AEDC-TSR-80-V60



LEVEL II

# HYPERVELOCITY TRACK TESTS OF THE NASA GALILEO PROBE HEATSHIELD

A. M. Adams
ARO, Inc.

December 1980

Period Covered: October 14, 1980 through November 24, 1980







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

**APPROVAL STATEMENT**

This report has been reviewed and approved.

JOSH L. SCOTT, Capt, USAF
Test Director, VKF Division
Deputy for Operations

Approved for publication:

FOR THE COMMANDER

John M. Rampy, Assistant Deputy
Aerospace Flight Dynamics Testing
Deputy for Operations

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| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>AEDC-TSR-80-V60 | 2. GOVT ACCESSION NO.<br>AD-A101 [illegible] | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>HYPERVELOCITY TRACK TESTS OF THE NASA GALILEO PROBE HEATSHIELD | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final Report, 14 October - 24 November 1980 |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>A. M. Adams, ARO, Inc., a Sverdrup Corporation Company | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Arnold Engineering Development Center<br>Air Force Systems Command<br>Arnold Air Force Station, TN 37389 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>921E07 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>NASA/Ames Research Center<br>Moffett Field, CA 94035 | | 12. REPORT DATE<br>December 1980 |
| | | 13. NUMBER OF PAGES<br>14 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION DOWNGRADING SCHEDULE<br>N/A |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available in Defense Technical Information Center (DTIC)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ablation test
Model recovery
Argon

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

Tests were conducted in a hypervelocity track facility to establish the ablative characteristics of the heatshield material for the NASA/Ames Galileo Probe. Data were obtained from eight shots at launch velocities ranging from 15,850 fps to 17,950 fps. Six of the shots were conducted through an argon environment. The test required the nosetip to be recovered intact. Measurements were made of the model velocity and in-flight surface temperature. A description of the test unit, test article, and test technique is presented herein.

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## NOMENCLATURE

| | |
|---|---|
| B | Bias contribution to uncertainty |
| $P_d$ | Pressure in downrange portion of the range |
| $P_u$ | Pressure in uprange portion of the range |
| 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) at the request of the National Aeronautics and Space Administration (NASA/Ames Research Center) under Program Element 921E07, Control Number 9E07-00-0. The NASA project sponsor was Mr. Chul Park. The NASA project monitor was Mr. Charles DeRose. The results of the test program were obtained by ARO, Inc., AEDC Group (a Sverdrup Corporation Company), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project Number V41G-02.

Eight tests were conducted in the Hypervelocity Track G, von Karman Gas Dynamics Facility (VKF), AEDC, from October 14, 1980 through November 24, 1980. The objective of the test program was to launch and recover the carbon phenolic heatshield model after flight through an argon atmosphere.

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 NASA/ARC, 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 technique, 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 30-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

The model design used for these tests is shown in Fig. 2. The nosetips were fabricated from a carbon phenolic 20° dixie-cup layup material. The model is comprised of an aluminum core, a Lexan® base, a heatshield, and the nosetip.

In addition to bonding with BA2112 epoxy, the nosetip specimens were mechanically anchored to the model body by four carbon-carbon pins placed 90° apart. The four pins were machined flush with the nosetip surface. The purpose of the carbon-carbon pins was to enhance the probability of nosetip recovery.

## 2.3 ARGON ENVIRONMENT

This test required an argon environment at 50 to 300 torr in the uprange section of the range for six of the eight shots. Air contamination of the argon environment was required to be less than 4 percent by volume. In order to provide this environment, the range was evacuated to approximately one torr of air and then filled to the desired pressure with argon. In order to insure the proper argon environment, gas samples were taken prior to each shot.

## 2.4 INSTRUMENTATION

The instrumentation used in this test included ten X-ray stations and six laser stations. These stations provided the necessary in-flight side view pictures, so that the nosetip characteristics could be monitored during flight. At three of the laser stations, oblique views were used to provide better nosetip surface viewpoints. 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 locations used for these tests.

# 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 encountered in the uprange section of the range. In this test the test environment is that of argon. Throughout the flight, characteristics of the nosetip are monitored photographically.

