WIND TUNNEL TESTS OF SPACE SHUTTLE EXTERNAL TANK INSULATION MATERIAL IN THE AEROTHERMAL TUNNEL AT ELEVATED (1440°F) TOTAL TEMPERATURE

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Calspan Field Services, Inc.

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ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This report has been reviewed and approved.

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Approved for publication:

FOR THE COMMANDER

J M Rampy

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Aerospace Flight Dynamics Test
Deputy for Operations

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

Wind tunnel tests of the Space Shuttle External Tank Foam Insulation were conducted in the von Karman Gas Dynamics Facility Tunnel C. For these tests, Tunnel C was run at Mach 4 with a total temperature of 1440°F and a total pressure which varied from 30-100 psia. Cold wall heating rates were changed by varying the test article support wedge angle and by adding or removing a shock generator or cylindrical protuberance.

CONTENTS

APPENDIXES

NOMENCLATURE

(See AEDC-TSR-82-V31)

1.0 INTRODUCTION

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E02, Control Number 9E02, at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Huntsville, Alabama for the Martin Marietta Corporation (Michoud Operations), New Orleans, Louisiana. The Martin Marietta Corporation project engineer was Mr. S. Copsey and the NASA/MSFC project manager was Mr. L. Foster. 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 performed in the von Karman Gas Dynamics Facility (VKF), Hypersonic Wind Tunnel (C), in two shifts on March 4, 1983 and March 9, 1983 under AEDC Project No. C739VC (Calspan No. V41C-1P). This was the third test entry on this project. The previous tests were reported in AEDC-TSR-82-V31 and this is a continuation (Addendum) to that report.

The objective of this test was to evaluate the response to convective and interference heating of various materials being considered for use on the Space Shuttle external tank thermal protection system. This entry examined specimens produced by using new processing techniques on previously tested types of materials. Some specimens were lighter weight, creating the potential for overall ET-TPS weight reduction. Debris production potential in convective heating environments simulating flight was also monitored by using high-speed movies on six runs.

A total of 95 samples was tested. Data were recorded at Mach number 4 with tunnel stilling chamber pressures of 30-100 psia at a stilling chamber temperature of 1900°R (1440°F). The cold wall heating rates of 0.5 to 20.5 Btu/ft^2-sec were obtained by varying the nominal wedge angle (WA) and by adding or removing a shock generator.

All test data including detailed logs and other information required to use the data have been transmitted to the user and sponsor as described in Table 7. Inquiries to obtain copies of the test data should be directed to NASA/MSFC/ED33, Marshall Space Flight Center, Huntsville, Alabama, 35812.

2.0 APPARATUS

2.1 TEST FACILITY

(See AEDC-TSR-82-V31)

2.2 TEST ARTICLE

(See AEDC-TSR-83-V31)

Many of the material specimens tested during this entry were similar to those tested during previous entries. One additional material, MA-25, was tested via four 12-in. x 20-in. x 0.5-in. specimens. An example of an MA-25 pretest photograph and a sketch of the MA-25 specimens are shown in Fig. 9. For a complete list of material specimens tested during this entry, see Table 8.

2.3 TEST INSTRUMENTATION

(See AEDC-TSR-82-V31)

The camera locations were the same as were used on the previous two entries. In addition, high-speed movies were taken on Runs 45-50 at the rate of 400 fps. All photographic data taken during the test are identified in Table 9.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

A summary of the nominal test conditions is given below:

M	PT,psia	TT,°R	RUNS
4.0	100	1900	1-22
4.0	60	1900	23-52
4.0	30	1900	53-94

A test summary showing the configurations tested and the variables for each is presented in Table 10.

3.2 TEST PROCEDURES

(See AEDC-TSR-82-V31)

3.3 DATA REDUCTION

(See AEDC-TSR-82-V31)

3.4 UNCERTAINTY OF MEASUREMENTS

(See AEDC-TSR-82-V31)

4.0 DATA PACKAGE PRESENTATION

A complete set of all photographic data and tabulated data for this test has been provided to Martin Marietta Corporation. Photographic data which show significant testing results and a complete set of tabulated data have been provided to NASA/Marshall Space Flight Center/ED33, Huntsville, Alabama. All test specimens for this test have been returned to the Martin Marietta Corporation.

