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HYPERVELOCITY TRACK TESTS OF THE ABLATIVE  
CHARACTERISTICS OF HEATSHIELD MATERIALS  
FOR THE NASA GALILEO PROBE

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A. M. Adams

Calspan Field Services, Inc.

**TECHNICAL REPORT**  
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August 1981

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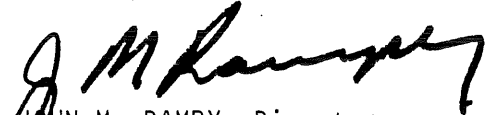
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FOR THE COMMANDER



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Hypervelocity Track Tests of the Ablative Characteristics of Heatshield Materials  
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## NOMENCLATURE

B	Bias contribution to uncertainty
p	Range Pressure
S	Precision index
$t_{95}$	95th percentile point for the two-tailed Student's "t" distribution
U	Total uncertainty
$V_i$	Range entrance velocity

## 1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E07, Control Number 9E07-00-1, at the request of the National Aeronautics and Space Administration (NASA/Ames Research Center), Moffett Field, CA 94035. The NASA project sponsor was Mr. Chul Park. The NASA project monitor was Mr. Charles DeRose. 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 tests were conducted in the von Karman Gas Dynamics Facility (VKF), under AEDC Project Number C378-VG.

The tests were conducted in the Hypervelocity Track G Facility of VKF, AEDC, from June 15, 1981 through July 22, 1981. The objective of the test program was to launch specified nosetip materials through an argon atmosphere and to recover the nosetips for post-flight analysis by NASA/Ames.

A copy of the final data package for this test program has been transmitted to NASA/Ames, the sponsor of the test program. Requests for copies of the data should be addressed to the NASA Sponsor, Entry Technology Branch, Mail Stop 229-4, Moffett Field, CA 94035. A copy of the final data package is on file on microfilm at AEDC.

Presented in this report are descriptions of the test unit including instrumentation, test procedure, data reduction techniques, and data quality estimates. Sample experimental data are presented in the Appendix.

## 2.0 APPARATUS

### 2.1 TEST FACILITY

The VKF Hypervelocity Track G is described in detail in Ref. 1. The test facility consists of a launcher, a 1000-ft-long tank equipped with a track to guide the test projectile, and a recovery tube to recover the model after testing. A schematic of the test facility is shown in Fig. 1.

The launcher used was a 2.5-in.-caliber, two-stage, light-gas gun approximately 150-ft long. The test chamber consists of a 10-ft-diam tank, 1000-ft long, which is divided into three sections. Each section can be maintained at any desired ambient pressure from one atmosphere down to a few millimeters of mercury. For these tests an argon environment was provided in the test chamber. The track, which consists of four rails inside a 7-in.-ID steel tube, guides the test model through the test chamber and into the recovery tube.

In the recovery tube, the test model energy is dissipated in the compression of a gas. The components of the recovery system are (1) a 200-ft section of converging rails to "guide" the projectile into the recovery tube, and (2) a 500-ft recovery tube composed of an assembly of 10-ft sections of 2.5-in.-ID by 4.5-in.-OD stainless steel tubing. The initial 50-ft of recovery tube extends into the test environment tank and is attached to the converging rail section.

## 2.2 TEST MODELS

Two model designs were used in this test program. These two designs, one of which is a conceptually new 2-in.-diam flat-face design, are shown in Figures 2 and 3 of this report. The nosetip specimens were fabricated from carbon/carbon (multidimensional), carbon phenolic (chopped molded), and carbon phenolic (20<sup>0</sup> dixie-cup) materials. The model is comprised of an aluminum core, a Lexan® base and the nosetip material. These models were designed to optimize the probability of nosetip recovery.

## 2.3 ARGON ENVIRONMENT

This test program required an argon gas environment throughout the entire range tank. The test pressures used ranged from a minimum of 25 torr to a maximum of 100 torr. In order to provide the purest argon environment possible, the range was evacuated to almost a complete vacuum and then filled to the desired pressure with argon gas. In no case did air contamination exceed 1.2 torr.

## 2.4 INSTRUMENTATION

The instrumentation used in the test program included twelve X-ray stations and seven laser stations. These stations provided the necessary in-flight side view pictures, so that the nosetip characteristics could be monitored during flight. Data from the X-ray and event time recording systems were used to determine the model position, orientation, and velocity.

Other instrumentation used on this test includes image-converter camera systems at various locations along the track. These cameras view the model nosetip from almost head-on and record the brightness temperature distribution on the nosetip. These camera installations are calibrated so that surface temperature distributions can be obtained from these photographs. Test environmental conditions at test time were measured by the pressure and temperature measurement systems. Table 1 lists the instrumentation and their locations as they were used for this test program.

## 3.0 TEST DESCRIPTION

### 3.1 TEST PROCEDURE AND CONDITIONS

The test conditions for all shots are given in Table 2.

Prior to the launching of the model, the complete model assembly was dimensionally inspected. This procedure established the pretest nosetip configuration.

The model is accelerated to the desired velocity by the two-stage launcher and enters the blast tank. The function of the blast tank is to separate and contain the muzzle gases and prevent them from entering the range tank. The blast tank is separated from the range tank by a quick-operating valve which closes behind the model.