The model then enters the downrange section of the range. The uprange and downrange sections are separated by a quick-acting valve so that a pressure differential can be maintained when desired.

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), "von Karman Gas Gas Dynamics Facility, Vol. 3," Arnold Engineering Development Center, June 1979.

2. Abernathy, R. B. and Thompson, J. W., Jr., "Handbook of Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5, February 1973.

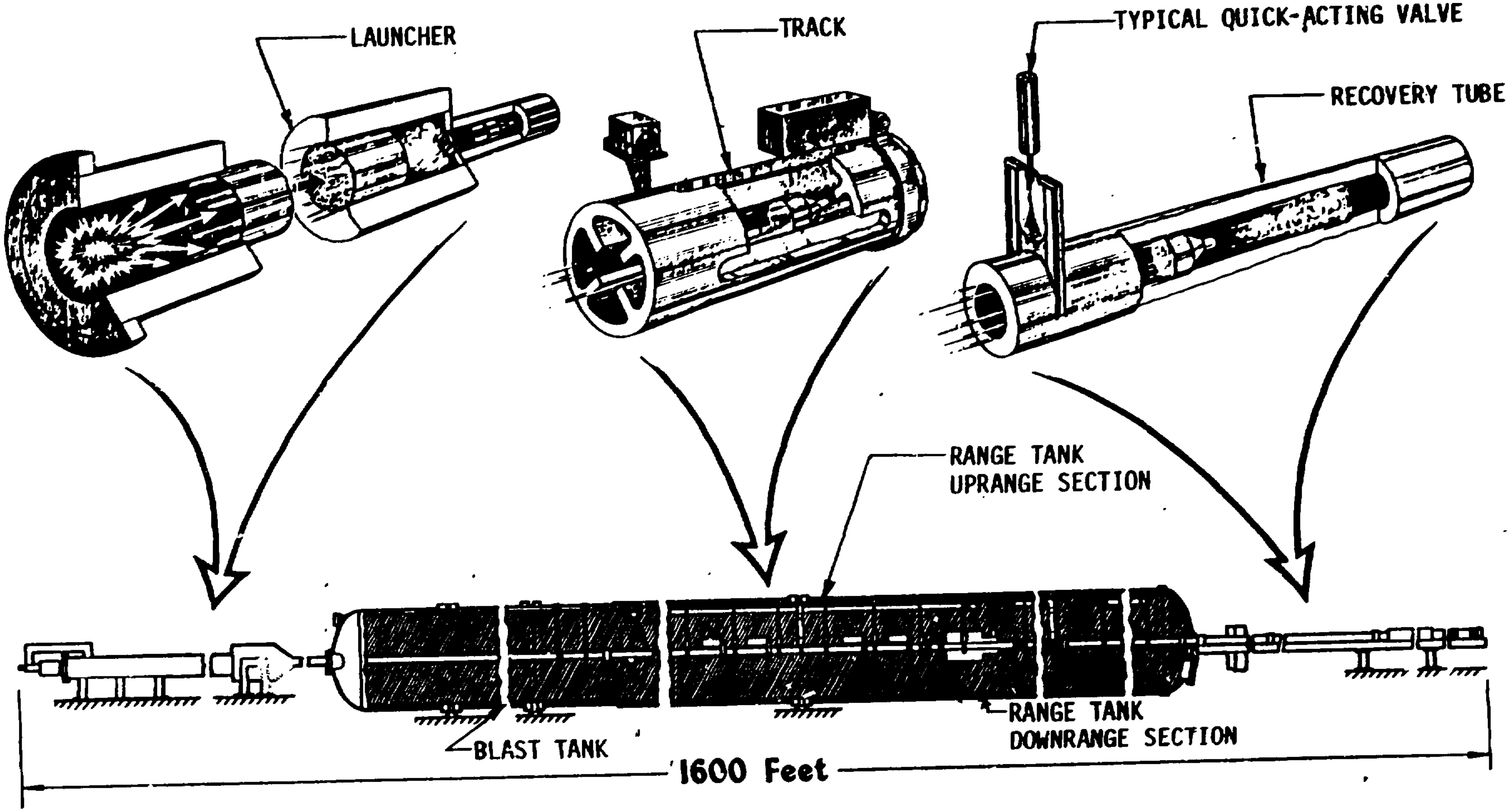


Figure 1. Hypervelocity Track G

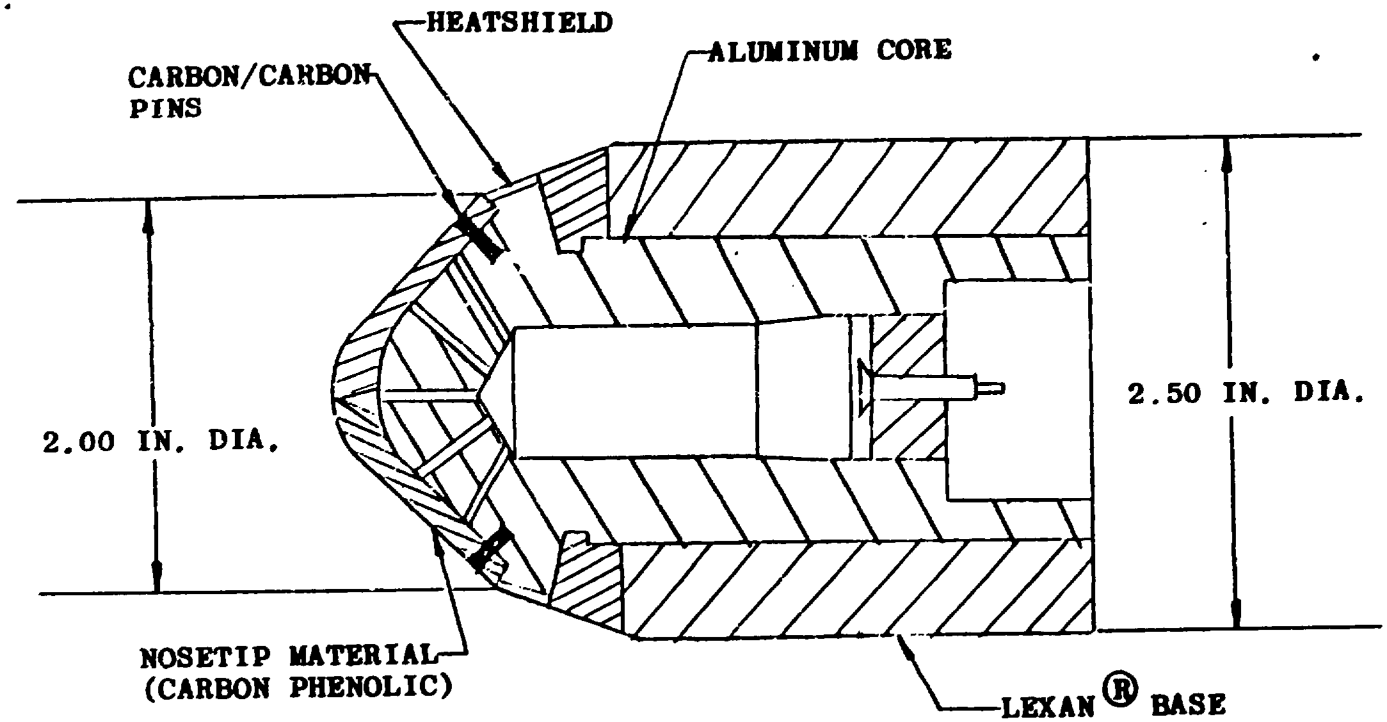


FIGURE 2. MODEL DRAWING

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 |
| | | X-1 | | 2.55 |
| | L-2 | | | 52.86 |
| | | X-2 | | 54.17 |
| | | | IC-4 | 94.63 |
| | | X-7 | | 150.92 |
| | | X-10 | | 220.92 |
| | L-11 | | IC-11 | 232.98 |
| QOV-3 | | | | 305.15 |
| | | X-15 | | 312.67 |
| | | X-18 | | 377.8 |
| | | | IC-20 | 395.3 |
| | L-19 | | | 398.11 |
| | | X-23 | | 472.67 |
| | | X-28 | | 577.80 |
| | | | IC-29 | 591.48 |
| | L-29 | | | 598.11 |
| | | X-34 | | 697.8 |
| | L-35 | | | 721.36 |
| | | X-40 | | 817.80 |
| | 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. | Vi (fps) | Pu (torr) | Pd (torr) | Nosetip Recovery | Remarks |
|---|---|---|---|---|---|---|
| 5457 | 6450 | 15,850 | 104 (AR) | 98 (air) | Yes | |
| 5471 | 6494 | 17,020 | 152 (AR) | 150 (air) | Yes | |
