ref. 5. The results are included in Table 1.

4.0 DATA PACKAGE PRESENTATION

The data package consists of two data formats, namely, the blunt 5-deg cone surface pressure results and the tabulated laser scattering millivolt outputs. Examples of the two data formats are given in Appendix III.

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1. Test Facilities Handbook (Eleventh Edition). "von Karman Gas Dynamic Facility, Vol. 3," Arnold Engineering Development Center, June 1979.

2. Lubard, S. C. and Helliwell, W. S. "Calculation of the Flow on a Cone at High Angle of Attack." R&D Associates RDA-TR-150, Santa Monica, CA, February 1970.

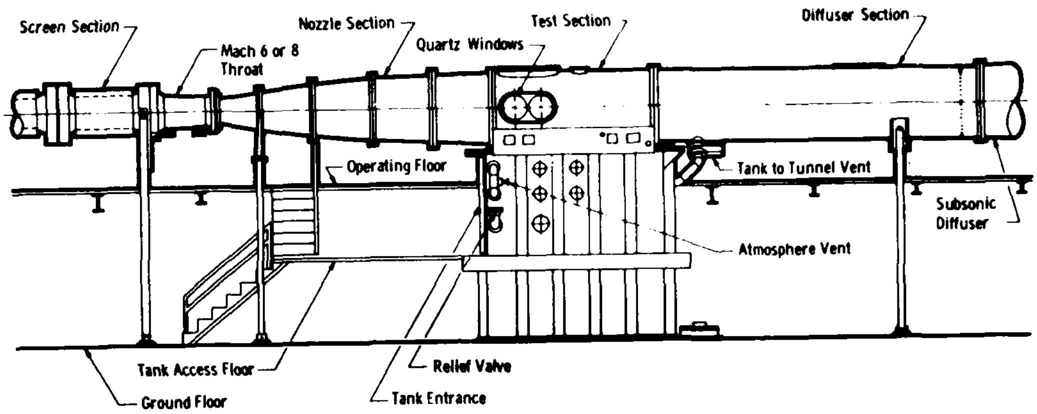
3. Mayne, Arloe W., Jr. "Calculation of the Laminar Viscous Shock Layer on a Blunt Biconic Body at Incidence to Supersonic and Hypersonic Flow." AEDC-TR-76-123, December 1976.

4. Brown, D. L. "Predicting Equilibrium Pressures from Transient Pressure Data." Aerospace Research Laboratories ARL 65-7, January 1965.

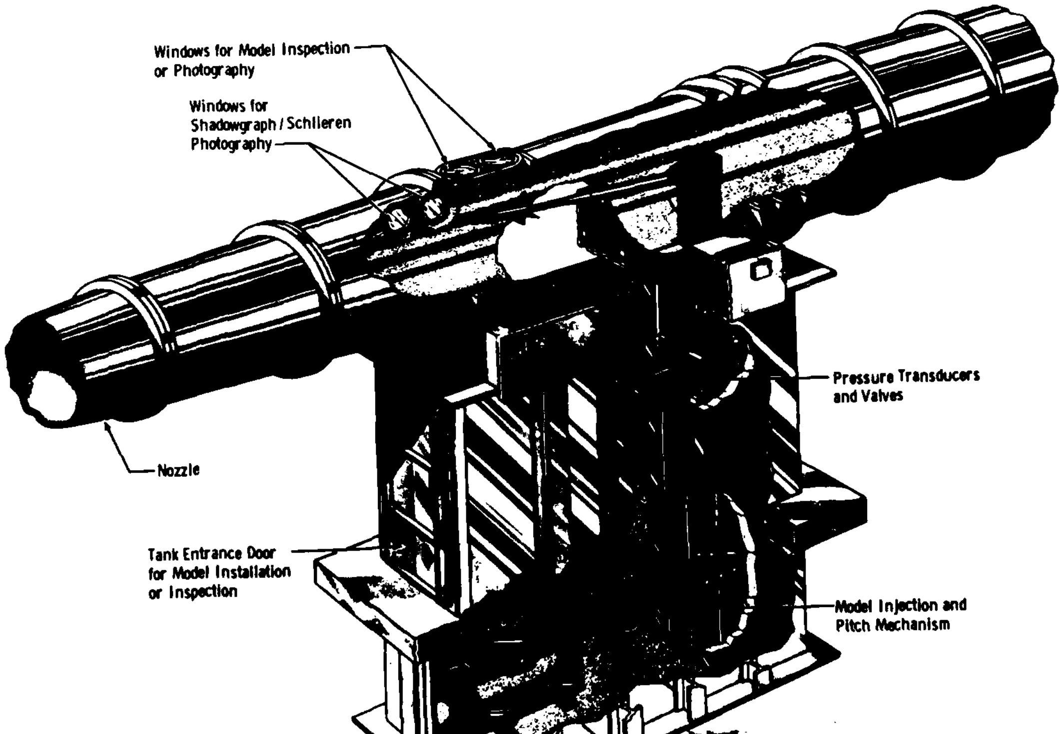
5. Thompson, J. W. and Abernethy, R. B. et al. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD755356), February 1973.

APPENDIX I

ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section
Figure 1. Tunnel B.

