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AIRESEARCH MANUFACTURING COMPANY

Los Angeles, California

HYPERSONIC RESEARCH ENGINE PROJECT - PHASE II
AEROTHERMODYNAMIC INTEGRATION MODEL
TEST PLAN

DATA ITEM NO. 2-2.01
NASA CONTRACT NO. NAS1-6666

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353

AIRESEARCH MANUFACTURING COMPANY

Los Angeles, California

HYPERSONIC RESEARCH ENGINE PROJECT - PHASE II
AEROTHERMODYNAMIC INTEGRATION MODEL
TEST PLAN
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AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
LOS ANGELES, CALIFORNIA

DOCUMENT CHANGE NOTICE

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DISPOSITION INSTRUCTION

☐ ERRATA SHEET (PARTIAL DOCUMENT). { ☐ FILE OPPOSITE PAGE AFFECTED. ☐ FILE AFTER TITLE PAGE. }
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DESCRIPTION OF CHANGE(S)

1. Revised title page to reflect latest revision.

2. Revised following pages in Appendix A.

A-39, A-49, A-51, A-54, A-55,
A-57 (is now A-57a and A-57b)
A-59, A-62, A-66, A-68, A-75, A-76, A-79, A-83, A-86, A-93, A-97, A-98, A-99
A-100 (is now A-100a and A-100b)
A-101, A-103, A-104
A-105 (is now A-105a and A-105b)
A-106, A-107, A-108
A-112
A-113, A-114
A-115 (is now A-115a and A-115b)

RED BY / DATE	CHECKED BY / DATE	APPROVED BY / DATE	CONFIG. CONTROL / DATE
Jilly 8-15-72	Y. H. Sun	YHS for Ed Harris	

FOREWORD

This test plan is submitted to the NASA Langley Research Center by the AiResearch Manufacturing Company of Los Angeles, California. The document was prepared in accordance with the guidelines established by paragraph 5.2.1.4.3.1 of NASA Statement of Work L-4947-B (Revised). It should be noted that the measurement plan for the Aerothermodynamic Integration Model test effort, which is to be carried out at the Plum Brook test facility of the NASA Lewis Research Center, was previously released on 9 June 1970 and identified as Data Item 2-1.01, AiResearch Document AP-70-6216.

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

TABLES

1. INTRODUCTION

This report defines the conditions and procedures for testing the Aerothermodynamic Integration Model (AIM) under NASA contract number NAS1-6666. The AIM is a wind tunnel model simulating an axisymmetric, dual-mode supersonic combustion ramjet. A layout drawing is given in Figure 1-1. The inlet cowl lip diameter is 18 in. The spike tip and cowl leading edge are zirconium copper. The remainder of the exposed surfaces are Nickel 200. All exposed surfaces are water cooled.

The AIM consists of the following major components and systems.

(a) Translating spike inlet

(b) Inlet spike hydraulic actuation and control system

(c) Dual mode combustor

(d) Gaseous hydrogen fuel system

(e) Exhaust nozzle

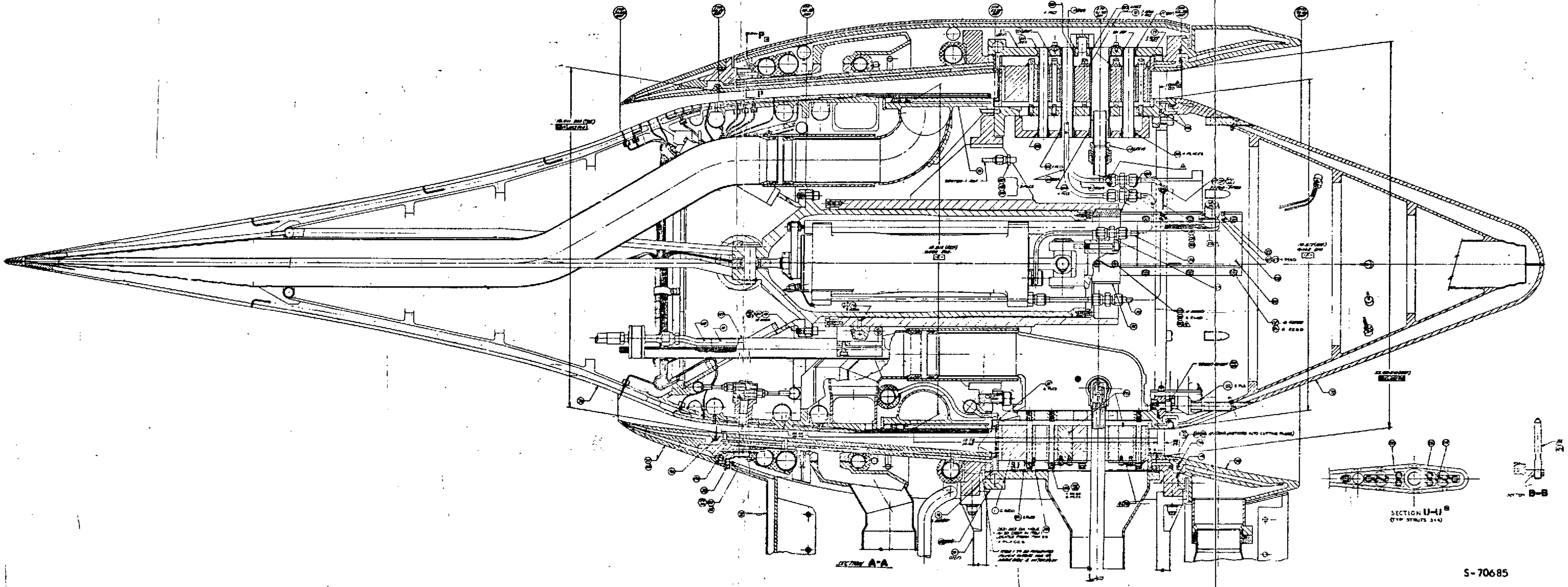
(f) Ignitor system

(g) Water cooling system

A water-cooled airflow meter replacing the AIM exhaust nozzle is supplied for calibrating the engine throughflow during wind tunnel operation. Flow is metered using a sonic nozzle with measured inlet conditions. A water-cooled combustor exit survey probe measuring gas properties, flow direction, and composition will be installed for some tests.

The AIM is designed for operation for Mach 4 through 6 in the subsonic combustion mode, and Mach 6 through 8 in the supersonic combustion mode. Ignition is obtained at low Mach numbers with oxygen/hydrogen torch-type ignitors. Transition to the supersonic combustion mode is achieved by switching fuel to alternate fuel injection locations.

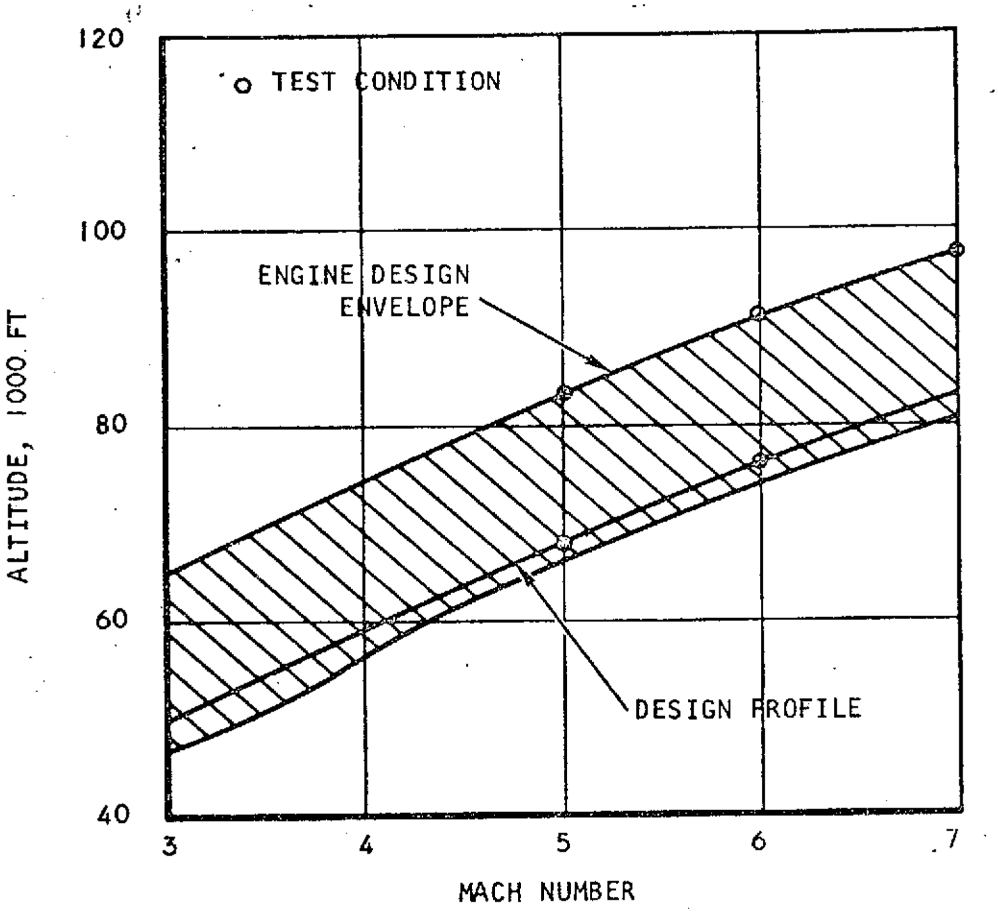
The AIM will be tested in the Hypersonic Tunnel Facility (HTF) at the NASA Lewis Research Center Plum Brook Station, Sandusky, Ohio. The test conditions are shown in the following plot.



S-70685

Figure 1-1. AIM Layout Drawing

AIM TEST CONDITIONS



S-72981

Tunnel flow conditions will vary between 206 psia, 2200°R at Mach 5, and 1000 psia, 3800°R at Mach 7.

The hot tunnel flow is synthesized using a mixture of nitrogen and oxygen. The nitrogen is supplied from a blowdown system through a carbon mass-storage heater. Unheated oxygen is mixed with the hot nitrogen just upstream of the wind tunnel nozzle. The run duration is limited to a maximum of approximately 2 to 3 min (depending on test conditions) due to facility constraints.

The AIM is controlled during testing by an automatic tape control system. The desired fuel flow rates, spike positions, and ignitor conditions to be run are programmed on tape before the test. The system controls the magnitude and duration of each setting so that a maximum amount of useful data is taken.

The AIM is fueled with gaseous hydrogen heated to 1460°R in an electrically powered facility heater. The model is equipped with eight fuel manifolds and injector nozzle banks--four in the innerbody and four in the outerbody. Fuel is delivered to any combination of two innerbody and three outerbody manifolds during a given run, through five sets of facility-mounted control valves and metering venturis.

The AIM is instrumented with 244 pressure taps and 102 thermocouples measuring wall pressures, skin temperatures, coolant temperature rise and pressure drop, and fuel injection conditions. Thrust, fuel flow to each set of fuel injectors, coolant flow, and spike position are also measured. Measurements taken from AIM instrumentation during any given run are limited to 152 pressures and 160 temperatures because of the limited data acquisition system capacity. The accuracy of instrumentation and component and cycle performance measurements is discussed in Reference 1. The effect of the nitrogen system which purges the outerbody cavities on the thrust measurement accuracy is discussed in Reference 2.

The test facility interface requirements for the AIM are described in Reference 2. The report defines the allowable loads, controls, fluid requirements, instrumentation and accuracy requirements, handling equipment, operational requirements and safety requirements.

2. OBJECTIVES

The objectives of the test, in compliance with Reference 3, are as follows.

(a) Provide a suitable measurement of the AIM internal performance.

(b) Determine the aerothermodynamic component interaction effects.

3. TEST SETUP

The test facility interface requirements are defined in Reference 1. The report defines the allowable loads, controls, fluids requirements handling equipment, operational requirements, and safety requirements.

4. INSTRUMENTATION

A listing of all AIM instrumentation is given in Table 4-I. This table includes the location and ranges of the measurements, and the identification tag numbers on the instrumentation leadouts. This supersedes the list given in References I and 2 and was current at the time of shipment of the AIM to the facility.

Because of the limitation in the number of data channels available, some of the instrumentation will not be connected for each test. A record code number defining the instrumentation to be connected is given in Table 4-I. The use of this code and the definition of the connected instrumentation for each test is given in Section 8. Also to be used in conjunction with Table 4-I is Figure 4-I, showing the locations of the cooling system ΔT thermocouples listed in Table 4-I.

A summary of the instrumentation measurements taken on each AIM component for each run type is given in Table 4-2. The locations of wall pressure and temperature measurements are plotted in Figures 4-2 to 4-7. These will be useful for identifying the instrumentation connected for each test and interpreting test results.

The instrumentation accuracy requirements and the effects of measurement inaccuracy upon the test results is discussed in Reference I.

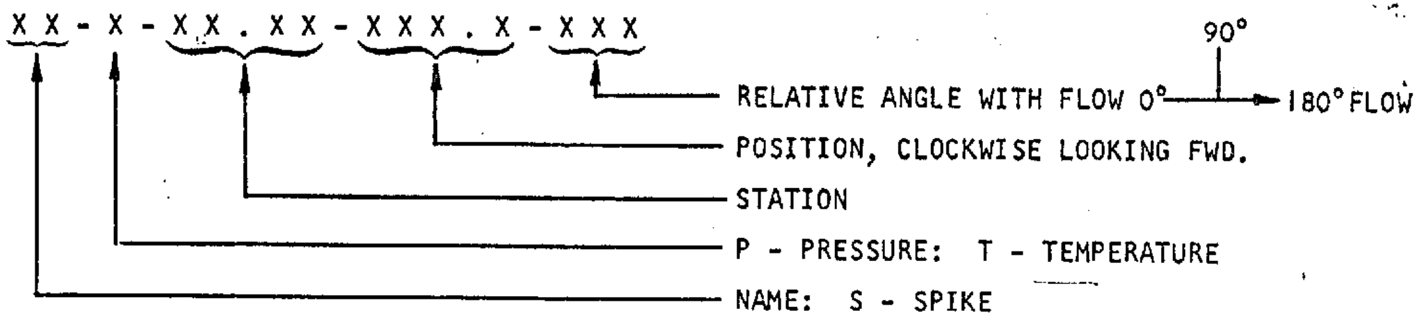
A series of calibration tests will be run prior to wind tunnel testing. The instrumentation requirements for these tests are given in Section 6. . .

TABLE 4-I

AIM INSTRUMENTATION

CODE FOR TABLES 4-IA THROUGH 4-IG

*DESCRIPTION



S - SPIKE
I - INNERBODY
NP - NOZZLE PLUG
C - COWL L. E.
CO - COWL L. E. - OUTSIDE
O - OUTER SHELL
N - NOZZLE SHROUD
NO - NOZZLE SHROUD - OUTSIDE

NOTES:

1. Pressure X/Y

   X - Transducer for low pressure run
   Y - Transducer for high pressure run

2. Scheduled use - numbers refer to presentation order on scope.

**T/C TYPE

CA = Chromel Alumel; CuC = Copper Constantan; PR = Platinum Platinum-Rhodium

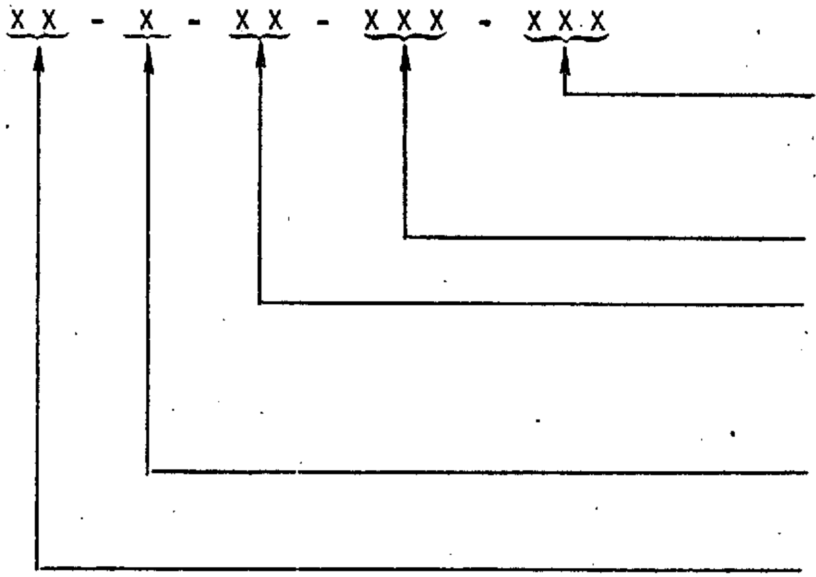
***RECORD CODE NUMBER

1. See Section 8.2 for Record Code definition.
2. "X" indicates connection to DAS.
3. Underline indicates visual readout in control room and connection to DAS.
4. Number indicates oscilloscope channel number.

TABLE 4-1 (Continued)

CODE FOR TABLE 4-1H

*DESCRIPTION



XX - X - XX - XXX - XXX

STATIC PORT LOCATION: CLOCKWISE LOOKING FWD. WITH RESPECT TO PROBE LOCATION ℄. (0 DEGREES IS ON SIDE OPPOSITE ENGINE ℄).

PROBE LOCATION: CLOCKWISE LOOKING FWD.

TYPE MEASUREMENT:
GS - GAS SAMPLE
TT - TOTAL TEMPERATURE
PT - TOTAL PRESSURE
PS - STATIC PRESSURE

TYPE PROBE:
G - GAS SAMPLE
P - PRESSURE

NAME: CE - COMBUSTOR EXIT PLANE

**T/C TYPE

CA = Chromel Alumel; CuC = Copper Constantan; PR = Platinum Platinum-Rhodium

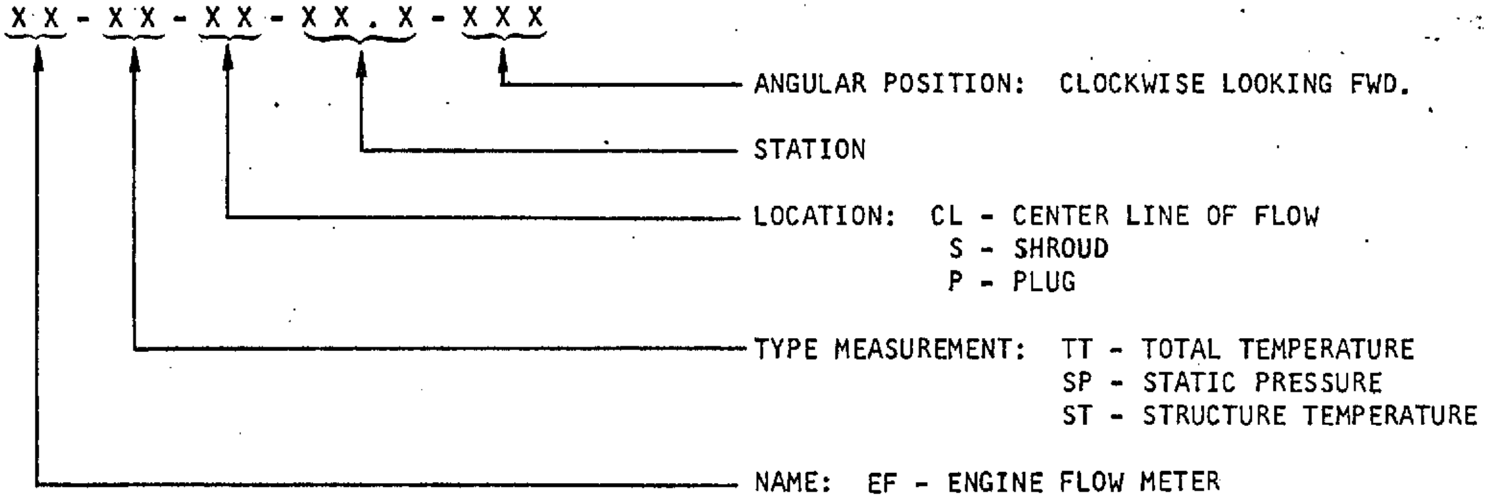
***RECORD CODE NUMBER

1. See Section 8.2 for Record Code definition.
2. "X" indicates connection to DAS.
3. Underline indicates visual readout in control room and connection to DAS.
4. Number indicates oscilloscope channel number.

