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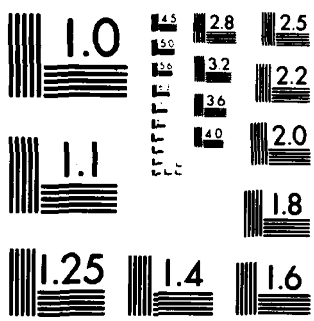

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WIND TUNNEL TESTS OF THE NASA SHUTTLE EXTERNAL TANK SLA/SOFI PANELS AT MACH NUMBERS FROM 0.60 TO 1.50

R. G. Meyer
Calspan Field Services, Inc.

June 1981

Final Report for Period 20 March 1981 - 21 March 1981

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ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
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APPROVAL STATEMENT

This report has been reviewed and approved.

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FOR THE COMMANDER

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Deputy for Operations

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SLA
Spray-on-Foam Insulation
SOFI

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

A test was conducted to determine whether exposure of the Super Light Ablator/Spray-on-Foam Insulation (SLA/SOFI) to the STS-1 launch trajectory dynamic pressures would produce additional cracks or cause separations from the cryogenic tank. Low-speed movies and stereo-photography were used to record the effects of the tunnel flow at free-stream Mach numbers from 0.60 to 1.50. Four configurations were tested in the Propulsion Wind Tunnel (16T) during the period from March 20 through 21, 1981.

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ILLUSTRATIONS

TABLES

NOMENCLATURE

CB	Test article center bottom stereo-photo target
CT	Test article center top stereo-photo target
GN_2	Gaseous nitrogen
GX	Silicone adhesive (GX6300) used to bond the SLA to the aluminum tank
LN_2	Liquid nitrogen
MACH	Free-stream Mach number
PT	Free-stream total pressure, psfa
Q	Free-stream dynamic pressure, psf
RUN	Run number (a data subset containing variations of only one independent parameter)
SLA	Super Light Ablator installed on the aluminum tank
SOFI	Spray-on-Foam Insulation
STS-1	Space Transportation System - first flight
TCn	Thermocouple, $(n = 1 \rightarrow 10)$, °F
X	Photogrammetric analysis X-axis, positive toward the tunnel floor, in., see Fig. 9
Y	Photogrammetric analysis Y-axis, positive upstream, in., see Fig. 9
Z	Photogrammetric analysis Z-axis, positive toward the centerline of the tunnel, in.

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E02, Control Number E02, at the request of NASA-Marshall Space Flight Center (NASA-MSFC). The NASA-MSFC project manager was Joseph Sims and the Martin-Marietta Aerospace project engineer was P. Click. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the aerospace flight dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in the AEDC Propulsion Wind Tunnel (16T) during the period from March 20 through 21, 1981, under AEDC Project Number C358PG.

The primary objective of this test was to determine whether exposure of the Super Light Ablator/Spray-on-Foam Insulation (SLA/SOFI) to the STS-1 launch trajectory dynamic pressures would produce additional cracks or cause separation from the cryogenic tank of the preselected debonded areas. Low-speed movies and stereo-photography were used to record the effects of the tunnel flow at free-stream Mach numbers from 0.60 to 1.50. The model was rigidly flush mounted in the east wall of the test section.

The purpose of this report is to document the test and to describe the test parameters. The report provides information to permit use of the data, but does not include any data analysis.

The final data from this test have been transmitted to NASA/MSFC and Martin-Marietta Aerospace. Requests for these data should be addressed to the National Aeronautics and Space Administration (NASA/MSFC), Marshall Space Flight Center, Huntsville, Alabama 35812. A copy of the final data is on file on microfilm at the AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

The AEDC Propulsion Wind Tunnel (16T) is a variable density, continuous-flow tunnel capable of being operated at Mach numbers from 0.20 to 1.5 and stagnation pressures from 120 to 4000 psfa. The maximum attainable Mach number can vary slightly depending upon the tunnel pressure ratio requirements with a particular test installation. The maximum stagnation pressure attainable is a function of Mach number and available electrical power. The tunnel stagnation temperature can be varied from about 80 to 160°F depending upon the cooling water temperature. The tunnel is equipped with a scavenging system which removes combustion products when testing with rocket motors or turbo-engines. The test section is 16 ft square by 40 ft long and enclosed by 60-deg inclined-hole perforated walls of 6 percent porosity. The general arrangement of the test section and the test article location is shown in Fig. 1. Additional information about the tunnel, its capabilities, and operating characteristics is presented in Ref. 1.

2.2 TEST ARTICLE

The test article was a 50-in. x 50-in. x 4-in. flat tank constructed of aluminum plate and capable of being cryogenically cooled with liquid nitrogen (LN_2). Super Light Ablator (SLA) and Spray-on-Foam Insulation (SOFI) covered both sides of the tank. The test article was designed to be flush mounted to the test section's east sidewall, with only one side exposed to the tunnel flow. The model location is shown in Fig. 1 and an installation photograph is shown in Fig. 2.

The SLA-561® insulation consisted of four 22-in. x 26-in. panels, 0.22-in. thick, bonded with GX6300® silicone adhesive to each side of the tank. Selected debonded areas were created beneath some of the SLA panels during the bonding process. SOFI insulation CPR-488® was sprayed over the SLA panels to a depth of 1.0 ±0.25-in. Slits were cut in the insulation over three of the debonded areas to simulate cracking of the insulation as was encountered on STS-1 on the launch pad at Kennedy Space Center. The debonded areas and simulated cracks are shown in Fig. 3.

A flat plate protuberance, shown in Fig. 4, was used during two tests to simulate the airflow disturbance caused by one of the External Tank bipod attachment fittings. A summary of test conditions and panel configurations is presented in Table 1.

2.3 INSTRUMENTATION

The aluminum tank was instrumented with ten Chromel®-Constantan thermocouples to monitor the extent of cryogenic cooling, both before and during testing. Low-speed movie cameras were operated during testing to record any loss of insulation from the model. Two 70-mm Hasselblad® cameras were used to obtain stereo-photographs to determine whether any small movements occurred in the insulation during testing. The location of these cameras relative to the model is shown in Fig. 5.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

The cryogenic flat tank was filled with liquid nitrogen before the test conditions were established. After the tank reached thermal equilibrium at -320°F the tunnel was brought on line and Mach number and total pressure were smoothly and continuously varied to simulate the STS-1 launch dynamic pressure profile from Mach number 0.60 to 1.50. The variation of dynamic pressure with Mach number for the proposed and actual test trajectory is shown in Fig. 6. Thermocouple and tunnel condition data were obtained at approximately 30-sec intervals throughout the sweep. Stereo-photographs were obtained at approximately 90-sec intervals.

All steady-state measurements were sequentially recorded by the facility on-line computer system, which reduced the data to engineering units, tabulated the data in the Tunnel 16T control room, and recorded the data on digital tape. Since the main objective was to determine if and where insulation separated from the tank, low-speed movie and closed circuit television cameras continuously recorded the events on and around the model.

3.2 DATA REDUCTION

All test article thermocouple readings were reduced to degree Fahrenheit form. Eighteen stereo-pairs were analyzed using the Analytical Stereo-Compiler (K&E DSC-3/80). A typical stereo-photo pair of tank No. 3, side A, with the protuberance installed is shown in Fig. 7. Also shown in Fig. 7 are two unintentional cracks which developed in the SOFI prior to testing. Both cracks were on Side A and resulted from pretest filling and draining of the liquid nitrogen. Typical data from the analysis are shown in Fig. 8. The data presented in Fig. 8a show the variation in tank skin position between the wind-off Run 3 and Mach number sweep Run 4 along a row of points on the lower part of the tank. Figure 8b shows the variations along a row of points on the upper part of the tank for the same runs. The locations on the SOFI surface of the target points used in the photogrammetric analysis are presented in Fig. 9.