All Dimensions in Inches

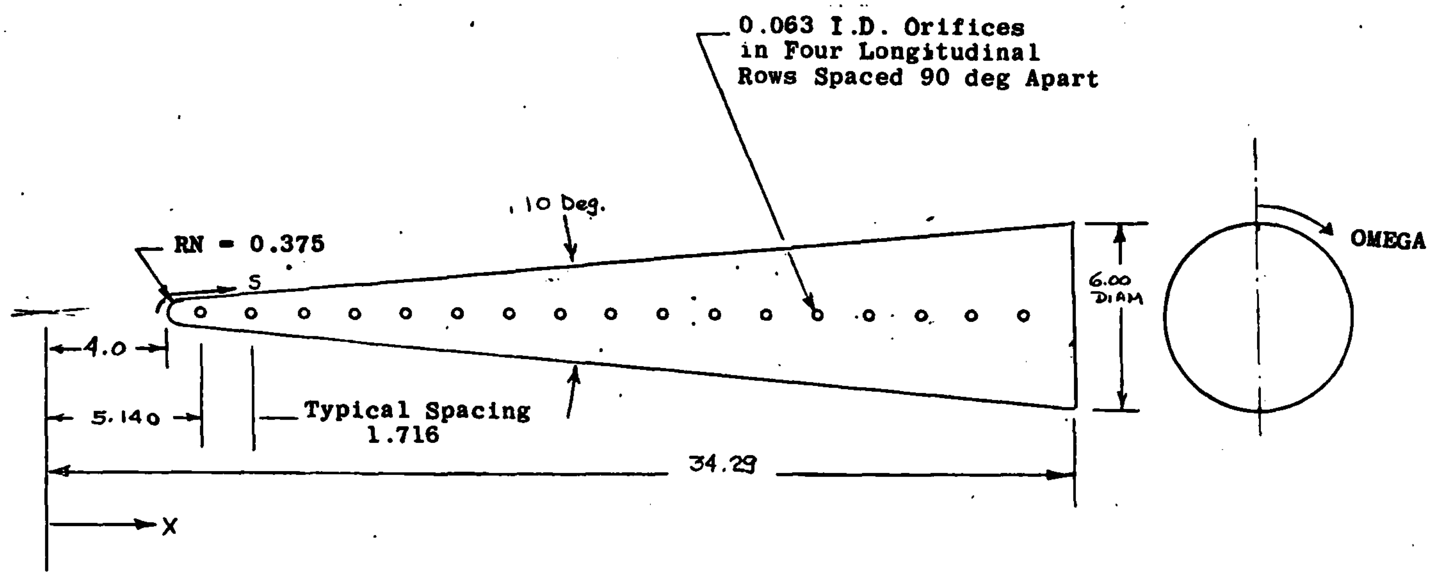


Fig. 2. VKF Standard Cone-Pressure Model

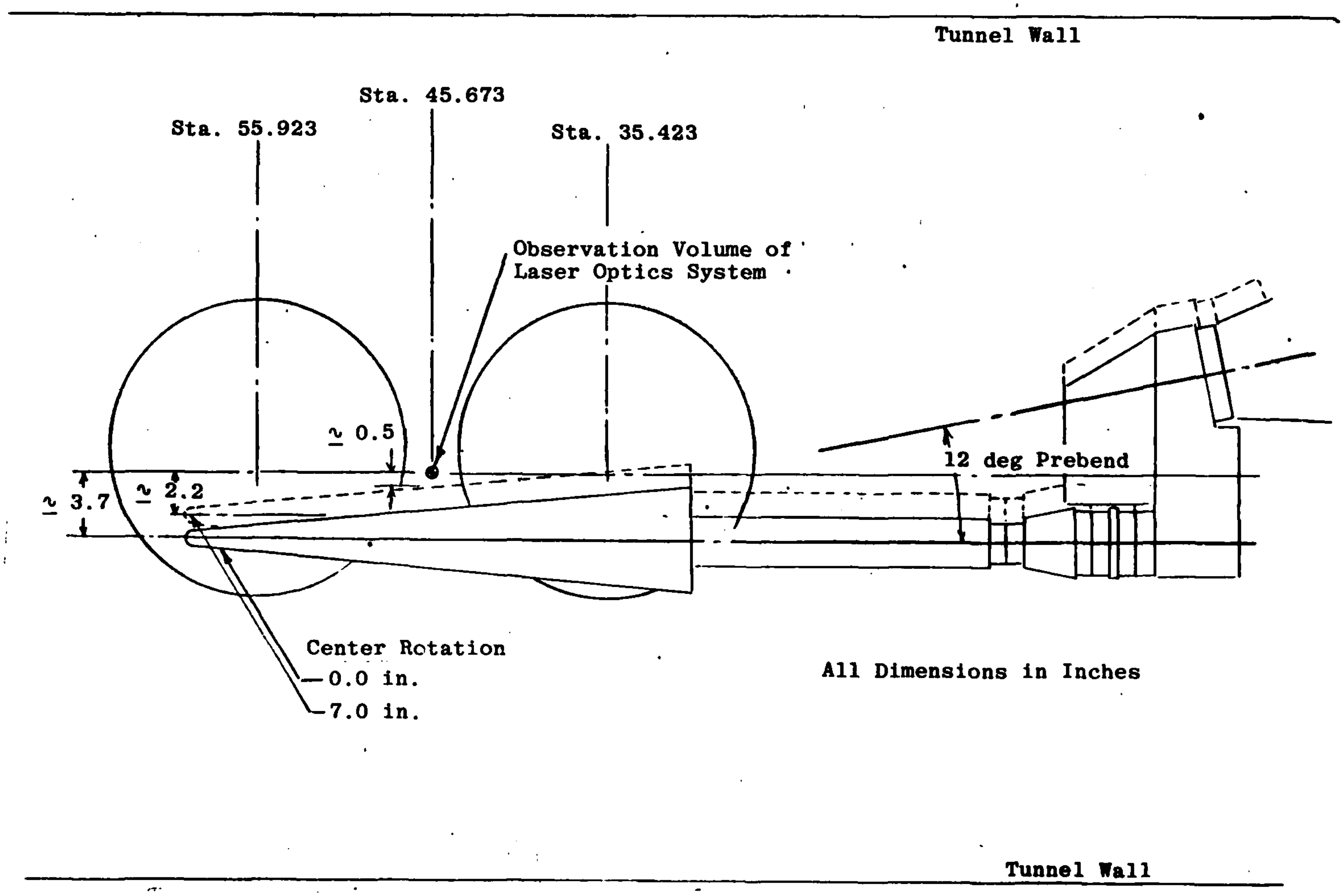


Figure 3. Tunnel B Installation for Laser Scattering Test

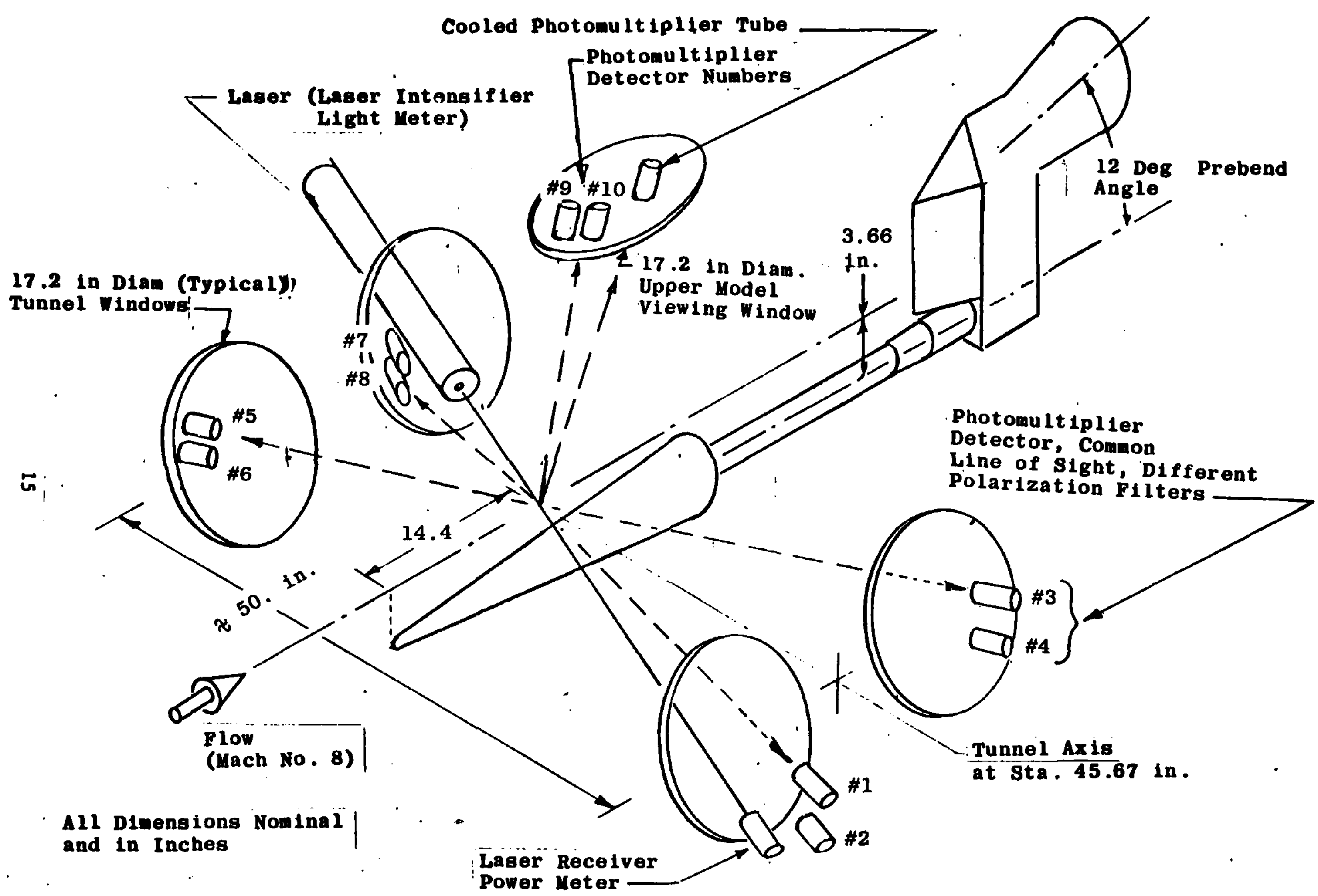
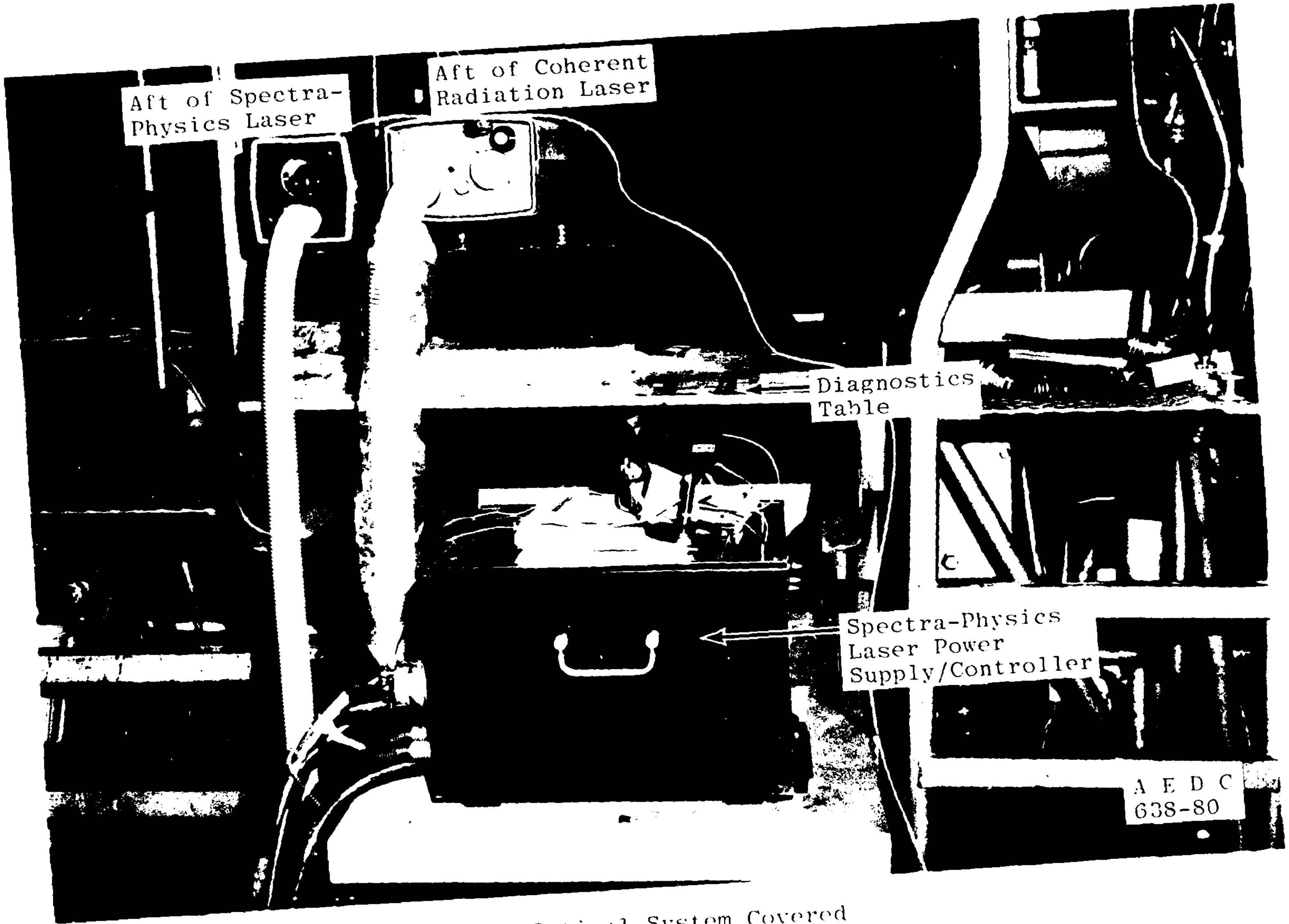
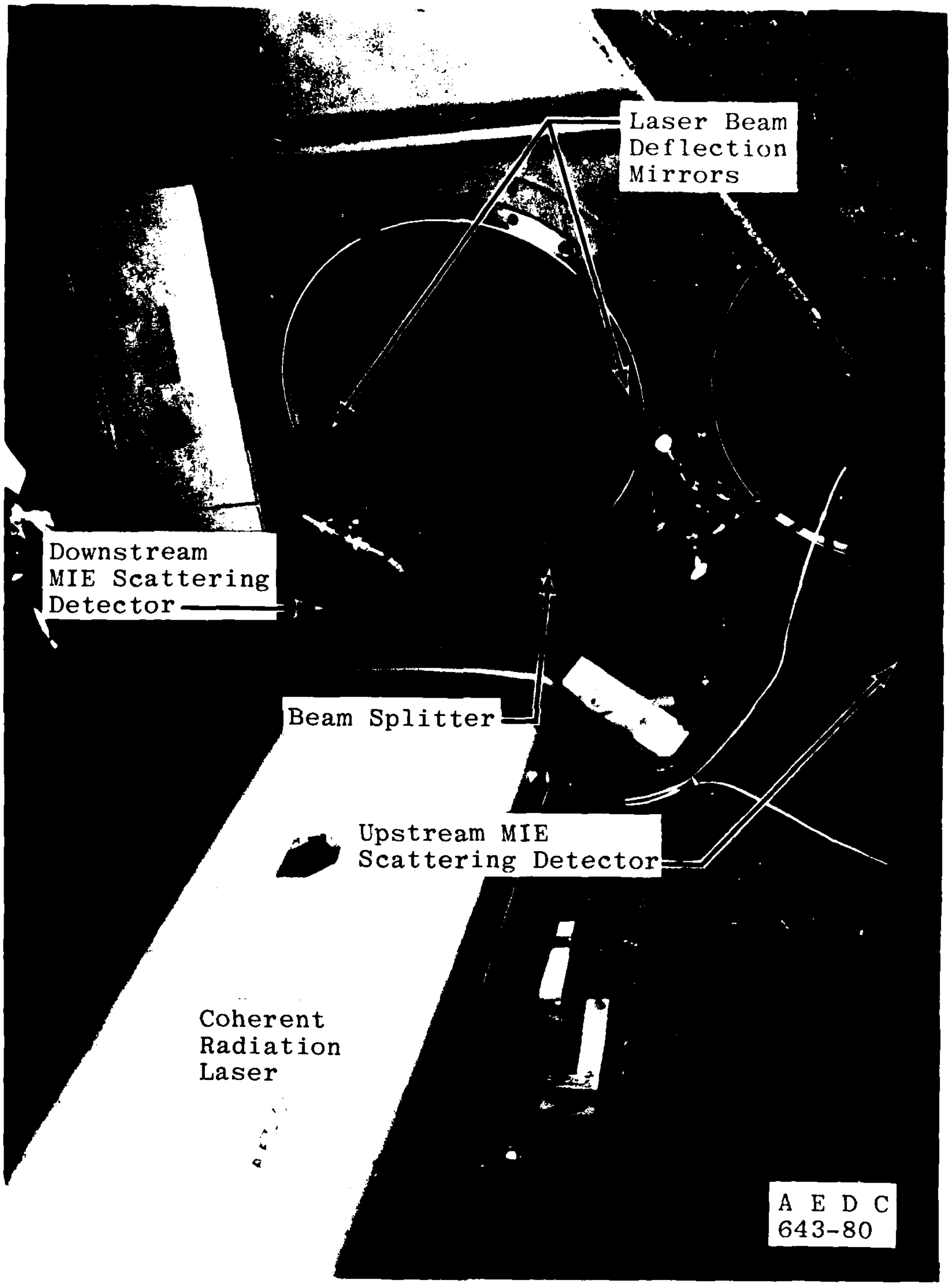