| 5472 | 6495 | 17,950 | 54 (AR) | 49 (air) | No | Failed in recovery |
| 5473 | 6496 | 17,750 | 203 (AR) | 200 (air) | Yes | |
| 5474 | 6497 | 17,450 | 100 (air) | 100 (air) | Yes | |
| 5475 | 6498 | 17,800 | 302 (AR) | 301 (air) | No | Failed in launch |
| 5476 | 6499 | 17,620 | 300 (AR) | 300 (air) | Yes | |
| 5477 | 6500 | 17,820 | 299 (air) | 300 (air) | Yes | |

## Table 3. Uncertainty in Test Parameters

| Parameter Designation | Estimated Measurement: Precision Index (S), Percent of Reading | Precision Index (S), Unit of Measurement | Precision Index (S), Degree of Freedom | Bias (B) (1), Percent of Reading | Bias (B) (1), 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Range Pressure | ± 1 | | 30 | 0 | | ± 2 | | 10 to 300 torr | Precision variable capacitive transducer | Remote null reading meter | Comparison with secondary standard |
| Model Velocity | ± 0.0011 | | 70 | ± 0.0034 | | ± 0.0046 | | 15000 to 19000 fps | Calculated from distance-time data | | |
| Range Temperature | | ± 0.90 | 30 | | ± 0.10 | | ± 1.88 | 50 to 100 deg F | Thermocouple | Multipoint Stripchart servopotentiometer | Comparison with secondary standard |
| Model Weight | | ± 1.0 | | | 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 | | ± 0.0044 | 43 | | ± 0.010 | | ± 0.0188 | 0 to 840 ft | X-Ray shadowgraphs | Photographic film | Range survey |