3.3 UNCERTAINTY OF MEASUREMENTS

Uncertainties (combinations of systematic and random errors) of the basic tunnel parameters, shown in Fig. 10, were estimated from repeat calibrations of the instrumentation and from the repeatability and uniformity of the test section flow during tunnel calibration. Uncertainties in the instrumentation systems were estimated from repeat calibration of the systems against secondary standards whose uncertainties are traceable to the National Bureau of Standards calibration equipment. The tunnel parameter and instrument uncertainties, for a 95-percent confidence level, are combined using the Taylor-series method of error propagation described in Ref. 2 to determine the uncertainties of the reduced parameters.

4.0 DATA PACKAGE PRESENTATION

The data package contained 1) tabulated point-by-point data sheets listing all data parameters, 2) test article still photographs and movie film, 3) the data from the stereo-photogrammetric analysis, 4) a data nomenclature describing the meaning of all parameters, 5) a test log for identification of test runs, test conditions, and test article configurations, and 6) a copy of this test summary report. An example of the tabulated data is shown in Table 2. All parameters on the data tabulation are defined in Table 3.

REFERENCES

1. Test Facilities Handbook (Eleventh Edition). "Propulsion Wind Tunnel Facility, Vol. 4." Arnold Engineering Development Center, April 1981.

2. Abernethy, R. B. and Thompson, J. W., Jr. "Handbook - Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD-755356, February 1972.