Figure 4 Laser - Photomultiplier Detector Installation with Model Injected



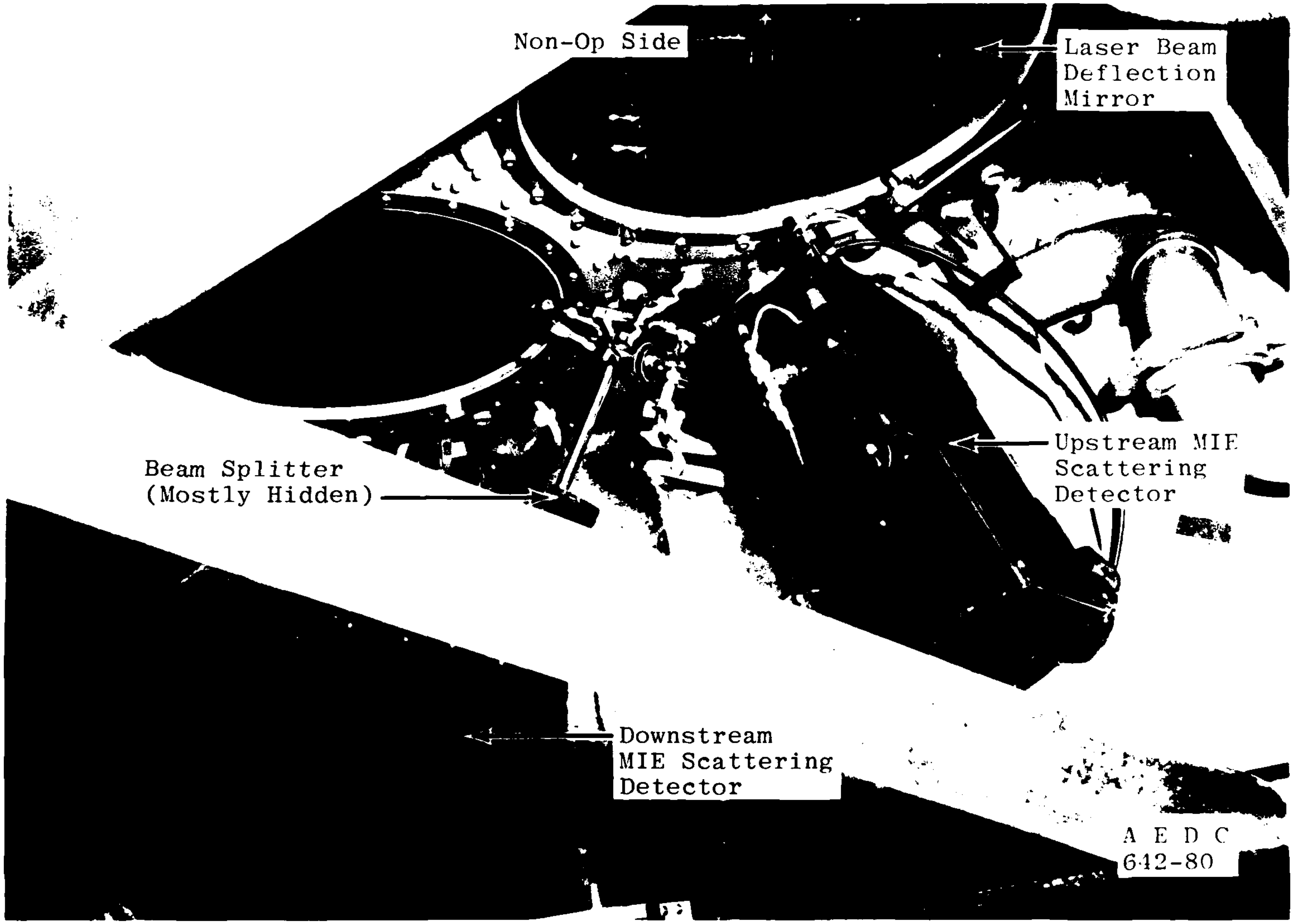
a. Optical System Covered

Figure 5. Dual Laser Installation, Nonoperating Side of Tunnel B

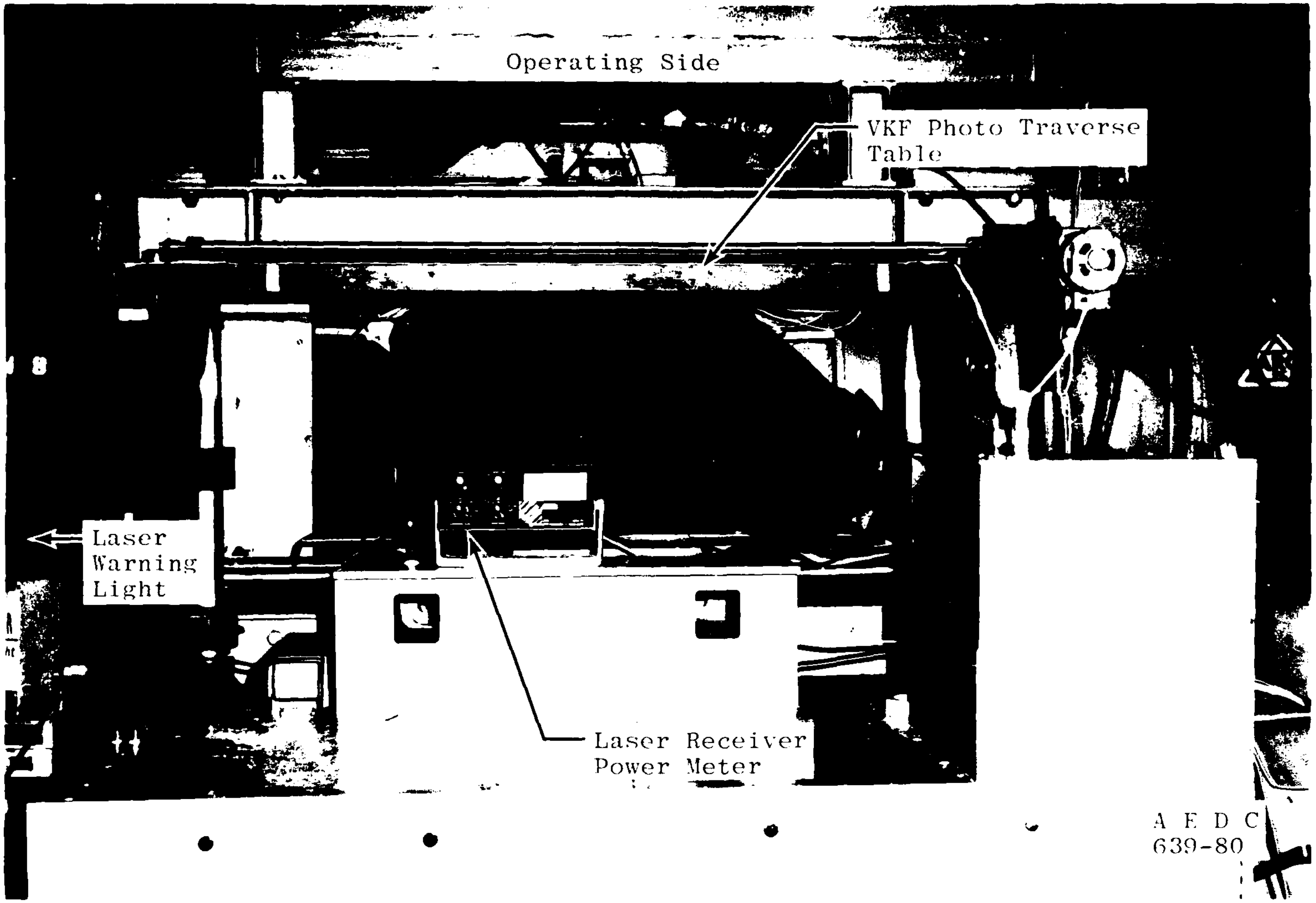


b. Downstream Laser Optics

Figure 5. Continued.

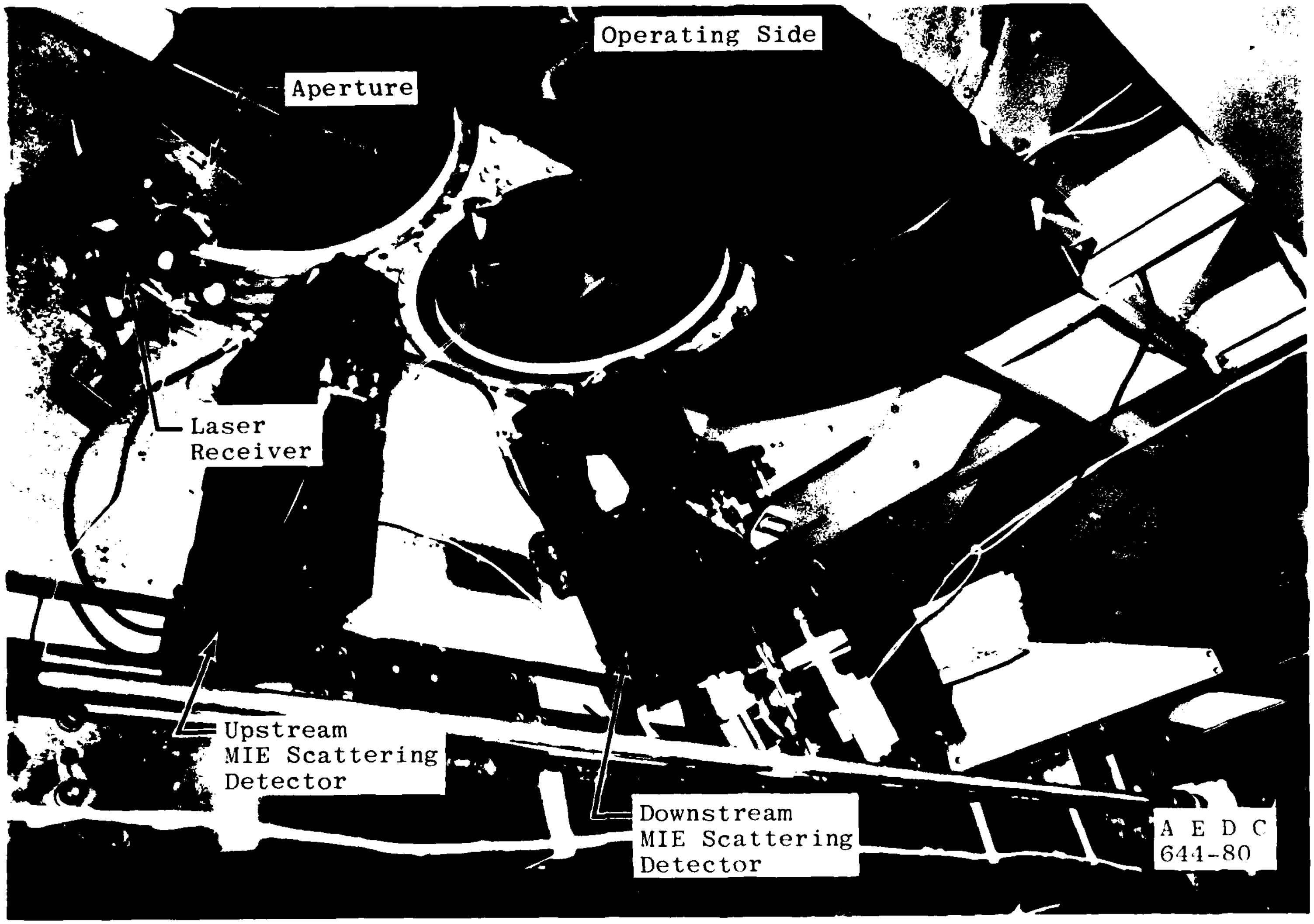


c. Upstream Laser Optics and Detectors
Figure 5. Concluded.



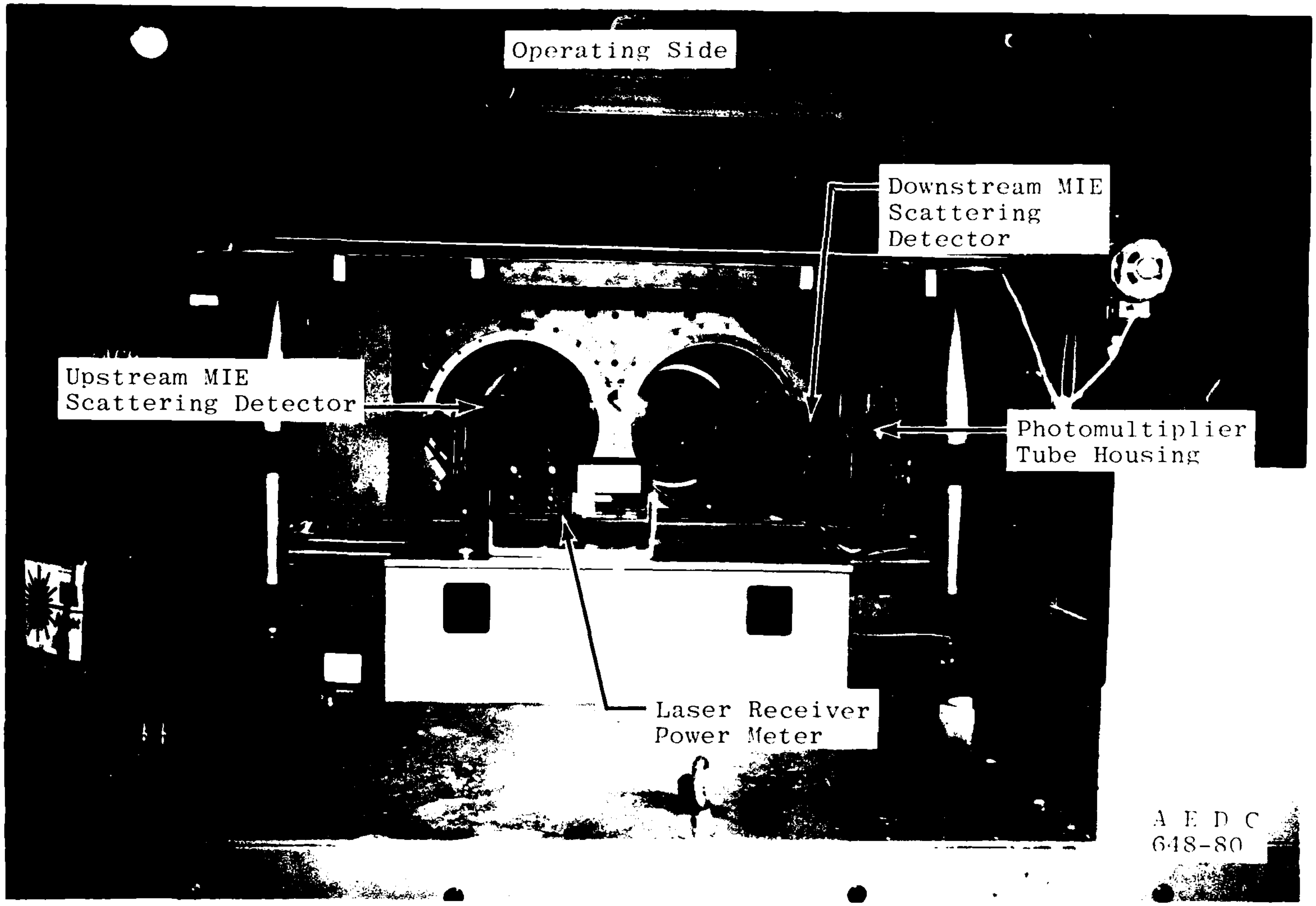
a. Optics Covered

Figure 6. Laser-Optics Installation on the Operating Side of Tunnel B



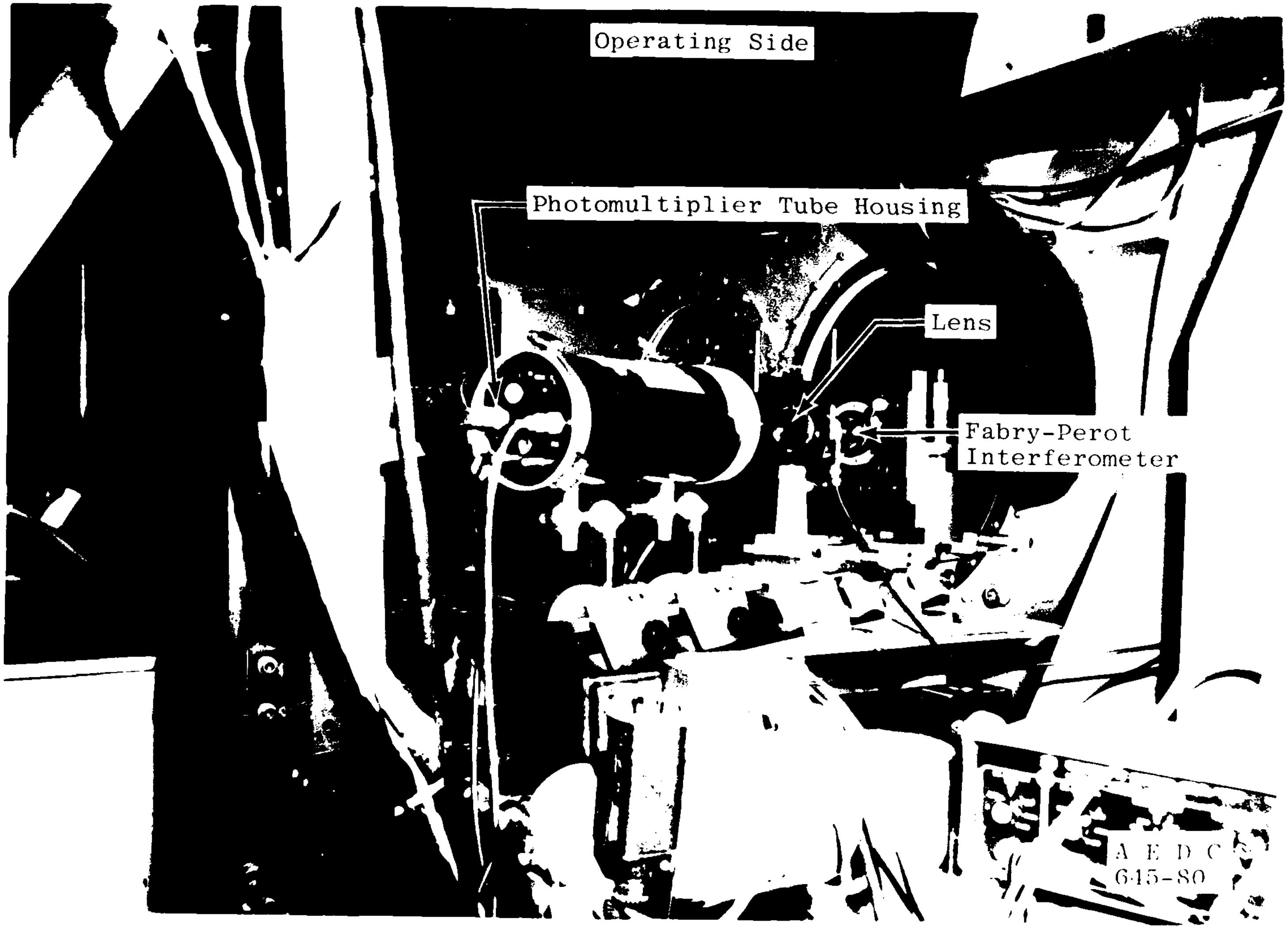
b. Optics Uncovered, Viewed from Above

Figure 6. Continued



c. Optics Uncovered, Viewed Directly into Tunnel Windows

Figure 6. Continued



d. Downstream View with Fabry-Perot Optics Systems

Figure 6. Concluded.