| Time Intervals | ± 0.0002 | ± 1X $10^{-7}$ | 100 | | 0 | ± 0.0004 | ± 2X $10^{-7}$ | 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 System) | | ± 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=5.5600D 02GRAMS PINF= 1.039 02TORR TINF= 5.3240D 02DEG. R

DRAG COEFF= 8.4630D-01 BASE DIAMETER= 2.5000D 00INS. DELTA TIME=1.0000D-03SEC. FINAL TIME= 7.0000D-02

CONSTANT DRAG COEFF INITIAL VELOCITY= 1.5850D 04

SHOT 5457

| TIME SEC. | DIST FT. | VEL FT./SEC. |
|---|---|---|
| 0.0 | 0.0 | 1.585000 04 |
| 1.000000D-03 | 1.585000 01 | 1.580870 04 |
| 2.000000D-03 | 3.165870 01 | 1.576760 04 |
| 3.000000D-03 | 4.742620 01 | 1.572670 04 |
| 4.000000D-03 | 6.315290 01 | 1.568600 04 |
| 5.000000D-03 | 7.883880 01 | 1.564550 04 |
| 6.000000D-03 | 9.448430 01 | 1.560520 04 |
| 7.000000D-03 | 1.100990 02 | 1.556510 04 |
| 8.000000D-03 | 1.256550 02 | 1.552530 04 |
| 9.000000D-03 | 1.411800 02 | 1.548560 04 |
| 1.000000D-02 | 1.566660 02 | 1.544620 04 |
| 1.100000D-02 | 1.721120 02 | 1.540690 04 |
| 1.200000D-02 | 1.875190 02 | 1.536790 04 |
| 1.300000D-02 | 2.028870 02 | 1.532900 04 |
| 1.400000D-02 | 2.182160 02 | 1.529040 04 |
| 1.500000D-02 | 2.335060 02 | 1.525190 04 |
| 1.600000D-02 | 2.487580 02 | 1.521360 04 |
| 1.700000D-02 | 2.639710 02 | 1.517550 04 |
| 1.800000D-02 | 2.791470 02 | 1.513760 04 |
| 1.900000D-02 | 2.942850 02 | 1.509990 04 |
| 1.970963D-02 | 3.050000 02 | 1.507330 04 |