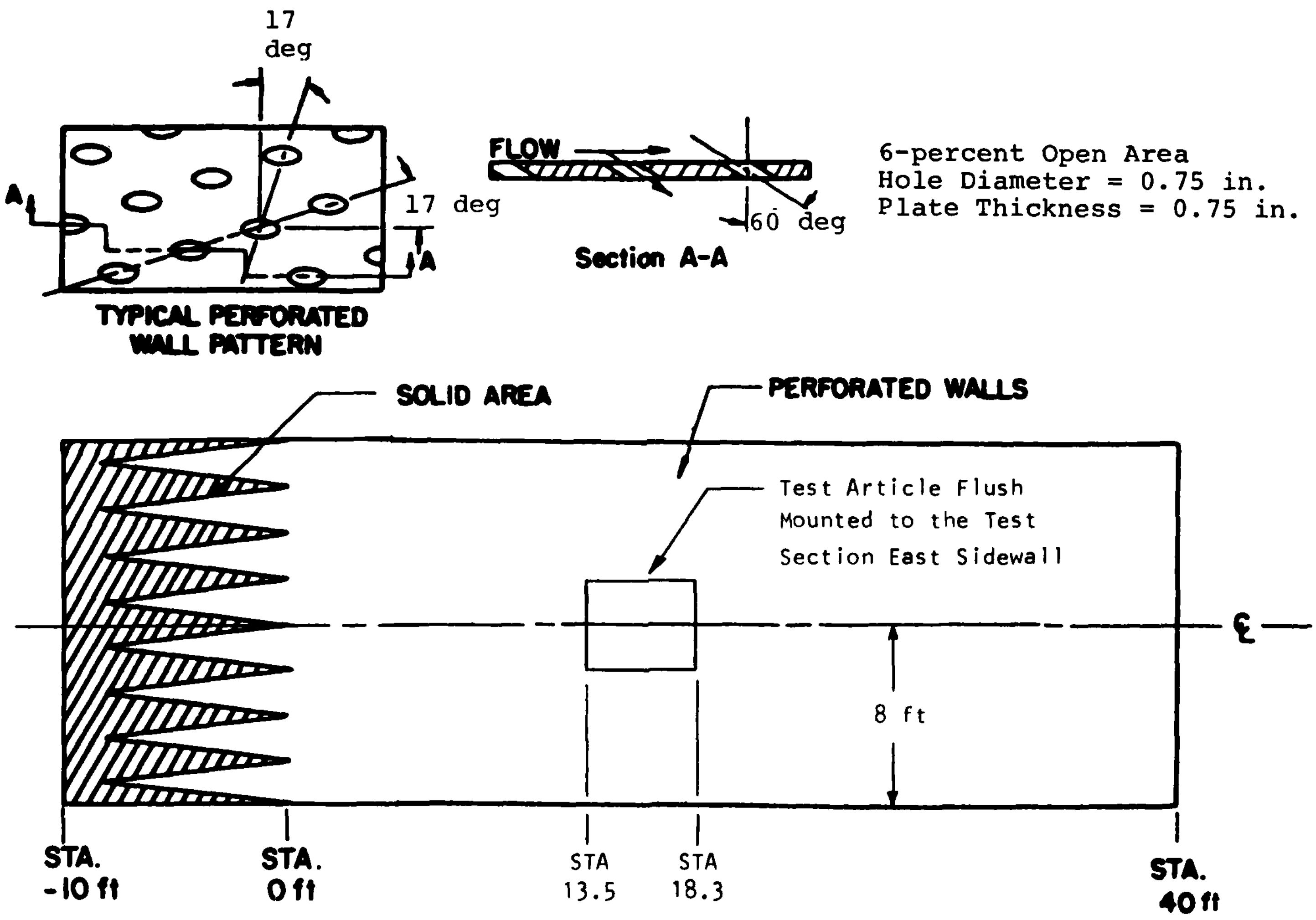


Figure 1. Test Article Location in Tunnel 16T

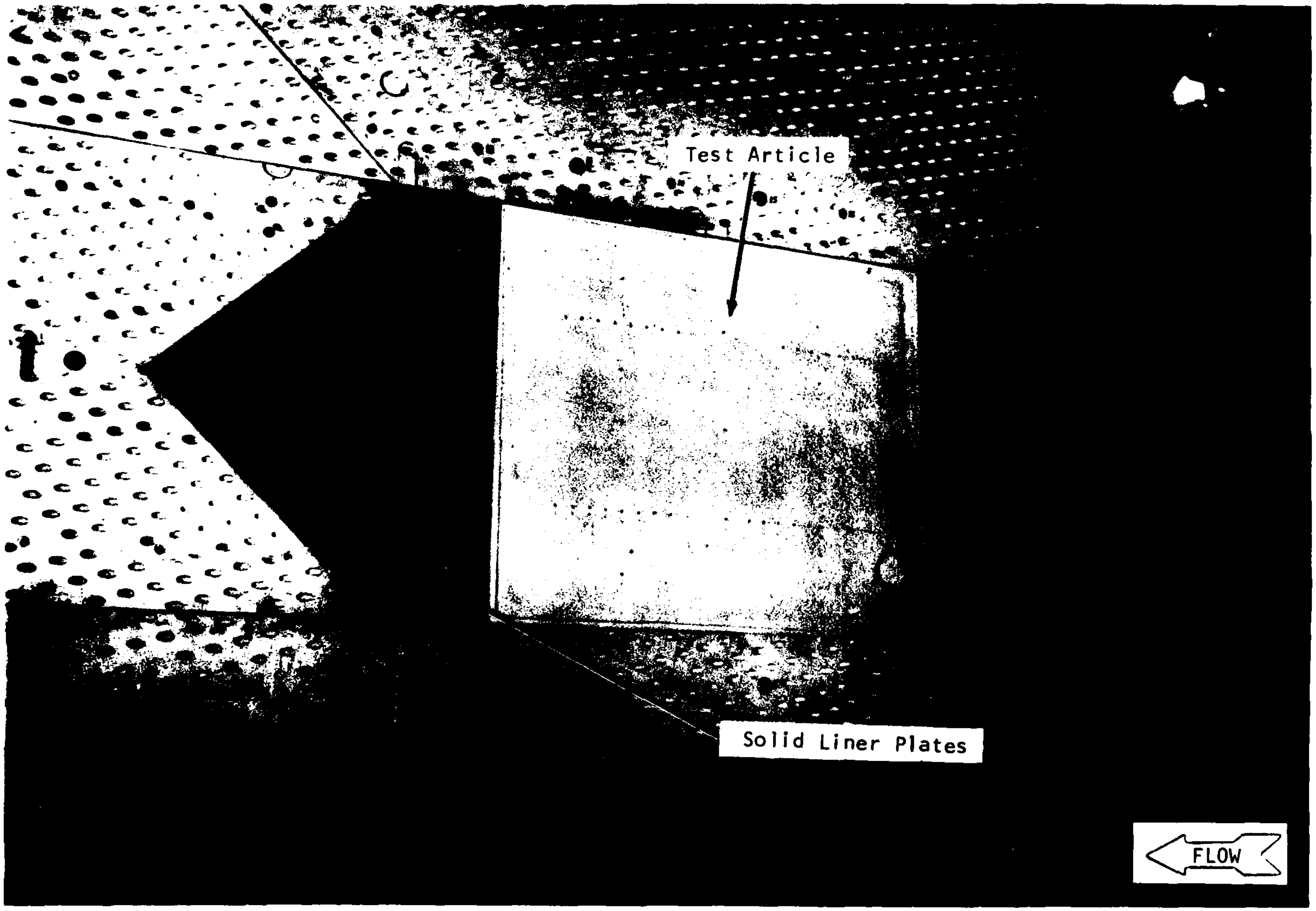
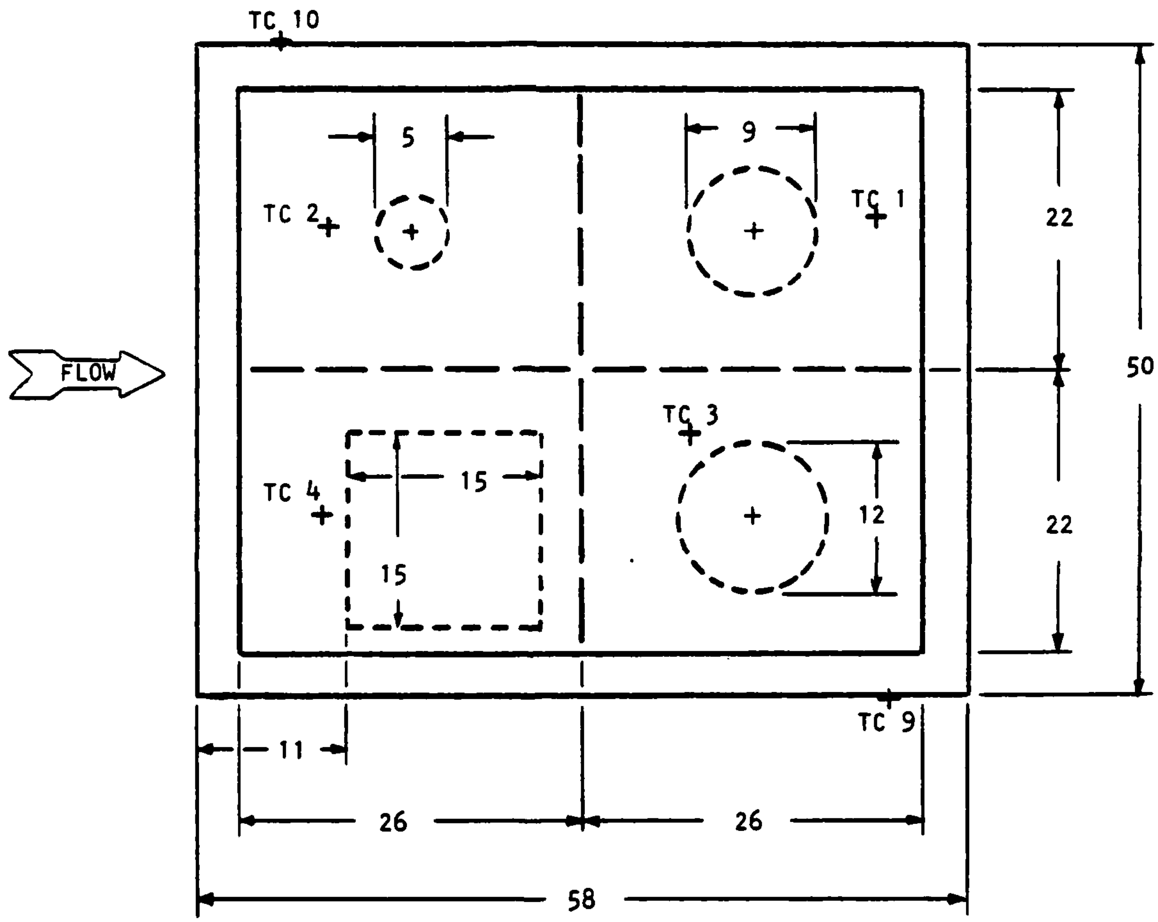