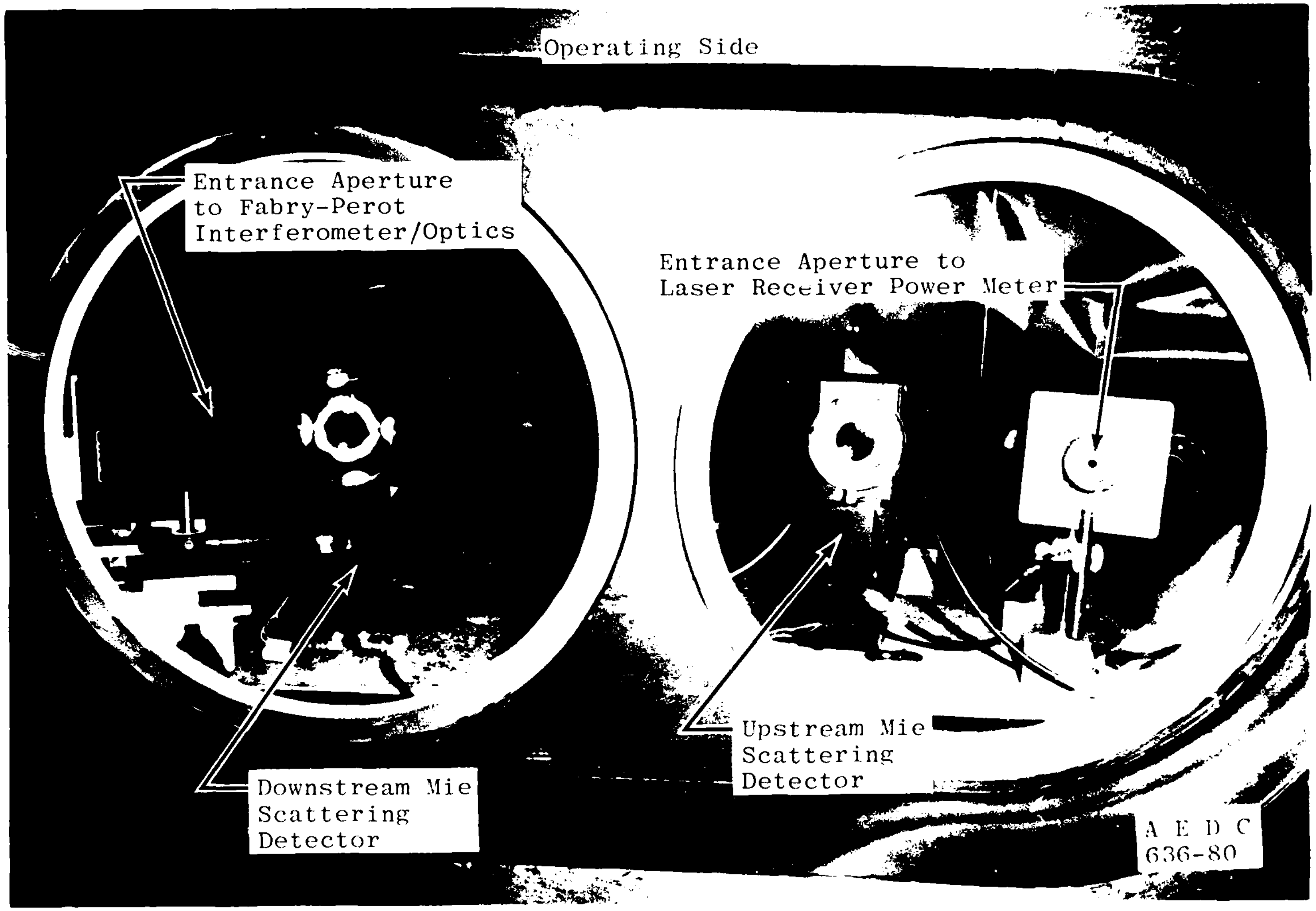


Figure 7. Laser-Optics System as Viewed from the Tunnel, Operating Side

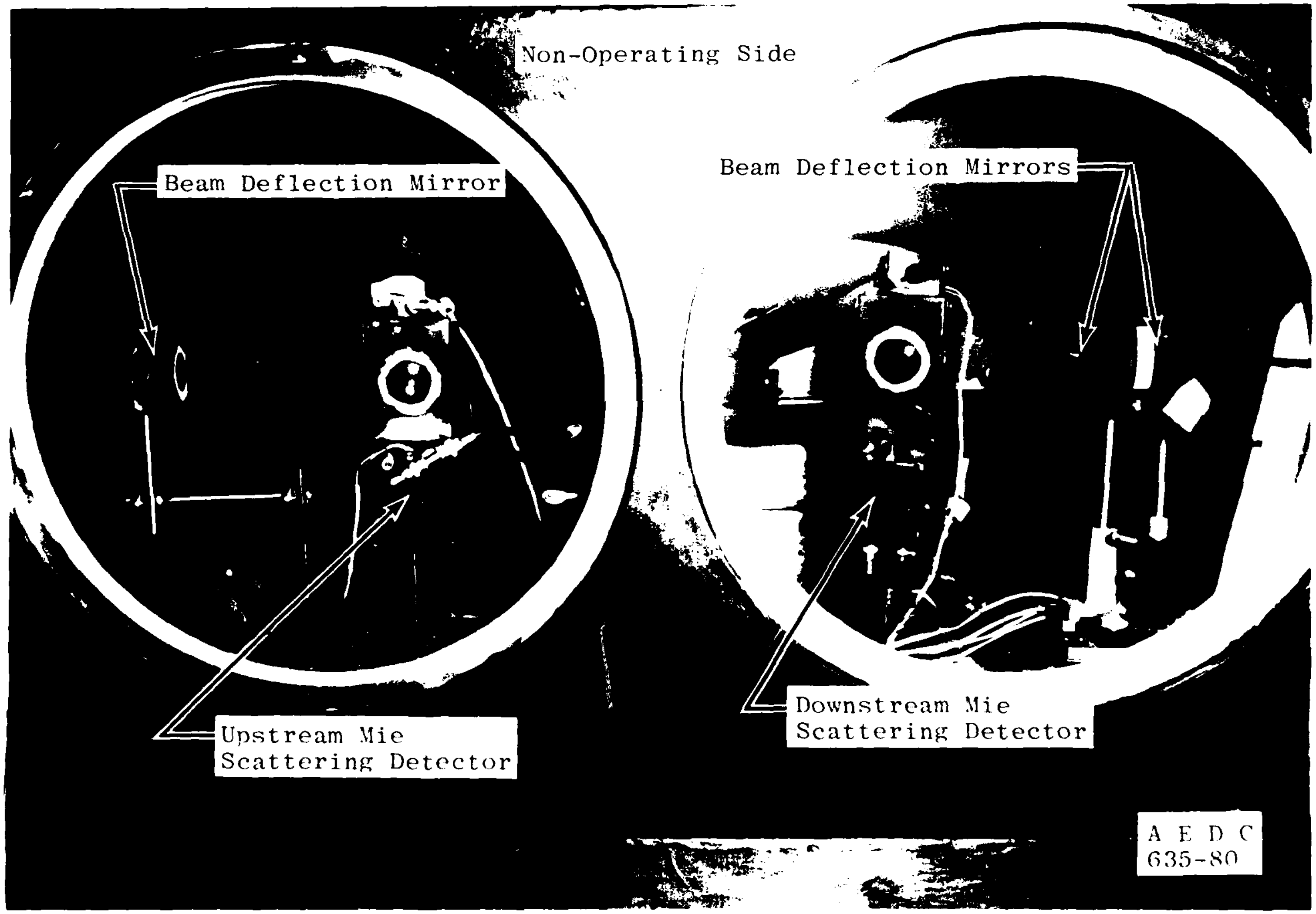
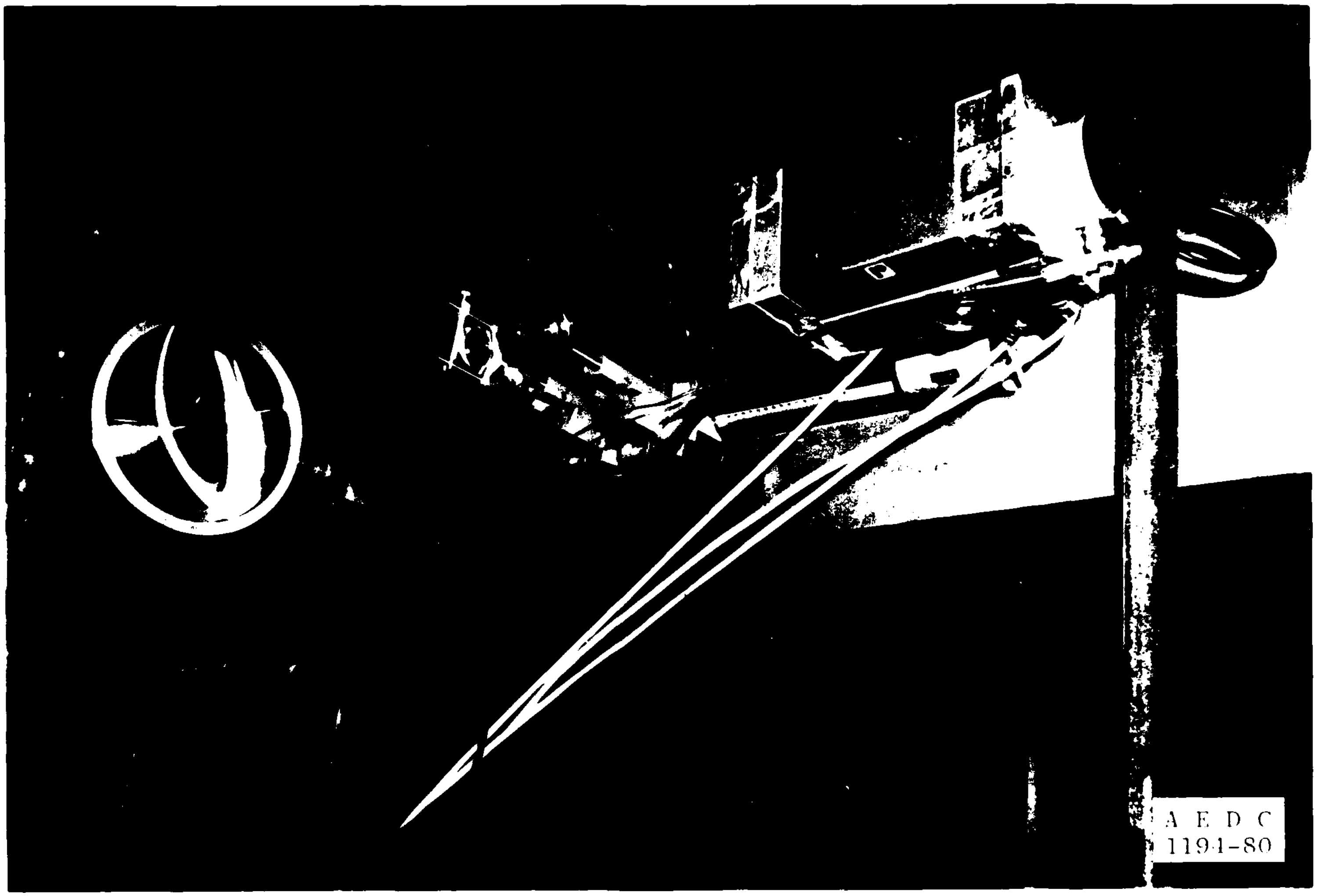


Figure 8. Laser-Optics System as Viewed within the Tunnel, Nonoperating Side

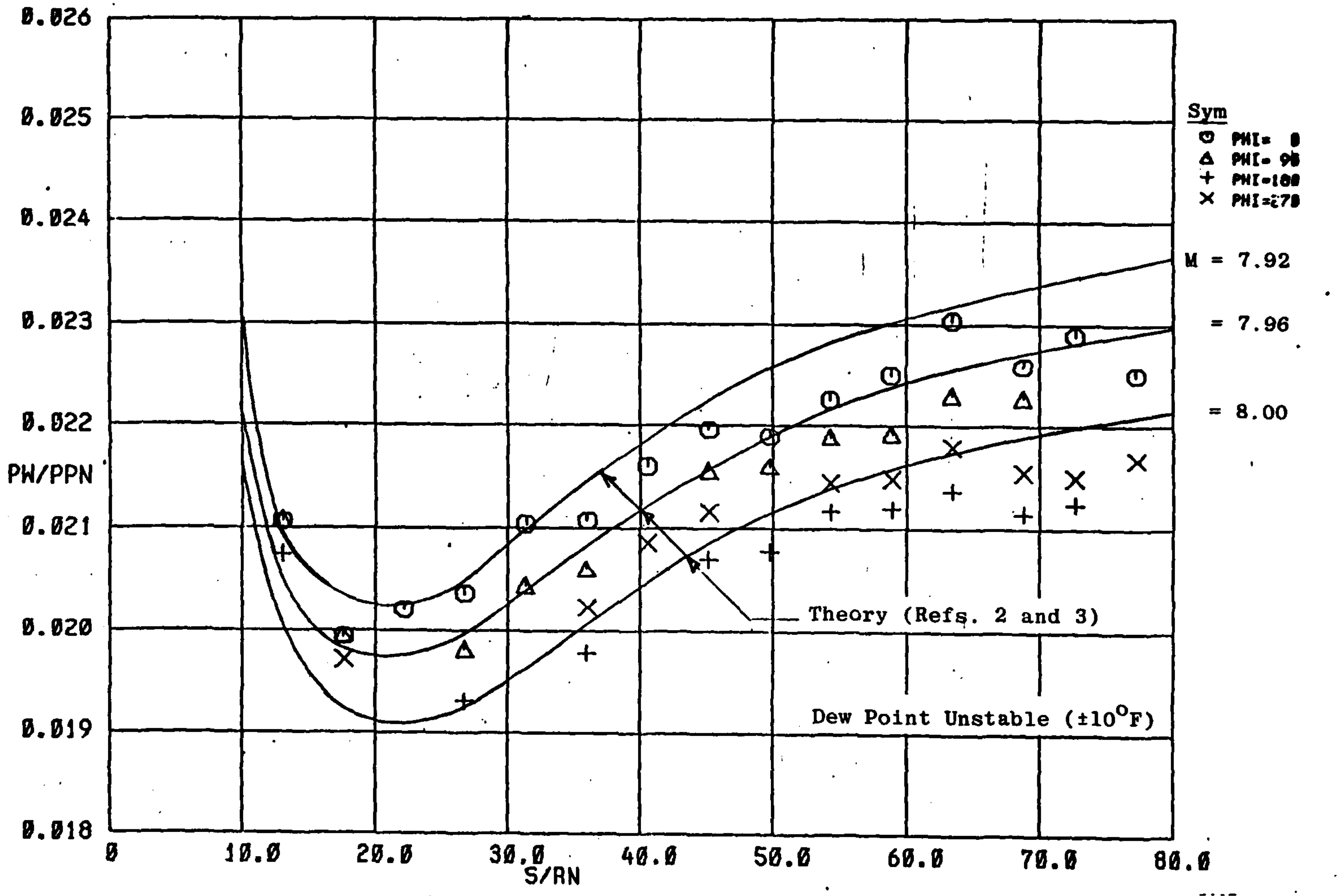
a. Mie Scattering Photomultipiier Detectors