The test environment of interest is first encountered in the uprange section of the range. In this test the test environment is that of argon. After passing through the uprange section the model then enters the downrange section of the range. The uprange and downrange sections can be separated by a quick-acting valve so that a pressure differential can be maintained when desired. In this particular test program, all shots had identical pressures in the uprange and downrange sections so that the use of a quick-acting valve was not required.

At the end of the downrange section the model enters the recovery tube. The recovery tube is charged with staged pressures so that the model can be non-destructively decelerated to a stop. The recovery tube terminates into a tapered rail section which mechanically arrests the model and allows the nosetip to be recovered intact.

### 3.2 DATA REDUCTION

The model velocity history is obtained from the timing data recorded during the shot combined with the known instrumentation locations. Once the velocity history is known, other quantities of interest (e.g., drag coefficient, model ballistic coefficient, and average velocity) are computed.

The ablation characteristics of the nosetip, in this test, were to be determined by NASA/Ames.

### 3.3 DATA UNCERTAINTY

Measurement uncertainty is a combination of bias and precision errors defined as (Ref. 2):

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

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, and depends on the sample size.

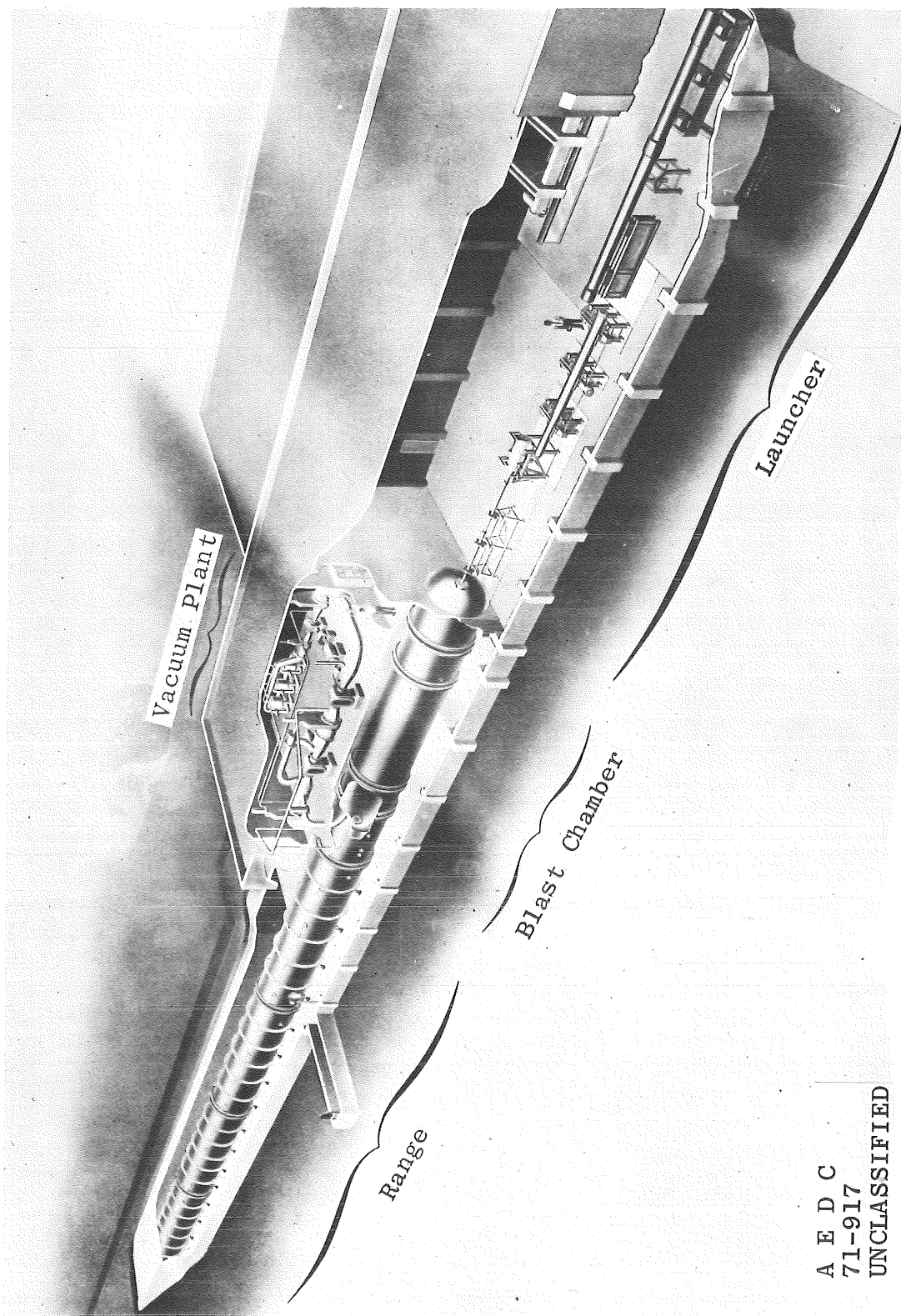
Estimates of the measured data uncertainties for this test are given in Table 3.