TABLE 4-I (Continued)

CODE FOR TABLE 4-II

*DESCRIPTION



XX-XX-XX-XX.X-XXX

ANGULAR POSITION: CLOCKWISE LOOKING FWD.

STATION

LOCATION: CL - CENTER LINE OF FLOW
S - SHROUD
P - PLUG

TYPE MEASUREMENT: TT - TOTAL TEMPERATURE
SP - STATIC PRESSURE
ST - STRUCTURE TEMPERATURE

NAME: EF - ENGINE FLOW METER

**T/C TYPE

CA = Chromel Alumel; CuC = Copper Constantan; PR = Platinum Platinum-Rhodium

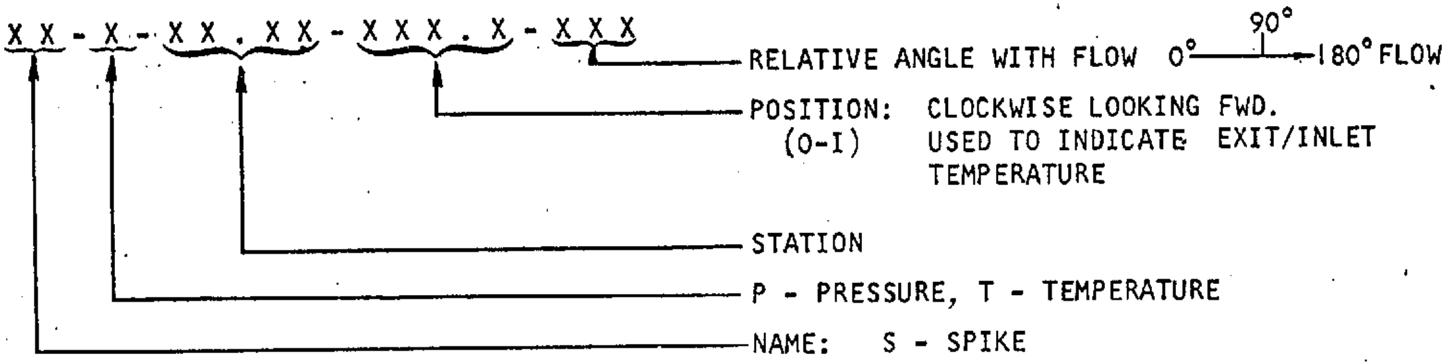
***RECORD CODE NUMBER

1. See Section 8.2 for Record Code definition.
2. "X" indicates connection to DAS.
3. Underline indicates visual readout in control room and connection to DAS.
4. Number indicates oscilloscope channel number.

TABLE 4-I (Continued)

CODE FOR TABLE 4-IK

*DESCRIPTION



NAME:
S - SPIKE
I - INNERBODY
NP - NOZZLE PLUG
C - COWL L. E.
CO - COWL L. E. - OUTSIDE
O - OUTER SHELL
N - NOZZLE SHROUD
NO - NOZZLE SHROUD - OUTSIDE
OCB - OUTER COWL BODY
ST - STRUT
HYD - HYDRAULIC

NOTES:

1. Pressure X/Y
   X - Transducer for low pressure run
   Y - Transducer for high pressure run
2. Scheduled use - numbers refer to presentation order on scope

**T/C TYPE

CA = Chromel Alumel; CuC = Copper Constantan; PR = Platinum Platinum-Rhodium

***RECORD CODE NUMBER

1. See Section 8.2 for Record Code definition.
2. "X" indicates connection to DAS.
3. Underline indicates visual readout in control room and connection to DAS.
4. Number indicates oscilloscope channel number.
5. "O" indicates visual readout in control room.

TABLE 4-1A

AIM INSTRUMENTATION
SPIKE

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-S	S-P-0.60-0-0	101	3		25	25	25	25	15	X	X	X	X	
2-S	S-P-14.4-0-90	102	3		10	10	10	10	10	│	│	│	│	
3-S	S-P-14.4-271-90	103	3		↓	↓	↓	↓	↓	│	│	│	│	
4-S	S-P-14.4-180-90	104	3		↓	↓	↓	↓	↓	│	│	│	│	
6-S	S-P-30.6-0-90	106	3		↓	↓	↓	↓	↓	│	│	│	│	
7-S	S-P-35.0-0-90	107	3		↓	↓	↓	↓	↓	│	│	│	│	
8-S	S-P-35.0-270-90	108	3		↓	↓	↓	↓	↓	X	X	X	X	
9-S	S-P-35.0-180-90	109	3		15/25 →	→	→	→	10/20	1	1	1	1	
10-S	S-P-35.0-89-90	110	3		10	10	10	10	10	2	2	2	2	
11-S	S-P-35.5-0-90	111	3		↓	↓	↓	↓	↓	3	3	3	3	
12-S	S-P-36.0-0-90	112	3		↓	↓	↓	↓	↓	4	4	4	4	
13-S	S-P-36.5-0-90	113	3		↓	↓	↓	↓	↓	5	5	5	5	
14-S	S-P-36.5-269-90	114	3		↓	↓	↓	↓	↓	6	6	6	6	
15-S	S-P-36.5-180-90	115	3		15/25 →	→	→	→	10/20	7	7	7	7	
16-S	S-P-36.5-89-90	116	3		10	10	10	10	10	8	8	8	8	
17-S	S-P-37.0-0-90	117	3		10/15	10/15	10/15	10/15	10	X	X	X	X	

TABLE 4-IA (Continued)

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
20-S	S-P-38.0-269-90	120	3		10/15	10/15	10/15	10/15	10		X	9	9	
24-S	S-P-39.0-0-90	124	4		15/25	15/25	10/20	10/20	10/15	X	X	X	X	
25-S	S-P-39.0-269-90	125	4		15/25	15/25	10/20	10/20	10/15		X	X	X	
26-S	S-P-39.0-180-90	126	4		15/25	→	→	→	10/20		10	10	10	
28-S	S-P-39.5-0-90	128	4		15/25	15/25	10/25	10/25	10/15	X	X	X	X	
29-S	S-P-40.0-0-90	129	4		15/25	15/25	15/25	15/25	10/20	|	|	|	|	
30-S	S-P-40.0-269-90	130	4		15/25	15/25	15/25	15/25	10/20	X	X	X	X	
31-S	S-P-40.0-180-90	131	4		15/25	→	→	→	10/20	11	11	11	11	
32-S	S-P-40.0-89-90	132	4		15/25	15/25	15/25	15/25	10/20	X	X	X	X	
33-S	S-P-41.5-0-90	133	4		50/75	→	→	→	25/20	|	12	12	12	
34-S	S-P-42.5-0-90	134	4		15/25	25/75	15/20	50/75	25/50	|	13	X	X	
39-S	S-P-44.5-0-90	139	4		15/25	50/75	15/20	50/75	25/50	X	14	X	X	
41-S	S-P-47.375-0-90	141	4		20/50	50/75	20/50	50/75	25/50	15	15	15	15	
42-S	S-P-47.375-269-90	142	4		↓	↓	↓	↓	↓	X	X	X	X	
43-S	S-P-47.375-180-90	143	4							X	X	X	X	
44-S	S-P-47.375-89-90	144	4							X	X	X	X	

TABLE 4-1A (Continued)

Measurement Number	Description*	Leadouts Ident Tag No.	Leadouts Leg No.	Leadouts T/C Type**	Pressure, psia; Temperature, °F, Limits M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	Record Code Number*** 1	2	3	4	Notes
45-S	S-P-48.17-0-90	145	4		50/75	→	→	→	25/50	16	16	16	16	
47-S	S-T-35.7-354	152	3	CA	1200	1200	1200	1200	1200	X	X	X	X	
48-S	S-T-38.0-354	153	3	CA	↓	↓	↓	↓	↓					
49-S	S-T-40.0-354	154	4	CA	↓	↓	↓	↓	↓					
50-S	S-T-42.0-354	155	4	CA	↓	↓	↓	↓	↓					
51-S	S-T-45.0-354	156	4	CA	↓	↓	↓	↓	↓	X	X	X	X	
52-S	LVDT									X	X	X	X	

TABLE 4-1B

AIM INSTRUMENTATION
INNERBODY

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes.
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-I	I-P-54.52-0-90	201	3		50/100	50/75	50/75	50/75	25/50	17	17	17	17	
2-I	I-P-54.53-269-90	202	3		50/100	50/75	50/75	50/75	25/50	X	X	X	X	
3-I	I-P-54.51-180-90	203	3		50/75 ⟶	⟶	⟶	⟶	25/50	X	X	X	X	
4-I	I-P-54.51-90-90	204	4		50/100	50/75	50/75	50/75	25/50	X	X	X	X	
5-I	I-P-56.0-0-90	205	4		50/100	50/75	50/75	50/75	25/50	18	18	18	18	
9-I	I-P-64.8-0-90	209	4		25/50	20/25	20/50	10/20	10	X	X	X	X	
13-I	I-T-60.0-240	254	3	CA	1200	1200	1200	1200	1200	│	│	│	│	
14-I	I-T-60.0-120	255	4	CA	1200	1200	1200	1200	1200	│	│	│	│	
15-I	I-T-64.8-355	256	4	CA	1200	1200	1200	1200	1200	X	X	X	X	

TABLE 4-1D

AIM INSTRUMENTATION
NOZZLE PLUG

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-NP	NP-P-66.64-60-90	301	4		20/25	20/25	20/25	10/20	10	X			X	
2-NP	NP-P-67.94-120-90	302	4		10	10/20	10	10	↓	↓			↓	
3-NP	NP-P-69.29-180-90	303	4		10	10	↓	↓	↓	↓			↓	
4-NP	NP-P-70.67-240-90	304	4		↓	↓	↓	↓	↓	↓			↓	
5-NP	NP-P-72.36-300-90	305	4		↓	↓	↓	↓	↓	↓			↓	
6-NP	NP-P-74.45-0-90	306	4		↓	↓	↓	↓	↓	↓			↓	
7-NP	NP-P-77.34-60-90	307	4		↓	↓	↓	↓	↓	↓			↓	
8-NP	NP-P-81.24-120-90	308	4		↓	↓	↓	↓	↓	↓			↓	
9-NP	NP-P-84.04-180-90	309	4		↓	↓	↓	↓	↓	↓			↓	
10-NP	NP-P-86.97-000-180	310	4		↓	↓	↓	↓	↓	↓			↓	
11-NP	NP-T-67.94-124.4	351	3	CA	1200	1200	1200	1200	1200	↓		X	↓	
12-NP	NP-T-70.67-245	352	3	CA	↓	↓	↓	↓	↓	↓		X	↓	
14-NP	NP-T-81.24-125	354	4	CA	↓	↓	↓	↓	↓	X		X	X	

TABLE 4-1E

AIM INSTRUMENTATION
COWL LEADING EDGE

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-CO	CO-P-35.5-83-90	401	4		15	15	15	15	15	X	X		X	
2-CO	CO-P-35.5-173-90	402	4		|	|	|	|	|	|	|		|	
3-CO	CO-P-35.5-263-90	403	3		|	|	|	|	|	|	|		|	
4-CO	CO-P-35.5-353-90	404	3		↓	↓	↓	↓	↓	|	|		X	
5-CO	CO-P-37.0-83-90	405	4		10	10	10	10	10	|	|			
6-CO	CO-P-37.0-173-90	406	4		|	|	|	|	|	|	|			
7-CO	CO-P-37.0-263-90	407	3		|	|	|	|	|	|	|			
8-CO	CO-P-37.0-353-90	408	3		|	|	|	|	|	|	|		X	
9-CO	CO-P-39.0-83-90	409	4		|	|	|	|	|	|	|			
10-CO	CO-P-39.0-173-90	410	4		|	|	|	|	|	|	|			
11-CO	CO-P-39.0-263-90	411	3		|	|	|	|	|	|	|			
12-CO	CO-P-39.0-353-90	412	3		|	|	|	|	|	|	|		X	
13-CO	CO-P-40.5-83-90	413	4		|	|	|	|	|	|	|		|	
14-CO	CO-P-40.5-173-90	414	4		|	|	|	|	|	|	|		|	
15-CO	CO-P-40.5-263-90	415	3		|	|	|	|	|	|	|		|	
16-CO	CO-P-40.5-353-90	416	3		↓	↓	↓	↓	↓	X	X		X	

TABLE 4-IE (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
17-CO	CO-P-40.0-210-110	417	3		10	10	10	10	10	X	X			
18-CO	CO-P-40.35-210-75	418	3		↓	↓	↓	↓	↓	↓	↓			
19-CO	CO-P-40.65-210-110	419	3		↓	↓	↓	↓	↓	↓	↓			
20-CO	CO-P-40.25-330-135	420	3		↓	↓	↓	↓	↓	↓	↓			
21-CO	CO-P-40.65-330-110	421	3		↓	↓	↓	↓	↓	↓	↓			
22-CO	CO-P-40.0-0-110	422	4		↓	↓	↓	↓	↓	↓	↓	X		
23-CO	CO-P-40.35-0-75	423	3		↓	↓	↓	↓	↓	↓	↓	X		
24-CO	CO-P-40.65-0-110	424	3		↓	↓	↓	↓	↓	↓	↓			
25-CO	CO-P-40.25-180-135	425	4		↓	↓	↓	↓	↓	↓	↓			
26-CO	CO-P-40.65-180-110	426	4		↓	↓	↓	↓	↓	↓	↓			
31-C	C-P-35.5-0-90	427	3		20/50	20/50	20/50	20/50	15/25	↓	↓	X	X	
32-C	C-P-36.0-0-90	428	4		↓	↓	↓	↓	↓	↓	↓	↓	↓	
33-C	C-P-36.5-0-90	429	4		↓	↓	↓	↓	↓	↓	↓	↓	↓	
34-C	C-P-36.5-180-90	430	3		↓	↓	↓	↓	↓	↓	↓	↓	↓	
35-C	C-P-37.0-0-90	431	4		↓	↓	↓	↓	↓	↓	↓	↓	↓	
36-C	C-P-37.0-90-90	432	4		↓	↓	↓	↓	↓	X	X	X	X	

TABLE 4-1E (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
37-C	C-P-37.0-180-90	433	3		15/25 →			→	10/20	X	X	19	19	
38-C	C-P-37.0-270-90	434	3		20/50	20/50	20/50	20/50	15/25	↓	↓	X	X	
39-C	C-P-37.5-0-90	435	4		↓	↓	↓	↓	↓	↓	↓	↓	↓	
40-C	C-P-38.0-0-86	436	4											
41-C	C-P-38.0-90-86	437	4											
42-C	C-P-38.0-180-86	438	4											
43-C	C-P-38.0-270-86	439	3											
44-C	C-P-38.5-0-94	440	4											
45-C	C-P-39.0-0-94	441	4											
46-C	C-P-39.0-90-94	442	4											
47-C	C-P-39.0-180-94	443	3											
48-C	C-P-39.0-270-94	444	3											
49-C	C-P-39.5-359-94	445	3											
50-C	C-P-40.0-0-90	446	4											
51-C	C-P-40.0-90-90	447	4											
52-C	C-P-40.0-180-90	448	3											
53-C	C-P-40.0-270-90	449	3		↓	↓	↓	↓	↓	X	X	X	X	

TABLE 4-1E (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes.
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
54-C	C-T-37.0-7	451	4	CA	1200	1200	1200	1200	1200	X	X	X	X	
55-C	C-T-39.0-7	452	4	CA	↓	↓	↓	↓	↓	|	|	|	|	
56-C	C-T-40.0-7	453	4	CA	↓	↓	↓	↓	↓	|	|	|	|	
58-C	C-T-40.0-187	455	3	CA	↓	↓	↓	↓	↓	|	|	|	|	
59-C	C-T-40.0-277	456	3	CA	↓	↓	↓	↓	↓	|	|	|	|	
60-C-0	CO-T-36.5-353	457	3	CA	↓	↓	↓	↓	↓	X	X	X	X	

TABLE 4-1F

AIM INSTRUMENTATION
OUTER SHELL

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-0	0-P-41.06-0-110	501	4		15/25	25/50	15/20	50/75	25/50	X	↑ SEE TABLE 4-1F-1 ↓	X	X	
2-0	0-P-41.06-180-110	502	4		50/75	→	→	→	25/50	20		20	20	
3-0	0-P-41.06-210-110	503	3		15/25	25/50	15/20	50/75	25/50			X	X	
4-0	0-P-41.06-330-110	504	3		↓	25/50	↓	↓	↓			↓	↓	
5-0	0-P-43.81-1-90	505	4		↓	50/75	↓	↓	↓	X		↓	↓	
6-0	0-P-43.81-90-90	506	4		↓	↓	↓	↓	↓	↓		↓	↓	
7-0	0-P-43.81-180-90	507	3		↓	↓	↓	↓	↓	↓		↓	↓	
8-0	0-P-43.81-270-90	508	3		↓	↓	↓	↓	↓	↓		↓	↓	
9-0	0-P-45.25-1-90	509	4		50/75	→	→	→	25/50	X		X	X	
10-0	0-P-47.00-1-90	510	4		20/50	50/75	20/50	50/75	25/50	21		21	21	
11-0	0-P-49.00-1-90	511	4		↓	↓	↓	↓	↓	X		X	X	
12-0	0-P-49.00-90-90	512	4		↓	↓	↓	↓	↓			X	X	
13-0	0-P-49.00-180-90	513	4		50/75	→	→	→	25/50			22	22	
14-0	0-P-49.00-270-90	514	3		20/50	50/75	20/50	50/75	25/50			X	X	
15-0	0-P-49.5-0-90	515	3		50/75	50/75	20/50	50/75	25/50			23	23	
16-0	0-P-50.4-0-90	516	4		50/75	50/75	25/75	50/75	25/50	X		X	X	

TABLE 4-1F (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
17-0	0-P-50.4-90-90	517	4		50/75	50/75	25/75	50/75	25/50		↑	X	X	
18-0	0-P-50.4-180-90	518	4		50/75	→	→	→	25/50			24	24	
19-0	0-P-50.4-270-90	519	3		50/75	50/75	25/75	50/75	25/50			25	25	
20-0	0-P-51.5-1-90	520	4		50/75	→	→	→	25/50			26	26	
21-0	0-P-52.5-0-90	521	3		50/100	50/75	50/75	50/75	25/50	X		X	X	
22-0	0-P-53.0-1-90	522	4		↓	↓	↓	↓	↓					
23-0	0-P-53.0-90-90	523	4		↓	↓	↓	↓	↓			X	X	
24-0	0-P-53.0-180-90	524	4		50/75	→	→	→	25/50			27	27	
25-0	0-P-53.0-270-90	525	3		50/100	50/75	50/75	50/75	25/50		SEE TABLE 4-1F-1	X	X	
26-0	0-P-54.5-0-90	526	3		↓	↓	↓	↓	↓					
27-0	0-P-56.5-0-90	527	4		↓	↓	↓	↓	↓	X				
28-0	0-P-57.5-0-90	528	3		50/100	50/75	50/75	50/75	25/50			X	X	
29-0	0-P-58.5-0-90	529	4		50/75	→	→	→	25/50	X		28	28	
30-0	0-P-59.5-0-90	530	3		50/75	25/50	50/75	25/50	15/25			29	29	
31-0	0-P-60.5-0-90	531	4		↓	↓	↓	25/50	15/25	X		30	30	
32-0	0-P-61.9-0-90	532	3		↓	↓	↓	20/50	10/20	X	↓	X	X	