A representative posttest photograph is shown in Fig. 10.

Samples of the tabulated data from the materials specimen runs are presented in Appendix III. A copy of all tabulated data has been retained on microfilm in the VKF.

Agreement of the test data to a flat plate solution using the Eckert reference method was good and an example can be seen in Fig. 11. Data repeatability from entry to entry was satisfactory and an example can be seen in Fig. 12.

REFERENCES

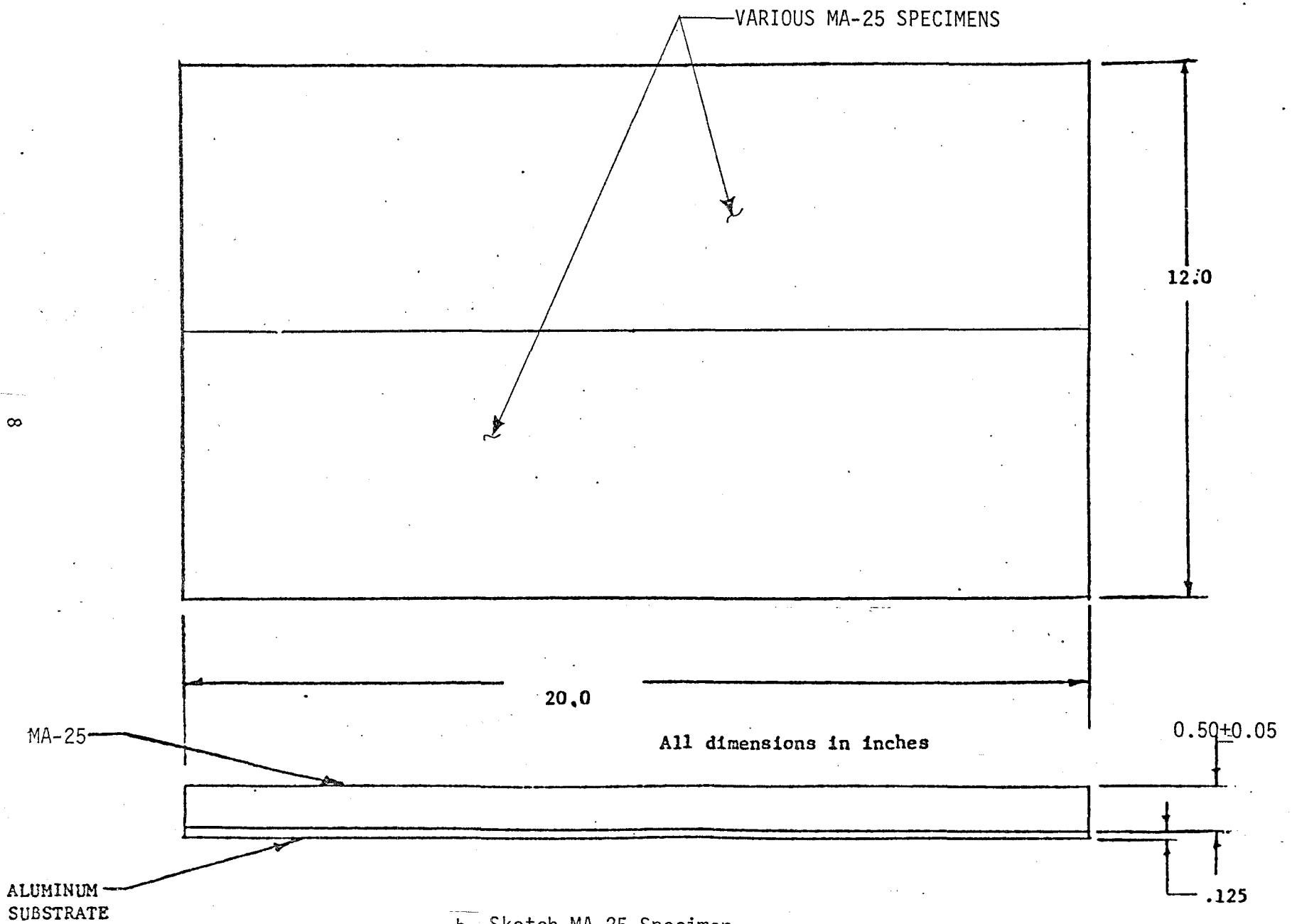
(See AEDC-TSR-82-V31)