### 4.0 DATA PACKAGE PRESENTATION

The final data package for this project was prepared under separate cover. The package presents the data summarizing the test conditions and test results, including the test setup, test article information, and trajectory data. Pretest model photographs and prints of in-flight X-ray and laser photographs, along with nosetip surface temperature data were transmitted to NASA/Ames during the test program. Recovered test specimens were returned to NASA/Ames at the conclusion of the test program. Sample data are included in the Appendix of this report.

## 5.0 REFERENCES

1. Test Facilities Handbook (Eleventh Edition-Revised), "von Karman Gas Dynamics Facility, Vol. 3," Arnold Engineering Development Center, April 1981.
2. Abernathy, R. B. and Thompson, J. W., Jr., "Handbook of Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 (AD755356), February 1973.



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Figure 1. Range G.

# HYPERVELOCITY TRACK G

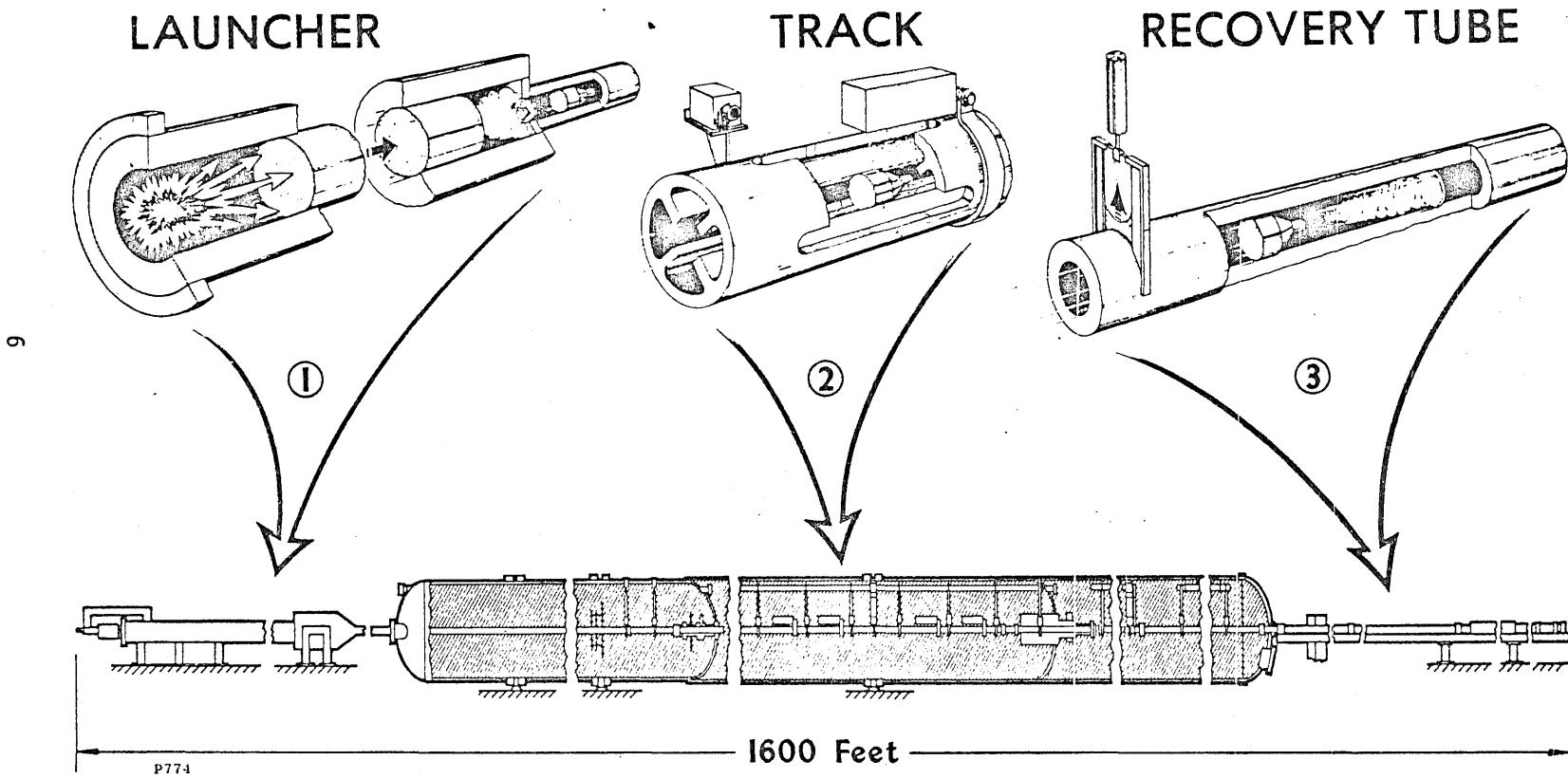


Figure 2. Hypervelocity Track G -  
Track Installation

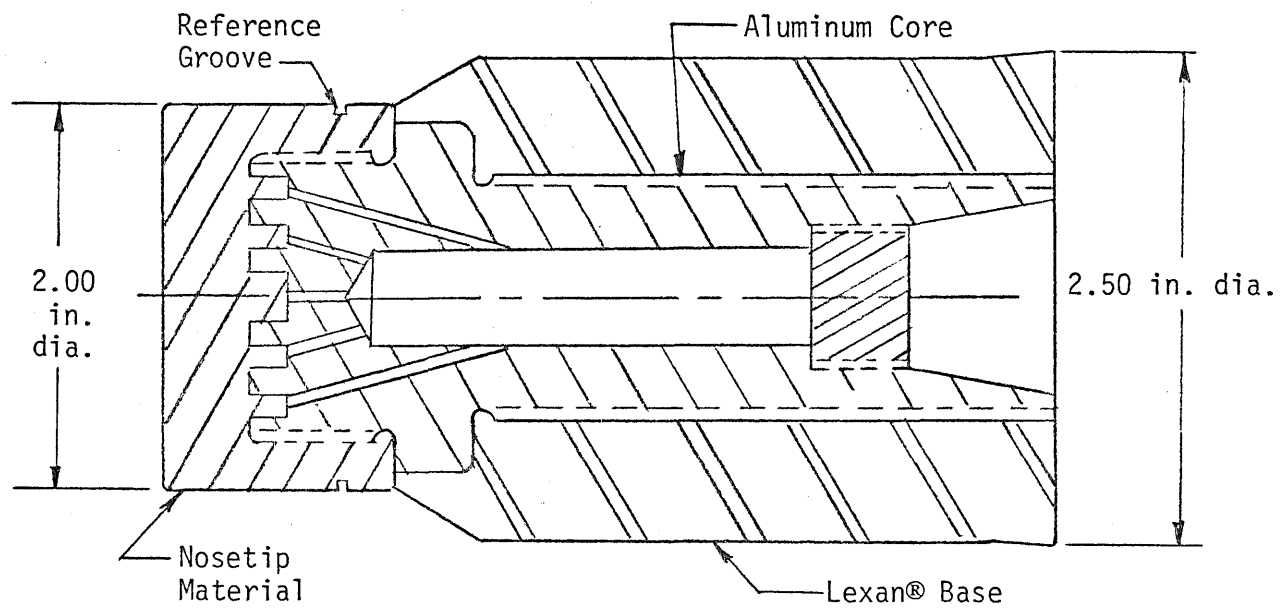


Figure 3. Model Drawing - Flat Face Design  
(Full Scale)

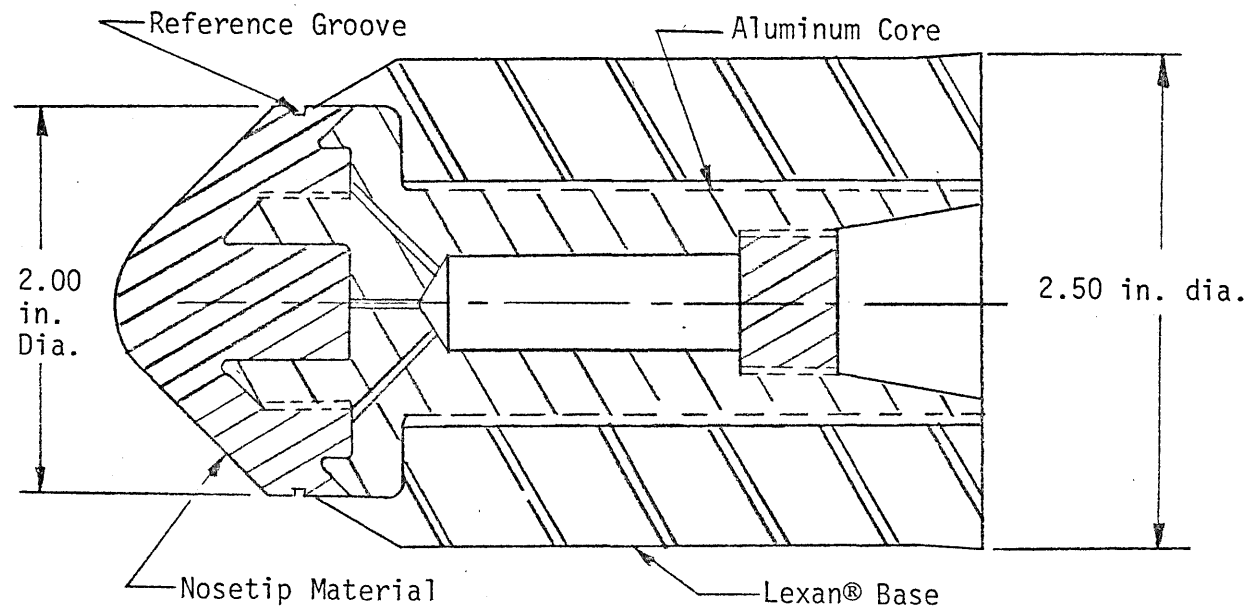


Figure 4. Model Drawing - Blunt Nose Design  
(Full Scale)