Table 4-IF (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
33-0	0-P-61.9-110-90	533	4		50/75	25/50	50/75	20/50	10/20	X	(SEE TABLE 4-IF-1)	X	X	
34-0	0-P-61.9-180-90	534	3		50/75	→	→	→	25/50	X		31	31	
35-0	0-P-61.9-290-90	535	3		50/75	20/50	50/75	20/50	10/20	X		32	32	
36-0	0-P-63.0-0-90	536	4		50/75	20/50	25/50	20/50	10/15			33	33	
37-0	0-P-64.0-0-90	537	4		25/50	20/50	25/50	15/25	10/15			34	34	
38-0	0-P-65.0-1-90	538	4		25/50	20/25	20/50	10/20	10	X		X	X	
39-0	0-T-42.0-0	551	3	CA	1200	1200	1200	1200	1200	↓	X	X	X	
40-0	0-T-42.6-0	552	3	CA	↓	↓	↓	↓	↓	↓	↓	↓	↓	
41-0	0-T-43.81-359	553	4	CA	↓	↓	↓	↓	↓	↓	↓	↓	↓	
42-0	0-T-45.25-359	554	4	CA	↓	↓	↓	↓	↓	↓	↓	↓	↓	
43-0	0-T-46.5-0	555	3	CA	↓	↓	↓	↓	↓	↓	X	↓	↓	
44-0	0-T-46.5-90	556	4	CA	↓	↓	↓	↓	↓	↓		↓	↓	
45-0	0-T-46.5-180	557	3	CA	↓	↓	↓	↓	↓	↓		↓	↓	
46-0	0-T-46.5-270	558	3	CA	↓	↓	↓	↓	↓	↓		↓	↓	
47-0	0-T-47.0-359	559	3	CA	↓	↓	↓	↓	↓	↓	X	↓	↓	
49-0	0-T-49.0-359	561	3	CA	↓	↓	↓	↓	↓	X	X	X	X	

TABLE 4-IF (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
50-0	0-T-50.0-0	562	3	CA	1200	1200	1200	1200	1200	X	X	X	X	
52-0	0-T-50.0-180	564	4	CA										
54-0	0-T-51.5-359	566	3	CA							X			
55-0	0-T-52.0-0	567	4	CA										
56-0	0-T-53.0-359	568	3	CA										
59-0	0-T-56.0-0	571	3	CA							X			
60-0	0-T-56.0-120	572	3	CA										
61-0	0-T-56.0-240	573	4	CA										
62-0	0-T-57.0-0	574	3	CA							X			
63-0	0-T-58.0-0	575	3	CA										
64-0	0-T-59.0-0	576	3	CA										
65-0	0-T-60.0-0	577	4	CA										
66-0	0-T-61.0-0	578	4	CA										
67-0	0-T-62.5-0	579	4	CA							X			
68-0	0-T-62.5-120	580	3	CA	↓	↓	↓	↓	↓					
69-0	0-T-62.5-240	581	4	CA						X	X	X	X	

TABLE 4-IF (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
70-0	0-T-63.5-0	582	3	CA	1200	1200	1200	1200	1200	X	X	X	X	
71-0	0-T-64.5-0	583	4	CA	↓	↓	↓	↓	↓	X	X	X	X	
72-0	0-T-65.25-359	584	3	CA	↓	↓	↓	↓	↓	X	X	X	X	

TABLE 4-1F-1

AIM INSTRUMENTATION
OUTER SHELL (FOR AIRFLOW METER TESTS)

Measure-ment Number	Description*	Leadouts: Ident Tag No.	Leadouts: Leg No.	Leadouts: T/C Type**	Pressure Limits, psia (No Combustion - W/Air Meter): M = 5		M = 6		M = 7	Record Code Number***: 1	2	3	4	Notes
1-0	0-P-41.06-0-110				15/25	NOT APPLICABLE	15/20	NOT APPLICABLE	25/50		X			
2-0	0-P-41.06-180-110				↓		↓		↓		35			
3-0	0-P-41.06-210-110				↓		↓		↓		X			
4-0	0-P-41.06-330-110				↓		↓		↓		↓			
5-0	0-P-43.81-1-90				↓		↓		↓		↓			
6-0	0-P-43.81-90-90				↓		↓		↓		↓			
7-0	0-P-43.81-180-90				↓		↓		↓		↓			
8-0	0-P-43.81-270-90				↓		↓		↓		X			
9-0	0-P-45.25-1-90				50/75		50/75		30/40		36			
10-0	0-P-47.00-1-90				25/50		20/50		15/20		X			
11-0	0-P-49.00-1-90				↓		↓		↓		↓			
12-0	0-P-49.00-90-90				↓		↓		↓		X			
13-0	0-P-49.00-180-90				50/75		50/75		25/50		37			
14-0	0-P-49.00-270-90				↓		20/50		15/20		X			
15-0	0-P-49.5-0-90				↓		50/75		25/50		38			
16-0	0-P-50.4-0-90				↓		25/50		15/20		39			
17-0	0-P-50.4-90-90				↓		25/50		15/20		X			

TABLE 4-IF-I (Continued)

Measure-ment Number	Description*	Leadouts			Pressure Limits, psia (No Combustion - W/Air Meter)					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5		M = 6		M = 7	1	2	3	4	
18-0	0-P-50.4-180-90				50/75	NOT APPLICABLE	50/75	NOT APPLICABLE	25/50		40			
19-0	0-P-50.4-270-90				↓		↓		↓		X			
20-0	0-P-51.5-1-90				↓		↓		↓		41			
21-0	0-P-52.5-0-90				↓		↓		↓		X			
22-0	0-P-53.0-1-90				↓		↓		↓		│			
23-0	0-P-53.0-90-90				↓		↓		↓		X			
24-0	0-P-53.0-180-90				↓		↓		↓		42			
25-0	0-P-53.0-270-90				↓		↓		↓		X			
26-0	0-P-54.5-0-90				↓		↓		↓		│			
27-0	0-P-56.5-0-90				↓		↓		↓		│			
28-0	0-P-57.5-0-90				↓		↓		↓		X			
29-0	0-P-58.5-0-90				↓		↓		↓		43			
30-0	0-P-59.5-0-90				↓		↓		↓		X			
31-0	0-P-60.5-0-90				↓		↓		↓		X			
32-0	0-P-61.9-0-90				↓		↓		↓		X			
33-0	0-P-61.9-110-90				↓		↓		↓		X			

TABLE 4-1F-1 (Continued)

Measurement Number	Description*	Leadouts			Pressure Limits, psia (No Combustion - W/Air Meter)					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5		M = 6		M = 7	1	2	3	4	
34-0	0-P-61.9-180-90				50/75	NOT APPLICABLE	50/75	NOT APPLICABLE	25/50		44			
35-0	0-P-61.9-290-90										X			
36-0	0-P-63.0-0-90													
37-0	0-P-64.0-0-90													
38-0	0-P-65.0-1-90										X			

TABLE 4-1G

AIM INSTRUMENTATION
NOZZLE SHROUD

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-N	N-P-66.68-300-80	601	3		20/25	20/25	20/25	10/20	10	X			X	
2-N	N-P-67.46-240.5-78	602	3		10/15	10/15	10/15	10/15	↓	↓			↓	
4-N	N-P-69.00-120-90	604	3		10	10	10	10	↓	↓			↓	
5-N	N-P-69.81-60-90	605	3		↓	↓	↓	↓	↓	↓			↓	
6-N	N-P-70.63-0-90	606	3		↓	↓	↓	↓	↓	↓			↓	
7-N	N-P-71.44-300-90	607	3		↓	↓	↓	↓	↓	↓			↓	
8-N	N-P-72.36-235-90	608	3		↓	↓	↓	↓	↓	↓			↓	
9-N	N-P-73.06-178-92.5	609	4		↓	↓	↓	↓	↓	↓			↓	
10-N	N-P-73.22-0-188	610	4		↓	↓	↓	↓	↓	↓			↓	
11-N	N-P-73.22-180-188	611	3		↓	↓	↓	↓	↓	↓			↓	
12-N	N-T-67.46-238.5	651	4	CA	1200	1200	1200	1200	1200	↓			↓	
13-N	N-T-69.0-115	652	4	CA	↓	↓	↓	↓	↓	↓			↓	
14-N	N-T-70.63-355	653	4	CA	↓	↓	↓	↓	↓	↓			↓	
15-N	N-T-72.26-240	654	4	CA	↓	↓	↓	↓	↓	↓			↓	
16-NO	NO-P-70.92-180-90	612	4		10	10	10	10	10	↓			↓	
17-NO	NO-P-70.92-330-90	613	3		10	10	10	10	10	X			X	

TABLE 4-IG (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
18-NO	NO-P-71.06-134.5-90	614	4		10	10	10	10	10	X				
19-NO	NO-P-71.06-150-90	615	4		↓	↓	↓	↓	↓	↓				
20-NO	NO-P-71.06-155-90	616	4		↓	↓	↓	↓	↓	↓				
21-NO	NO-P-71.97-0-90	617	4		↓	↓	↓	↓	↓	↓			X	
22-NO	NO-P-71.97-180-90	618	4		↓	↓	↓	↓	↓	↓			X	
23-NO	NO-P-71.97-183.5-90	619	3		↓	↓	↓	↓	↓	↓				
24-NO	NO-P-71.97-192.3-90	620	3		↓	↓	↓	↓	↓	↓				
25-NO	NO-P-71.97-201.3-90	621	3		↓	↓	↓	↓	↓	X				
26-NO	NO-P-71.97-210-90	622	3		↓	↓	↓	↓	↓					
27-NO	NO-P-71.97-218.8-90	623	3		↓	↓	↓	↓	↓	X				
28-NO	NO-P-71.97-227.7-90	624	3		↓	↓	↓	↓	↓	↓				
29-NO	NO-P-71.97-236.5-90	625	3		↓	↓	↓	↓	↓	↓			X	
30-NO	NO-P-71.97-330-90	626	3		↓	↓	↓	↓	↓	↓			X	
31-NO	NO-P-71.97-340-90	627	4		↓	↓	↓	↓	↓	↓				
32-NO	NO-P-71.97-346.8-90	628	4		↓	↓	↓	↓	↓	↓				
33-NO	NO-P-71.97-353.4-90	629	4		↓	↓	↓	↓	↓	↓				
34-NO	NO-P-72.45-150-60	630	4		↓	↓	↓	↓	↓	↓			X	
35-OC	OCB-P-66.34-180	29			↓	↓	↓	↓	↓	X				

TABLE 4-1H

AIM INSTRUMENTATION
COMBUSTOR EXIT PLANE

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-CE	CE-P-PT-0-000	701			50/75	50/75	50/75	50/75	25/50			X		
2-CE	CE-P-PS-0-13	702			25/50	25/50	25/50	25/50	10/15			│		
3-CE	CE-P-PS-0-109	703			↓	↓	↓	↓	↓			│		
4-CE	CE-P-PS-0-193	704			↓	↓	↓	↓	↓			│		
5-CE	CE-P-PS-0-283	705			↓	↓	↓	↓	↓			│		
6-CE	CE-P-PT-110-000	706			50/75	50/75	50/75	50/75	25/50			│		
7-CE	CE-P-PS-110-18	707			25/50	25/50	25/50	25/50	10/15			│		
8-CE	CE-P-PS-110-108	708			↓	↓	↓	↓	↓			│		
9-CE	CE-P-PS-110-198	709			↓	↓	↓	↓	↓			│		
10-CE	CE-P-PS-110-288	710			↓	↓	↓	↓	↓			│		
11-CE	CE-P-PT-180-000	711			50/75	50/75	50/75	50/75	25/50			│		
12-CE	CE-P-PS-180-1	712			25/50	25/50	25/50	25/50	10/15			│		
13-CE	CE-P-PS-180-91	713			↓	↓	↓	↓	↓			│		
14-CE	CE-P-PS-180-181	714			↓	↓	↓	↓	↓			│		
15-CE	CE-P-PS-180-271	715			↓	↓	↓	↓	↓			│		
16-CE	CE-P-PT-280-000	716			50/75	50/75	50/75	50/75	25/50			X		

TABLE 4-1H (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
17-CE	CE-P-PS-280-355	717			25/50	25/50	25/50	25/50	10/15			X		
18-CE	CE-P-PS-280-85	718			↓	↓	↓	↓	↓					
19-CE	CE-P-PS-280-175	719			↓	↓	↓	↓	↓					
20-CE	CE-P-PS-280-265	720			↓	↓	↓	↓	↓					
21-CE	CE-P-PT-330-000	721			50/75	50/75	50/75	50/75	25/50					
22-CE	CE-P-PS-330-3	722			25/50	25/50	25/50	25/50	10/15					
23-CE	CE-P-PS-330-93	723			↓	↓	↓	↓	↓					
24-CE	CE-P-PS-330-183	724			↓	↓	↓	↓	↓					
25-CE	CE-P-PS-330-273	725			↓	↓	↓	↓	↓					
26-CE	CE-G-GS-30	736			↓	↓	↓	↓	↓					
27-CE	CE-G-TT-30	751		PR	2600	2600	2600	2600	2600					
28-CE	Ref. Temp for 27-CE	756			200	200	200	200	200					
29-CE	CE-G-PT-30	726			50/75	50/75	50/75	50/75	25/50					
30-CE	CE-G-PS-30	727			40/60	40/60	40/60	40/60	20/30					
31-CE	CE-G-GS-70	737			—	—	—	—	—					
32-CE	CE-G-TT-70	752		PR	2600	2600	2600	2600	2600			X		

TABLE 4-IH (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes.
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
33-CE	Ref. Temp for 32-CE	757			200	200	200	200	200			X		
34-CE	CE-G-PT-70	728			50/75	50/75	50/75	50/75	25/50					
35-CE	CE-G-PS-70	729			40/60	40/60	40/60	40/60	20/30					
36-CE	CE-G-GS-170	738			—	—	—	—	—					
37-CE	CE-G-TT-170	753		PR	2600	2600	2600	2600	2600					
38-CE	Ref. Temp for 37-CE	758			200	200	200	200	200					
39-CE	CE-G-PT-170	730			50/75	50/75	50/75	50/75	25/50					
40-CE	CE-G-PS-170	731			40/60	40/60	40/60	40/60	20/30					
41-CE	CE-G-GS-260	739			—	—	—	—	—					
42-CE	CE-G-TT-260	754		PR	2600	2600	2600	2600	2600					
43-CE	Ref. Temp for 42-CE	759			200	200	200	200	200					
44-CE	CE-G-PT-260	732			50/75	50/75	50/75	50/75	25/50					
45-CE	CE-G-PS-260	733			40/60	40/60	40/60	40/60	20/30					
46-CE	CE-G-GS-350	740			—	—	—	—	—					
47-CE	CE-G-TT-350	755		PR	2600	2600	2600	2600	2600					
48-CE	Ref. Temp for 47-CE	760			200	200	200	200	200					
49-CE	CE-G-PT-350	734			50/75	50/75	50/75	50/75	25/50					
50-CE	CE-G-PS-350	735			40/60	40/60	40/60	40/60	20/30			X		

TABLE 4-II

AIM INSTRUMENTATION
ENGINE FLOW METER

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5		M = 6		M = 7	1	2	3	4	
1-EF	EF-TT-CL-80.0-45	851		PR	1600	NOT APPLICABLE	2300	NOT APPLICABLE	3100		X			
2-EF	EF-TT-CL-80.0-135	852		PR	↓		↓		↓		│			
3-EF	EF-TT-CL-80.0-225	853		PR	↓		↓		↓		│			
4-EF	EF-TT-CL-80.0-315	854		PR	↓		↓		↓		│			
5-EF	EF-SP-S-82.4-0	801			50/75		50/75		25/50		│			
6-EF	EF-SP-S-82.4-90	802			↓		↓		↓		│			
7-EF	EF-SP-S-82.4-180	803			↓		↓		↓		│			
8-EF	EF-SP-S-82.4-270	804			↓		↓		↓		│			
9-EF	EF-SP-P-82.4-0	805			↓		↓		↓		│			
10-EF	EF-SP-P-82.4-90	806			↓		↓		↓		│			
11-EF	EF-SP-P-82.4-180	807			↓		↓		↓		│			
12-EF	EF-SP-P-82.4-270	808			↓		↓		↓		│			
13-EF	EF-SP-S-85.6-0	809			25/50		25/50		15/25		│			
14-EF	EF-SP-S-85.6-90	810			↓		↓		↓		│			
15-EF	EF-SP-S-85.6-180	811			↓		↓		↓		│			
16-EF	EF-SP-S-85.6-270	812			↓		↓		↓		X			

TABLE 4-II (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes.
		Ident Tag No.	Leg No.	T/C Type**	M = 5		M = 6		M = 7	1	2	3	4	
17-EF	EF-SP-P-85.6-0	813			25/50	NOT APPLICABLE	25/50	NOT APPLICABLE	15/25		X			
18-EF	EF-SP-P-85.6-90	814			↓		↓		↓		↓			
19-EF	EF-SP-P-85.6-180	815			↓		↓		↓		↓			
20-EF	EF-SP-P-85.6-270	816			↓		↓		↓		↓			
21-EF	EF-ST-S-85.8-0	855		CA	500		500		↓		↓			
22-EF	EF-ST-S-85.8-90	856		CA	↓		↓		↓		↓			
23-EF	EF-ST-S-85.8-180	857		CA	↓		↓		↓		↓			
24-EF	EF-ST-S-85.8-270	858		CA	↓		↓		↓		↓			
25-EF	EF-ST-P-85.8-5	859		CA	↓		↓		↓		↓			
26-EF	EF-ST-P-85.8-95	860		CA	↓		↓		↓		↓			
27-EF	EF-ST-P-85.8-185	861		CA	↓		↓		↓		↓			
28-EF	EF-ST-P-85.8-275	862		CA	↓		↓		↓		↓			
28A-EF	EF-ST-P-77.4-195	863		CA	1600		2300		3100		↓			
28B-EF	EF-ST-S-77.4-165	864		CA	↓		↓		↓		↓			
29-EF	EF-Temp Rake Z = 1.3555	865		PR	↓		↓		↓		↓			
30-EF	EF-Temp Rake Z = 1.038	866		PR	↓		↓		↓		X			

TABLE 4-II (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5		M = 6		M = 7	1	2	3	4	
31-EF	EF-Temp Rake Z = 0.731	867		PR	1600	NOT APPLICABLE	2300	NOT APPLICABLE	3100		X			
32-EF	EF-Temp Rake Z = 0.432	868		PR	↓		↓		↓		│			
33-EF	EF-Temp Rake Z = 0.142	869		PR	↓		↓		↓		│			
34-EF	EF-Rake-ST-S-78.93-165 (Plug Wall)	870		CA	500		500		500		│			
35-EF	EF-Rake-ST-S-78.86-165 (Shroud Wall)	871		CA	500		500		500		X			

TABLE 4-1K

AIM INSTRUMENTATION
FLUIDS

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
1-F	S-P-1A-188	901	3			50/75		50/75	50/75			X	X	Fuel manifold press.
2-F	S-P-1A-335	902	3			50/75		50/75	50/75					
3-F	S-P-1C-185	903	3			50/75		50/75	50/75			X	X	
4-F	S-P-1C-335	904	3			50/75		50/75	50/75					
5-F	S-P-2C-185	905	4			100/200		200/500	100/150			X	X	
6-F	S-P-2C-335	906	4			100/200		200/500	100/150					
7-F	I-P-3B-95	909	4		150/300		150/300		50/100			X	X	
8-F	I-P-3B-275	910	4		150/300		150/300		50/100					
9-F	0-P-1B-90	911	4			50/75		50/75	50/75			X	X	
10-F	0-P-1B-270	912	3			50/75		50/75	50/75					
11-F	0-P-4-90	913	4			50/75		50/75	50/75			X	X	
12-F	0-P-4-270	914	3			50/75		50/75	50/75					
13-F	0-P-2A-90	915	4			100/200		200/500	100/150			X	X	
14-F	0-P-2A-270	916	3			100/200		200/500	100/150					
15-F	0-P-3A-90	917	4		150/300		150/300		50/100			X	X	
16-F	0-P-3A-270	918	3		150/300		150/300		50/100					