Figure 9. Optical Recording System on Top of Tunnel B

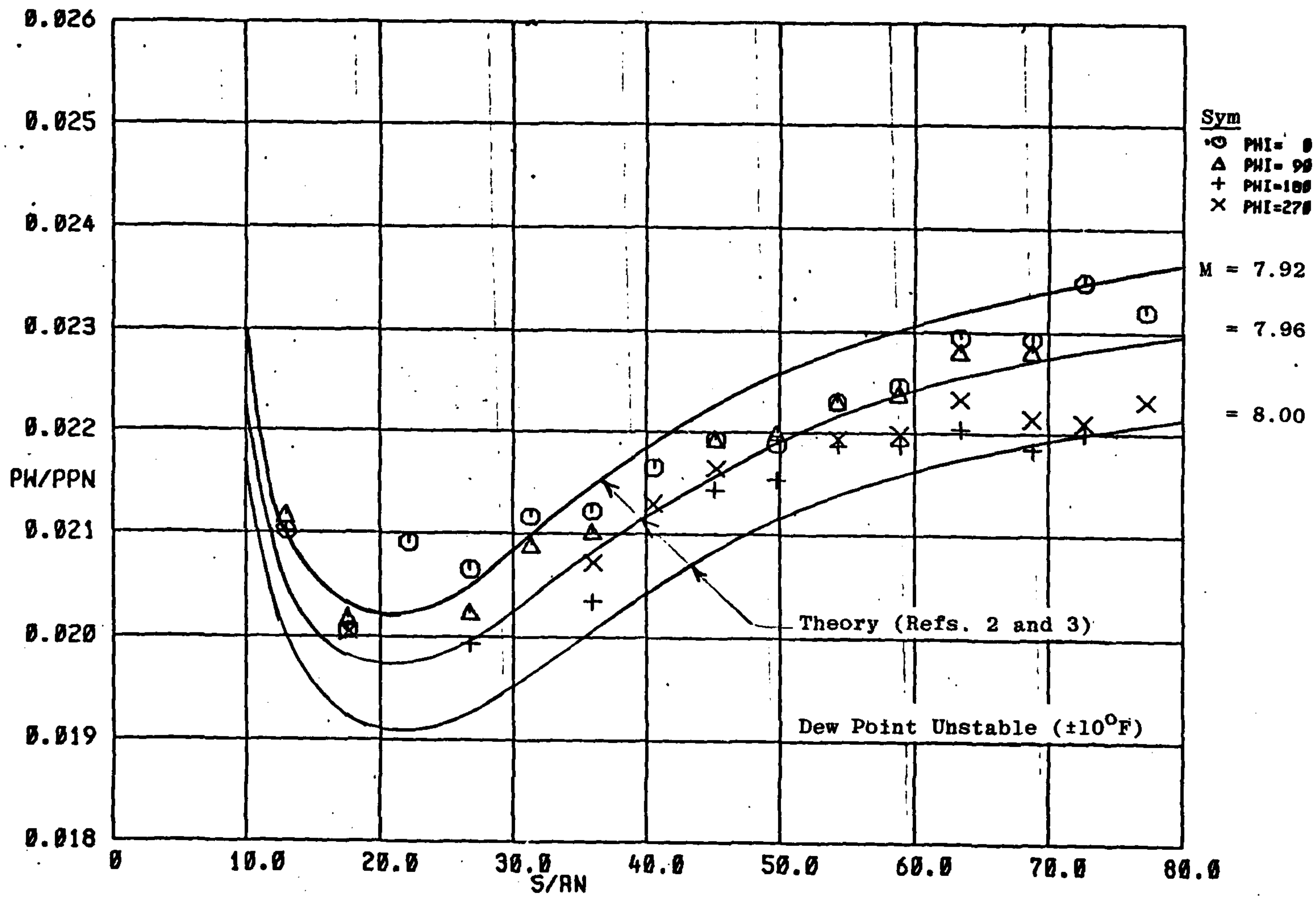


b. Cooled Photomultiplier

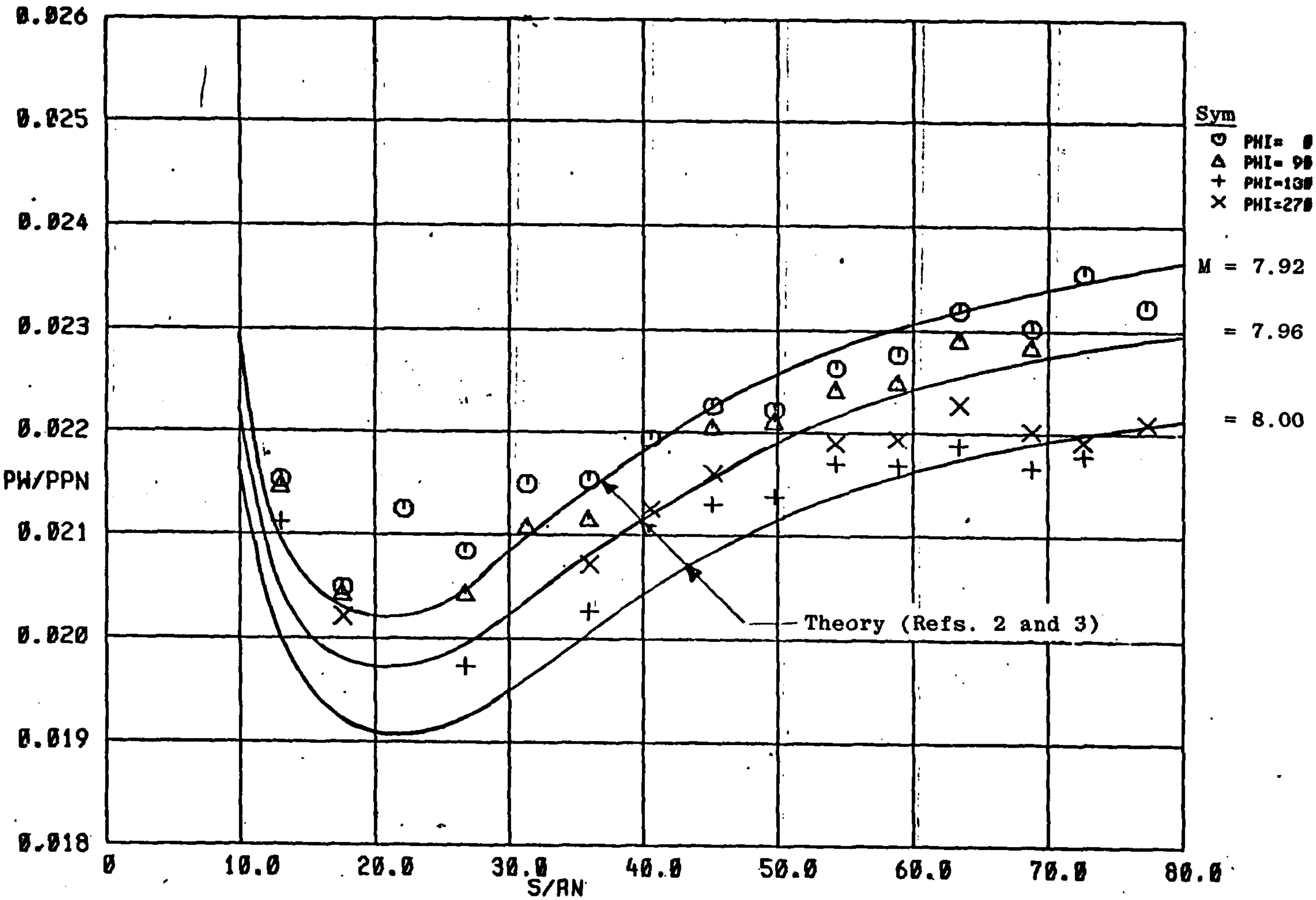
Figure 9. Concluded



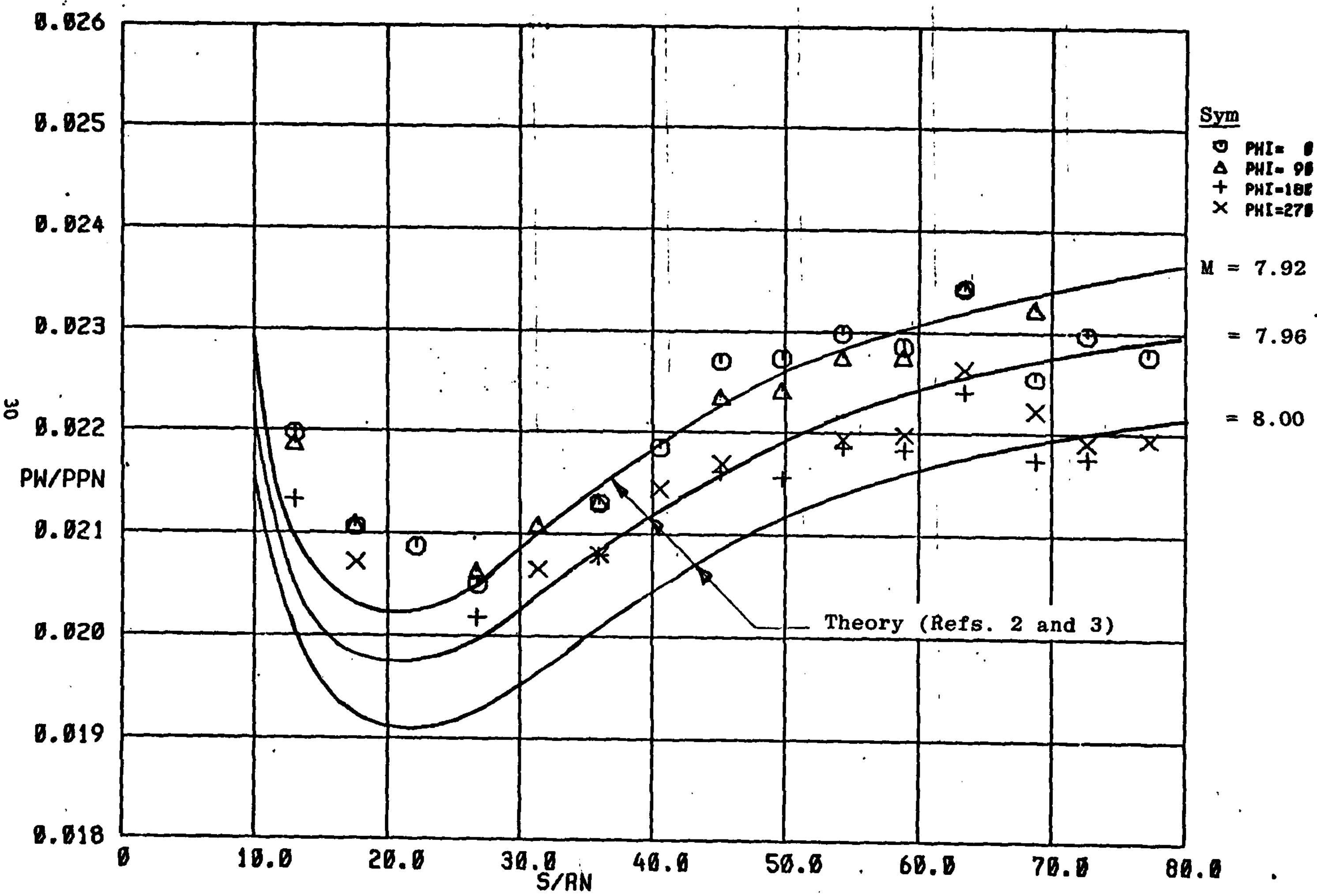
a. PT = 685 psia, Dew Pt = +10°F, C.R. = 7.00 in.
Figure 10. 5-Deg Blunt Cone (Calibration Body) Pressure Distributions