TABLE 1. TEST EQUIPMENT SETUP

Equipment Designation				Equipment Location
Range Reference	Laser	X-Ray	IC	Distance from Range Entrance, ft
Launcher Exit				-48.15
		X-A		-42.61
		X-B		-27.61
Range Entrance (QOV 1 & QOV 2)				0.0
	L-2	X-1		2.55
		X-2		52.86
			IC-4	54.17
		X-7		94.63
		X-10		150.92
	L-11			220.92
QOV-3				305.15
		X-15		312.67
		X-18		377.8
			IC-20	395.3
	L-19			398.11
		X-23		472.67
	L-24			492.98
		X-28		577.80
			IC-29	591.48
	L-29			598.11
		X-34		697.8
	L-35			721.36
		X-40		817.80
			IC-41	831.48
	L-41			841.35
Recovery Tube Entrance				875.24
QOV-4				920.21

QOV = Quick-Operating Valve  
 IC = Image-Converter Camera

TABLE 2. TEST SUMMARY

Shot No.	Model No.	Model Configuration and Material	$V_i$ (fps)	$P$ (torr)	Recovery	In-Flight Data
5591	6608	Flat Face/Carbon Carbon Multi-Dimensional	17,930	49.2	Yes	Yes
5595	6607	Blunt Nose/Carbon Phenolic Chopped Molded	17,070	100.2	Yes	Yes
5599	6652	Flat Face/Carbon Phenolic Chopped Molded	17,780	50.3	No	Yes
5601	6653	Flat Face/Carbon Phenolic Chopped Molded	17,990	50.2	Yes	Yes
5602	6654	Flat Face/Carbon Phenolic Chopped Molded	17,600	24.8	No	Yes
5603	6655	Blunt Nose/Carbon Phenolic Chopped Molded	17,380	74.9	Yes	Yes
5604	6651	Flat Face/Carbon Phenolic 20° Dixie Cup	17,750	50.3	Yes	Yes
5605	6650	Flat Face/Carbon Carbon Multi-Dimensional	17,600	75.0	Yes	Yes

NOTE: Argon gas used full range on all shots.

Table 3. UNCERTAINTY IN TEST PARAMETERS

Parameter Designation	ESTIMATED MEASUREMENT							Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{99}S)$					
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement				
Range Pressure	+1		30	0		+2		10 to 300 torr	Precision Variable capacitive transducer	Remote Null Reading Meter	Comparison with Secondary Standard
Model Velocity	+0.005		30	+0.0024		+0.01		15000 to 19000 fms	Calculated from distance-time data		
Range Temperature		+0.90	20		+0.10		+1.98	50 to 100 deg F	Thermocouple	Multipoint Stripchart Servopotentiometer	Comparison with Secondary Standard
Model Weight		+1.0	30		0		+2.042	400 to 600 gram	Laboratory Pan Scale	Handwritten from scale	Comparison with secondary standard
Specimen Weight		+0.0012	30		0		+0.0024	5 to 20 gram	Laboratory Pan Scale	Handwritten from scale	Comparison with secondary standard
Distance Downrange		+0.005	30				+0.01	0 to 840 ft	X-Ray Shadowgraphs	Photographic Film	Range Survey
Time Intervals	+0.0002	+1X 10 <sup>-7</sup>	100		0	+0.0004	+2X 10 <sup>-7</sup>	0 to 0.080 sec	24-bit counter	Modcomp Computer	Comparison with primary standard
Brightness Temperature (Gen I System)		+40	5		+25		+130	1600 to 3300 Deg K	Photopyrometer	Photographic Film	Comparison with secondary standard
Brightness Temperature (Gen II Sys)		+40	5		+25		+130	1400 to 2000 Deg K	Photopyrometer	Photographic Film	Comparison with secondary standard

(1) Listed bias estimates were assumed except for brightness temperatures.

APPENDIX A  
REPRESENTATIVE DATA OBTAINED

The representative data shown include a sample position and velocity history (Table A-1). Figure A-1 shows a typical nosetip in-flight temperature distribution. Figure A-1 (a) shows the isothermal contours and the locations of the vertical and horizontal temperature scans which are shown respectively as Figure A-1 (b) and (c).