TABLE 4-1K (Continued)

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
17-F	S-T-1A-172	951	3	CA		1100		1100	1100	X	X	X	X	Fuel manifold temp
18-F	ST-T-1A-330	952	3	CA		1100		1100	↓					↓
19-F	S-T-1C-180	953	4	CA		1100		1100	↓	X	X	X	X	↓
20-F	S-T-1C-330	954	4	CA		1100		1100	↓					↓
21-F	S-T-2C-180	955	3	CA		1100		1100	↓	X	X	X	X	↓
22-F	S-T-2C-330	956	3	CA		1100		1100	↓					↓
23-F	I-T-3B-90	957	4	CA	1100		1100		↓	X	X	X	X	↓
24-F	I-T-3B-270	958	4	CA	1100		1100		↓					↓
25-F	0-T-1B-90	959	4	CA		1100		1100	↓	X	X	X	X	↓
26-F	0-T-1B-270	960	3	CA		↓		↓	↓					↓
27-F	0-T-2A-90	961	4	CA		↓		↓	↓	X	X	X	X	↓
28-F	0-T-2A-270	962	3	CA		↓		↓	↓					↓
29-F	0-T-4-90	963	4	CA		↓		↓	↓	X	X	X	X	↓
30-F	0-T-4-270	964	3	CA		↓		↓	↓					↓
31-F	0-T-3A-90	965	4	CA	1100		1100		↓	X	X	X	X	↓
32-F	0-T-3A-270	966	3	CA	1100		1100		↓					↓

TABLE 4-1K (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
33-F	S-P-O_2 (System 1)	907	3		500							X	X	Ignitor press.
35-F	O-P-O_2 (Systems 2,3)	919	4									X	X	
37-F	S-P-H_2 (System 1)	908	4							X	X	X	X	
39-F	O-P-H_2 (Systems 2,3)	920	4							X	X	X	X	Ignitor press.
41-F	S-P-H_2O-IN (TIP)	921	4		300	300	300	300	300	0	0	0	0	Facility/AIM interface flange measurements
42-F	I-P-H_2O-IN	922	4		200	200	200	200	200					
43-F	ST-P-H_2O-IN -L.E.	923	4		500	500	500	500	500					
44-F	ST-P-H_2O-IN -S	924	4		300	300	300	300	300					
45-F	O-P-H_2O-IN	925	3		300	300	300	300	300					
46-F	OCB-P-H_2O-IN -L.E.	926	4		300	300	300	300	300					
47-F	OCB-P-H_2O-IN -FWD	927	4		200	200	200	200	200					
48-F	OCB-P-H_2O-IN-CENTER	928	4		150	150	150	150	150					
49-F	OCB-P-H_2O-IN -AFT	929	4		150	150	150	150	150					
50-F	S-P-H_2O-OUT (TIP)	930	4		75	75	75	75	75					
51-F	I-P-H_2O-OUT	931	3		40	40	40	40	40					
52-F	ST-P-H_2O-OUT-L.E.	932	3		75	75	75	75	75	0	0	0	0	

TABLE 4-1K (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes.
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
53-F	ST-P-H_2O-OUT-S	933	3		75	75	75	75	75	O	O	O	O	Facility/AIM interface flange measurements
54-F	O-P-H_2O-OUT	934	3		40	40	40	40	40					
55-F	OCB-P-H_2O-OUT-A	935	3		40	40	40	40	40					
56-F	OCB-P-H_2O-OUT-B	936	3		40	40	40	40	40					
57-F	OCB-P-H_2O-OUT-C	937	3		40	40	40	40	40					
58-F	OCB-P-H_2O-OUT-D	938	3		40	40	40	40	40	O	O	O	O	
59-F	S-ΔT-H_2O-(O-I)-OUT	9671	4		2	2	2	2	2	X	X	X	X	
59-F	" -IN	9672	4											
60-F	I-ΔT-H_2O-(O-I)-OUT	9681	3		110	110	110	110	110					
60-F	" -IN	9682	4											
61-F	ST-ΔT-H_2O-(O-I)-LE-OUT	9691	3		15	15	15	15	15					
61-F	" -IN	9692	3											
62-F	ST-ΔT-H_2O-(O-I)-S-OUT	9701	3		55	55	55	55	55					
62-F	" -IN	9702	4											
63-F	O-ΔT-H_2O-(O-I)-OUT	9711	3		45	45	45	45	45					
63-F	" -IN	9712	3							X	X	X	X	

TABLE 4-1K (Continued)

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
64-F	HYD-P-IN	939	-							0	0	0	0	On press. gage
65-F	HYD-P-OUT	940	-							0	0	0	0	At cell only
66-F	ΔT1 B	9721	4	CuC	15	15	15	15	15	X	X	X	X	See Figure 4-1 for location
66-F	ΔT1 A	9722	3											
67-F	ΔT1 B	9731	4		15	15	15	15	15					
67-F	ΔT1 A	9732	3											
68-F	ΔT2 D	9781	3		25	25	25	25	25					
68-F	ΔT2 C	9782	4											
69-F	ΔT2 D	9791	4		25	25	25	25	25					
69-F	ΔT2 C	9792	4											
70-F	ΔT3 F	9801	3		15	15	15	15	15					
70-F	ΔT3 E	9802	3											
71-F	ΔT3 F	9811	4		15	15	15	15	15					
71-F	ΔT3 E	9812	4											
72-F	ΔT4 H	9821	4		50	50	50	50	50					
72-F	ΔT4 G	9822	4	CuC						X	X	X	X	

TABLE 4-IK (Continued)

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
73-F	ΔT4 H	9831	4	CuC	50	50	50	50	50	X	X	X	X	See Figure 4-1 for location
73-F	ΔT4 G	9832	4											
74-F	ΔT5 J	9741	3		35	35	35	35	35					
74-F	ΔT5 K	9742	3											
75-F	ΔT5 J	9751	4		35	35	35	35	35					
75-F	ΔT5 K	9752	4											
76-F	ΔT6 MI	9761	3		50	50	50	50	50					
76-F	ΔT6 LS	9762	3											
77-F	ΔT6 M	9771	4		50	50	50	50	50					
77-F	ΔT6 L	9772	4											
78-F	ΔT7 P	9841	3		40	40	40	40	40					
78-F	ΔT7 N	9842	3											
79-F	ΔT7 P	9851	4		40	40	40	40	40					
79-F	ΔT7 N	9852	4											
80-F	O-ΔT-H_2O-(O-I)-OUT	9861	4		45	45	45	45	45					
80-F	" -IN	9862	4							X	X	X	X	

TABLE 4-1K (Continued)

Measure-ment Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
81-F	O-P-H_2O-OUT	941	3		40	40	40	40	40	O	O	O	O	Interface flange
82-F	O-P-H_2O-IN	942	4		300	300	300	300	300	O	O	O	O	
83-F	I-T_1 H_2O Man.	987	3	CA	100	100	100	100	100	X	X	X	X	
84-F	I-T_2 H_2O Man.	988	4	CA	100	100	100	100	100	X	X	X	X	
85-F	FWD.Cavity Press PA1	25	3		25	25	25	25	25	X	X	X	X	
86-F	" " " PA2	26	3		25	25	25	25	25	↓	↓	↓	↓	
87-F	AFT " " PB1	27	3		25	25	25	25	25	↓	↓	↓	↓	
88-F	AFT " " PB2	28	3		25	25	25	25	25	↓	↓	↓	↓	
89-F	IN.Body Cav.Press PIC	147	4		50	50	50	50	50	↓	↓	↓	↓	
90-F	" " " Temp TIC	148			200	200	200	200	200	X	X	X	X	
91-F	FWD.Cav.Temp TA1				↓	↓	↓	↓	↓	↓				
92-F	" " " TA2				↓	↓	↓	↓	↓	↓				
93-F	AFT " " TB1				↓	↓	↓	↓	↓	↓				
94-F	" " " TB2				↓	↓	↓	↓	↓	X	X	X	X	

TABLE 4-1K (Continued)

Measurement Number	Description*	Leadouts			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
		Ident Tag No.	Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
95-F	Water Inlet Press. #1,Z = 3.02	943			250	250	250	250	250	0	0	0	0	Gas sample probe cooling pressures. Z is vertical distance from probe mount to line.
96-F	Water Inlet Press. #2,Z = 4.77	944			↓	↓	↓	↓	↓	|	|	|	|	↓
97-F	Water Inlet Press. #3,Z = 7.85	945			↓	↓	↓	↓	↓	|	|	|	|	↓
98-F	Water Outlet Press. #1,Z = 4.67	946			↓	↓	↓	↓	↓	|	|	|	|	↓
99-F	Water Outlet Press. #2,Z = 7.71	947								0	0	0	0	

TABLE 4-IL

AIM INSTRUMENTATION
FACILITY

Measurement Number	Description	Symbol			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes.
			Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
	GN_2 HEATER													
1-T	Annulus Gas Temp.	TAG												
2-T	Heater Inlet Press.	PIH												
3-T	Annulus-to-Core ΔP	DPAC												
4-T	Port N33 to Heater Inlet ΔP	DPHI												
5-T	Circumferential (N24 - N33) ΔP	DPC												
6-T	Heater In-to-Out ΔP	DPH												
	GN_2 PIPING													
7-T	Venturi 4365 Press.	PVN												
8-T	Venturi 4365 ΔP 1	DPNV1												
9-T	Venturi 4365 ΔP 2	DPNV2												
10-T	Venturi 4365 Temp.	TNV												
11-T	Orifice 430 Press.	PNO												

TABLE 4-IL (Continued)

Measurement Number	Description	Symbol	Leg No.	T/C Type**	Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
					M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
12-T	Orifice 430 ΔP	DPNO												
13-T	Orifice 430 Temp.	TNO												
	GO_2 PIPING													
14-T	Orifice 102 Press.	POO												
15-T	Orifice 102 ΔP	DPOO												
16-T	Orifice 102 Temp.	TOO												
17-T	Mixer Press.	PM												
	HOT TRAIN													
18-T	Heater Exit Temp. 1	THE1												
19-T	Heater Exit Temp. 2	THE2												
20-T	Heater Exit Temp. 3	THE3												
21-T	Radiat.Valve Temp. 1	TRV1												

TABLE 41L (Continued)

Measurement Number	Description	Symbol			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
			Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
22-T	Radiat. Valve Temp. 2	TRV2												
23-T	Radiat. Valve Temp. 3	TRV3												
24-T	Diluent Inj. Flange Temp. 1	TDF1												
25-T	Diluent Inj. Flange Temp. 2	TDF2												
26-T	Film Cooling Flange Temp. 1	TCF1												
27-T	Film Cooling Flange Temp. 2	TCF2												
28-T	Diluent Inj. Flange Film Cooling Temp.	TFF												
29-T	Mixer Liner Temp. 1	TML1												
30-T	2	TML2												
31-T	3	TML3												
32-T	4	TML4												
33-T	5	TML5												
34-T	6	TML6												
35-T	7	TML7												
36-T	Adapter Exit N Temp.	TAEN												

TABLE 4-IL (Continued)

Measure-ment Number	Description	Symbol			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
			Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
37-T	Adapter Inlet N Temp.	TAIN												
38-T	Adapter Exit S Temp.	TAES												
39-T	Adapter Inlet S Temp.	TAIS												
40-T	Nozzle Metal Temp. 1	TNM1												
41-T	Nozzle Metal Temp. 2	TNM2												
42-T	Nozzle Metal Temp. 3	TNM3												
43-T	Nozzle Metal Temp. 4	TNM4												
44-T	Nozzle Total Press. 1	PT01												
45-T	Nozzle Total Press. 2	PT02												
46-T	Nozzle T/C Rdg. 1	TNT1												
47-T	Ref. Temp. for Probe 46-T	TNR1												
48-T	H_2O Temp. for Probe 46-T	TRW1												
49-T	Nozzle Tot.Temp.(Low)	TNT2												
50-T	Ref. Temp. for Probe 49-T	TNR2												
51-T	H_2O Temp. for Probe 49-T	TRW2												

TABLE 4-IL (Continued)

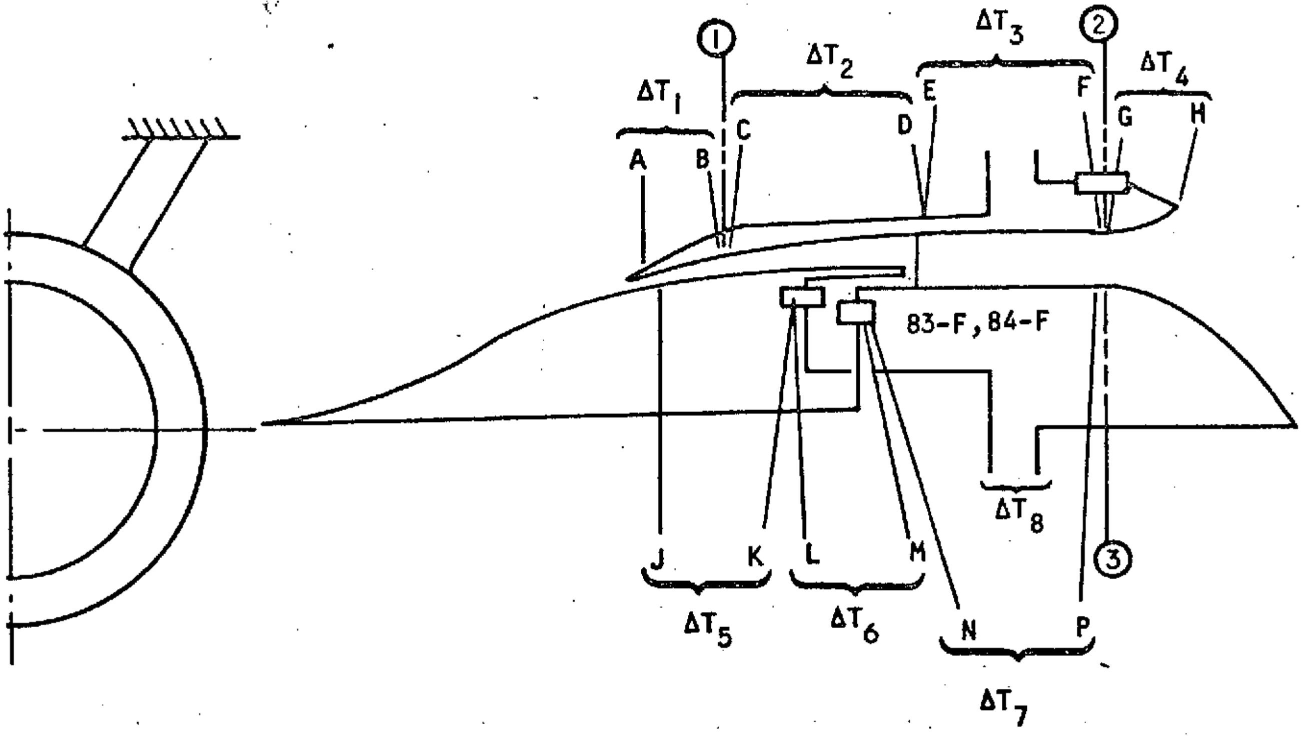
Measurement Number	Description	Symbol			Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
			Leg No.	T/C Type**	M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
52-T	Cell Press.	PCEL												
52A-T	Nozzle Exit Static Press.	PSOM												
	EJECTOR													
53-T	Eject. Inlet Temp. 1	TEI1												
54-T	2	TEI2												
55-T	3	TEI3												
56-T	4	TEI4												
57-T	5	TEI5												
58-T	6	TEI6												
59-T	Sump H_2O Temp.	TSW												

TABLE 4-IL (Continued)

Measurement Number	Description	Symbol	Leg No.	T/C Type**	Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
					M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
	FUEL AND THRUST													
60-T	Fuel Venturi Press. System A	PVA												
61-T	Fuel Venturi Press. System B	PVB												
62-T	Fuel Venturi Press. System C	PVC												
63-T	Fuel Venturi Press. System D	PVD												
64-T	Fuel Venturi Press. System E	PVE												
65-T	Fuel Venturi ΔP System A	DPVA												
66-T	Fuel Venturi ΔP System B	DPVB												
67-T	Fuel Venturi ΔP System C	DPVC												
68-T	Fuel Venturi ΔP System D	DPVD												
69-T	Fuel Venturi ΔP System E	DPVE												

TABLE 4-IL (Continued)

Measure-ment Number	Description	Symbol	Leg No.	T/C Type**	Pressure, psia; Temperature, °F, Limits					Record Code Number***				Notes
					M = 5 Sub.C	M = 5 Sup.C	M = 6 Sub.C	M = 6 Sup.C	M = 7 Sup.C	1	2	3	4	
70-T	Fuel Venturi Manifold Temp.	TFVM												
71-T	Load Cell Reading	FLC												
	PURGE LINE METERS													
72-T	Purge Line Meter Press.	PPM												
73-T	Purge Line Meter ΔP	DPPM												
74-T	Purge Line Meter Temp.	TPM												
75-T	Makeup Line Meter Press.	PMM												
76-T	Makeup Line Meter ΔP	DPMM												
77-T	Makeup Line Meter Temp.	TMM												



T/C Location	Sta. Ref.
A. COWL L.E. ON FLOW DIVIDER	35.58
B. COWL L.E.	
C. OUTERBODY	
D. OUTERBODY	
E. OUTERBODY	
F. OUTERBODY	
G. NOZZLE SHROUD	
H. NOZZLE SHROUD ON FLOW DIVIDER	
J. SPIKE ASSY	
K & L. WATER MANIFOLD	
M & N. WATER MANIFOLD	
P. NOZZLE PLUG	

Notes

1. CODE
   - ① COWL L.E. - OUTERBODY
   - ② OUTERBODY - NOZ. SHROUD
   - ③ INNERBODY - NOZ. PLUG
2. ΔT_8 PREVIOUSLY INSTALLED
3. INSTALL ALL T/C IN COOLANT PASSAGE AS SHOWN UNLESS OTHERWISE NOTED

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Figure 4-1. Cooling System ΔT Thermocouple Locations

TABLE 4-2

INSTRUMENTATION SUMMARY

Component	Number of Measurements									
	Total AIM Instrumentation		Record Code Number (Type of Run)							
			1 N_2 Purge and O.P. Check Run		2 Airflow Meter Runs		3 Combustor Performance Runs		4 Engine Performance Runs	
	Press.	Temp	Press.	Temp	Press.	Temp	Press.	Temp	Press.	Temp
Spike	33	5	30	5	33	5	33	5	33	5
Innerbody	6	3	6	3	6	3	6	3	6	3
Nozzle Plug	10	3	10	3				3	10	3
Cowl Leading Edge										
Inner	21	5	21	5	21	5	21	5	21	5
Outer	26	1	26	1	26	1	2		10	1
Outerbody	38	29	23	29	38	22	38	29	38	29
Nozzle Shroud										
Inner	10	4	10	4				0	10	4
Outer	20	0	19	0					7	
Combustor Exit Rake	35	10					35	10		
Fluids										
Fuel Manifold	16	16		8	5	8	8	8	8	8
Ignitor	4		2		2		4		4	
H_2O Temp and ΔT		22		22		22		22		22
Cavity Press.	5		5		5		5		5	
Cavity Temp		5		5		1		1		1
Flow Meter										
Shroud	8	5			8	5				
Plug	8	5			8	5				
Rake		5				5				
Probes		4				4				
Total (on DAS)	240	122	152	85	152	86	152	86	152	81
H_2O Press. (not on DAS)	20		20		20		20		20	
Facility	31	45								