SECOND LEVEL CONDITIONS: PI= 9.0200D 01

DRAG COEFF = 8.4630D-01 VELOCITY= 1.5073D 04

| TIME SEC. | DIST FT. | VEL FT./SEC. |
|---|---|---|
| 2.070960D-02 | 3.200730 02 | 1.504770 04 |
| 2.170963D-02 | 3.351210 02 | 1.502210 04 |
| 2.270963D-02 | 3.501430 02 | 1.499670 04 |
| 2.370963D-02 | 3.651400 02 | 1.497130 04 |
| 2.470963D-02 | 3.801110 02 | 1.494600 04 |
| 2.570963D-02 | 3.950570 02 | 1.492080 04 |
| 2.670963D-02 | 4.099780 02 | 1.489570 04 |
| 2.770963D-02 | 4.248740 02 | 1.487070 04 |
| 2.870960D-02 | 4.397440 02 | 1.484570 04 |
| 2.970963D-02 | 4.545900 02 | 1.482090 04 |
| 3.070960D-02 | 4.694110 02 | 1.479610 04 |
| 3.170963D-02 | 4.842070 02 | 1.477140 04 |
| 3.270963D-02 | 4.989780 02 | 1.474680 04 |
| 3.370963D-02 | 5.137250 02 | 1.472220 04 |
| 3.470963D-02 | 5.284470 02 | 1.469780 04 |
| 3.570963D-02 | 5.431450 02 | 1.467340 04 |
| 3.670963D-02 | 5.578190 02 | 1.464910 04 |
| 3.770963D-02 | 5.724680 02 | 1.462490 04 |
| 3.870960D-02 | 5.870930 02 | 1.460080 04 |
| 3.970963D-02 | 6.016940 02 | 1.457680 04 |
| 4.070960D-02 | 6.162700 02 | 1.455280 04 |
| 4.170960D-02 | 6.308230 02 | 1.452890 04 |
| 4.270963D-02 | 6.453520 02 | 1.450510 04 |
| 4.370960D-02 | 6.598570 02 | 1.448130 04 |
| 4.470963D-02 | 6.743380 02 | 1.445770 04 |
| 4.570960D-02 | 6.887960 02 | 1.443410 04 |
| 4.670960D-02 | 7.032300 02 | 1.441060 04 |
| 4.770963D-02 | 7.176410 02 | 1.438720 04 |
| 4.870963D-02 | 7.320280 02 | 1.436380 04 |
| 4.970963D-02 | 7.463920 02 | 1.434050 04 |
| 5.070963D-02 | 7.607320 02 | 1.431730 04 |
| 5.170963D-02 | 7.750500 02 | 1.429420 04 |
| 5.270963D-02 | 7.893440 02 | 1.427120 04 |
| 5.370960D-02 | 8.036150 02 | 1.424820 04 |
| 5.470960D-02 | 8.178630 02 | 1.422530 04 |
| 5.570963D-02 | 8.320890 02 | 1.420250 04 |
| 5.670963D-02 | 8.462910 02 | 1.417970 04 |
| 5.770963D-02 | 8.604710 02 | 1.415700 04 |
| 5.870963D-02 | 8.746280 02 | 1.413440 04 |
| 5.970963D-02 | 8.887620 02 | 1.411190 04 |
| 6.070963D-02 | 9.028740 02 | 1.408940 04 |
| 6.170963D-02 | 9.169630 02 | 1.406700 04 |
| 6.270963D-02 | 9.310300 02 | 1.404470 04 |
| 6.370963D-02 | 9.450750 02 | 1.402240 04 |
| 6.470963D-02 | 9.590980 02 | 1.400030 04 |
| 6.570963D-02 | 9.730980 02 | 1.397810 04 |
| 6.670963D-02 | 9.870760 02 | 1.395610 04 |
| 6.770963D-02 | 1.001030 03 | 1.393410 04 |
| 6.870963D-02 | 1.014970 03 | 1.391220 04 |
| 6.970963D-02 | 1.028880 03 | 1.389040 04 |

Table A-1.