APPENDIX I

ILLUSTRATIONS

a. MA-25 Specimen

Figure 9. Specimen Configuration



b. Sketch MA-25 Specimen
Figure 9. Concluded

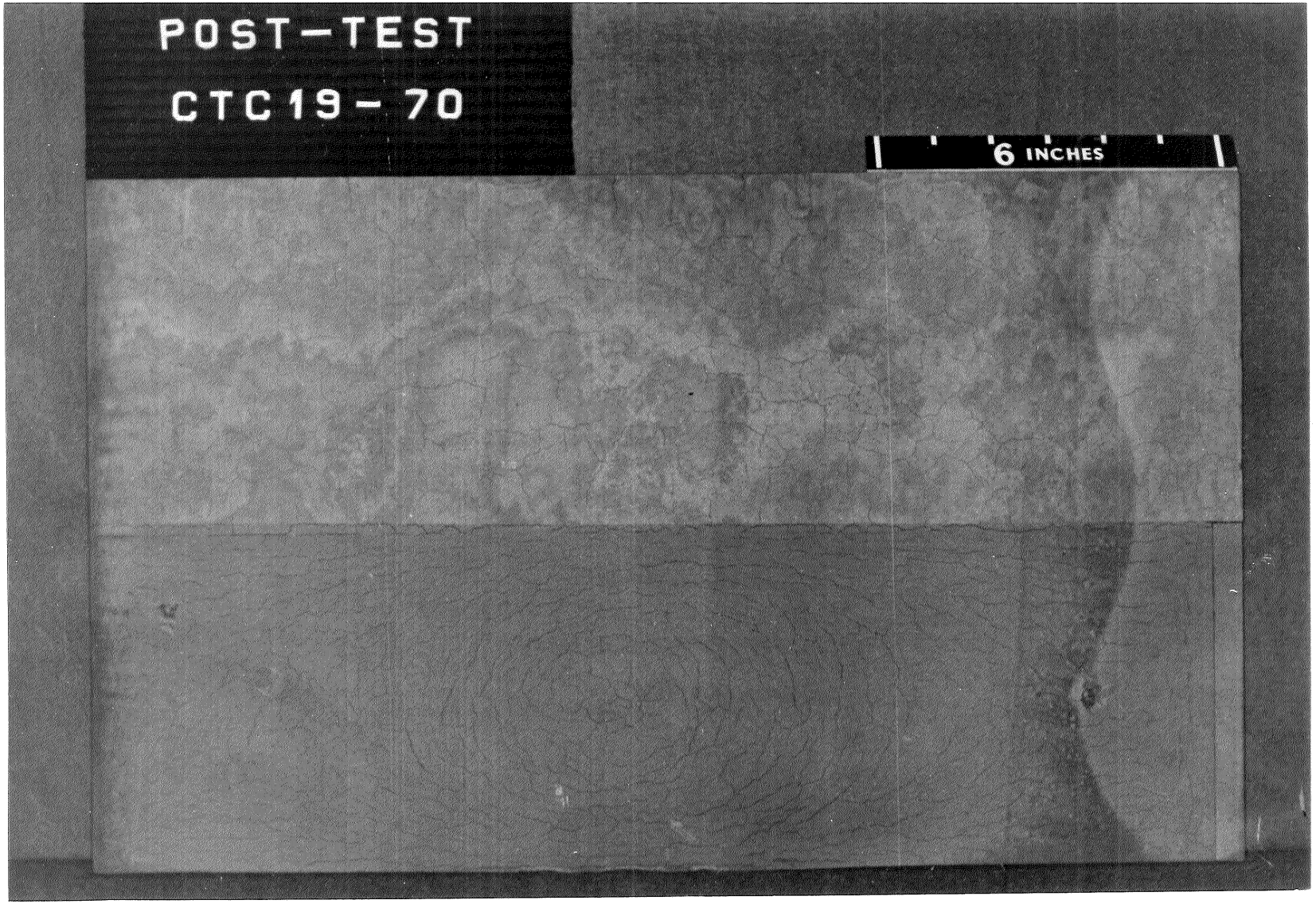


Figure 10. Posttest Photograph