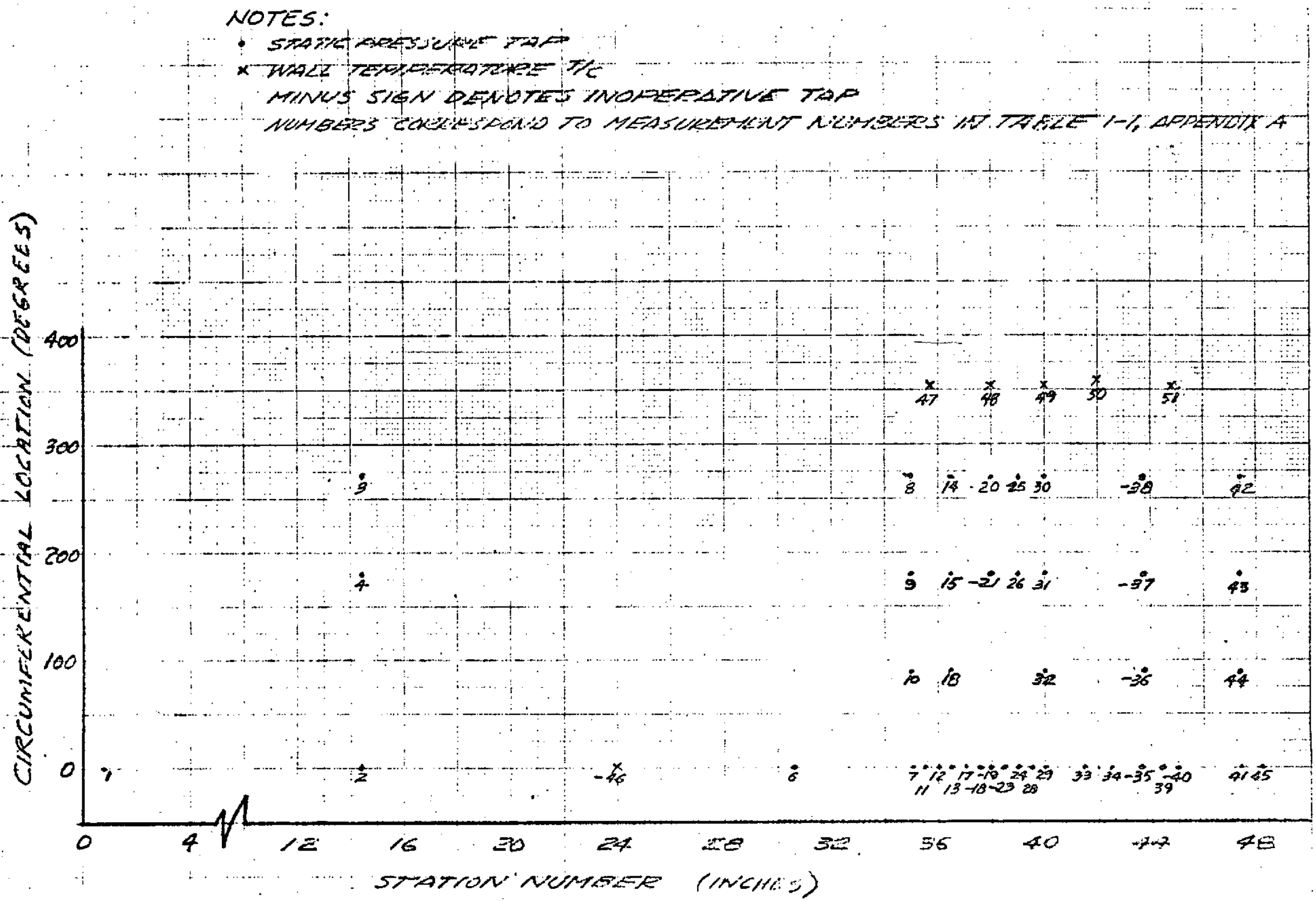


Figure 4-2. Spike Instrumentation Locations

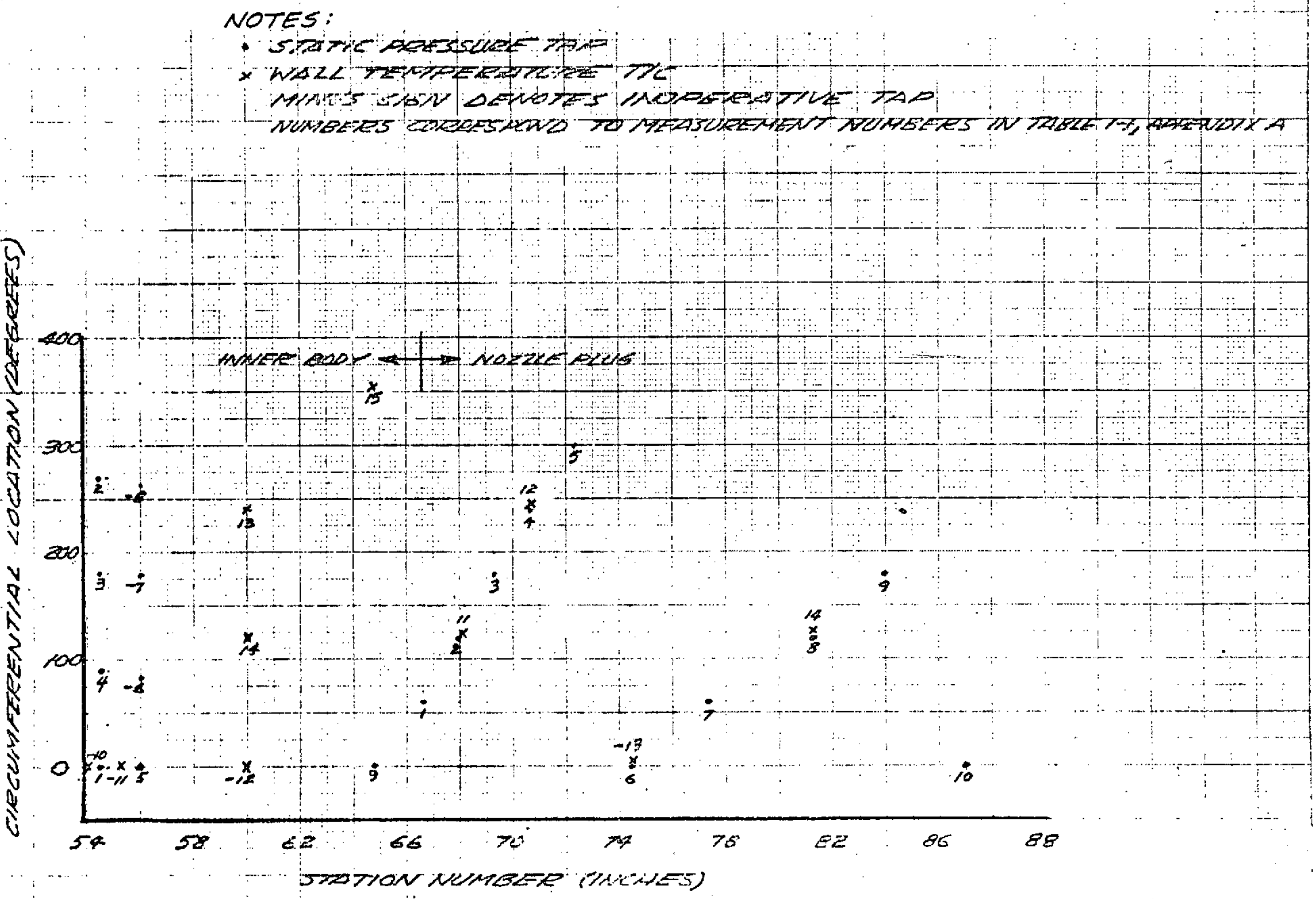


Figure 4-3. Innerbody and Nozzle Plug Instrumentation Locations

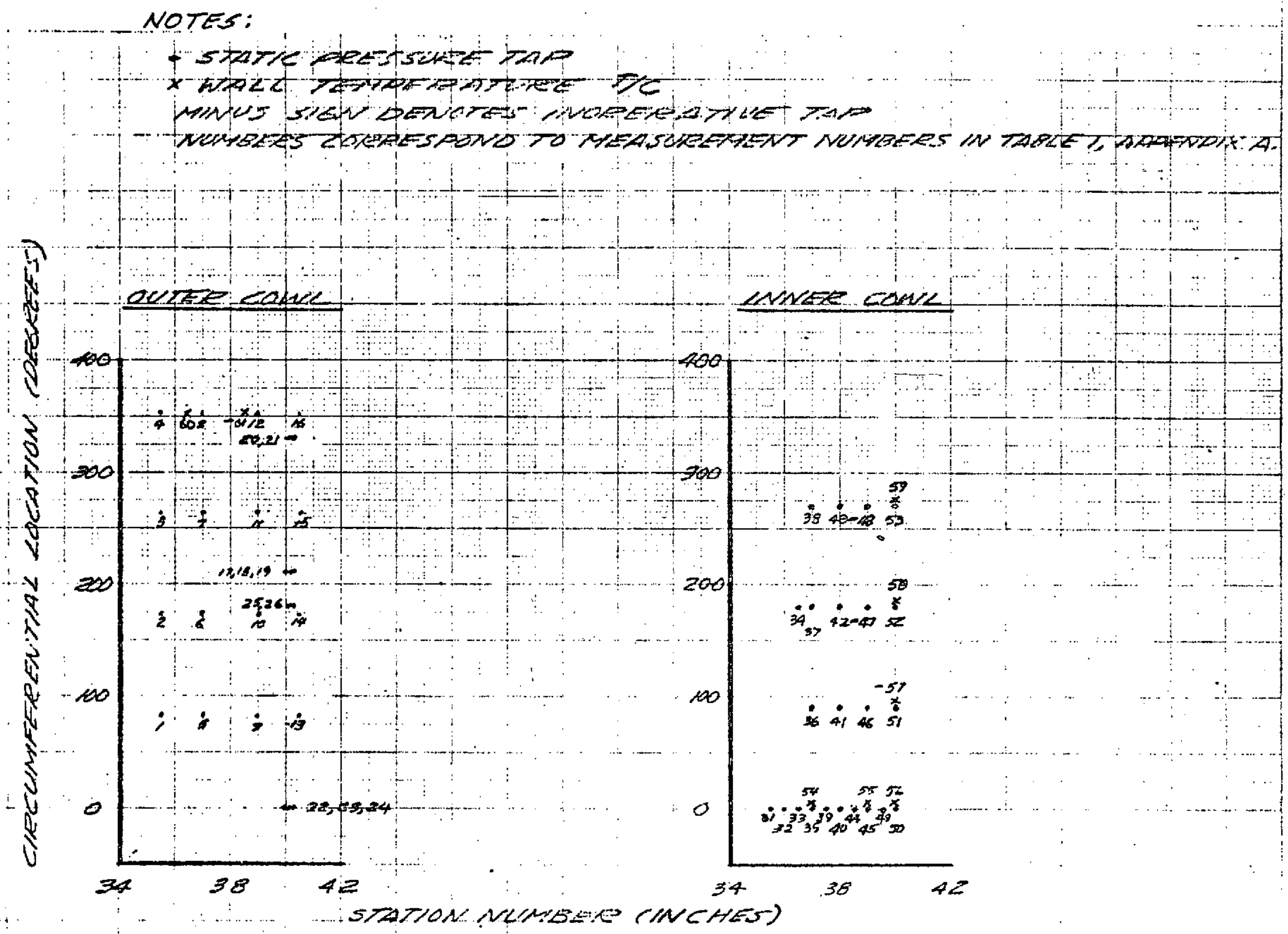


Figure 4-4. Cowl Leading Edge Instrumentation Locations

NOTES:

- • STATIC PRESSURE TAP
- x WALL TEMPERATURE T/C
- MINUS SIGN DENOTES INOPERATIVE TAP
- NUMBERS CORRESPOND TO MEASUREMENT NUMBERS IN TABLE I, APPENDIX A

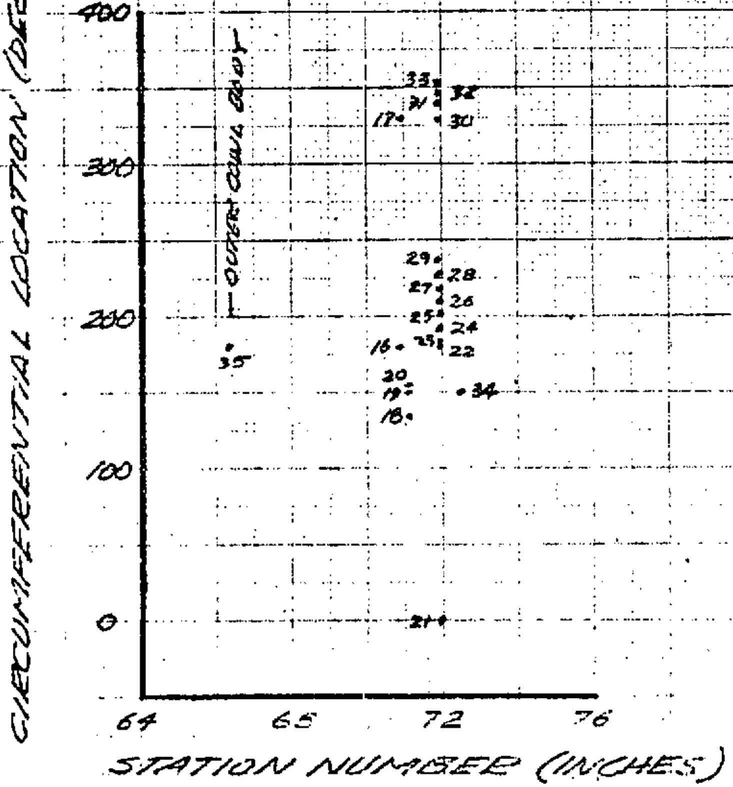


Figure 4-5. Outer Nozzle Shroud Instrumentation Locations

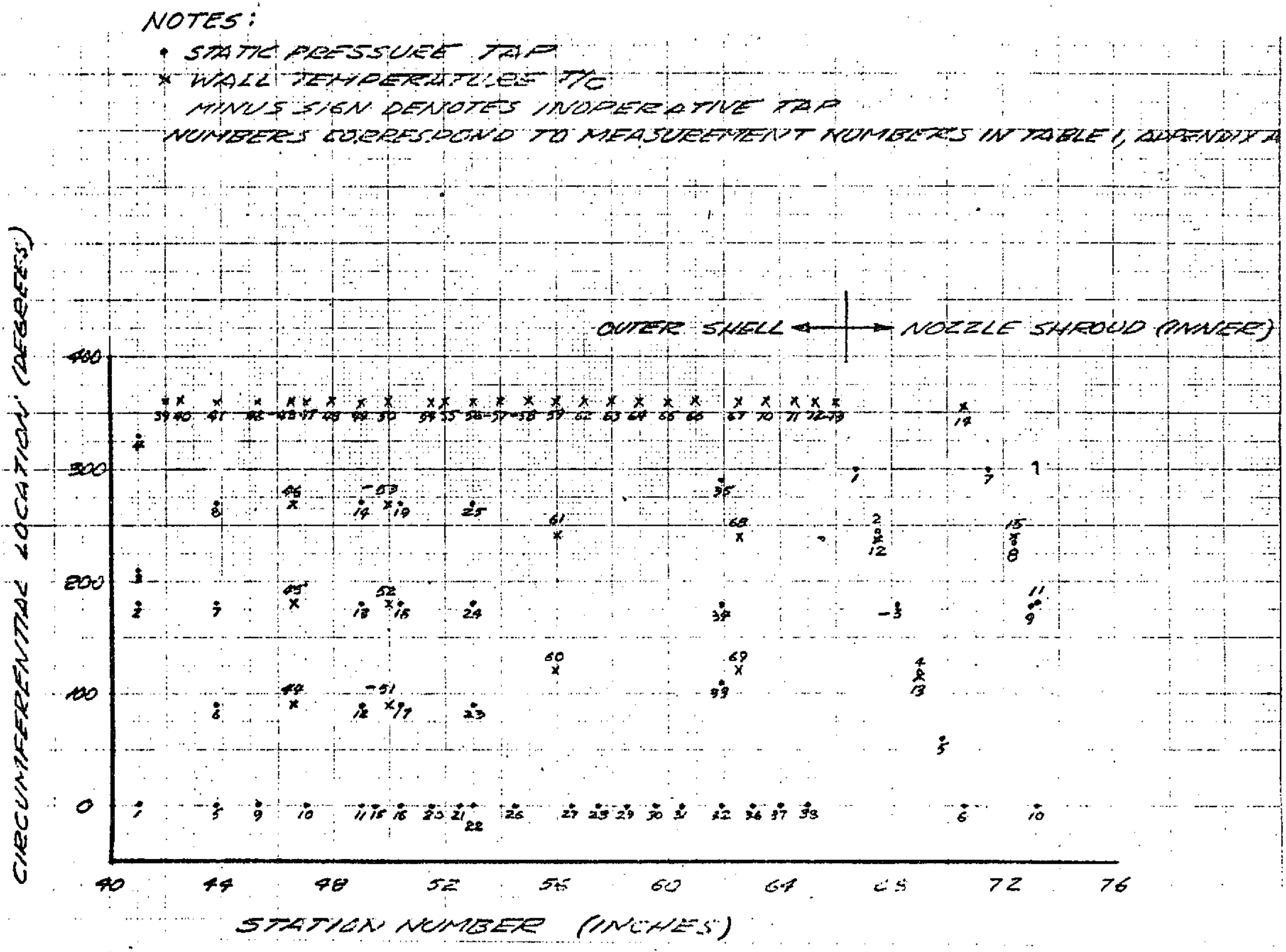


Figure 4-6. Outer Shell and Nozzle Shroud Instrumentation Locations

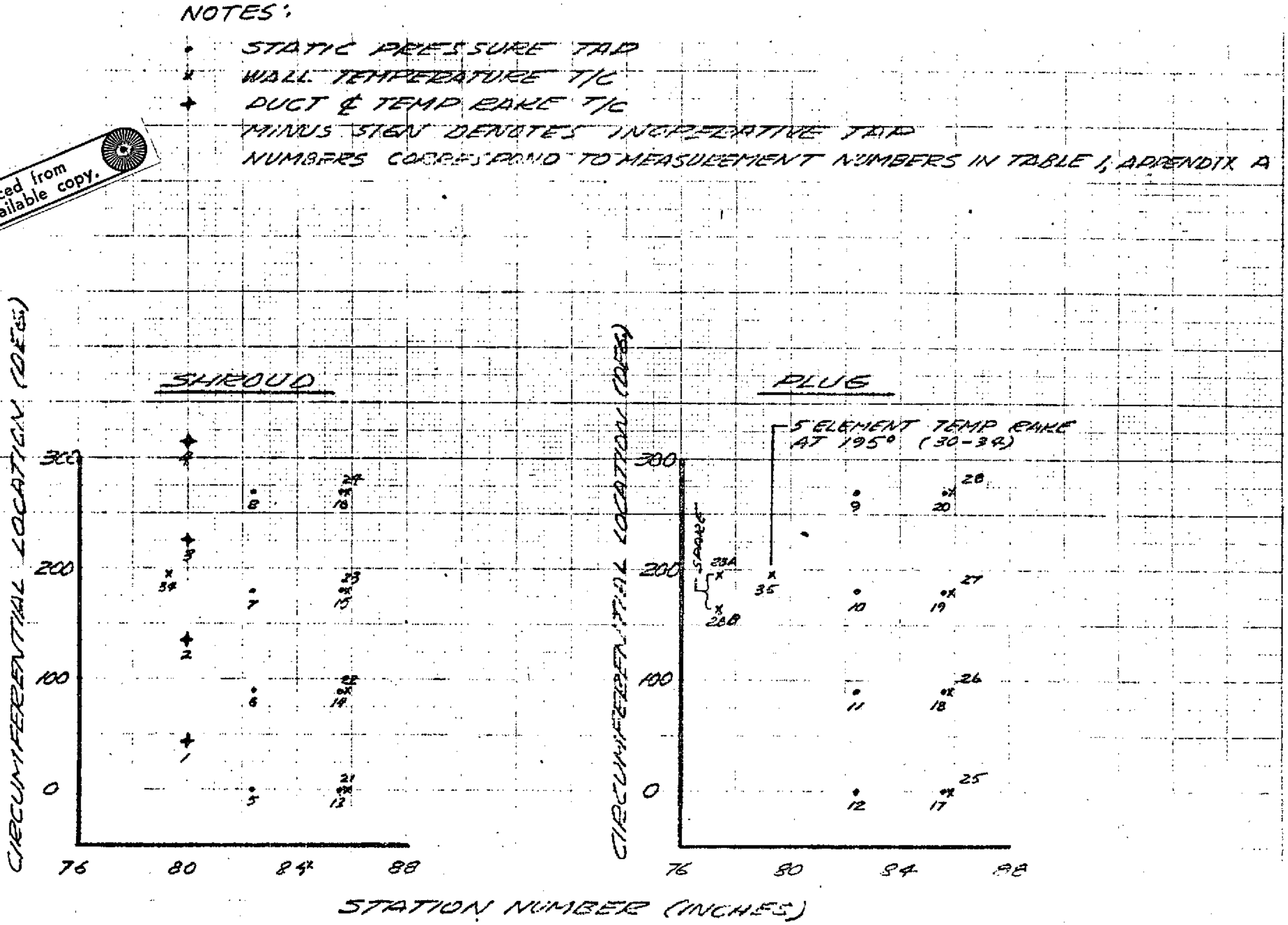


Figure 4-7. Airflow Meter Instrumentation Locations

5. DATA REDUCTION

The data reduction computer program is defined in Appendix A of this report. The test data will be recorded on the Plum Brook SEL Data Acquisition System. The data tape will be transported to LeRC immediately following a test. Here the data will be put into the IBM 360-65 computer. At this time preliminary data can be printed by requesting with a coded typewriter input into the computer. The same typewriter prints the requested data. The above functions can also be performed using remote teletypewriter terminals which are to be installed at NASA Plum Brook, Langley, and AiResearch at Torrance. The teletypewriter data will be analyzed in sufficient detail to establish the requirements for the next run. A complete listing of the data and selected plots will be available two to three days after the run.