Figure 2. Model Installed in Tunnel 16T



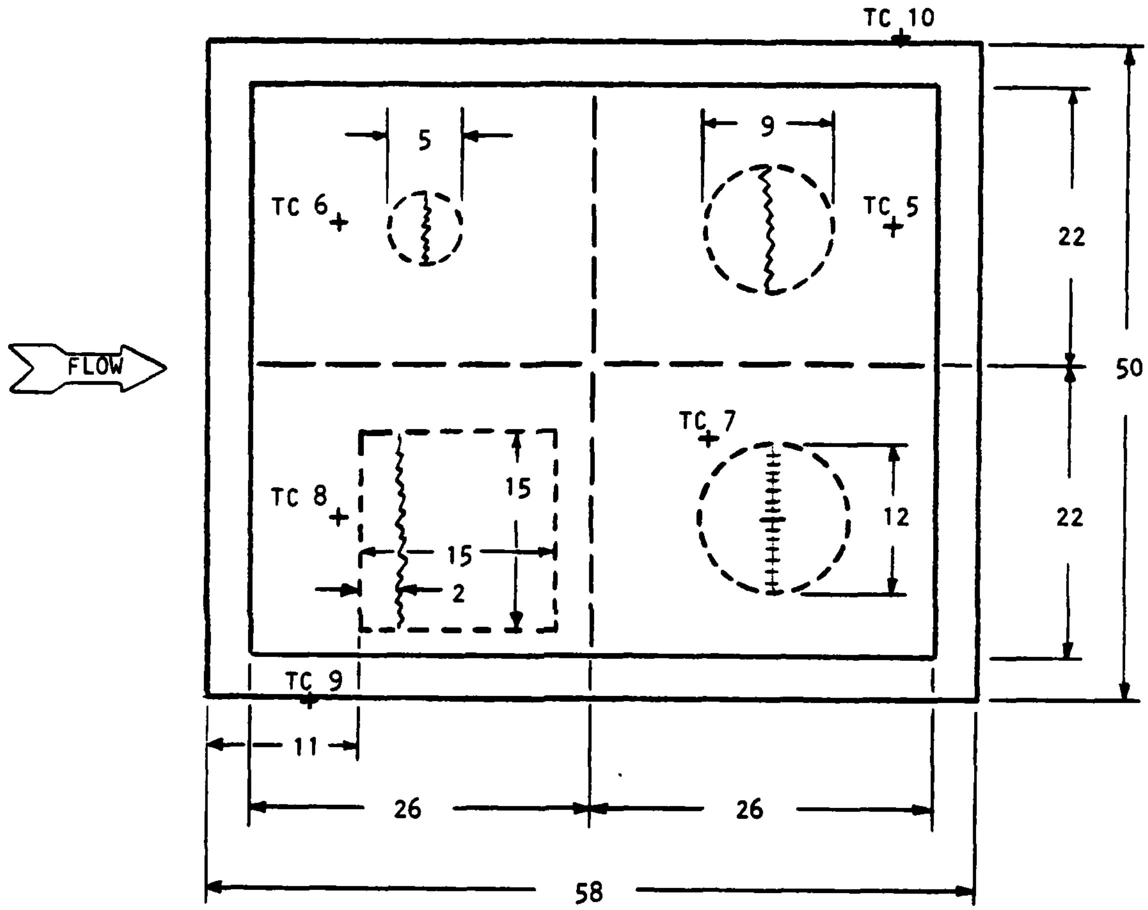
+ THERMOCOUPLE LOCATION

- - - DEBONDED AREAS

DIMENSIONS IN INCHES

a. Tank 3, Side A

Figure 3. Geometry of Debonded and Slit Areas in SLA/SOFI Panels



+ THERMOCOUPLE LOCATION

〰 SLIT THRU SOFI/SLA/GX

+++++++ SLIT THRU SLA/GX ONLY

- - - DEBONDED AREAS

DIMENSIONS IN INCHES

b. Tank 3, Side B