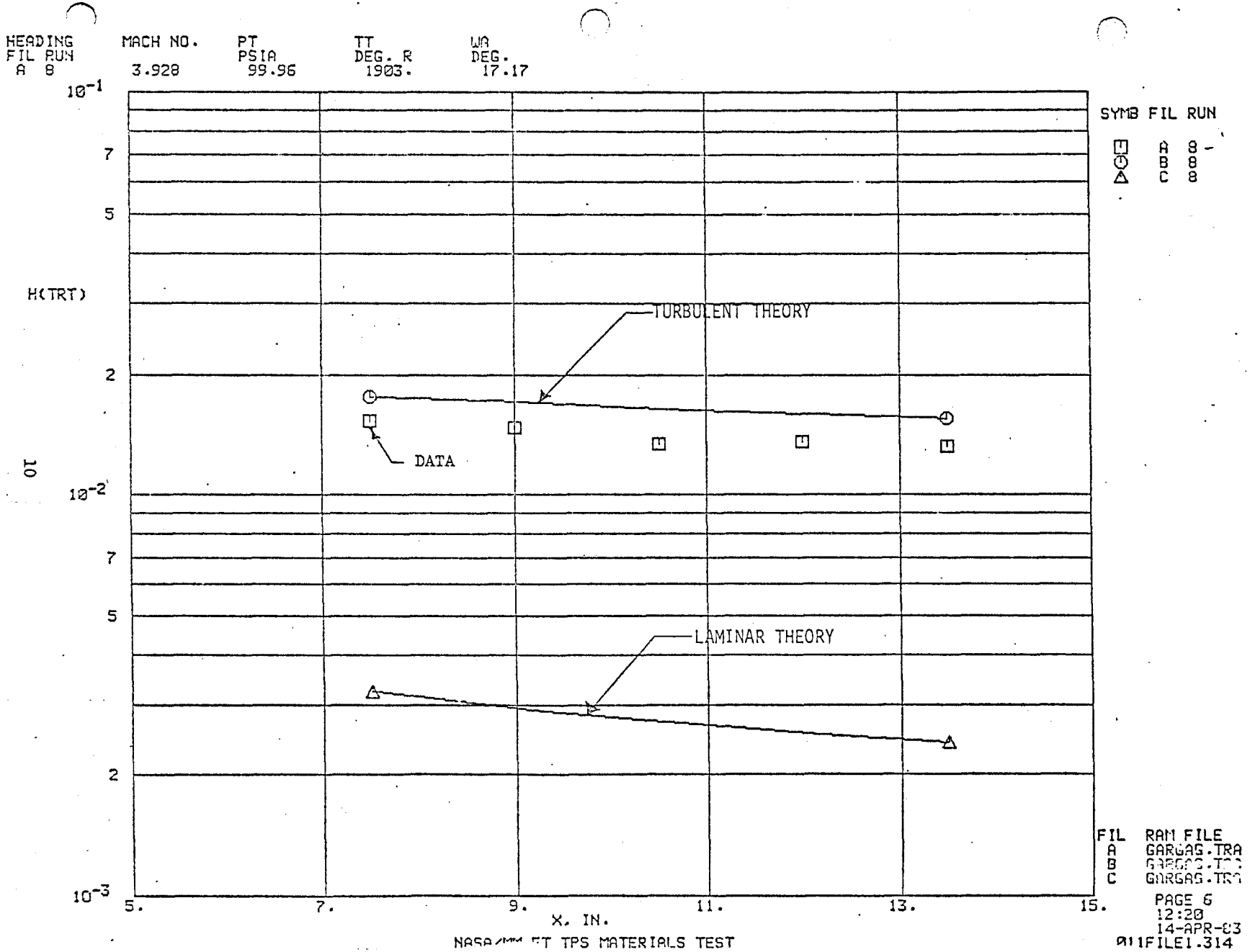
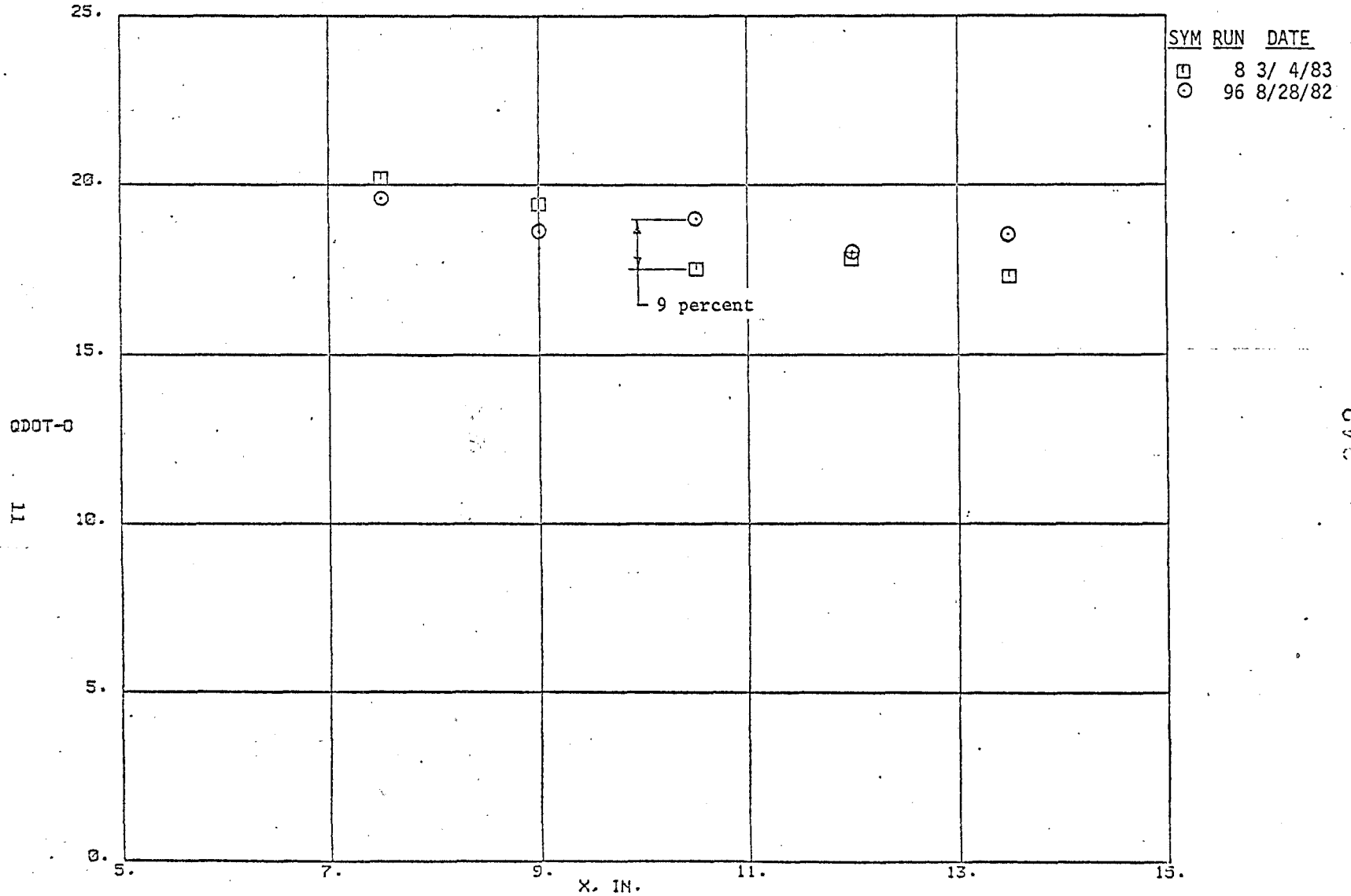