Velocity and Position History

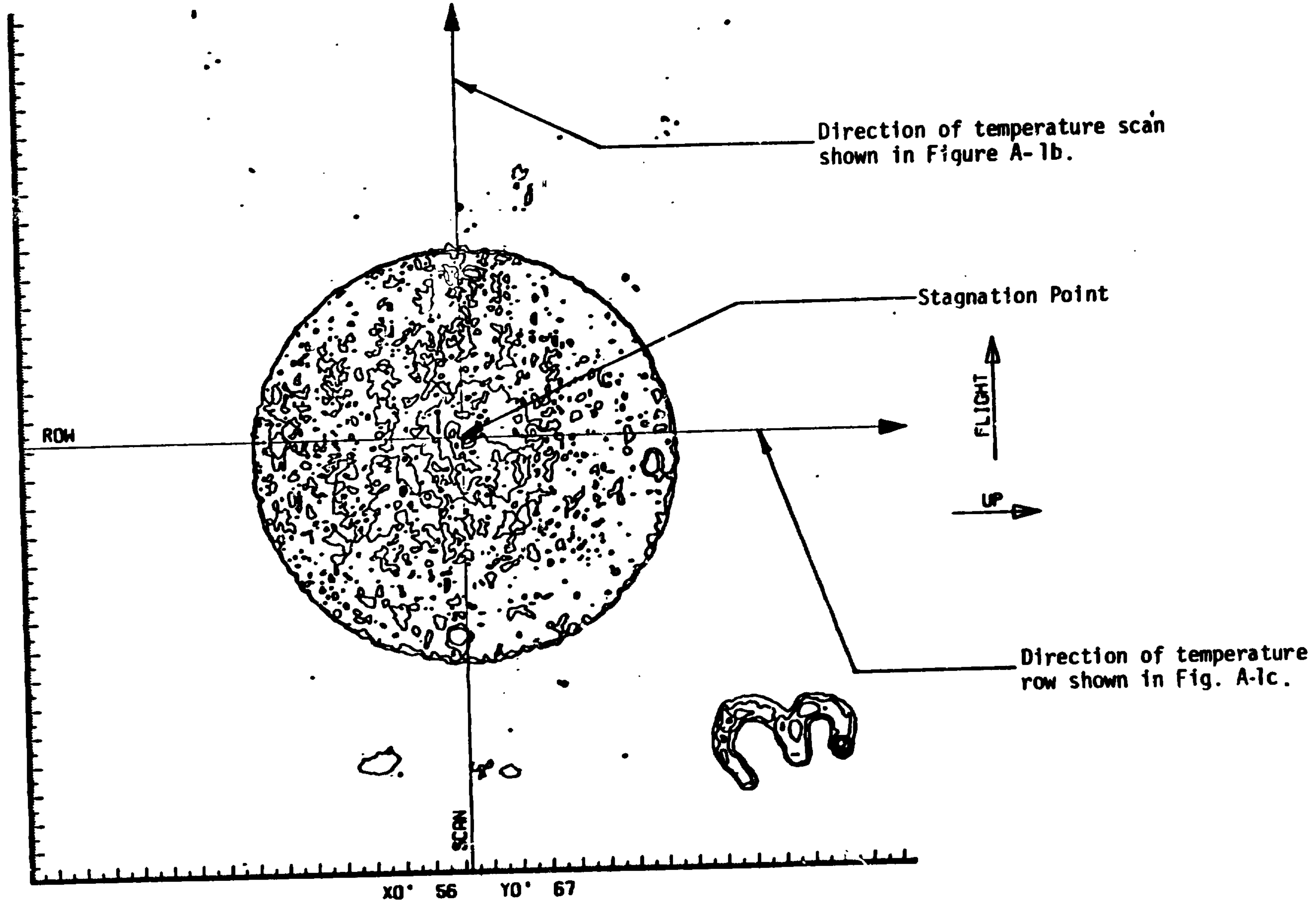


Figure A-1. In-Flight Surface Temperature Data