6. PRETEST PROCEDURES

When the test setup has been completed, certain pretest calibrations and adjustments must be make prior to wind tunnel testing. These procedures are defined below.

6.1 COOLING SYSTEM TRIMMING

6.1.1 Background

The AIM cooling system consists of nine separate cooling circuits. Each circuit has a separate supply and discharge line. Each circuit must be trimmed to obtain the design flow rate and inlet and discharge pressure. This is necessary to provide the required water velocities in the cooling jackets at a pressure level sufficient to prevent boiling. Trimming is done by adjusting the facility trim valves up and downstream of each circuit. Different trim settings will be required on the innerbody and outerbody circuits when the airflow meter is installed in place of the AIM exhaust nozzle.

A similar procedure will be required for the combustor exit rake cooling circuit.

6.1.1.1 Configuration

The first trimming will be done with the AIM in its performance test configuration with the exhaust nozzle installed. A facility orifice meter will be provided to measure the flow rate in each cooling circuit. The facility "Annubar" flowmeters will also be installed in each circuit. When the system is trimmed with the airflow meter installed,an orifice meter will be required in both the supply and outlet lines of the outerbody cooling circuit. This is discussed below in Section 6.1.1.3.

6.1.1.2 Instrumentation

Cooling system pressures (measurement numbers 41-F through 59-F will be connected to pressure gages. Also the instrumentation for the facility orifice meters and Annubar meters will be connected to pressure gages.

6.1.1.3 Procedure

Flow will be admitted through the facility orifice meter to one circuit at a time. The remaining circuits will be blocked off. Trimming will be done by adjusting the facility trim valves up and downstream of the AIM to obtain the flow rates and pressures defined in Table 3-3 in Reference 2. All pressures apply to the facility interface values (measurement numbers 41-F through 59-F).

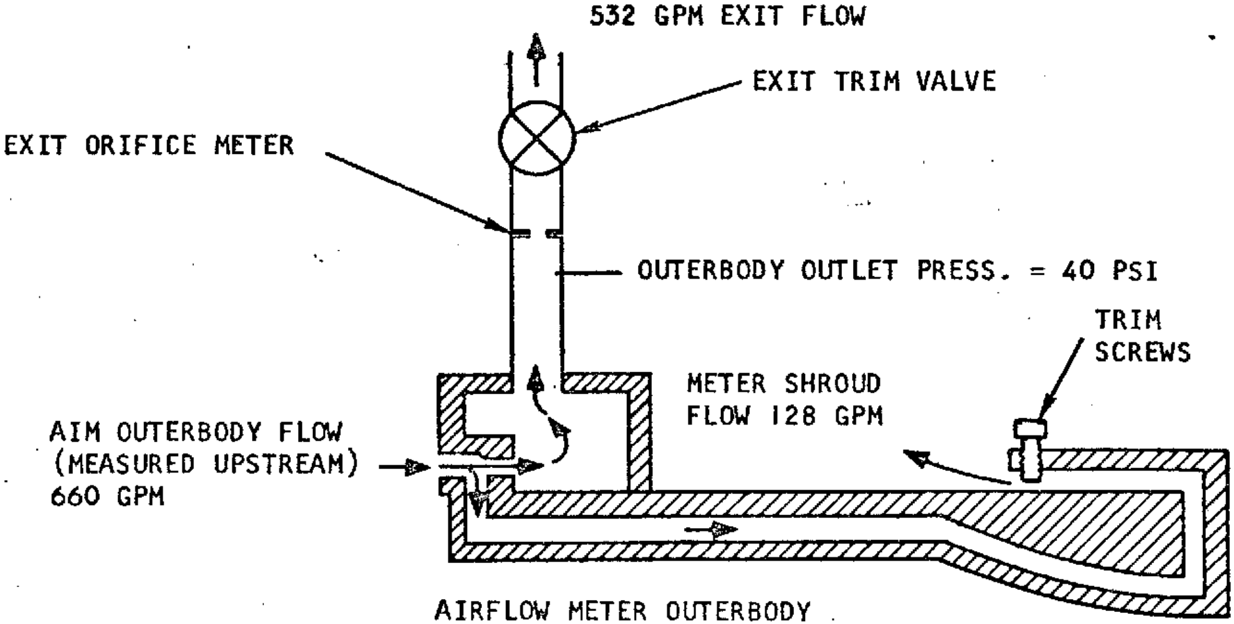
The valves will be gradually opened and the pressures and flow rate monitored to set the design conditions. The pressures will at no time be allowed to exceed the maximum values listed in Table 3-3 (Reference 2). Adequate precaution must be taken against water hammer or air entrainment in the system. The tolerances are ±5 percent on flow rate and ±10 psi on inlet and discharge pressure.

When trimming is completed in a system, the Annubar flowmeter in that system will be calibrated against the facility orifice meter. Cooling system pressure drop data will also be included in the calibration. Calibration will be done by increasing the cooling system inlet pressures in 50 psi increments up to the desing inlet pressure and recording all flowmeter and cooling system inlet and discharge pressures at each setting. The data will be hand reduced to obtain the relationship between Annubar ΔP and the flow rate measured by the facility flowmeter. The data will be used in the performance analysis computer program in computing heat rejected to the cooling system. The Annubar ΔP will be measured during wind tunnel testing for the innerbody and outerbody cooling circuits to determine the flow rates. Flow rates in the remaining circuits will be determined by entering the calibration curves with the Annubar ΔP's set for the test. The Annubar ΔP's will periodically be checked against the cooling circuit ΔP's determined during calibration. If the relationship between these ΔP's has changed, then a blockage in the cooling system is indicated.

6.1.1.3.1 Airflow Meter Trimming

When the airflow meter is installed, the innerbody and outerbody systems must be re-trimmed due to the change in the cooling system configuration. Re-trimming will be done when the airflow meter is installed for wind tunnel testing.

The flowmeter outerbody cooling circuit differs from the nozzle shroud in that a portion of the flow is discharged into the tunnel flow. The system is shown in the following sketch.



AIRFLOW METER OUTERBODY COOLING CIRCUIT

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The system will be trimmed using the outerbody inlet trim valve and flowmeter, the exit trim valve and flowmeter, and the flowmeter trim screws.

The following conditions must be met.

Outerbody inlet pressure (measurement number 45-F)	210 psia
Outerbody inlet flow rate	660 gpm
Outerbody outlet pressure	40 psia
Outerbody exit flow rate	532 gpm

The innerbody cooling circuit will be re-trimmed to the values defined in Table 3-3 in Reference 3.

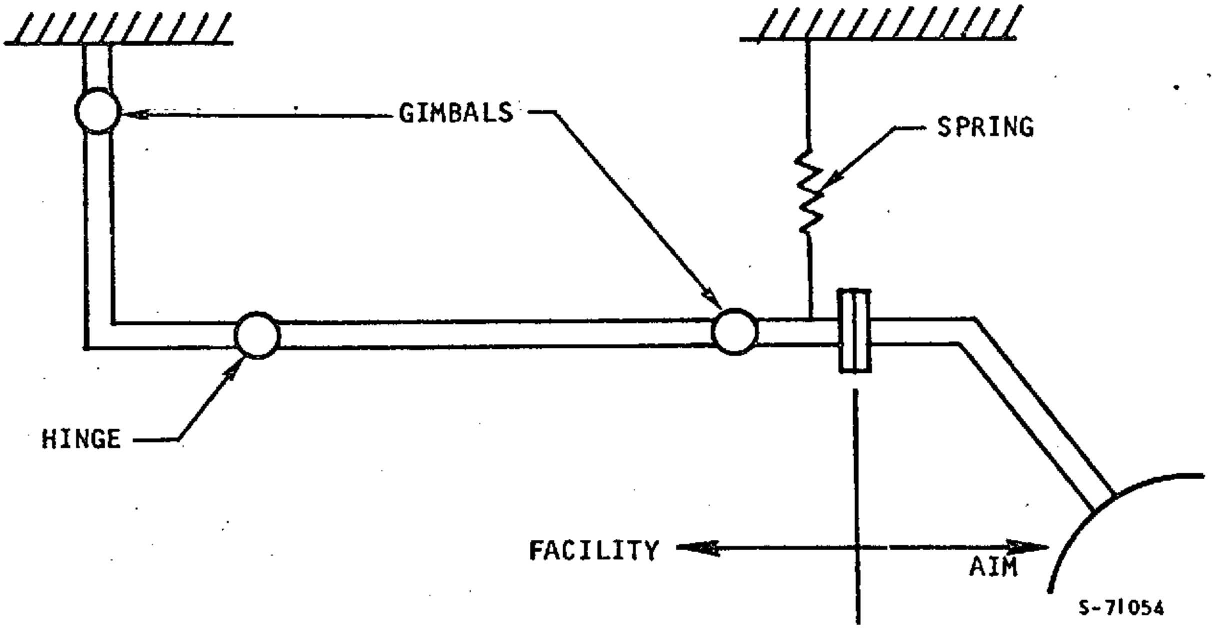
6.1.1.3.2 Combustor Exit Rake Trimming

When the combustor exit rake is installed, the cooling circuit will be trimmed to the values defined in Reference 2, supplemental serial number 20.

6.2 FUEL LINE FLANGE MOMENT CHECK

6.2.1 Background

A typical fuel line connection from the facility to the AIM is shown in the sketch below:

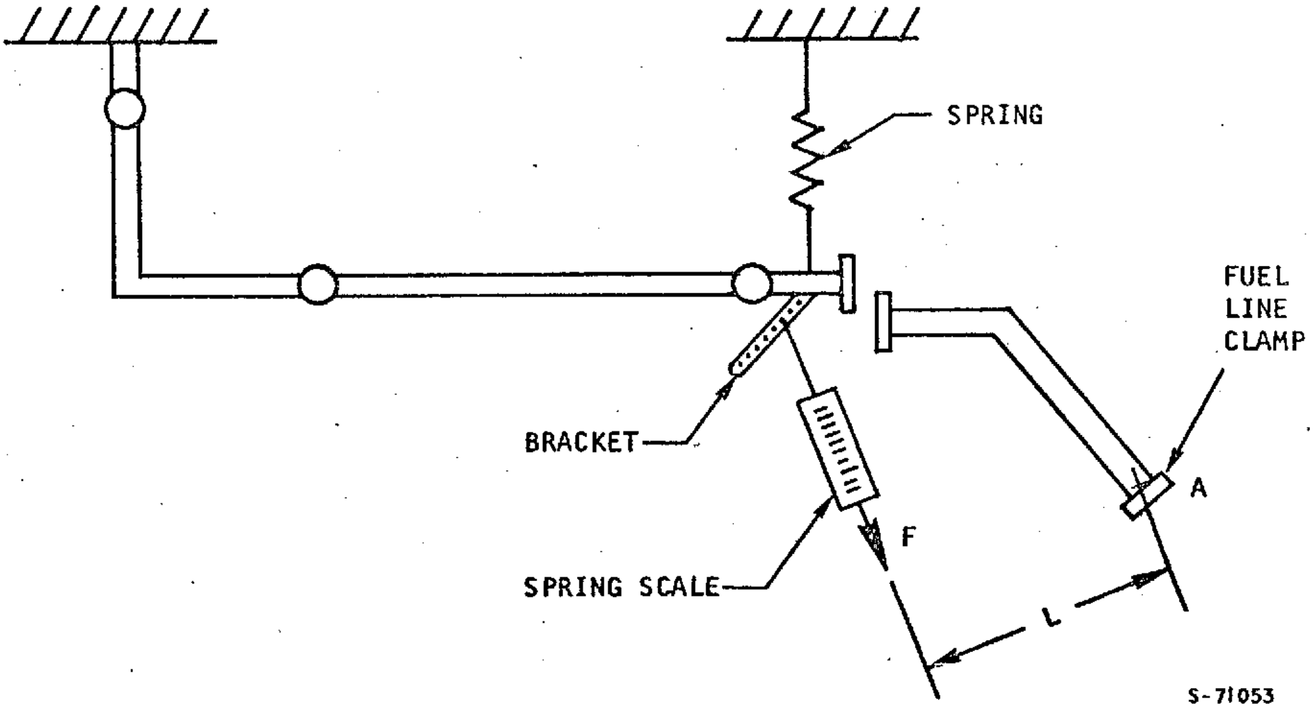


Bellows and hinges are located in the facility piping to minimize the forces applied to the AIM piping to prevent overstress due to thermal expansion and pressure forces.

The AIM and facility piping will be deliberately misaligned in their relaxed positions; thus, a force will be applied to deflect the piping into the connected position. When the piping is heated during testing, the force will pass through a null position and reverse direction. This will result in the minimum applied moment in the worst condition.

6.2.2 Moment Measurement Procedure

When the connections are made to the facility, a method must be devised to determine the moment applied to the AIM fuel lines. A suggested method is outlined in the following sketch.



The solid lines show the pipes in the relaxed position. A bracket is attached to the facility piping to connect a spring scale. The attach point of the scale is adjustable along the length of the bracket. A force, F, will be applied through the scale to deflect the facility piping to the attached position. Axial vertical, and horizontal alignment must be achieved. The attach point of the scale to the bracket can be adjusted so the correct combination of force and moment can be applied to deflect the piping into axial alignment when the required vertical and horizontal deflections are obtained. When the required deflections are obtained, the force, F, and the distance to the AIM fuel line clamp (point A) will be noted. The moment, M, about the attach point is given by $M = FL$. The moment must not exceed the values given in the following table.

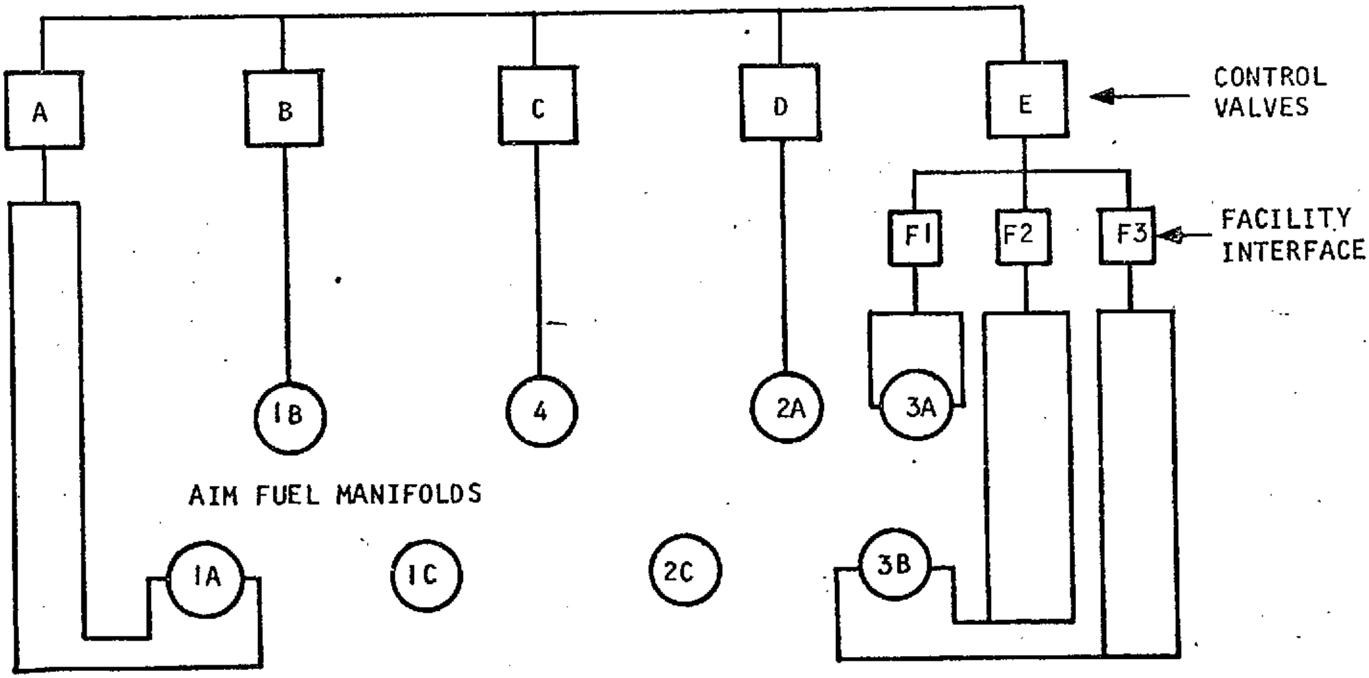
Fuel Line Diameter, in.	Allowable Moment, In.-lb	
	1000°F	70°F
0.625	33	60
0.750	106	190
1.00	200	360
1.25	320	580

The moment in the hot position will be estimated analytically by calculating the pipe deflections and using the spring rates measured in the test defined above. The increase in stiffness of the gimbal joints due to internal pressure must be considered. This will be done analytically or by pressurizing the piping and measuring moments with and without internal pressure.

6.3 FUEL SYSTEM TRIMMING

6.3.1 Background

A fuel system sketch is given below.



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Valve E controls the flow to manifolds 3A and 3B. A preliminary calibration of the fuel system was performed at NASA Plum Brook "A" site. The results showed the flow rate in system 3A to be 41 percent higher than that in 3B with a fixed pressure at the facility interface. The flow rates must be equal to obtain the design condition in the combustor; therefore a trim orifice must be placed at location F1 to reduce the flow rate. The orifice size required to obtain an equal flow split was determined from calibration tests to be 0.518 in.