Figure 11. Comparison of Tunnel Data with Analytical Calculation



NASA/MM ET TPS MATERIALS TEST

Figure 12. Data Repeatability

APPENDIX II

TABLES

TABLE 7. Data Transmittal Summary

The following items were transmitted to the User and Sponsor:

	User	Sponsor
	Mr. Steve Copsey Martin-Marietta Michoud Operations P.O. Box 29340 New Orleans, LA 70189	Mr. Lee Foster ED/33 MSFC Marshall Space Flight Center Huntsville, AL 35812
Item	No.of Copies	No. of Copies
Final Data Package Vols. 1 and 2 of 2	3	3
Installation Photos	1 each 8x10 prints	1 each 8x10 prints
Specimen Pretest Photos	1 each 8x10 prints	1 each 8x10 prints
Specimen Posttest Photos	1 each 8x10 prints	1 each 8x10 prints
70 mm Sequence	1 contact print 1 duplicate negative	1 contact print
70 mm Shadowgraph Stills	1 contact print 1 duplicate negative	1 contact print
16 mm Direct Movies	1 work print	1 work print
16 mm Shadowgraph Movies	1 work print 1 duplicate negative	1 work print
Video tape	1 copy	1 copy

TABLE 8. Material Summary

SAMPLE NUMBER	RUN NUMBER	SAMPLE MATERIAL	FIG. NO.
SN-1	92	MA-25	5g
SN-2	94	↓	↓
SN-3	91	NCFI w/MA-25	
SN-25	90	NCFI w/SLA	
SN-51	93	MA-25	
SN-52	95	↓	↓
CTC16-18	76	PDL-4034	5a
19	63	BX 250/PDL/CPR	5c
CTC19- 1	40	NCFI-2265	5a
2	23	↓	↓
3	33		
4	52		
5	64		
6	77		
7	1		
8	6		
9	88	↓	↓
10	90	NCFI-2265 w/Protuberance	5g
11	41	NCFI-2265	5a
12	24	↓	↓
13	34		
14	53		
15	65		
16	78		
17	2		
18	7		
19	42		
20	25		
21	35		
22	54		
23	66		
24	79		
25	3		
26	8		
27	43		
28	26		
29	36		
30	55		
31	67		
32	80		
33	4		
34	9		
35	44		
36	27		
37	37		
38	56		
39	68		
40	81		
41	5		
42	10		
43	89		
44	91	NCFI-2265 w/Protuberance	5g

w/Protuberances

TABLE 8. Concluded

SAMPLE NUMBER	RUN NUMBER	SAMPLE MATERIAL	FIG. NO.
CTC19-45	45	PDL-4034	5a
46	57		
47	69		
48	82		
49	46		
50	83		
51	58		
52	70		
53	47		
54	59		
55	71		
56	84		
57	85		
58	48		
59	72		
60	60		
61	49		
62	86		
63	61		
64	73		
65	50		
66	62		
67	74		
68	87		
69	11	MA-25	9a
70	12		
71	20		
72	21		
73	13	AI-1015	5i
74	14		
75	28	E.A.	
76	32		
77	16		
78	29	SEA.	
79	38		
80	17		
81	30	50% RED. SEA.	
82	39		
83	18		
84	31	E.A.	
85	22		
86	19		
87	15	SLA 0126	
88	51	CPR-488	5a
89	75		

TABLE 9. Photographic Data Summary

	Camera Type	Frame Rate	Camera Location	Sample View	Film Roll No.	RUN No.
Camera 1	Varitron 70 mm still	1 per 25 sec to 1 per 4 sec	Top upstream window	Top of specimen on centerline with projected grid lines	0950 0952 0954 0925 0927 0929	1-19 20-40 41-44 45-67 68-89 90-95
Camera 2	DBM-55 16 mm movie	24 fps	Top upstream window	Top of specimen on centerline with protected grid lines	04555 04556 04557 04558 04559 04565 04566 04567 04568 04569 04570 04571 04572 04573 04574 04575 04576	1-9 10-20 21-29 30-39 40-44 *45 *46 *47 *48 *49 *50 51-58 59-67 68-77 78-84 85-92 93-95
Camera 3	Varitron 70 mm still	1 per 2 sec to 1 per 4 sec	Operating side upstream window	Left side view of forward portion of specimen on centerline	0951 0953 0955 0926 0928 0930	1-19 20-40 41-44 45-67 68-89 90-95