a. Isothermal contour

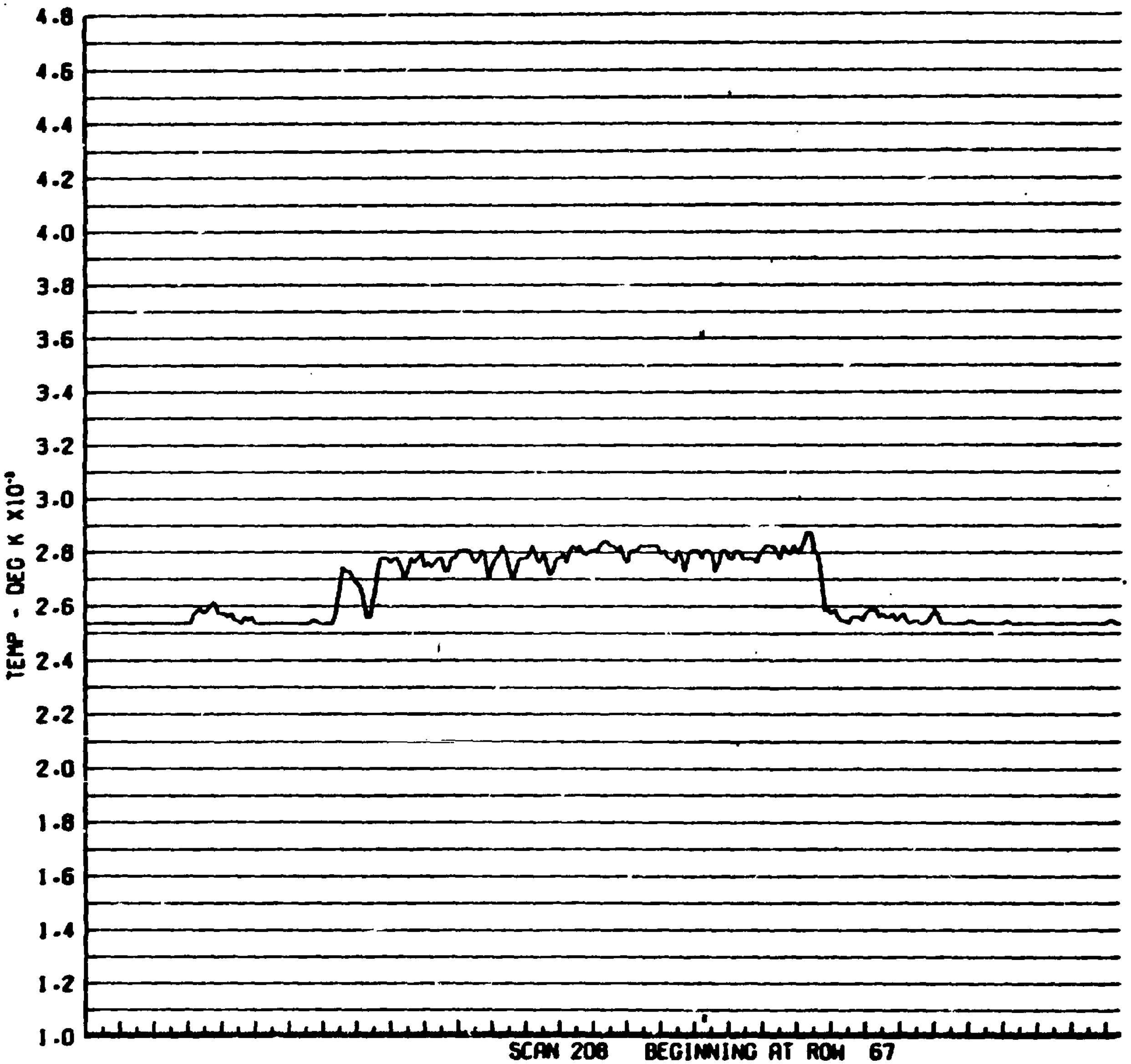


Figure A-1 Continued