b. PT = 685 psia, Dew Pt = $-5^{\circ}F$, C.R. = 7.00 in.
Figure 10. Continued

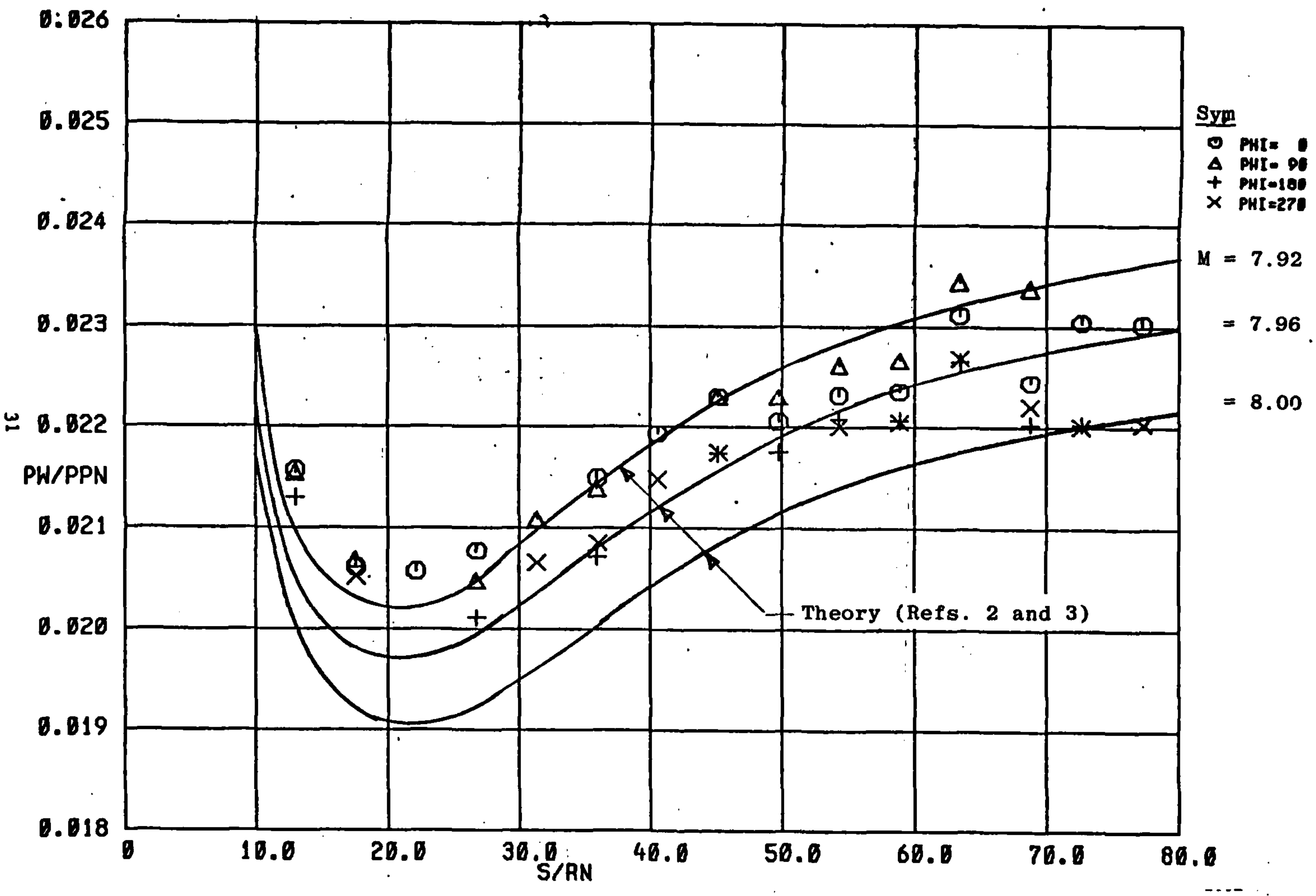


c. PT = 685 psia, Dew Pt. = $-27^{o}F$, C.R. = 7.00 in.
Figure 10. Continued

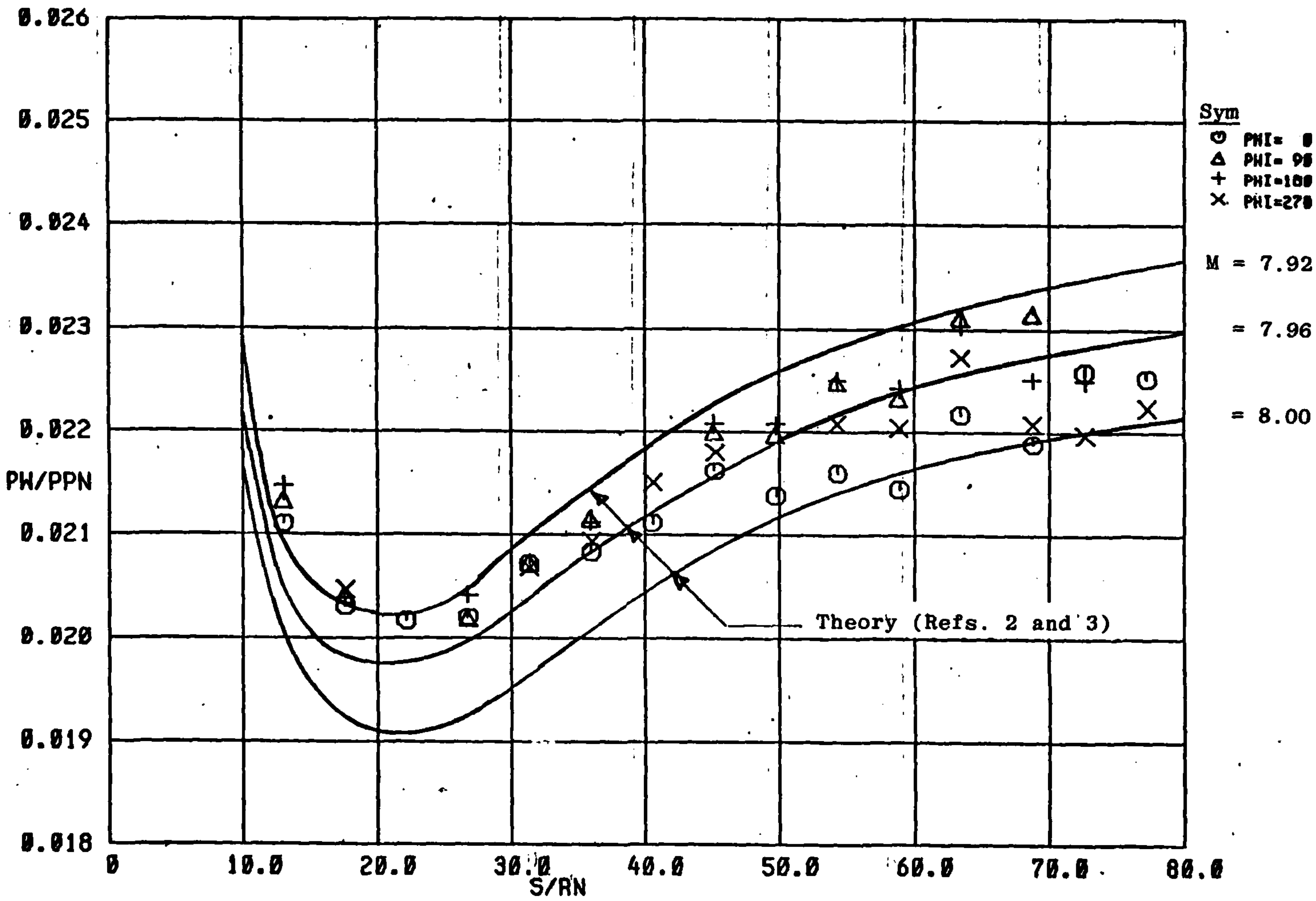


d. PT = 690 psia, Dew Pt. = -59°F, C.R. = 0.07 in.

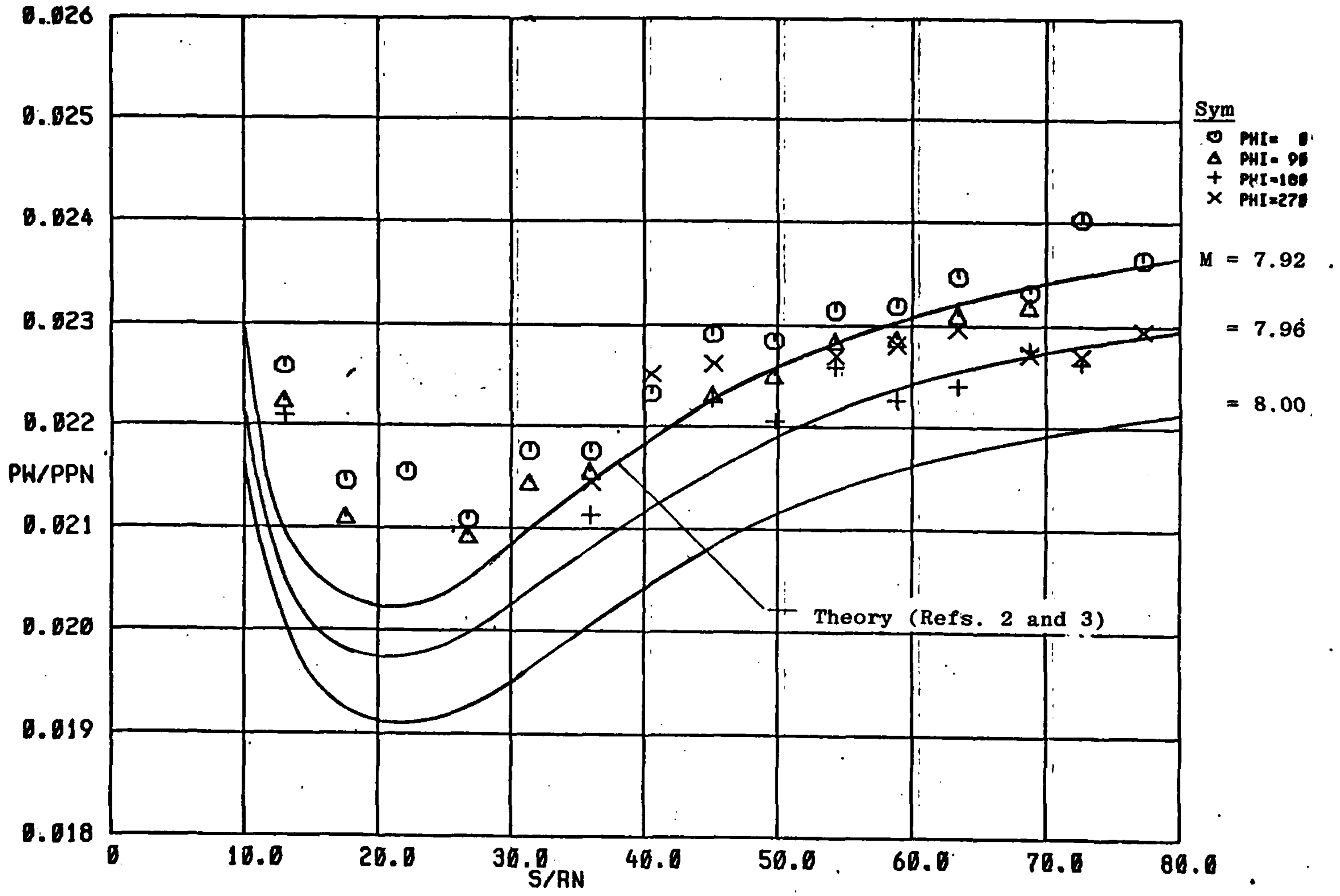
Figure 10. Continued



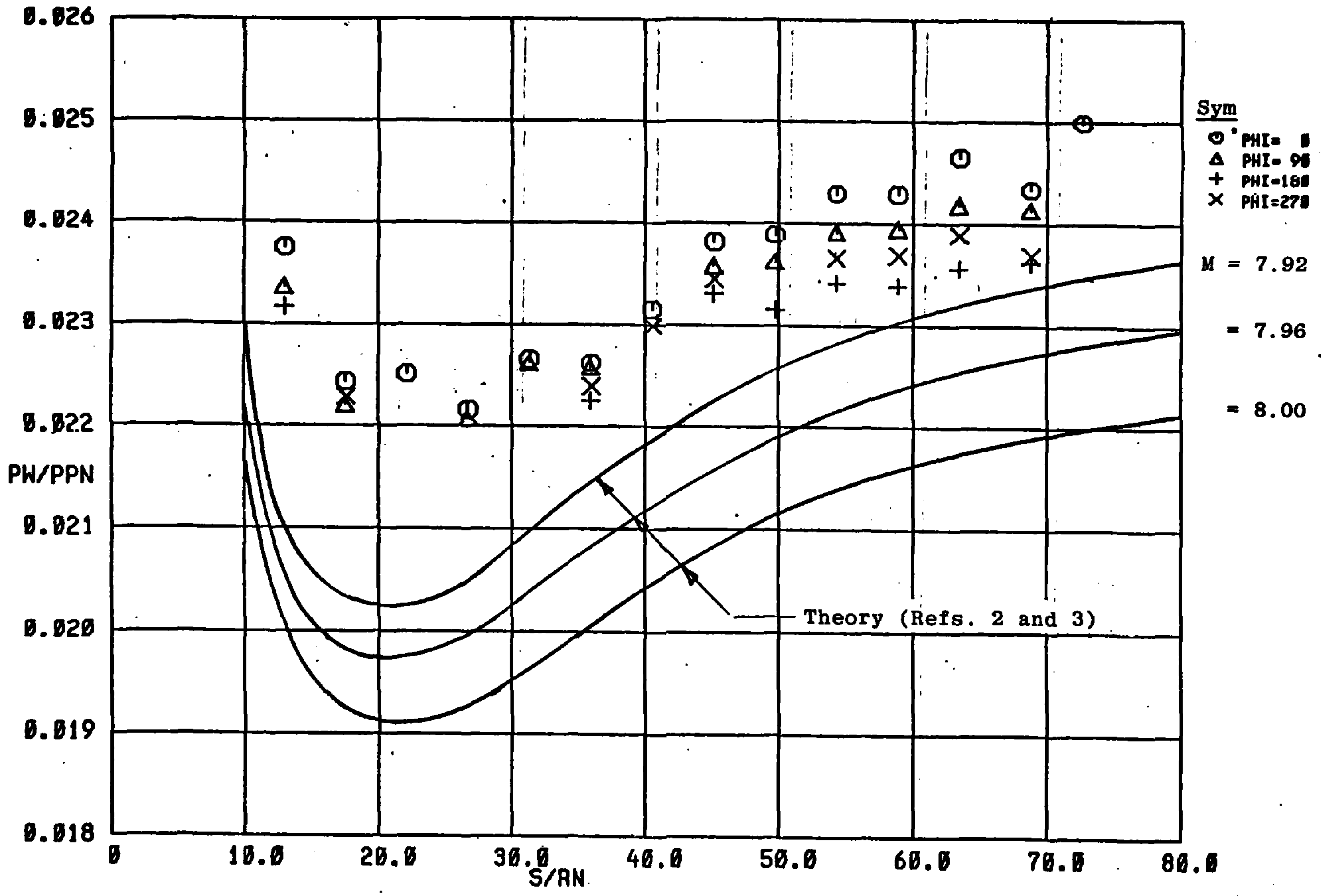
e. PT = 686 psia, Dew Pt = $-59^{o}F$, C.R. = 7.04 in.
Figure 10. Continued