Figure 3. Concluded

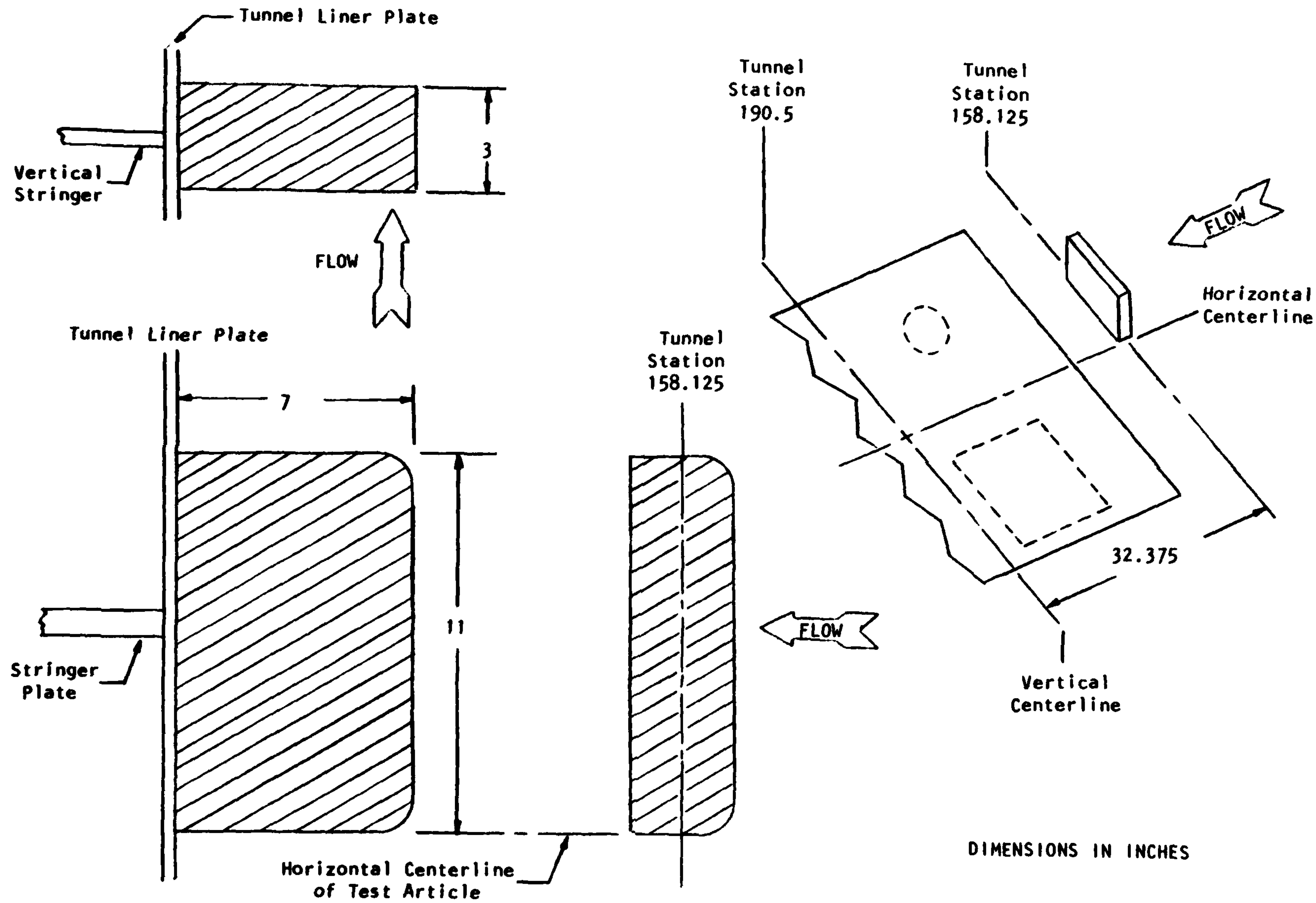


Figure 4. Geometry of Simulated Bipod Attachment Protuberance

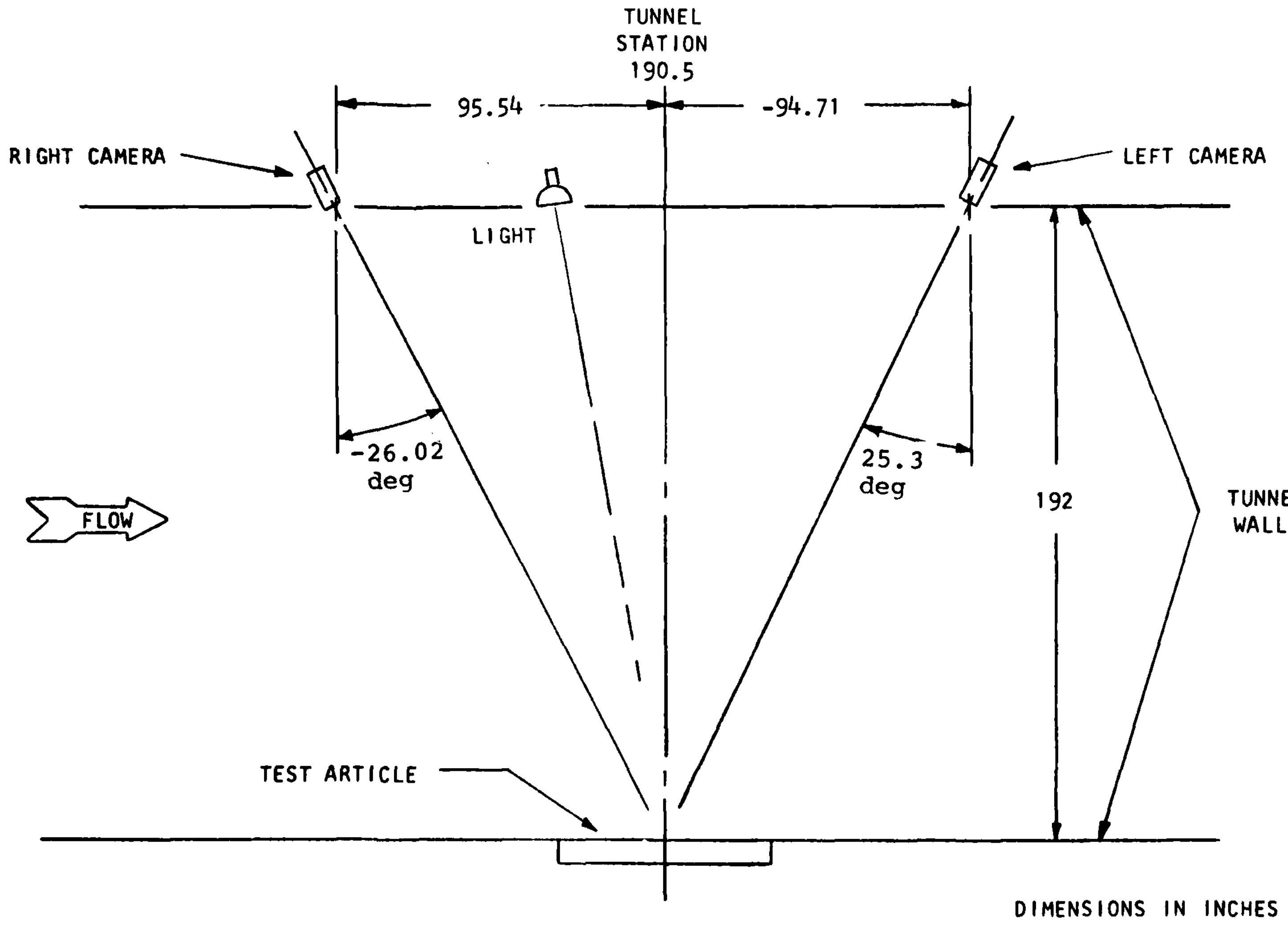


Figure 5. Location of Stereo-Photography Cameras Relative to the Model

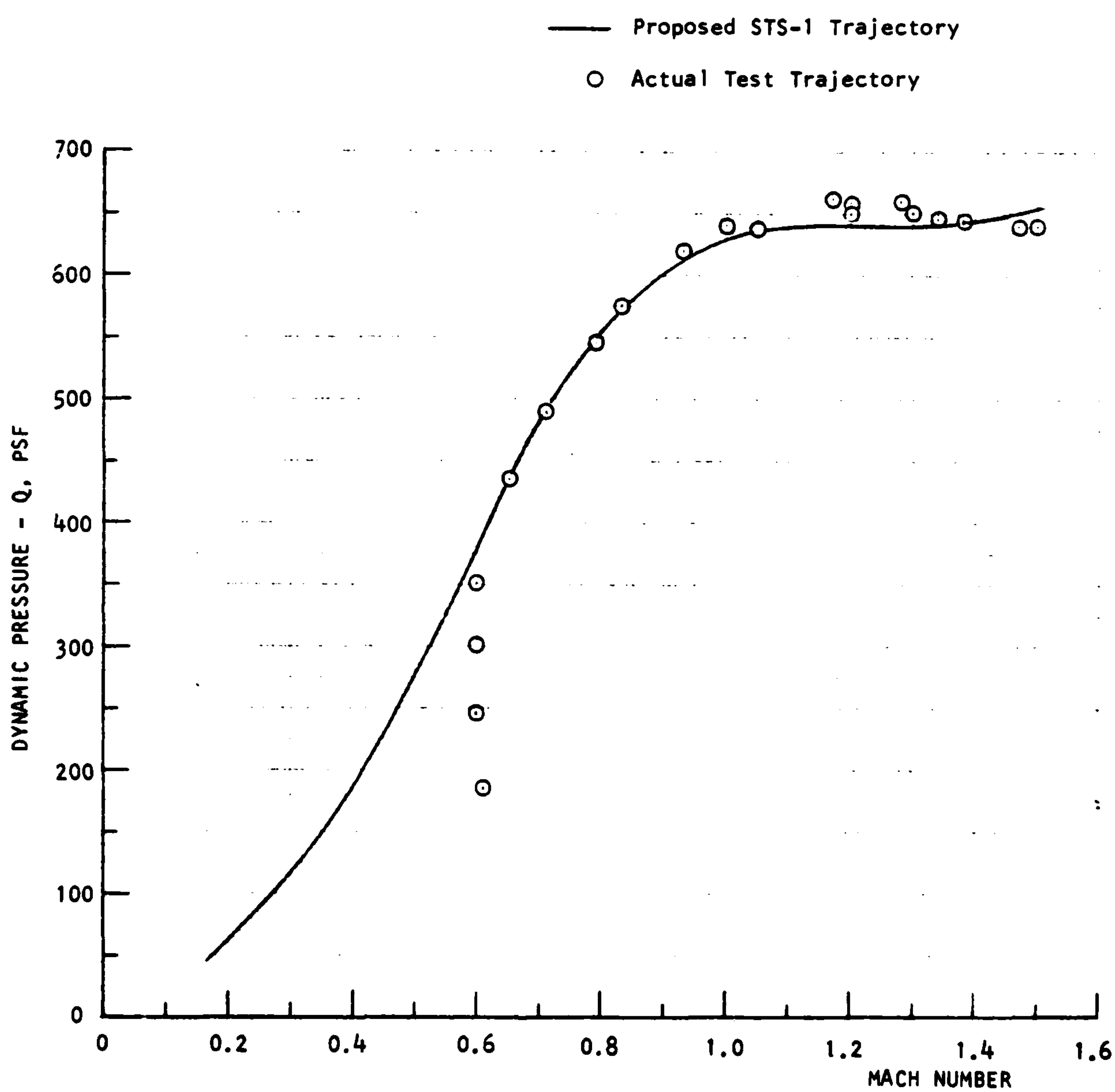
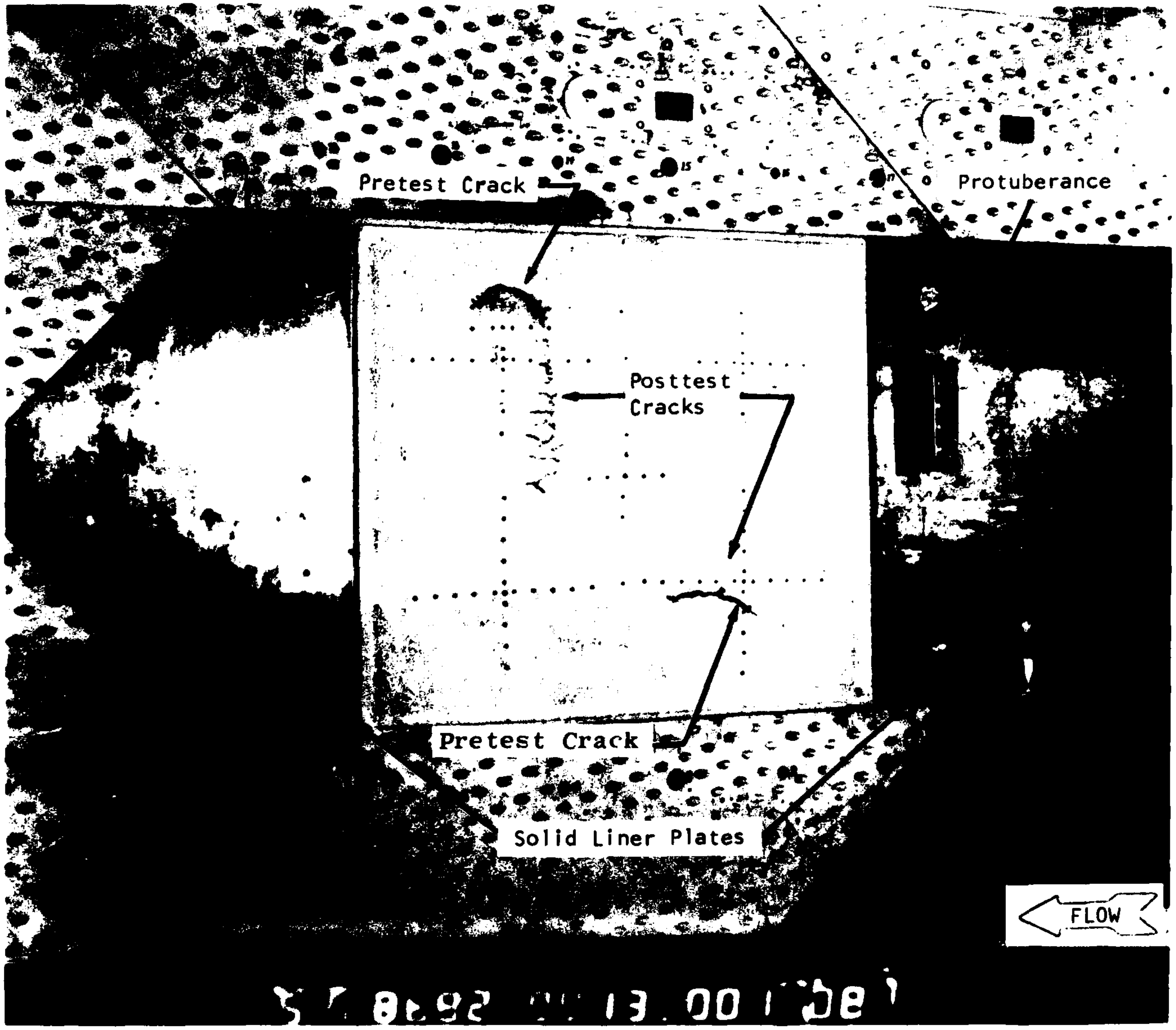
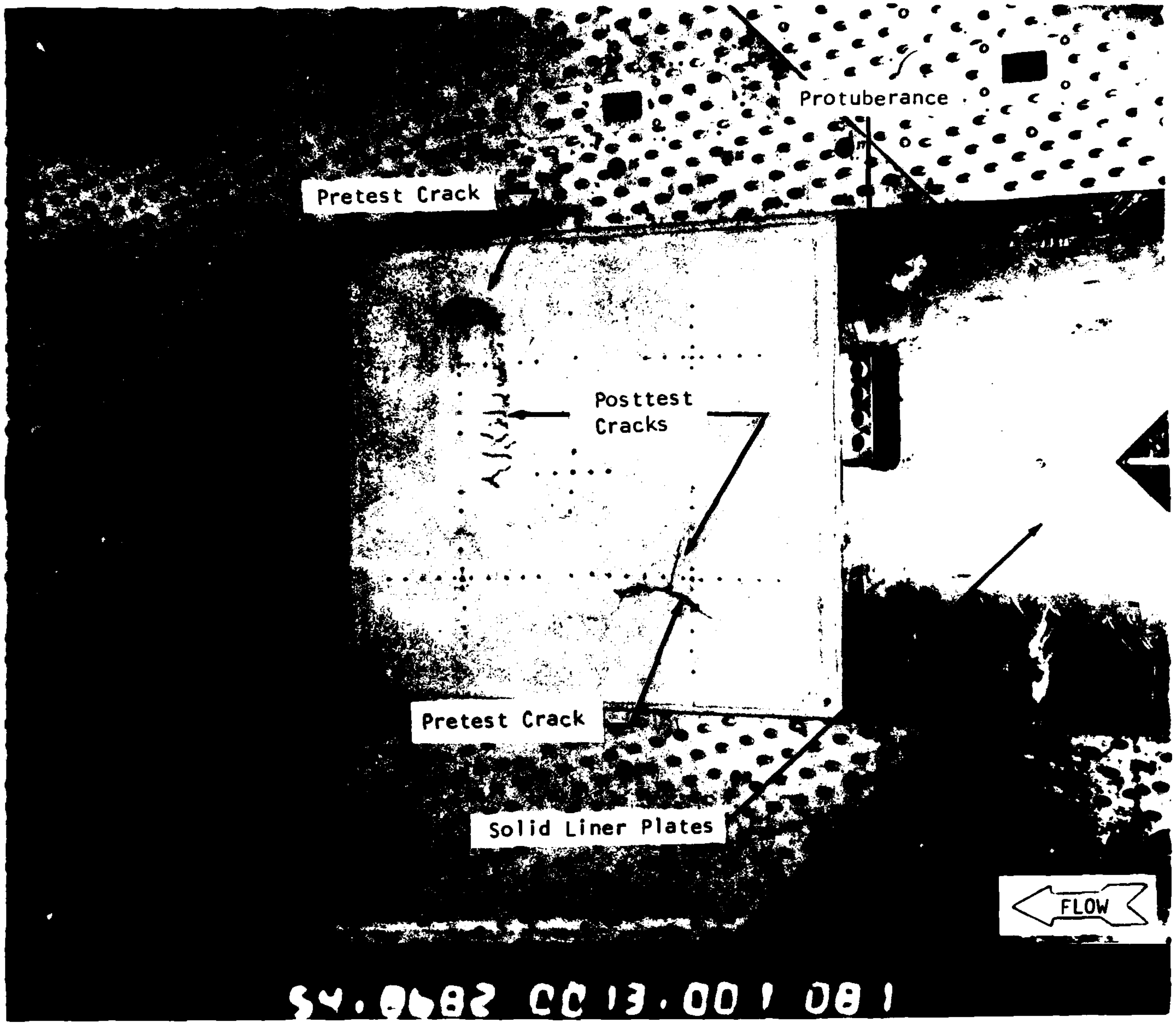