b. Vertical temperature scan

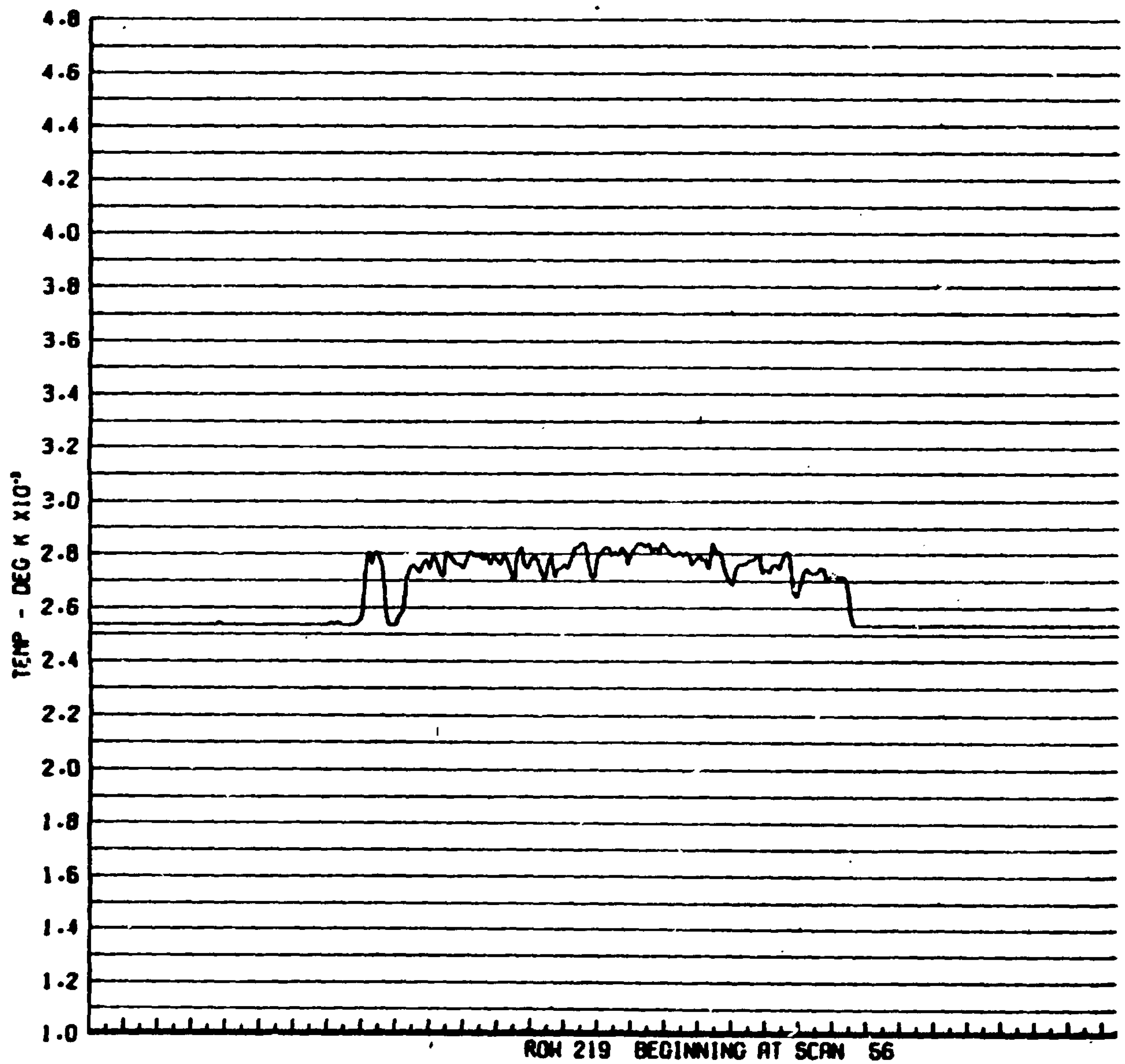


Figure A-1 Continued

c. Horizontal temperature row