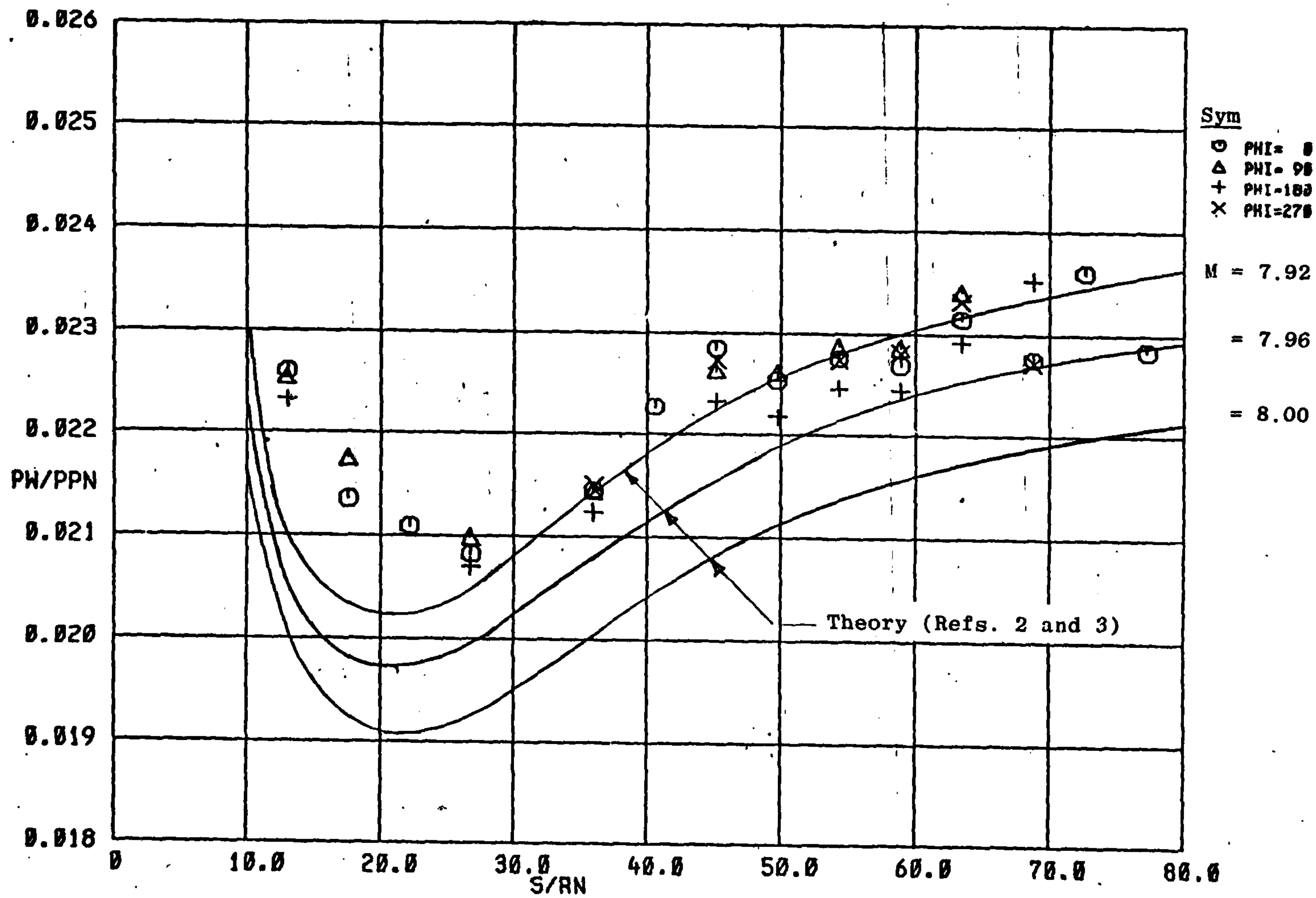
f. PT = 460 psia, Dew PT = -53°F, C.R. = 7.04 in.
Figure 10. Continued



g. PT = 228 psia, Dew PT = 22, C.R. = 7.00 in.
Figure 10. Continued



h. PT = 230 psia, Dew PT = -25°F, C.R. = 7.00 in.
Figure 10. Continued



i. PT = 230 psia, Dew PT = $-51^{O}F$, C.R. = 0.04 in.
Figure 10. Concluded

APPENDIX II

TABLES

TABLE 1. ESTIMATED UNCERTAINTIES

a. Basic Measurements

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT* Precision Index (S) Percent of Reading	Precision Index (S) Unit of Measurement	Degree of Freedom	Bias (B) Percent of Reading	Bias (B) Unit of Measurement	Uncertainty ±(B + t_{95}S) Percent of Reading	Uncertainty ±(B + t_{95}S) Unit of Measurement	Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
PT, psia		±0.02 ±0.02 ±0.11 ±0.11	>30	±0.25 ±0.25	±0.26 ±0.58	<±0.30 <±0.34	0.30 0.80	<104 104-200 200-232 232-1000	Bell and Howell Variable Capacitance Transducer	Digital Data Acquisition System (DDAS), Analog to Digital Converter (A/D)	End-to-End Calibration of Multiple Pressure Levels Using a Measuring Device Calibrated in the Standards Laboratory
TT, °F		±1 ±1	↓	±0.375	±2	< 0.8	4	32-530 530-2300	Chromel ®-Alumel ® Thermocouples	Doric Temperature Instrument/Digital Multiplexer	NBS Conformity by Voltage Substitution Calibration
ALPHA, deg		±0.025	↓		0		0.05	-3 to 27	Potentiometer	DDAS, A/D	Heidenhain Rotary Encoder RD700 Resolution - 0.0006 deg Overall Accuracy - 0.001 deg
PW, psia Standard Pressure System		0.00075 0.002 0.005	↓	0.3 0.2 0.2		(0.3% + .0015 psia) (0.2% + .004 psia) (0.2% + .010 psia)		<1 ≤5 ≥15	Baratron WIANCKO Variable Reluctance Transducers	↓	End-to-End Calibration of Multiple Pressure Levels Using Air Weight Tester
PREF, μHg.		±25	↓	Not Defined			±50	<1000	Heating Vacuum Gauge	↓	Comparison to Facility Standard
DEW Pt, °F		±2.5	↓	↓			±5		Dupont 510 Moisture Analyzer	↓	Periodically Checked Against Interlab Standard

*Thompson, J. W. and Abernethy, R. B. et al. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.

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TABLE 1. Concluded

b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT* Precision Index (S) Percent of Reading	Precision Index (S) Unit of Measurement	Degree of Freedom	Bias (B) Percent of Reading	Bias (B) Unit of Measurement	Uncertainty $\pm(B + t_{95}S)$ Percent of Reading	Uncertainty $\pm(B + t_{95}S)$ Unit of Measurement	RE
M		0.010			0		0.020	3.0×10^6
P,psia	±0.81			±0.25		±1.87		↓
PT2,psia	±0.56			±0.25		±1.37		↓
RE,ft^{-1}	±0.37			±0.43		±1.17		↓
RHO,lbm/ft^3	±0.58			±0.35		±1.51		↓
U,ft/sec	±0.04			±0.12		±0.20		↓

*Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.

VB-16a (9-79)

TABLE 2.

VKF TUNNEL B TEST LOG

PAGE 1 OF 4	
PROJECT V418-45	DATE 16 Jan '80
ARO TEST PERSONNEL W.T. Strike, D.A. Wagner	

USER: PWT/ATD

REPRESENTATIVE(S): L.L. Price, D.P. Weaver

PROJECT TITLE: AEDC/DOTR Laser Scattering Applications Development

MODEL: 6° Blunt Cone (Calibration Body)

Run	Configuration	Config. Confirmed	M	PT psia	TT °F	α, deg	Dew Pt. °F	Laser Data	Cone Data	Cone in Tank		Time	Remarks
1	Laser/Cone	[illegible]	0	14.1	79	0		✓				1519	Laser Scan Rate 0.03 sec. per pt.
2								✓				1539	LRPH Gain 10
3									✓			1600	
4				0.6					✓			1646	Tunnel Evacuated
5			7.99	692	890		-23	✓		✓		1742	LRPH Gain 1, Dryers out of
6							↓	✓		✓		1750	Tunnel Circuit
7							-3	✓				1758	D.P. Changing -23 °F to +18 °F, then -3
8							+10		✓			1802	
9							+9	✓		✓		1824	
10			7.95	231	890		+20	✓		✓		1858	
11							+26	✓				1911	
12							↓		✓			1912	
13			7.99	692	890		-5		✓			2001	Dryers added to circuit
14							-7	✓				2014	
15							-27	✓		✓		2020	
16								✓				2025	
17							↓		✓			2027	
18			7.95	231	890		-10	✓		✓		2059	
19							-12	✓				2105	
20	↓	↓	↓	↓	↓	↓	-22		✓			2107	

NOMENCLATURE: Cone Data consists of surface pressure measurements
Gains for PD1 to PD9 are 10., PD10 is 1000. Gain for LTLM is 1.0
Run 7 to 9 D.P. Oscillating, 2min. cycles from +16 to +2 °F. (D.P. IS Dew Pt)

VB-2 (8/77)

TABLE 2. Continued

VKF TUNNEL B TEST LOG

PAGE 2 OF 4	
USER: PWT/ATD	PROJECT TITLE: AEDC/DOTR Laser Scattering Applications Development
REPRESENTATIVE(S): L.L. Price, D.P. Weaver	MODEL: 6° Blunt Cone (Calibration Body)
PROJECT: V418-45	DATE: 16 Jan '80
ARO TEST PERSONNEL: W.T. Strike, D.A. Wagner	

Run	Configuration	Config. Confirmed	M	PT psia	TT °F	α, deg	Dew Pt °F	Laser Data	Cone Data	Cone in Tank		Time	Remarks
21	Laser/Cone	JCJ	0	0.8	80			✓		✓		2127	
22		↓	↓	14.4	↓			✓		✓		2133	
				Calibration Runs on 17 Jan '80									
8022			0	14.4	80			✓		✓			
8024								✓		✓			
8025								✓		✓			
8026								✓		✓			
8027			↓	↓	↓			✓		✓			
													18 Jan '80
23			0	14.4	80							0817	
24				0.7								0923	
				NO TEST DATA									Unable to establish dry conditions in the test section after 2hrs. of operation. Dew pt -24°F. Dew pt upstream of heater is -30°F. Dew pt. at plant is -50°F

NOMENCLATURE

VB-2 (9/77)

TABLE 2. Continued

VKF TUNNEL B TEST LOG

PAGE 3 OF 4

USER	PROJECT TITLE	PROJECT	DATE
PWT / ATD	AEDC/DOTR Laser Scattering Applications Development	V418-45	11 Feb '80
REPRESENTATIVE(S): L.L. Price, D.P. Weaver	MODEL: 5° Blunt Cone (Calibration Body)	ARO TEST PERSONNEL: W.T. Strike, D.A. Wagner	

Run	Configuration	Config. Confirmed	M	PT psia	TT °F	α, deg ①	Dew Pt °F	Laser Data	Cone Data	C.R. (in)	Cone in Tank	Time	Remarks
8100	Laser/Cone	[illegible]	0	14.4	80	0	— No Data —					1755	Gains: LIHM, LRPM, PD1-PD3, PD5-PD9 in 10. PD4, PD10 or 100.
8101				↓	↓							1901	
25				1.15	↓		*	✓		7.0	✓	2144	
26			7.99	692	890		-58	✓			✓	2310	
27							↓	✓				2346	
28								✓		5.66		2357	
29								✓		4.32		0018	
30								✓		0		33	
31								No Data				35	No Data
32									✓			36	
33							↓		✓	7.0		45	
34			7.95	231	870		-52		✓			114	- Poor data quality, Press. on 1st value [illegible] (PT=0) not valid.
35							↓		✓	0		119	
36							-50	✓		7.0		132	
37							↓	✓				136	- Changed Photomultiplier Detector Voltage Excitation
[illegible]							↓	✓			✓	148	
[illegible]			7.9[illegible]	115	890		*	✓			✓	209	
[illegible]							*	✓				216	
[illegible]			7.98	46[illegible]	[illegible]20		-52	✓				234	
[illegible]							↓	✓			✓	236	

NOMENCLATURE

* Dew Pt not valid — Just reading house air supply dewpt.