Figure 6. Variation of Dynamic Pressure with Mach Number

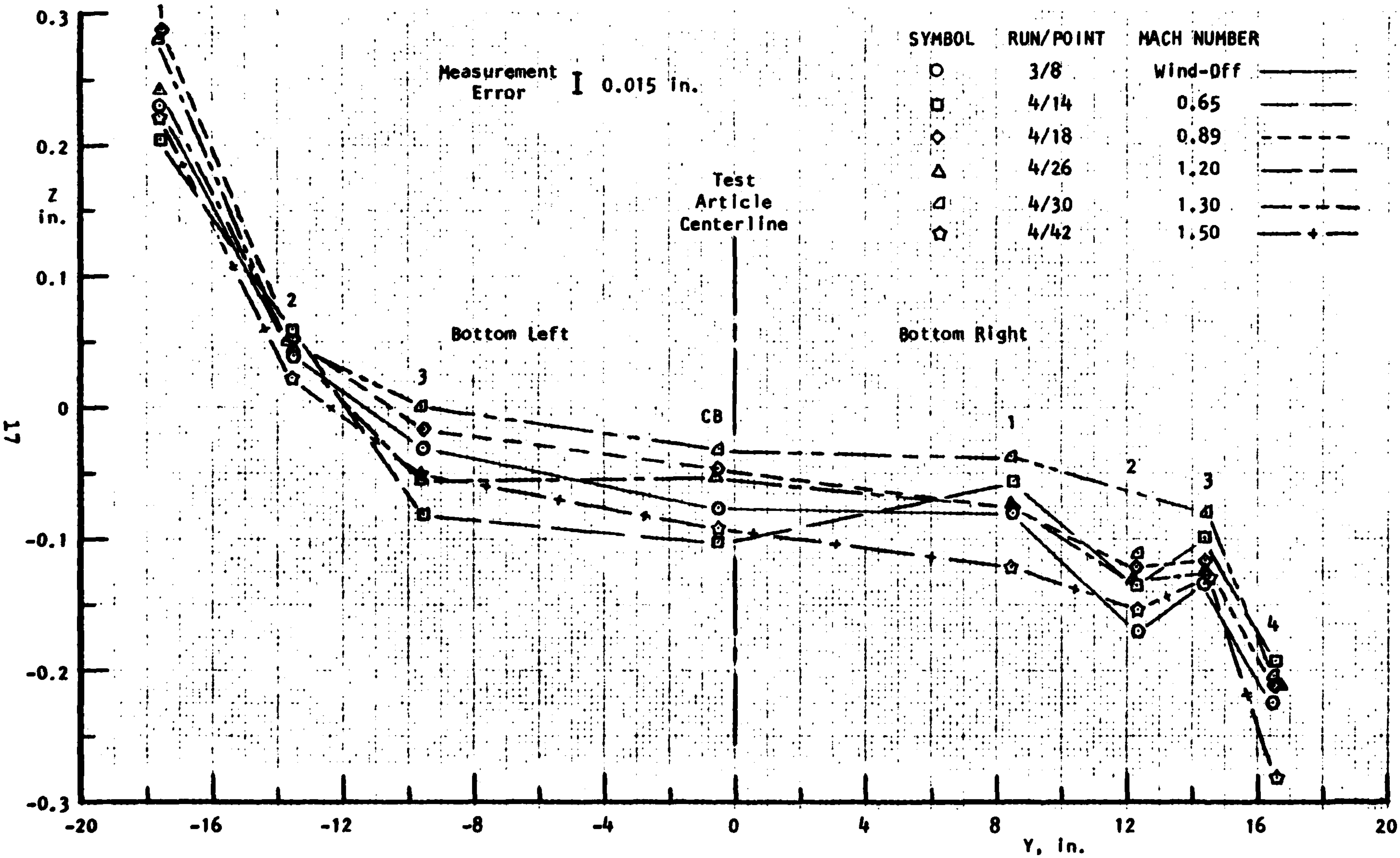


a. Left Camera

Figure 7. Typical Stereo-Photo Pair of Tank 3, Side A, with Flat Face Protuberance