The flow split must be checked in the wind tunnel and the orifice adjusted as necessary to obtain an equal split. The procedure is defined below.

6.3.2 Configuration

Facility fuel system E will be connected to manifolds 3A and 3B. The fuel-metering system will be operative for the test. The system will be connected to an ambient temperature nitrogen supply. Orifices of 0.518 in. diameter will be installed in system 3A at the facility interface.

6.3.3 Instrumentation

The following parameters will be displayed at the cell during the test.

Parameter	Symbol	Listing Code Number	Range, psia
Fuel manifold 3A press. 1	PM3A1	15-F	15-500
Fuel manifold 3A press. 2	PM3A2	16-F	15-500
Fuel manifold 3B press. 1	PM3B1	7-F	15-500
Fuel manifold 3B press. 2	PM3B2	8-F	15-500
Fuel manifold 3A temp 1	TM3A1	31-F	Ambient
Fuel manifold 3A temp 2	TM3A2	32-F	Ambient
Fuel manifold 3B temp 1	TM3B1	23-F	Ambient
Fuel manifold 3B temp 1	TM3B2	24-F	Ambient

Sufficient facility instrumentation will be connected to measure flow rate in system E. 500 psi pressure gages will be connected to the 3A and 3B fuel lines at the facility interface.

6.3.4 Test Conditions and Procedures

The following procedure will be used for the test.

1. Connect an ambient temperature nitrogen supply to fuel system E.
2. Block off fuel system 3A at the facility interface.
3. Measure flow rate in system 3B at AIM fuel manifold pressures of 50, 100, 150, 200, 250 psia.

4. Place a 0.518 in. diameter orifice plate in the 3A fuel lines at the facility interface locations.
5. Repeat step (3) for system 3A.
6. Compare the flow rates in each system and adjust the trim orifice size to obtain an equal flow split.

6.4 FUEL SYSTEM FLOW CHECK

6.4.1 Background

A functional check of the fuel control and measurement system will be made prior to wind tunnel testing. Cold nitrogen will be flowed through each facility fuel system and AIM fuel manifold in the combinations used in wind tunnel testing. The tape control will be used to set the conditions. The SEL data acquisition system and the AIM data reduction computer program defined in Appendix A will be used for data reduction. The effective fuel injector areas will be computed and compared to the measured physical areas. Injector discharge coefficients will be computed. Instrumentation stabilization times will be checked in the process.

6.4.2 Configuration

The fuel, tape control, and data acquisition systems will be operative for this test. The facility fuel systems which are connected to the AIM manifolds are defined in Section 6.4.4.

The facility fuel system will be connected to an ambient temperature nitrogen supply.

6.4.3 Instrumentation

All fuel-metering venturis and fuel manifold instrumentation will be connected to the data acquisition system for the tests. This instrumentation was defined in Table 4-1, measurement numbers 60-T through 70-T and 1-F through 32-F. A visual readout of each AIM fuel manifold pressure must be available during the test to verify that the selected conditions are set. Also, a 500-psi pressure gage will be connected to each fuel line at the facility interface.

6.4.4 Procedure

A suitable check of the tape control and facility fuel lines must be made prior to testing to ensure that pressures applied to the AIM fuel system at the facility interface will at no time exceed the values defined below.

Fuel System	Allowable Inlet Pressure At Facility Interface, psia
1A	500
1B	500
1C	500
4	500
2A	500
2C	500
3A	650
3B	650

Before the system is operated using the tape control, a test will be performed to determine the relationship between each fuel system flow rate and the fuel line inlet pressure at the facility interface. The fuel control valve in each system will be manually opened while monitoring the fuel line inlet pressure. Metering venturi readings, fuel inlet pressure, and fuel manifold pressure will be read when the fuel inlet pressure reaches the value listed in the table above. The data will be reduced to determine the maximum flow rates corresponding to the limiting fuel line inlet pressures.

When the maximum flow rates have been determined as defined above, the system will be operated using the tape control. A 30-sec burst of nitrogen will be applied at each of the following conditions.

Test Number	Facility Fuel System	Fuel Manifold	Nitrogen Flow, % of Max.
1	A	1A	25, 50, 75, 100
	B	1B	25, 50, 75, 100
	C	4	25, 50, 75, 100
	D	2A	25, 50, 75, 100
2	A	1C	25, 50, 75, 100
	A	2C	25, 50, 75, 100
3	E	3A	25, 50, 75, 100
	E	3B	25, 50, 75, 100

The control valve will be closed at the end of each burst for 10 sec on the 1A system and then re-opened as quickly as possible to set the next pressure. This will determine a typical blowdown time of the piping downstream of a control valve and the time required to set a new flow rate. This data will be useful for planning fuel schedules for combustion limit tests where the combustor must be extinguished before re-introducing fuel.

6.4.5 Data Reduction

Data will be recorded by the SEL data acquisition system. The tape will input into the AIM data reduction program defined in Appendix A which will compute the fuel injector discharge coefficients. The program is designed for hydrogen flow rate calculations. The calculations need not be converted to nitrogen for the calibration tests, since the discharge coefficient equations are independent of gas composition. Absolute values of flow rate need not be computed. Reynold's number effects may be neglected because the venturi calibration data shows the discharge coefficient to be independent of Reynold's number.

6.5 FORCE SYSTEM CALIBRATION

Following the cooling system trimming, the initial calibration of the force system will be performed. The thrust measurement load cell will be calibrated. Also, the effects on load cell reading of flow in the cooling, fuel, and nitrogen purge systems will be determined. The calibration procedures are defined in the following paragraphs.

6.5.1 Force Balance Calibration

6.5.1.1 Purpose

The purpose of this test is to establish the relationship between axial force applied to the AIM and the load cell millivolt output.

6.5.1.2 Configuration

The AIM will be mounted in the cell with the thrust calibration fixture, T-704200, replacing the nozzle plug. Force will be applied with a hand-operated hydraulic system through a calibration load cell.

6.5.1.3 Instrumentation

The instrumentation consists of the service load cell and the calibration load cell furnished by LeRC.

6.5.1.4 Test Conditions and Procedure

The load cell will be calibrated in 500-lb increments up and down scale in both the thrust and drag directions. For the calibration tests described in Sections 6.3.1 through 6.3.3, the load cell will be calibrated in 25-lb increments up to 300 lb thrust and drag.

6.5.2 Coolant Pressure Force Calibration

6.5.2.1 Purpose

An extraneous force may be applied to the load cell due to internal pressure in the cooling system piping. The purpose of this test is to detect and eliminate any extraneous forces. If the force cannot be eliminated on a timely basis it will be calibrated as a function of water pressure. The calibration curve will be used as a thrust correction in the data reduction computer program.

6.5.2.2 Configuration

The AIM will be installed in the cell in its performance test configuration with the nozzle plug installed. The cooling system trimming (see paragraph 6) will be completed before this test.

6.5.2.3 Instrumentation

The water inlet pressures (measurement numbers 41-F through 59-F) and load cell output (measurement number 71-T) will be visually read at the cell during the test.

6.5.2.4 Test Conditions and Procedure

Water will be flowed through each cooling circuit up to the pressures defined in Table 3-3 of Reference 3. Data recordings will be taken at ±50-psi increments up and down scale. The cell will be at ambient pressure.

6.5.3 Fuel System Force Calibration

An extraneous force may be applied to the load cell when the fuel system is in operation. This force may be due to internal pressure in the system or thermal expansion of the fuel lines; therefore, two types of force tests must be performed.

(a) Fuel pressure calibration tests with ambient temperature nitrogen or air

(b) Fuel temperature calibration tests with hot nitrogen or air.

The tests are defined below.

6.5.3.1 Fuel Pressure Force Calibration

6.5.3.1.1 Background

The purpose of this test is to detect and eliminate or calibrate any extraneous forces that are applied to the load cell due to internal pressure in the fuel lines. When a fuel system is pressurized, the axial component of thrust from the fuel injector jets is absorbed by the load cell. This introduces a complication in determining the calibration force. In the case of the innerbody, the injector thrust will be eliminated by blocking the 1A, 1C, and 2C fuel lines at the bellows inside of the innerbody cavity. The lines will then be pressurized without flow to obtain the calibration force versus fuel manifold pressure. The outerbody fuel systems 1B and 4 and innerbody system 3B have normal injection, and therefore, small axial thrust forces would be expected. Systems 2A and 3A have forward oblique injection. The axial thrust of these systems is given below.

System	Manifold Pressure, psia	Ideal Axial Thrust, lb
2A	342	74
3A	270	106

With potential forces as high as those shown, a precise calibration for systems 2A and 3A cannot be expected. These systems can be pressurized and the force checked against the above ideal values. This will give indication if there is a gross error. Calibration data from the remaining systems will also indicate if there is a significant problem in this area.

6.5.3.1.2 Configuration

The AIM will be in its performance test configuration with the nozzle plug installed. The fuel systems will be connected to an ambient temperature nitrogen supply. Innerbody fuel systems (1A, 1C, and 2C) will be blocked off.

6.5.3.1.3 Instrumentation

The following parameters will be displayed at the test cell during the test. Handwritten recording of the data is satisfactory.

Parameter	Symbol	Code Number
Load cell reading	FLC	71-T
Innerbody cavity press.	PIC	95-F
Fuel manifold 1A press. I	PM1AI	1-F
Fuel manifold 1C press. I	PM1CI	3-F
Fuel manifold 2C press. I	PM2CI	5-F
Fuel manifold 3B press. I	PM3BI	7-F
Fuel manifold 1B press. I	PM1BI	9-F
Fuel manifold 4 press. I	PM4I	11-F
Fuel manifold 2A press. I	PM2AI	13-F
Fuel manifold 3A press. I	PM3AI	15-E

A 500 psi pressure gage will be connected to each fuel line at the facility interface.

6.5.3.1.4 Test Conditions and Procedure

Based on the above considerations, the procedure for the fuel pressure calibration will be as follows.

(1) Block off the innerbody fuel systems (1A, 1C, 2C) at the primary and secondary bellows. AiResearch will provide the hardware for this.

(2) Pressurize the systems one at a time with ambient temperature nitrogen, and take load cell and fuel manifold pressure readings at the following pressures.

Fuel System	Manifold Pressure, psia
1A	20, 40, 60, 80
1B	
1C	50, 150, 250, 350
4	
2A	
2C	
3A	50, 150, 200, 270
3B	

If a significant extraneous force is observed, an attempt will be made to eliminate it. If this cannot be done on a timely basis, a calibration curve based on the data from step (2) will be made. A correction to the data due to cell pressure may be necessary. This is discussed in Section 6.5.4.

6.5.3.2 Fuel Temperature Force Calibration

6.5.3.2.1 Purpose

The purpose of this test is to detect and eliminate any forces applied to the load cell due to the thermal expansion of the fuel lines.

6.5.3.2.2 Configuration

The fuel, nitrogen purge, cooling systems, fuel line heaters will be operative. Nitrogen will be supplied to the fuel systems through the facility fuel heater.

6.5.3.2.3 Instrumentation

The following parameters will be displayed in the cell area during the test.

Item No.	Parameter	Symbol	Listing Number
1	Load cell reading	FLC	71-T
2	Innerbody cavity press.	PIC	85-F
3	Forward cavity temp	TIC	
4	Forward cavity press. 1	PA1	85-F
5	Forward cavity press. 2	PA2	86-F
6	Aft cavity press. 1	PB1	87-F
7	Aft cavity press. 2	PB2	88-F
8	Purge line meter press.	PPM	72-T
9	Purge line meter ΔP	DPPM	73-T
10	Makeup line meter press.	PMM	75-T
11	Makeup line meter press.	DPMM	76-T
12	Innerbody H_2O inlet press.	I-P-H_2O-IN	42-F
13	Outerbody H_2O inlet press.	O-P-H_2O-IN	45-F
14	Fuel manifold 1A temp	TM1A1	17-F
15	Fuel manifold 1C temp	TM1C1	19-F
16	Fuel manifold 2C temp	TM2C1	21-F
17	Fuel manifold 3B temp	TM3B1	23-F
18	Fuel manifold 1B temp	TM1B1	25-F
19	Fuel manifold 2A temp	TM2A1	27-F
20	Fuel manifold 4 temp	TM41	29-F
21	Fuel manifold 3A temp	TM3A1	31-F
22	Fuel manifold 1A press.	PM1A1	1-F
23	Fuel manifold 1C press.	PM1C1	3-F
24	Fuel manifold 2C press.	PM2C1	5-F
25	Fuel manifold 3B press.	PM3B1	7-F
26	Fuel manifold 1B press.	PM1B1	9-F
27	Fuel manifold 4 press.	PM41	11-F
28	Fuel manifold 2A press.	PM2A1	13-F
29	Fuel manifold 3A press.	PM3A1	15-F

Three thermocouples measuring the innerbody cavity temperature will be connected to the nozzle plug thermocouple patch panel; the measurement numbers for these temperatures are 11-NP, 12-NP, and 14-NP. These thermocouples are temporary and will be installed during test setup.

Fuel line inlet pressure will be measured in each system at the facility interface.

6.5.3.2.4 Procedure

The procedure for the calibration is as follows:

1. Remove the AIM nozzle plug. Connect fuel manifolds 3A and 3B to fuel system E. Connect manifold 1C and 4 to fuel systems A and C, respectively.
2. Bubble check the 1C and 3B crossover tube flange connections using cold nitrogen at 100 psi fuel manifold pressure. Replace the nozzle plug. Leave out the plugs in the mounting flange bolt access holes.
3. Record the load cell null reading.
4. Set the innerbody cavity nitrogen purge system at maximum flow.
5. Set the outerbody forward and aft purged cavity pressures at 1 psig.
6. Set the innerbody and outerbody water inlet pressures at 50 psig.
7. Break in the connected fuel systems as described below. (See paragraph 6.5.3.3 for background). Gradually open the fuel control valves while monitoring fuel line inlet pressures and innerbody cavity and fuel manifold temperatures. Do not exceed the fuel line inlet pressures given in paragraph 6.4.4. Shut down the hot nitrogen flow if any innerbody cavity temperature exceeds 125°F. Adjust the fuel control valves to hold the fuel manifold temperatures at 500°F for 20 min. Do not preheat the fuel lines before admitting hot nitrogen. Increase the fuel manifold temperature to 1000°F in no less than 10 min.
8. Increase the fuel line inlet pressure to 500 psia for 10 sec and then close all fuel control valves.
9. Shut down all nitrogen purge and the water cooling systems.
10. Immediately take the load cell readings and set the water cooling and nitrogen purge system at their previous operating conditions.
11. Allow fuel manifolds to cool to 125°F. Then shut down the innerbody and outerbody nitrogen purge.

12. Repeat steps 1-10 with manifolds 1A, 1B, 2A, and 2C.

13. Replace the plugs in the nozzle plug flange bolt access holes.

14. Set the innerbody cavity pressure at 5 psig.

15. Set the innerbody water inlet pressure at the design value (200 psia).

16. Set the fuel line inlet pressure in systems 1A and 2C at 500 psia. Allow the fuel manifold temperatures in these systems to stabilize at 1000°F for 1 min. Monitor the innerbody cavity temperatures. If these temperatures exceed 125°F, close the fuel control valves immediately. Leave the water cooling and nitrogen purge systems operative during shutdown until the fuel manifold temperatures cool down to 125°F.

17. Monitor the load cell reading during the tests and record any significant changes in reading and the conditions at the time of the change.

6.5.3.3 Fuel System Breakin

A break-in procedure must be followed when the AIM fuel system is first heated. This is necessary because bench tests have shown that the insulating compound used on the fuel lines can outgas flammable solvents. Heavy smoke and several small flames were observed when an insulated pipe specimen was suddenly subjected to 1000°F flow. After five min, the solvents were driven off and normal operation was observed.

To prevent a fire damage problem in the AIM cavities, the fuel temperature will be brought up slowly for the first heating; then, the solvents will be driven off before their autogenous ignition tempereratute is reached. Slow heating also reduces solvent vapor pressure generated within the insulation. This reduces the chance of insulation damage due to vapor pressure. The procedures for break-in are given in paragraph 6.5.3.2.4.

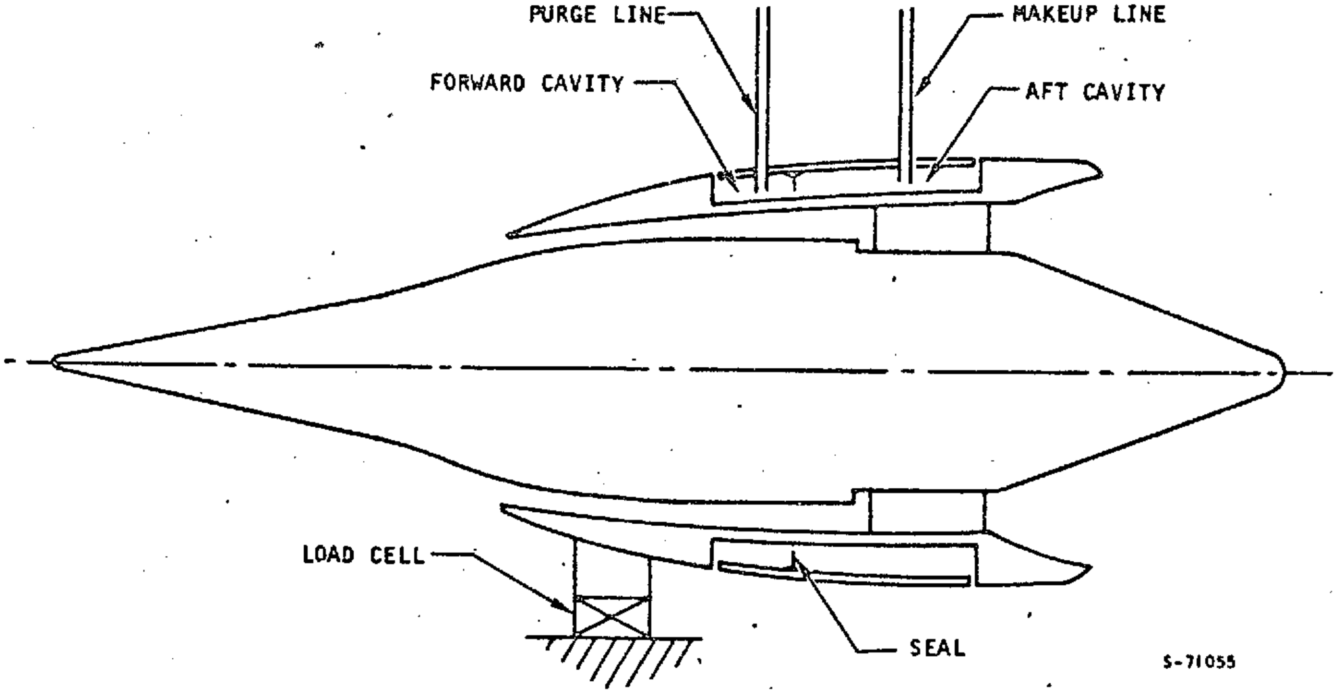
6.5.4 Cell Pressure Force Calibration

If significant tare forces due to internal pressure in the piping are found to exist in the preceding tests, the effect of cell pressure on the calibrations must be investigated. This will be necessary because the net forces on the piping depend on the difference between the system pressure and cell pressure.

The effect of cell pressure will be calibrated by setting the pressure in a system at the design value and evacuating the cell. Load cell readings will be taken with the test cell at ambient pressure and during cell evacuation. If the data is found to correlate with system pressure minus cell pressure, no further tests of the system are required. If no correlation is found, further tests and corrective procedures will be required depending on the nature of the problem.

6.5.5 Nitrogen Purge System Calibration

The thrust correction due to nitrogen purge is described in detail in Appendix B. The purge system is described briefly referring to the following sketch.