* Frame Rate 400 fps

TABLE 9. Concluded

	Camera Type	Frame Rate	Camera Location	Sample View	Film Roll No.	RUN No.
Camera 4	DBM-55 16 mm	24 fps	Operating side upstream window	Left side view of forward portion of specimen on centerline	04560 04561 04562 04563 04564 04577 04578 04579 04580 04581 04582 04583 04584 04585 04586 04587 04588	1-9 10-20 21-29 30-39 40-44 *45 *46 *47 *48 *49 *50 51-58 59-67 68-77 78-84 85-92 93-95
Camera 5	Varitron 70 mm shadowgraph stills	1 per 15 sec to 1 per RUN	Upstream window	NA	0948 0923	1-44 45-95
Camera 6	Varitron 70 mm shadowgraph stills	1 per 15 sec to 1 per RUN	Downstream window	NA	0949 0924	1-44 45-95
Camera 1A	Video tape	NA	Top upstream window	Top of specimen on centerline	NA	1-95

* Frame Rate 400 fps

TABLE 10. Run Summary

RUN	SAMPLE NO.	PROTUB. NUMBER	PT psia	TT °R	WA deg	SGA deg	TIME EXPT.
1	CTC19- 7	None	100	1900	9.0	None	44.4
2	17						45.3
3	25						45.0
4	33						46.7
5	41				9.0		45.6
6	8				17.2		41.4
7	18						41.3
8	26						41.5
9	34						41.4
10	42					None	41.4
11	69					5	61.3
12	70						61.3
13	73						61.3
14	74						61.3
15	87						61.4
16	77						27.2
17	80						20.7
18	83						28.5
19	86					5	24.2
20	71					10	62.2
21	72					10	62.0
22	85		100		17.2	5	26.7
23	2		60		9.0		42.6
24	12						47.1
25	20						47.0
26	28				9.0		46.7
27	36				9.1		46.0
28	75						63.0
29	78						61.7
30	81						62.2
31	84						62.6
32	76				9.1		61.7
33	3				17.2		33.0
34	13						41.4
35	21						41.1
36	29						41.5
37	37						41.4
38	79						47.1
39	82				17.2	5	55.7
40	1				10.1	None	63.0
41	11				10.0		61.2
42	19						61.2
43	27						61.5
44	35						62.2
45	45						42.4
46	49						41.0
47	53						41.4
48	58						41.2

TABLE 10. Concluded

RUN	SAMPLE NO.	PROTUB. NUMBER	PT psia	TT °R	WA deg	SGA deg	TIME EXPT.
49	CTC19-61	None	60	1900	10.0	None	40.9
50	65						41.3
51	88		60		10.0	None	46.2
52	4		30		1.0	5	61.3
53	14						61.6
54	22						60.9
55	30						61.2
56	38						61.0
57	46						47.1
58	51						46.0
59	54						46.1
60	60						46.2
61	63						46.2
62	66						46.2
63	CTC16-19				1.0		47.6
64	CTC19- 5				8.9		47.4
65	15						47.2
66	23						46.6
67	31						47.2
68	39						47.2
69	47						31.0
70	52						31.2
71	55						31.3
72	59						31.0
73	64						31.3
74	67						31.2
75	89						31.1
76	CTC16-18					5	31.4
77	CTC19- 6				8.9	None	61.9
78	16				9.0		61.5
79	24						61.4
80	32						61.0
81	40						61.6
82	48						61.9
83	50						61.0
84	56						61.2
85	57						61.3
86	62						61.1
87	68				9.0		61.4
88	9				1.0		60.7
89	43	None					61.4
90	10	SN-25					20.8
91	44	SN-3					16.1
92	PLATE	SN-1					61.5
93	PLATE	SN-51			1.0		60.7
94	PLATE	SN-2			9.0		61.7
95	PLATE	SN-52	30	1900	9.0	None	61.6