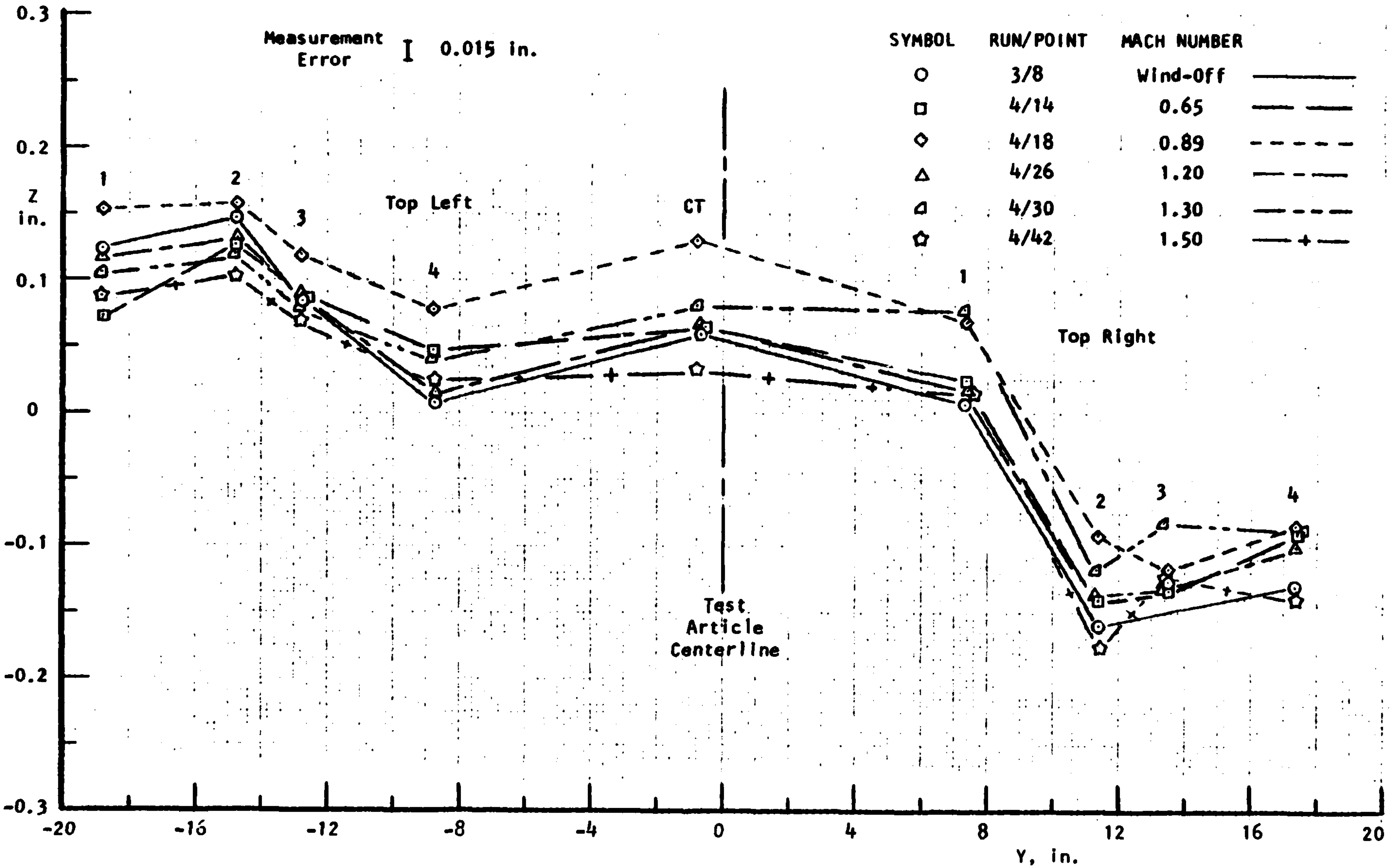


b. Right Camera
Figure 7. Concluded



a. Lower Row Targets, Tank 3, Side B

Figure 8. Variation in Tank Skin Position for Wind-Off Run 3 and Mach Sweep Run 4