① Model pitch angle adjusted less than 0.25 deg to null model windward and leeward pressure [illegible]

VB-2 (8/77)

TABLE 2. Concluded

VKF TUNNEL B TEST LOG

PAGE	4 OF 4
USER	PWT / ATD
REPRESENTATIVE(S)	L.L. Price, D.R. Weaver
PROJECT TITLE	AEDC/DOTR Laser Scattering Applications Development
MODEL	5° Blunt Cone (Calibration Body)
PROJECT	V41B-45
DATE	11 Feb 80
ARO TEST PERSONNEL	W.T. Strike, D.A. Wagner

Run	Configuration	Config. Confirmed	M	PT psia	TT °F	α, deg	Dew Pt °F	Laser Data	Cone Data	C.R. (in)	Cone in Tank	Time	Remarks
43	Laser/Cone	[illegible]	7.98	462	890	0	-54	✓		7.0	✓	0240	
44								✓				0245	Reset Photomultiplier Detector Voltages to original setting
45				↓					✓			0247	
End				0.6			↓				✓	0309	Tunnel evacuated
8047				↓			N.D.				✓	0314	
8048	↓	↓	↓	14.4	↓	↓	↓			↓	✓	0323	

NOMENCLATURE N.D. ~ Not determined

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APPENDIX III

DATA PACKAGE FORMATS

UNCLASSIFIED

DATE COMP D 18-FEB-80
TIME COMP...D 13:38:09
DATE RECORDED 12-FEB-80
TIME RECORDED 2:50: 8
PROJECT NUMBER V41B-45

LASER SCATTERING APPLICATIONS DEVELOPMENT

PROJECT NUMBER V41B-45

PAGE 1
RUN 45
M = 7.98
RE= 2.02E+06

DATA TYPE=2
PT(PSIA) = 460.1
TT(DEG-R)= 1342.

CENTER OF ROTATION = 7.04
FROST POINT(DEG-F)= -53.
ALPHA(DEG)= -12.03

RN(INCHES)=0.375
PTS(PSIA)= 3.950

ORIFICE NO.	X (IN.)	S/RN	OMEGA (DEG)	PW	PW/P	PW/PT2	PW/PNN	PW/PWF	PWI/PWF	PRMS/PW	K
1	5.140	3.812	0.0	0.1512	3.156	0.0383	0.0374	0.9921	0.6089	0.0085	0.7236
9	8.570	12.994	0.0	0.0853	1.781	0.0216	0.0211	0.9989	0.5900	0.0042	1.8566
13	10.290	17.598	0.0	0.0821	1.714	0.0208	0.0203	1.0063	0.6955	0.0043	1.2848
17	12.000	22.176	0.0	0.0816	1.702	0.0206	0.0202	1.0029	0.6326	0.0041	1.9964
21	13.720	26.780	0.0	0.0817	1.705	0.0207	0.0202	1.0001	0.5919	0.0046	1.8101
25	15.430	31.357	0.0	0.0838	1.749	0.0212	0.0207	1.0063	0.7071	0.0045	2.4423
29	17.150	35.961	0.0	0.0843	1.759	0.0213	0.0208	1.0012	0.5933	0.0035	1.9394
33	18.860	40.539	0.0	0.0854	1.782	0.0216	0.0211	1.0014	0.6466	0.0038	1.8867
37	20.580	45.143	0.0	0.0874	1.825	0.0221	0.0216	1.0051	0.6698	0.0041	1.9908
41	22.290	49.720	0.0	0.0864	1.805	0.0219	0.0214	1.0029	0.7230	0.0032	2.2782
45	24.000	54.298	0.0	0.0874	1.823	0.0221	0.0216	0.9983	0.6826	0.0039	2.0963
49	25.720	58.902	0.0	0.0867	1.810	0.0220	0.0214	0.9945	0.5729	0.0079	1.5312
53	27.430	63.479	0.0	0.0897	1.872	0.0227	0.0222	0.9928	0.5935	0.0089	1.4732
57	29.420	68.806	0.0	0.0885	1.848	0.0224	0.0219	0.9984	1.2371	0.0010	0.5492
61	30.860	72.661	0.0	0.0914	1.907	0.0231	0.0226	0.9978	1.3654	0.0013	0.5666
65	32.590	77.265	0.0	0.0911	1.901	0.0231	0.0225	1.0002	1.0004	0.0002	0.0000
2	5.140	3.812	90.0	0.1542	3.219	0.0390	0.0381	1.0002	0.9365	0.0004	0.3867
6	6.860	8.417	90.0	0.1024	2.138	0.0259	0.0253	0.9966	1.2125	0.0009	0.4277
10	8.570	12.994	90.0	0.0862	1.800	0.0218	0.0213	1.0013	0.9381	0.0013	0.4282
14	10.290	17.598	90.0	0.0825	1.723	0.0209	0.0204	0.9981	0.9901	0.0016	0.4163
22	13.720	26.780	90.0	0.0817	1.705	0.0207	0.0202	1.0022	0.9535	0.0007	0.3990
26	15.430	31.357	90.0	0.0838	1.750	0.0212	0.0207	1.0018	0.9400	0.0007	0.4290
30	17.150	35.961	90.0	0.0856	1.786	0.0217	0.0212	1.0022	0.9255	0.0007	0.4362
34	18.860	40.539	90.0	0.0874	1.824	0.0221	0.0216	1.0020	0.9881	0.0002	0.2364
38	20.580	45.143	90.0	0.0890	1.857	0.0225	0.0220	1.0011	0.9698	0.0003	0.4128
42	22.290	49.720	90.0	0.0889	1.855	0.0225	0.0220	1.0006	0.9542	0.0006	0.4858
46	24.000	54.298	90.0	0.0909	1.898	0.0230	0.0225	1.0058	0.9415	0.0082	0.3733
50	25.720	58.902	90.0	0.0903	1.885	0.0229	0.0223	1.0010	0.9243	0.0005	0.5045
54	27.430	63.474	90.0	0.0935	1.951	0.0237	0.0231	1.0010	0.9389	0.0004	0.4733
58	29.420	68.806	90.0	0.0936	1.954	0.0237	0.0231	0.9956	1.2984	0.0015	0.4660

a. Page 1

1. Typical Pressure Distribution Tabulation

UNCLASSIFIED

DATE COMPU[illegible] 18-FEB-80
TIME COMPL 13:38:12
DATE RECORDED 12-FEB-80
TIME RECORDED 2:50: 8
PROJECT NUMBER V41B-45

LASER SCATTERING APPLICATIONS DEVELOPMENT

PROJECT NUMBER V41B-45

PAGE 2
RUN 45
M = 7.98
RE= 2.02E+06

DATA TYPE=2
PT(PSIA) = 460.1
TT(DEG-R)= 1342.

CENTER OF ROTATION = 7.84
FROST POINT(DEG-F)= -53.
ALPHA(DEG)= -12.03

RN(INCHES)=0.375
PTS(PSIA)= 3.950

ORIFICE NO.	X (IN.)	S/RN	OMEGA (DEG)	PW	PW/P	PW/PT2	PW/PNN	PW/PWF	PWI/PWF	PRMS/PW	K
3	5.140	3.812	180.0	0.1547	3.229	0.0392	0.0382	0.9996	0.9228	0.0006	0.4222
11	8.570	12.994	180.0	0.0868	1.813	0.0220	0.0215	1.0014	0.9341	0.0013	0.4332
23	13.720	26.780	180.0	0.0826	1.724	0.0209	0.0204	1.0032	0.9470	0.0011	0.3771
31	17.150	35.961	180.0	0.0854	1.783	0.0216	0.0211	1.0015	0.9340	0.0010	0.4396
39	20.580	45.143	180.0	0.0893	1.864	0.0226	0.0221	1.0005	0.9787	0.0003	0.3829
43	22.290	49.720	180.0	0.0893	1.864	0.0226	0.0221	1.0003	0.9650	0.0005	0.4726
47	24.000	54.298	180.0	0.0910	1.899	0.0230	0.0225	1.0005	0.9493	0.0006	0.4815
51	25.720	58.902	180.0	0.0907	1.893	0.0230	0.0224	1.0002	0.9380	0.0007	0.5068
55	27.430	63.479	180.0	0.0931	1.944	0.0236	0.0230	1.0006	0.9565	0.0006	0.4582
59	29.420	68.806	180.0	0.0910	1.900	0.0230	0.0225	0.9970	1.3007	0.0010	0.5282
63	30.860	72.661	180.0	0.0910	1.900	0.0230	0.0225	1.0010	0.9113	0.0006	0.5265
4	5.140	3.812	270.0	0.1542	3.220	0.0390	0.0381	1.0002	0.9316	0.0004	0.4017
16	10.290	17.598	270.0	0.0828	1.728	0.0210	0.0205	0.9891	1.4469	0.0054	0.4301
28	15.430	31.357	270.0	0.0836	1.746	0.0212	0.0207	0.9908	1.3615	0.0023	0.4418
32	17.150	35.961	270.0	0.0847	1.768	0.0214	0.0209	1.0017	0.9355	0.0006	0.4503
36	18.860	40.539	270.0	0.0870	1.816	0.0220	0.0215	0.9920	1.3869	0.0018	0.4558
40	20.580	45.143	270.0	0.0882	1.841	0.0223	0.0218	1.0006	0.9888	0.0002	0.3645
48	24.000	54.298	270.0	0.0893	1.864	0.0226	0.0221	1.0010	0.9619	0.0005	0.4238
52	25.720	58.902	270.0	0.0891	1.861	0.0226	0.0220	1.0003	0.9521	0.0004	0.5139
56	27.430	63.479	270.0	0.0919	1.919	0.0233	0.0227	1.0004	0.9576	0.0003	0.4891
60	29.420	68.806	270.0	0.0893	1.864	0.0226	0.0221	1.0005	0.9799	0.0025	0.9405
64	30.860	72.661	270.0	0.0889	1.856	0.0225	0.0220	0.9989	0.9152	0.0021	0.6265
68	32.580	77.265	270.0	0.0899	1.877	0.0228	0.0222	1.0005	0.9556	0.0004	0.5108
NOSE PRESSURE											
69	3.716	0.001	0.0	4.0438	84.413	1.0238	1.0000	1.0000			

b. Page 2

1. Concluded

UNCLASSIFIED

DATE COMPUTED 18-FEB-80
TIME COMPUTED 13:37:44
DATE RECORDED 12-FEB-80
TIME RECORDED 2:45:20
PROJECT NUMBER V41B-45

LASER SCATTERING APPLICATIONS DEVELOPMENT

PROJECT NUMBER V41B-45

PAGE 1
RUN 44
M = 7.98
RE= 2.02E+06

DATA TYPE=1
PT(PSIA) = 459.6
TT(DEG-R)= 1342.

CENTER OF ROTATION = 7.84
FROST POINT(DEG-F)= -54.
ALPHA(DEG)= -12.02

RN(INCHES)=0.375
PTS(PSIA)= 3.945

LASER SCATTERING MEASUREMENTS

NUMBER OF SAMPLES = 300

TIME BASE (SEC) = 10.0

	TARE		READING		DELTA	
	AVERAGE	SUM	AVERAGE	SUM	AVERAGE	SUM
TOUT	1.8864E+04	1.8864E+04	1.3673E+06	1.3673E+06	1.3485E+06	1.3485E+06
LILM	3.6576E+02	1.0973E+05	3.6644E+02	1.0993E+05	3.6644E+02	1.0993E+05
LRPM	-9.7371E-01	-2.9211E+02	9.0899E+01	2.7270E+04	9.1872E+01	2.7562E+04
RATIO					25.07 %	
PD1	9.3953E-01	2.8186E+02	-1.4394E+02	-4.3182E+04	-1.4488E+02	-4.3464E+04
PD2	5.7983E-02	1.7395E+01	-3.8379E+00	-1.1514E+03	-3.8959E+00	-1.1688E+03
PD3	2.1932E-01	6.5796E+01	-9.9772E+01	-2.9932E+04	-9.9991E+01	-2.9997E+04
PD4	-5.6152E-03	-1.6846E+00	-1.6298E-01	-4.8895E+01	-1.5737E-01	-4.7211E+01
PD5	8.1787E-02	2.4536E+01	-4.1972E+00	-1.2592E+03	-4.2790E+00	-1.2837E+03
PD6	-5.0639E-01	-1.5192E+02	-3.3840E+00	-1.0152E+03	-2.8776E+00	-8.6328E+02
PD7	3.3549E-01	1.0065E+02	-6.5216E+01	-1.9565E+04	-6.5551E+01	-1.9665E+04
PD8	-7.1106E-01	-2.1332E+02	-5.1634E+01	-1.5490E+04	-5.0923E+01	-1.5277E+04
PD9	-2.9155E+01	-8.7465E+03	-1.0889E+02	-3.2668E+04	-7.9738E+01	-2.3921E+04
PD10	-1.9328E-03	-5.7983E-01	-4.8498E+00	-1.4549E+03	-4.8479E+00	-1.4544E+03

a, Summary Sheet

2. Typical Laser-Optics Tabulation

** TARES FOR RUN NO 44 **

NO OF LOOPS= 300

	AVERAGE VALUES	SUMS
TOUT	18864.	18864.
LILM	365.76	0.10973E+06
LRPM	-0.97371	-292.11

PHOTO-MULTIPLIER READINGS

	AVERAGES	SUMS
PD1	0.93953	281.86
PD2	0.57983E-01	17.395
PD3	0.21932	65.796
PD4	-0.56152E-02	-1.6846
PD5	0.81767E-01	24.536
PD6	-0.50639	-151.92
PD7	0.33549	100.65
PD8	-0.71106	-213.32
PD9	-29.155	-8746.5
PD10	-0.19328E-02	-0.57983

***** RAW COUNTS, SCALE FAC AND GAINS *****

	AVERAGE VALUES	SUMS	S FAC	GAIN	SF/GAIN
TOUT	18864.0	18864.	1.00000000	1.00	1.000000
LILM	5992.5	1797760.	.61035156	10.00	0.061035
LRPM	-16.0	-4786.	.61035156	10.00	0.061035

FOR PHOTO-MULTIPLIERS

	AVERAGE VALUES	SUMS	S FAC	GAIN	SF/GAIN
PD1	15.4	4618.	.61035156	10.00	0.061035
PD2	1.0	285.	.61035156	10.00	0.061035
PD3	3.6	1078.	.61035156	10.00	0.061035
PD4	-0.9	-276.	.61035156	100.00	0.006104
PD5	1.3	402.	.61035156	10.00	0.061035
PD6	-8.3	-2489.	.61035156	10.00	0.061035
PD7	5.5	1649.	.61035156	10.00	0.061035
PD8	-11.6	-3495.	.61035156	10.00	0.061035
PD9	-477.7	-143302.	.61035156	10.00	0.061035
PD10	-0.3	-95.	.61035156	100.00	0.006104

b. Gains/Scale Factor Tabulations

2. Concluded

LMED

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