APPENDIX III

SAMPLE TABULATED AND PLOTTED DATA

ARVIN/CALSPAN FIELD SERVICES, INC.
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/MM ET TPS MATERIALS TEST
PAGE 2

DATE COMPUTED 4-MAR-8
TIME COMPUTED 12:42:4
DATE RECORDED 4-MAR-8
TIME RECORDED 12:43:
PROJECT NUMBER V--C-1

RUN	SAMPLE	PROTUB	TIMEINJ SEC	TIMECL HOUR MIN SEC MSEC	TIMEEXPT SEC	SGA DEG	WA DEG
1	CTC19- 7	NONE	2.641	12 43 7 853	44.38	NONE	9.020

M	PT PSIA	TT DEG R	T DEG R	P PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	I(TT) BTU/LBM
3.93	99.66	1899.7	487.8	6.812E-01	4252.92	3.769E-03	3.563E-07	1.398E+06	4.782E+02

WEDGE GARDON GAGE DATA

GAGE	X (IN)	Y (IN)	TGE (DEG R)	TW (DEG R)	QDOT (BTU/FT2-SEC)	H(TT) (BTU/FT2-SEC-R)	QDOT-Q (BTU/FT2-SEC)
1	7.50	0.00	535.8	605.2	1.225E+01	9.462E-03	1.362E+01
2	9.00	0.00	532.5	578.1	1.177E+01	8.905E-03	1.282E+01
3	10.50	0.00	526.6	590.9	1.052E+01	8.036E-03	1.157E+01
4	12.00	0.00	526.6	591.6	1.036E+01	7.920E-03	1.140E+01
5	13.50	4.50	532.4	583.9	1.057E+01	8.031E-03	1.156E+01
6	13.50	3.10	532.1	599.0	1.031E+01	7.923E-03	1.141E+01
7	13.50	1.75	531.6	572.6	1.006E+01	7.579E-03	1.091E+01
8	13.50	0.00	532.8	591.6	1.061E+01	8.112E-03	1.168E+01
9	13.50	-1.75	532.8	570.0	1.005E+01	7.561E-03	1.088E+01
10	13.50	-3.10	531.4	580.1	1.000E+01	7.579E-03	1.091E+01
11	13.50	-4.50	533.1	595.2	9.982E+00	7.652E-03	1.102E+01

Gardon Gage Data

Sample 3. Heat Transfer Data

RUN 1

DATE 4-MAR-83
TIME COMPLETED 12:42:43
DATE RECORDED 4-MAR-83
TIME RECORDED 12:43: 1
PROJECT NUMBER V--C-1P

RUN	SAMPLE	PROTUB	TIMEINJ SEC	TIMECL HOUR MIN SEC MSEC	TIMEEXPT SEC	SGA DEG	WA DEG
1	CTC19- 7	NONE	2.641	12 43 7 853	44.38	NONE	9.020

M	PT PSIA	TT DEG R	T DEG R	P PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	I(TT) BTU/LBM
3.93	99.66	1899.7	487.8	6.812E-01	4252.92	3.769E-03	3.563E-07	1.398E+06	4.782E+02

CAMERA	PIC NO.	TIME SEC	TIMEEXP SEC	
TOP	1	0.19		
OS	1	0.19		
TOP	2	3.70	2.22	
OS	2	3.70	2.22	
SHG	1	4.86	3.38	
TOP	3	7.43	5.95	
OS	3	7.43	5.95	
TOP	4	11.16	9.68	
OS	4	11.16	9.68	
TOP	5	14.91	13.43	
OS	5	14.91	13.43	
TOP	6	18.66	17.18	
OS	6	18.66	17.18	
TOP	7	22.43	20.94	
OS	7	22.43	20.94	
TOP	8	26.19	24.71	
OS	8	26.20	24.72	
TOP	9	29.96	28.48	
OS	9	29.96	28.48	
TOP	10	33.73	32.25	
OS	10	33.73	32.25	
TOP	11	37.50	36.01	
OS	11	37.50	36.01	
TOP	12	41.27	39.78	
OS	12	41.27	39.78	
TOP	13	45.02	43.54	
OS	13	45.02	43.54	
			44.38	MODEL HAS LEFT CENTERLINE

Sample 4. Photographic Data

RUN 1