INITIAL CONDITIONS: WEIGHT=4.5000D-02GRAMS PINE=1.0020D-02TORR TIME=5.4377D-02DEG. R

DRAG COEFF=9.9880D-01 BASE DIAMETER=2.5000D-00INS. DELTA TIME=1.0000D-03SEC. FINAL TIME=7.0000D-02

CONSTANT DRAG COEFF INITIAL VELOCITY=1.7070D-04

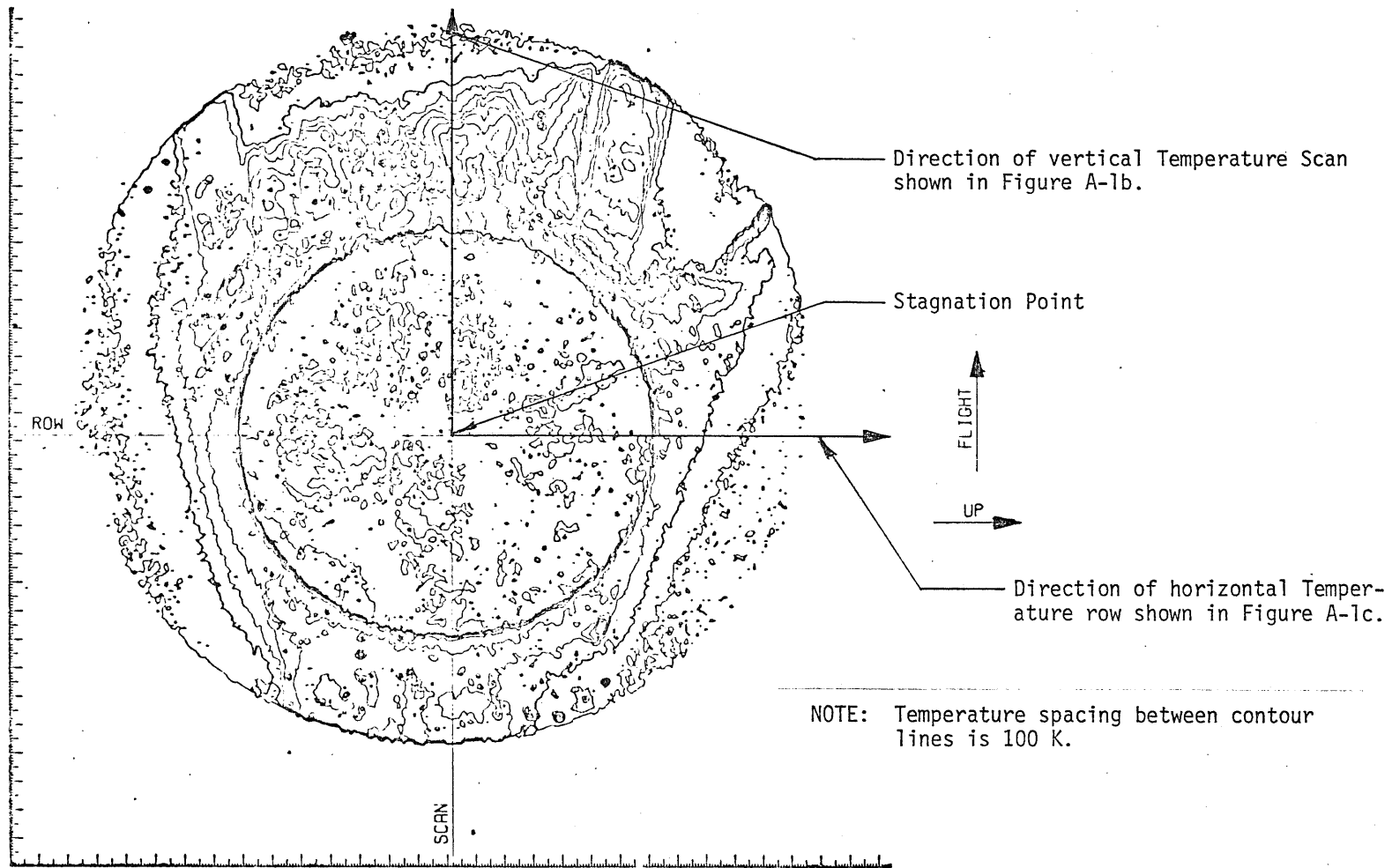
SHOT 5595

TIME SEC.	DIST FT.	VEL FT./SEC.	BETA LBS/SQ.F	PSTAG ATM.	HSTAG BTU/LB.
0.0	0.0	1.707000 04	2.915280 01	4.994520 01	5.946080 03
1.000000-03	1.707000 01	1.700270 04	2.915280 01	4.955230 01	5.900340 03
2.000000-03	3.407270 01	1.693600 04	2.915280 01	4.916400 01	5.855130 03
3.000000-03	5.100870 01	1.686980 04	2.915280 01	4.878030 01	5.810450 03
4.000000-03	6.787850 01	1.680410 04	2.915280 01	4.840110 01	5.766300 03
5.000000-03	8.468260 01	1.673890 04	2.915280 01	4.802630 01	5.722650 03
6.000000-03	1.014210 02	1.667420 04	2.915280 01	4.765580 01	5.679520 03
7.000000-03	1.180960 02	1.661000 04	2.915280 01	4.728960 01	5.636880 03
8.000000-03	1.347060 02	1.654630 04	2.915280 01	4.692700 01	5.594730 03
9.000000-03	1.512520 02	1.648310 04	2.915280 01	4.656980 01	5.553060 03
1.000000-02	1.677350 02	1.642040 04	2.915280 01	4.621500 01	5.511860 03
1.100000-02	1.841550 02	1.635810 04	2.915280 01	4.586330 01	5.471140 03
1.200000-02	2.005140 02	1.629630 04	2.915280 01	4.552050 01	5.430880 03
1.300000-02	2.168100 02	1.623500 04	2.915280 01	4.517860 01	5.391070 03
1.400000-02	2.330450 02	1.617420 04	2.915280 01	4.484050 01	5.351700 03
1.500000-02	2.492190 02	1.611380 04	2.915280 01	4.450620 01	5.312780 03
1.600000-02	2.653330 02	1.605380 04	2.915280 01	4.417570 01	5.274290 03
1.700000-02	2.813870 02	1.599430 04	2.915280 01	4.384860 01	5.236230 03
1.800000-02	2.973810 02	1.593530 04	2.915280 01	4.352560 01	5.198590 03
1.847810-02	3.050000 02	1.590720 04	2.915280 01	4.337240 01	5.180760 03