b. Upper Row Targets, Tank 3, Side B

Figure 8. Concluded

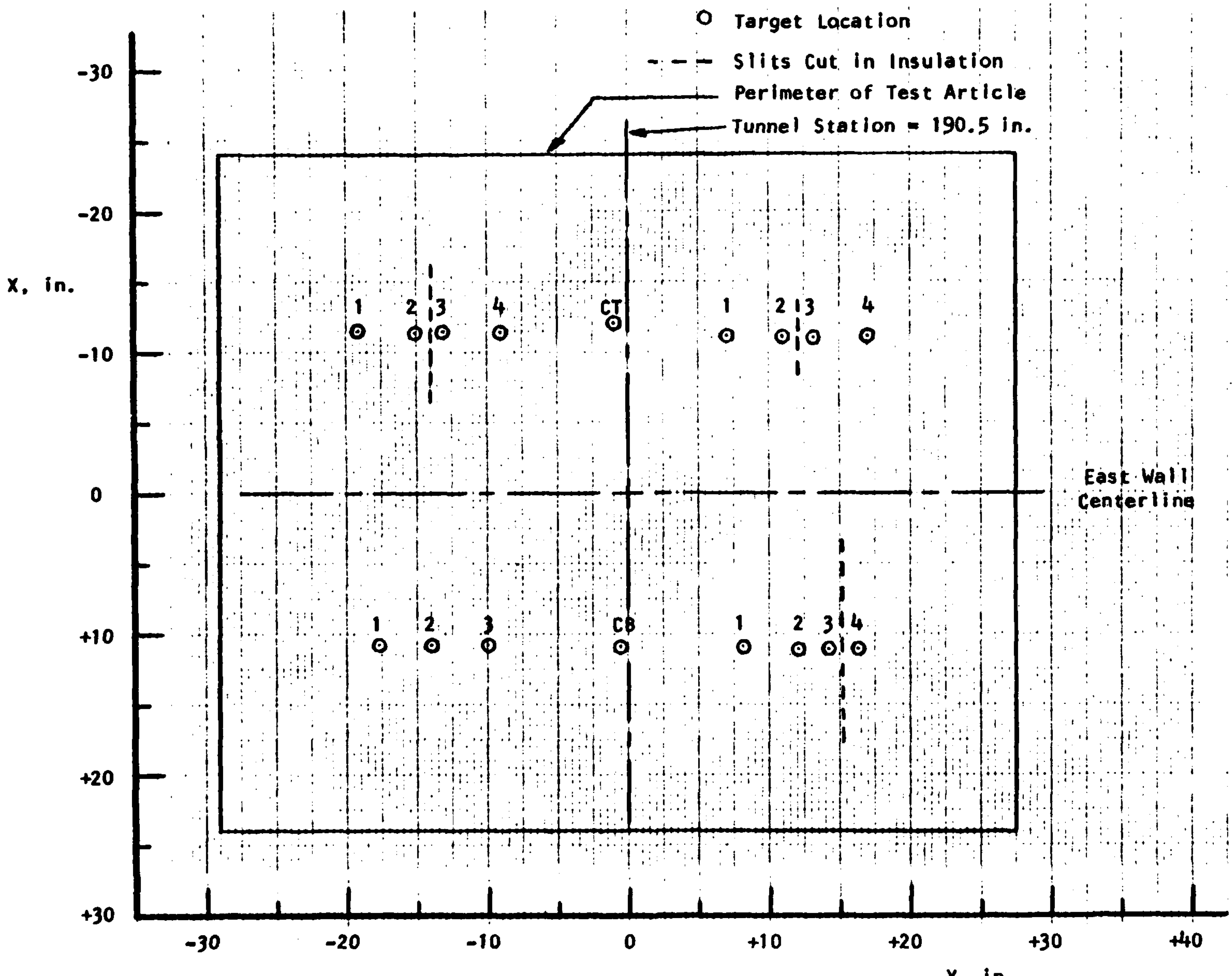


Figure 9. Location of the Upper and Lower Row Targets for Tank 3, Side B

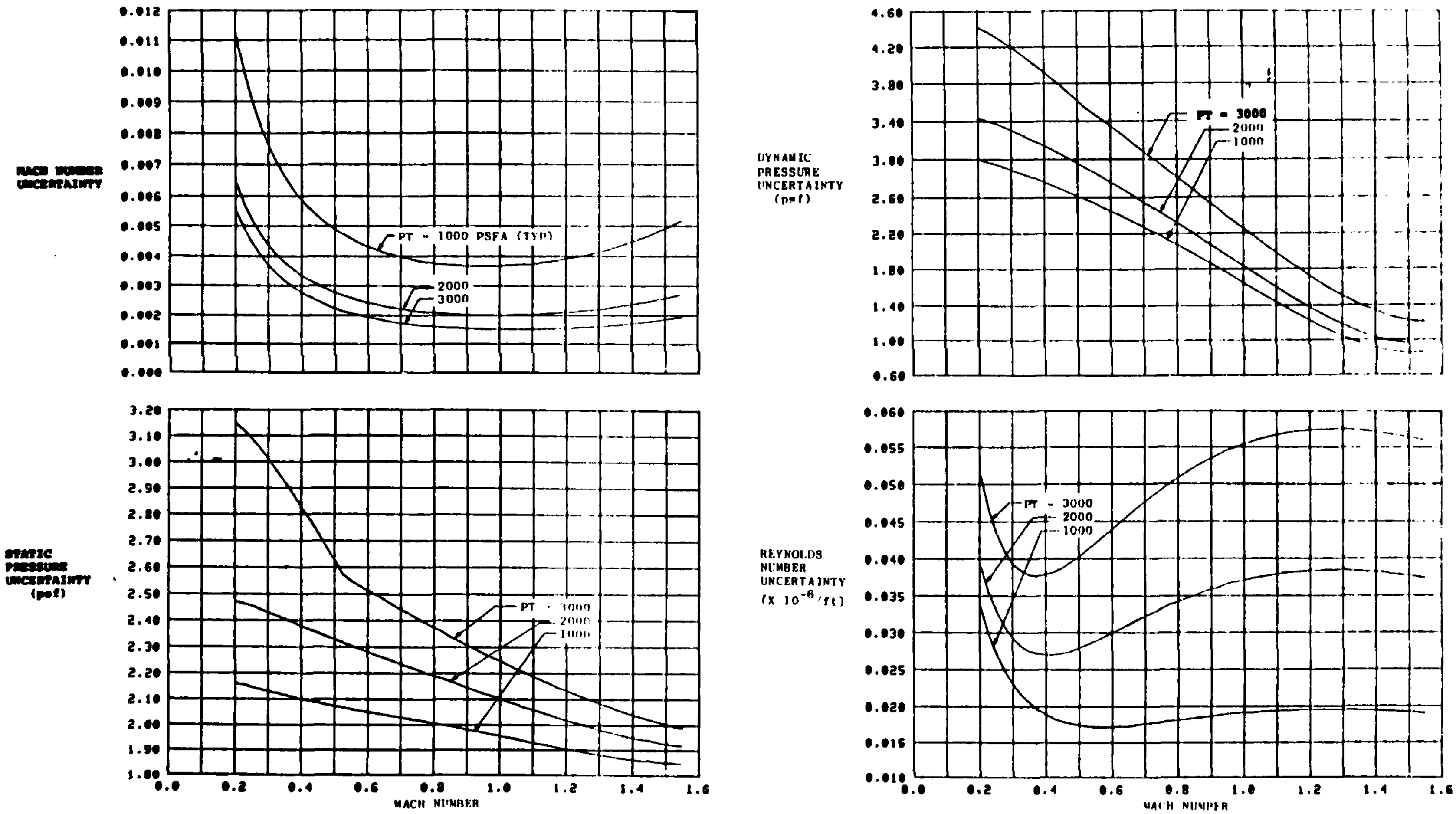


Figure 10. Estimated Uncertainties in Wind Tunnel Parameters

Table 1. Test Program Run Number Summary

TEST ARTICLE TANK NUMBER	TANK SIDE	SLA THICKNESS	CRACKS	PROTUBERANCE	RUN NUMBER	REMARKS
3	B	0.22 in.	YES	OFF	3	Pre-run Wind-Off
					4	Mach 0.61 to 1.50*
					5	Mach 1.41 to 0.40*
					6	Post-run Wind-Off
3	B	0.22 in.	YES	ON	7	Mach 0.60 to 1.50 to 0.20*
					8	Post-run Wind-Off
3	A	0.22 in.	NO**	OFF	9	Pre-run Wind-Off
					10	Mach 0.65 to 1.50 to 0.75*
					11	Post-run Wind-Off
3	A	0.22 in.	NO**	ON	12	Pre-run Wind-Off
					13	Mach 0.62 to 1.50 to 0.74*
					14	Post-run Wind-Off

*Data taken while changing tunnel test conditions

**Two unintentional cracks produced by thermal stress were present before testing began

Table 2. Sample Tabulated Data Printout

DATE 25-MAR-81 PROJECT NO P430-305
ARVIN/CALSPAN FIELD SERVICES, INC,
AEDC DIVISION
PROPULSION WIND TUNNEL
ARNOLD AIR FORCE STATION, TENNESSEE

RN	PN	PROJECT	TEST	DATE	DAY HR MIN SEC	MODE	DELPI	PROD DATE	WINDOFF		SET	CART	TRANSONIC 16T
4	13	P43G-305	TF-597	3/20/81	79120151110	0	416	25-MAR-81	3/	2	2	1.	

M	PT	P	Q	REX10-6	TT	TTR	H	PC	DP	WA	TPR	SHX10+3
.601	1926.0	1509.1	381.2	3.016	100.1	559.8	9050.	1521.4	405.5	0.01	1.123	0.577

MODEL CONFIGURATION

TANK/SIDE		SLA THICKNESS	CRACKS	PROTUBERANCE
3	B	.22	YES	OFF

THERMOCOUPLE READINGS TANK SIDE A

TC10
-329.1

TC1	TC2
-337.5	-334.0

TC3	TC4
-334.2	-335.3

TC9
-336.6

THERMOCOUPLE READINGS TANK SIDE B

TC10
-329.1

TC5	TC6
-333.3	-336.9

TC7	TC8
-331.8	-336.6

TC9
-336.6

Table 3. Tabulated Data Nomenclature

CRACKS	Indicates by "YES" or "NO" whether there are man-made breaks in the insulation covering the tank side being tested
M	Free-stream Mach number
P	Free-stream static pressure, psfa
PN	Point number (a single record of all test variables)
PROTUBERANCE	Indicates by "ON" or "OFF" whether there is a protuberance mounted upstream of the test tank to simulate the airflow disturbance caused by one of the bipod attachment fittings
Q	Free-stream dynamic pressure, psf
REX10-6	Free-stream unit Reynolds number, per foot
RN	Run number (a data subset containing variations of only one independent parameter)
SLA THICKNESS	The thickness of the Super Light Ablator (SLA) insulation panels bonded to the tank aluminum, in.
TANK/SIDE	Test article tank number and side being tested
TC1-10	Tank thermocouple readings, °F
TT	Free-stream stagnation temperature, °F

DATE
FILME
-8