TABLE A-1. Velocity and Position History

SECOND LEVEL CONDINTINS: PI=1.00100 02 DRAG COEFF = 9.9880D-01 VELOCITY= 1.5907D 04

1.947810-02	3.209070 02	1.584880 04	2.915280 01	4.301180 01	5.143770 03
2.047810-02	3.367560 02	1.579090 04	2.915280 01	4.269790 01	5.107180 03
2.147810-02	3.525470 02	1.573340 04	2.915280 01	4.238740 01	5.070990 03
2.247810-02	3.682800 02	1.567630 04	2.915280 01	4.208030 01	5.035200 03
2.347810-02	3.839570 02	1.561960 04	2.915280 01	4.177650 01	4.999790 03
2.447810-02	3.995760 02	1.556330 04	2.915280 01	4.147600 01	4.964770 03
2.547810-02	4.151390 02	1.550740 04	2.915280 01	4.117880 01	4.930120 03
2.647810-02	4.306470 02	1.545200 04	2.915280 01	4.088470 01	4.895840 03
2.747810-02	4.460990 02	1.539690 04	2.915280 01	4.059370 01	4.861930 03
2.847810-02	4.614960 02	1.534220 04	2.915280 01	4.030590 01	4.828380 03
2.947810-02	4.768380 02	1.528790 04	2.915280 01	4.002110 01	4.795190 03
3.047810-02	4.921260 02	1.523400 04	2.915280 01	3.973930 01	4.762350 03
3.147810-02	5.073600 02	1.518050 04	2.915280 01	3.946050 01	4.729850 03
3.247810-02	5.225400 02	1.512730 04	2.915280 01	3.918470 01	4.697700 03
3.347810-02	5.376680 02	1.507450 04	2.915280 01	3.891170 01	4.665880 03
3.447810-02	5.527420 02	1.502210 04	2.915280 01	3.864150 01	4.634390 03
3.547810-02	5.677640 02	1.497000 04	2.915280 01	3.837420 01	4.603230 03
3.647810-02	5.827340 02	1.491830 04	2.915280 01	3.810960 01	4.572390 03
3.747810-02	5.976530 02	1.486700 04	2.915280 01	3.784770 01	4.541870 03
3.847810-02	6.125200 02	1.481600 04	2.915280 01	3.758860 01	4.511660 03
3.947810-02	6.273360 02	1.476540 04	2.915280 01	3.733210 01	4.481760 03



a. Isothermal Contour  
Figure A-1. In-Flight Surface Temperature Data

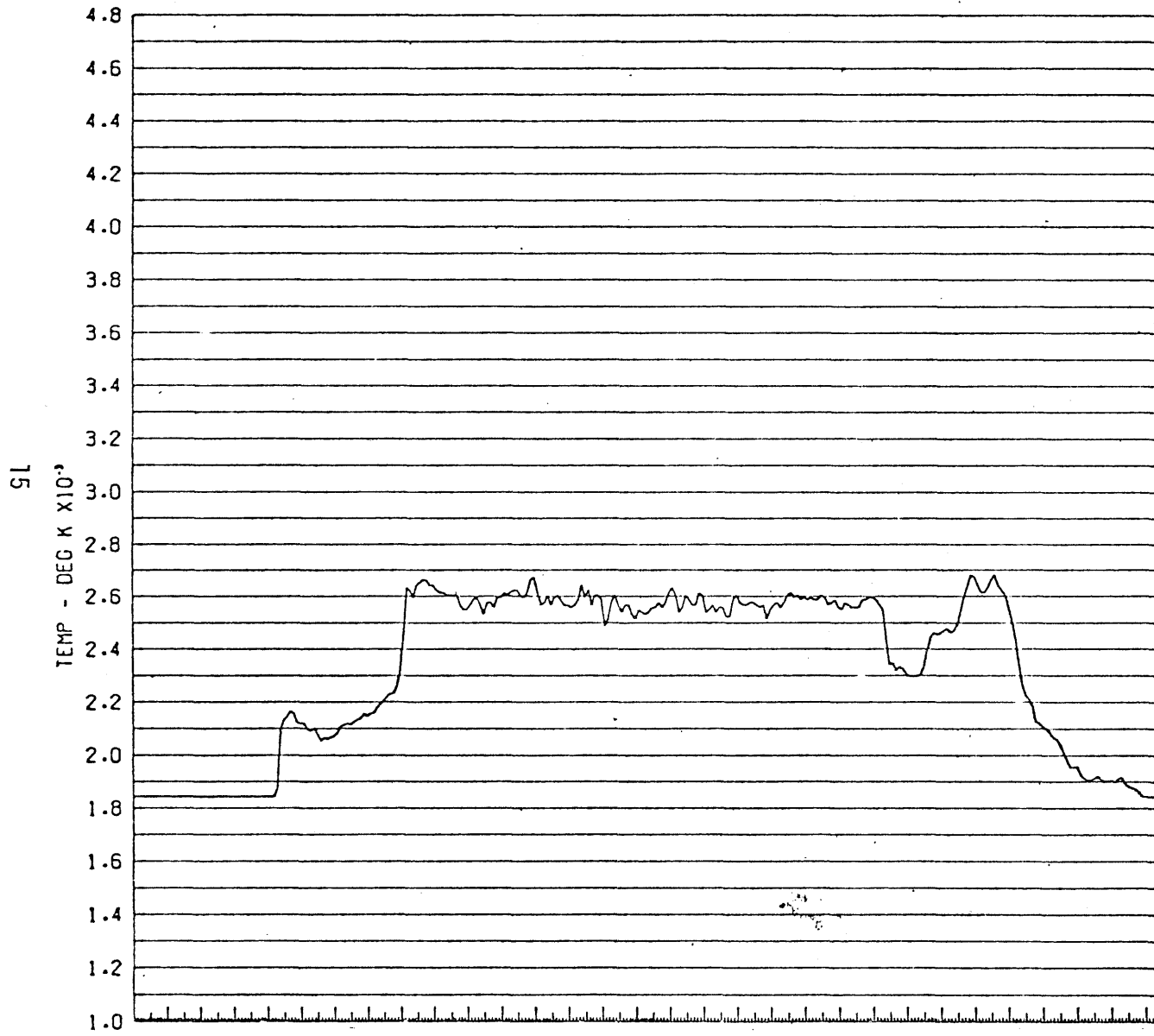


Figure A-1 Continued  
b. Vertical Temperature Scan

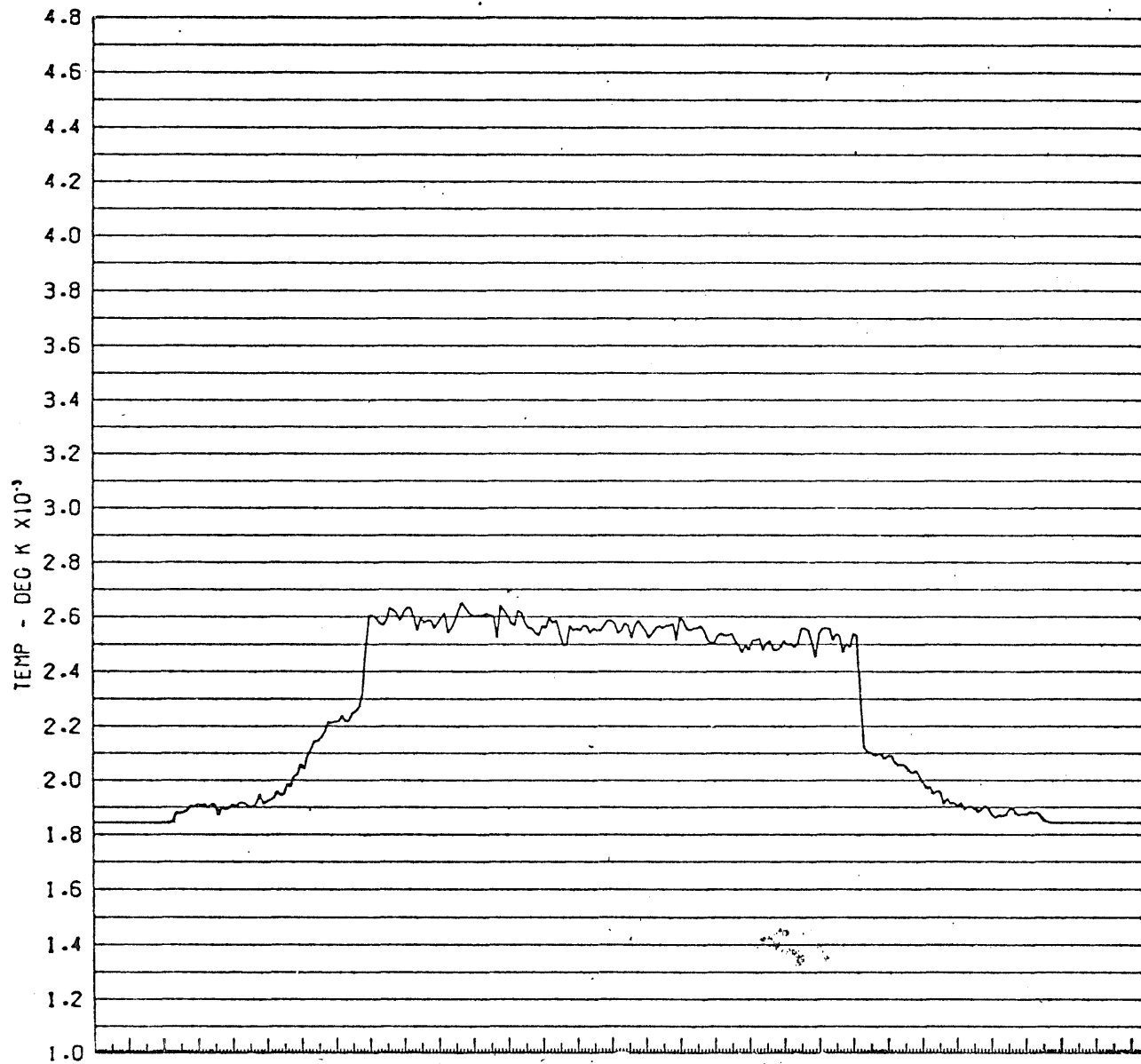


Figure A-1 Concluded  
c. Horizontal Temperature Row