Nitrogen fed to the forward outerbody cavity through the purge line exerts a thrust force on the AIM. Nitrogen fed to the aft cavity through the makeup line exerts a drag force. The forward and aft cavity pressures must be systematically varied and the load cell force measured to calibrate the system. The calibration data will be used to correct AIM thrust measurements.

The final calibrations will be run with external flow. These tests are defined in Section 7.1. The following section defines a static (no external flow) calibration to check out the purge system. The data will also be useful for checking the external flow calibrations.

6.5.5.1 Static Calibration

The purpose of this test is to determine the effect of outerbody cavity pressures on load cell force with no external flow. Also cavity pressure instrumentation response times will be determined. Response time data will be used to determine the number of points to be taken during a given run when the cavity pressures are varied during the external flow calibrations.

6.5.5.1.1 Configuration

The AIM will be installed in the cell with the thrust measurement and nitrogen purge systems operative. A load cell in the 500-lb range would be desirable. The test cell will be evacuated for the test.

6.5.5.1.2 Instrumentation

The following parameters will be recorded on the data acquisition system for the test.

Item No.	Parameter	Symbol	Code Number
1	Load cell reading	FLC	71-T
2	Forward cavity press. 1	PA1	85-F
3	Forward cavity press. 2	PA2	86-F
4	Aft cavity press. 1	PB1	87-F
5	Aft cavity press. 2	PB2	88-F
6	Purge line meter press.	PDM	72-T
7	Purge line meter ΔP	DPPM	73-T
8	Makeup line meter press.	DMM	75-T
9	Makeup line meter ΔP	DPMM	76-T
10	Cell press.	PCEL	52-T

Visual displays of items (1) through (5) will be available to the operator controlling the pressures.

6.5.5.1.3 Procedure

The following procedure will be followed for calibration.

1. Evacuate cell.
2. Set a value of PB1. The following values will be tested.

$$\frac{PB1}{PCEL} = 1.1,\ 1.5,\ 2.0,\ 2.5,\ 3.0$$

3. Adjust PA1 to obtain the following load cell readings and take a data point at each.

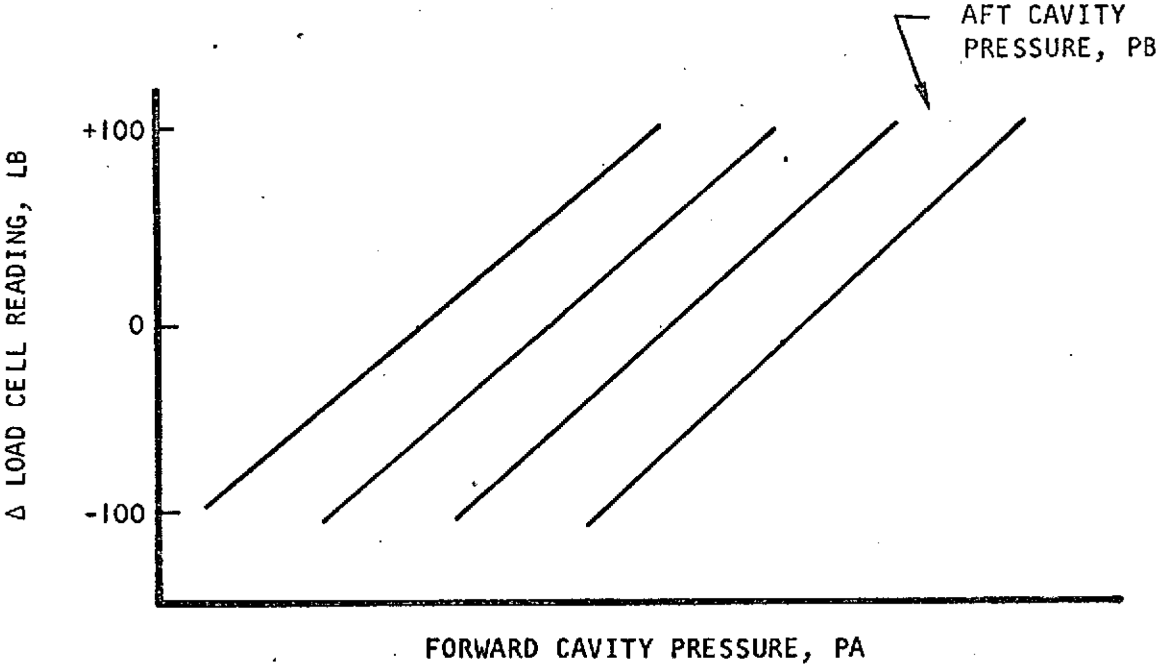
$$FLC = -100,\ -50,\ 0,\ +50,\ +100$$

PA1 shall not exceed 20 psia to prevent overloading the purge seal. At low values of PB1 the above values of FLC may not be obtainable while holding a constant value of PB1. If PB1 is seen to increase with PA1, this means the makeup line regulator is completely closed and therefore incapable of control. In this case proceed to the next data point.

4. When pressures are changed, the response time of the instrumentation will be noted.

6.5.5.1.4 Data Reduction

The results of the test shall be plotted as shown below.



In order to make the plot, the aft cavity pressure must remain constant while the data for each curve is taken; also, the cell pressure must remain constant. Special attention must be given to maintaining stable pressures during the test. Hand reduction of the data is acceptable.

7. WIND TUNNEL TEST DESCRIPTION

A total of 46 wind tunnel tests are planned. A summary of the test objectives and the wind tunnel conditions for each test are given in Section 8 (Table 8-1). The tests are listed in the order of performance. The specific requirements for these tests are summarized in Table 8-2 of Section 8 and defined in detail in Section 8.

The tests are composed of five basic types.

(a) Nitrogen purge system tests

(b) Operational checkout test

(c) Airflow meter tests

(d) Combustor performance tests

(e) Engine performance tests

Each type of test is described in the following paragraphs.

7.1 NITROGEN PURGE SYSTEM TESTS

A series of tests similar to the static calibration test defined in Section 6.5.5.1 will be performed with external flow. The tests will provide thrust correction data to be applied to force balance readings obtained during wind tunnel testing. The effect of purge on the force balance readings is described in Section 6.5.5.

The test will also serve as an operational check on the instrumentation, data acquisition, and tape control systems. Load cell readings will be compared to an oscillograph trace. This will provide a check to determine if the data sampling rate is adequate to obtain a true average reading. Instrumentation response times will also be investigated.

The detailed requirements for the nitrogen purge system tests are defined in Section 8. The tunnel conditions and inlet spike position and angle of attack settings for the tests are repeated below for this discussion.

Run No.	M_o	α	P_{TO}, psia	T_{TO}, °R	Inlet, ΔX
1	6	0	466	1500	4.23
2	6	0	466	1500	1.9
3	6	3	466	1500	4.23
23	7	0	520	2500	2.88
40	5	0	206	1500	4.23

At each of the above conditions, a minimum of 25 combinations of forward and aft purged cavity pressures will set to determine load cell reading with external flow. The cavity pressures to be set will be based on the results of the static calibration defined in Section 6.5.5.1.

Run 1 is the basic calibration at Mach 6.0. Run 2 will be compared to Run 1 to check the effect of spike position. Run 3 will be compared to Run 1 to check the effect of angle of attack. If the data shows that the calibration is significantly influenced by angle of attack or spike position, then additional runs will be required to further investigate these variables.

The AIM cooling system will be in operation during these tests. Because the tunnel temperature is relatively low, the water inlet pressure may be run below the design value to reduce noise in the thrust measurement system. The pressure to be set will be based on experience gained during the coolant pressure calibration defined in Section 6.5.2.

7.2 OPERATIONAL CHECKOUT TESTS

The detailed requirements for the operational checkout tests are defined in Section 8. The test is described below.

The operational checkout test (test No. 4) will serve to check the effects of an intermediate temperature on the AIM and facility. The test will be performed at 2000°R, which lies between the values for the nitrogen purge system tests and the subsequent tests at higher temperatures. The test will also provide spot checks on the nitrogen purge system calibration. Two 1-sec bursts of ignitor spark will be applied to each ignitor system to check the effect of the transmitted signal on the tape control system.

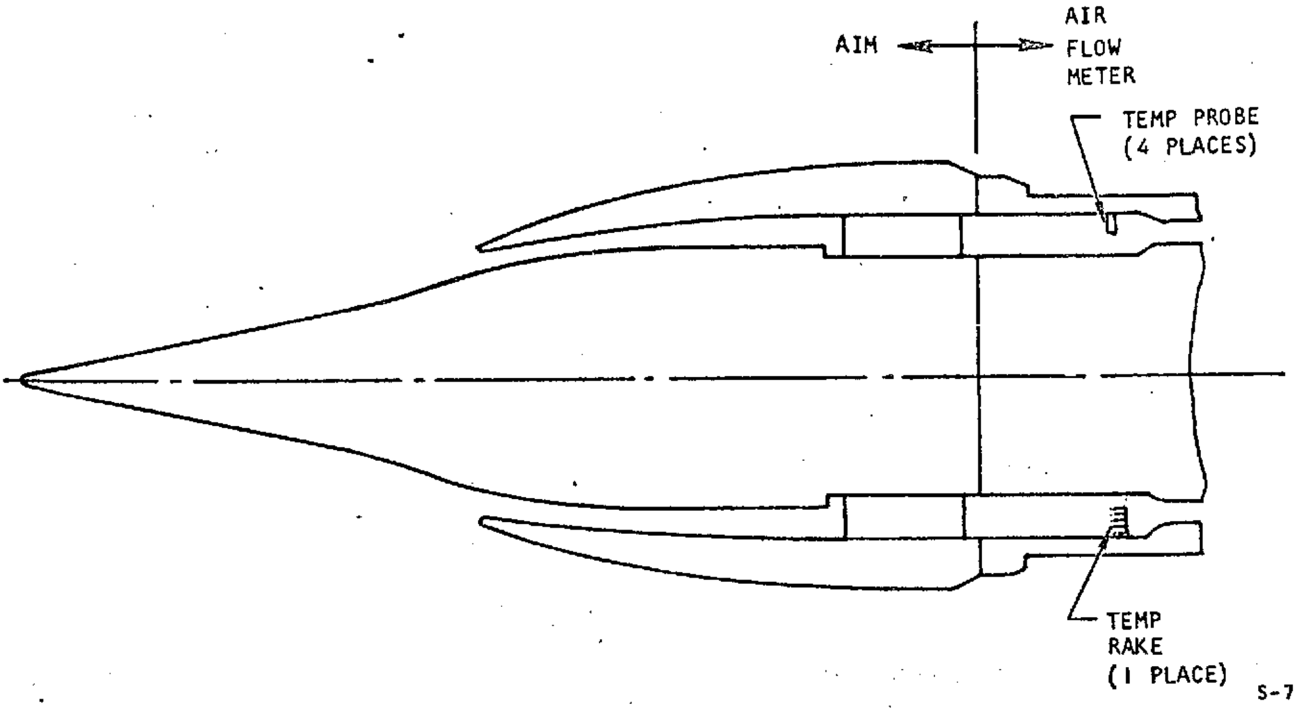
The purged cavity pressures to be set will be based on the results of the previous purge tests. The cavity pressures will not be run as low as on the previous tests to prevent the higher temperature gas from entering the purged cavities.

7.3 AIRFLOW METER TESTS

The detailed requirements for the airflow meter tests are defined in Section 8. The test is discussed below.

The purpose of the airflow meter tests is to measure the airflow captured by the inlet at various tunnel conditions, spike positions, and angle-of-attack settings to be run during performance testing. Also, a complete inlet wall pressure survey and a measurement of inlet pressure recovery are made.

The meter (PN 950804) replaces the AIM exhaust nozzle, as shown in the following sketch.



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The meter is water-cooled, steel-skinned structure. It is designed so that the flow entering the AIM inlet will encounter a pseudo-normal shock system within the duct. The flow will then enter the meter throat approach section subsonically and reaccelerate to sonic velocity at the throat exit. The weight flow will be calculated from the measured duct flow conditions and flow area. Four circumferentially spaced probes measure the duct centerline total temperature. The radial temperature profile is measured by a five-element rake. Pressure is measured by wall taps in the duct constant-area section and in the meter throat. The flow calculation procedures are defined in Appendix A, paragraph 3.2.1.1.3.

The force balance system will be in operation for these tests to provide additional development experience.

7.4 COMBUSTOR PERFORMANCE TESTS

The detailed requirements for the combustor performance tests are defined in Section 8. The tests are described below.

The performance of the combustor as a component is determined in these tests. The combustor exit properties will be measured by a facility-mounted, water-cooled rake which extends through the AIM exhaust nozzle into the combustor exit. The rake assembly is drawing number 950592. The probe drawing numbers are 950593 and 950594.

The rake instrumentation consists of five conical and five gas sampling probes. The conical probes measure flow total pressure, Mach number and direction. The gas sample probes measure gas composition and total temperature. The measurements are made on the duct annulus centerline at various circumferential locations. Combustor parameters, including combustion efficiency, pressure drop, exit gas composition, and entering and exit flow properties are determined from the measured quantities.

The interaction between the combustor and inlet will be investigated. The inlet can be effected by the combustor because the pressure rise caused by the fuel injection and combustion can propogate upstream through the subsonic portion of the boundary layer into the inlet. This causes the boundary layer to thicken and can thereby affect the inlet pressure recovery and stability. The extent of this effect depends on fuel injection quantity and location. High fuel/air ratios close to the inlet cause a greater disturbance but are conducive to higher performance. Performance is potentially higher at this condition because combustion Mach numbers are lower and the combustion length is effectively longer. The AIM is designed so that the above effects can be investigated by varying the fuel injection quantity and location by using the alternate fuel manifolds provided. These investigations are made at various tunnel Mach numbers, angles of attack, and spike positions so that an adequate range of combustor inlet flow conditions are covered.

The performance of the combustor will be evaluated at Mach 6 with subsonic combustion. This condition is obtained by injecting fuel at Stations 3a and 3b. Combustor performance measurements will be made at various fuel/air ratios. The effect of altitude will be investigated by varying the tunnel total pressure and temperature. Transition from subsonic to supersonic combustion and vice versa will be demonstrated. This is accomplished by switching fuel to the appropriate fuel stations during the runs.

At the Mach 5 condition, the combustor performance will be evaluated with the hydrogen/oxygen ignitors. The combustor performance and combustion limits will be evaluated with various combinations of ignitor locations, equivalence ratios, and altitude conditions.

A valid thrust measurement is not expected with the combustor exit rake installed. This is because the probe shocks will probably impinge on the AIM surfaces, thereby distorting the pressures. However, the thrust-balance system will be in operation to provide additional development experience.

7.5 ENGINE PERFORMANCE TESTS

The detailed requirements for the engine performance tests are defined in Section 8. The tests are described below.

The internal performance of the AIM cycle will be measured in the engine performance tests. The combustor exit rake will be removed so that the thrust measurement will not be affected by the rake shock waves. The thrust will be measured at various tunnel conditions, equivalence ratios, spike positions, and angle-of-attack conditions. The final selection of the conditions will be based on the results of the combustor performance tests defined in Section 7.4.

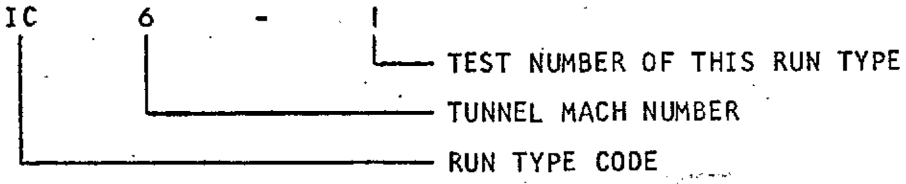
The measured thrust will be corrected for all extraneous forces described in Sections 6.5 and 7.1. The external drag of the cowl and afterbody will be obtained from wall-pressure measurements. The above variables will be combined to determine the thrust and specific impulse of the internal flow through the AIM. Also, exhaust nozzle performance will be computed using the measured conditions.

8. WIND TUNNEL TEST REQUIREMENTS

The planned wind tunnel tests are summarized in Table 8-1. The test requirements for each wind tunnel test are defined in detail in the test requirements sheets given in Table 8-2. These sheets define the tunnel conditions, test setup, instrumentation hookup, and engine operating conditions to be used. The information under each of the headings in Table 8-2 that is not self explanatory is defined below. Figure 8-1 shows the locations of ignitors.

8.1 TEST ID NUMBER

The test identification number nomenclature is as follows.



The run type code is given below.

OC	Operational checkout
PF	Purge force calibration
WC	Airflow meter test
IC	Combustor performance test
ICN	Engine performance test

The test ID number will be printed on the heading of the data printout for each test.

8.2 DATA REQUIREMENTS

The instrumentation and data reduction required for each test are defined under this heading. The nomenclature is defined below.

(a) Visual Code--This code defines the instrumentation to be displayed in the test control room. The instrumentation corresponding to each code number is defined on the instrumentation list given in Table 4-1.

TABLE 8-1

SUMMARY OF AIM WIND TUNNEL TESTS

RUN	M_o	PTO, PSIA	TTO, °R	α	FUEL SYSTEMS	FUEL SCHED.	INLET ΔX, IN.	COMBUSTION MODE	RUN TYPE AND PURPOSE
1	6	466	1500	0	-	-	4.23	-	Purge force, nominal case
2	6	466	1500	0	-	-	1.90	-	Purge force, effect of spike position
3	6	466	1500	3	-	-	4.23	-	Purge force, effect of angle of attack
4	6	466	2000	0	-	-	4.23	-	Operation checkout, effect of higher TTO
5	6	466	3000	0	-	-	0, 1.71, 2.52 4.23, aft stop	-	Airflow calibration, effect of altitude
6	6	930	2946	0	-	-	0, 1.71, 2.52 4.23, aft stop	-	Airflow calibration, nominal case
7	6	930	2946	3	-	-	0, 1.71, 2.52 4.23, aft stop	-	Airflow calibration, effect of angle of attack
8	6	930	2946	0	1a, 1b	1	4.23	Supersonic	Inlet-combustor performance, ignition and inlet unstart limits
9	6	930	2946	0	1a, 1b, 2a, 2c	2	4.23	Supersonic	Inlet-combustor performance, injector optimization
10	6	930	2946	0	1c, 4, 2a, 2c	2	4.23	Supersonic	Inlet-combustor performance, injector optimization
11	6	930	2946	0	1a, 1b, 1c, 4	3	4.23	Supersonic	Inlet-combustor performance, injector optimization
12	6	930	2946	0	TBD	TBD	4.23	Supersonic	Inlet-combustor performance, injector optimization
13	6	466	3000	0	1a, 1b, 2a, 2c	2	4.23	Supersonic	Inlet-combustor performance, effect of altitude
14	6	700	3000	0	1a, 1b, 2a, 2c	2	4.23	Supersonic	Inlet-combustor performance, effect of altitude
15	6	930	2946	0	1a, 1b, 2a, 2c	2	Aft stop	Supersonic	Inlet-combustor performance, effect of spike position
16	6	930	2946	0	1a, 1b, 2a, 2c	2	2.52	Supersonic	Inlet-combustor performance, effect of spike position
17	6	930	2946	0	1a, 1b, 2a, 2c	2	1.71	Supersonic	Inlet-combustor performance, effect of spike position
18	6	930	2946	0	3a, 3b	4	4.23	Subsonic	Inlet-combustor performance, subsonic combustion
19	6	930	2946	0	3a, 3b	5	4.23	Subsonic & transition	Engine performance, subsonic combustion and transition
20	6	930	2946	0	1a, 1b, 2a, 2c	2	4.23	Supersonic	Engine performance, nominal case
21	6	466	2946	0	1a, 1b, 2a, 2c	2	4.23	Supersonic	Engine performance, effect of altitude
22	6	930	2946	3	1a, 1b, 2a, 2c	2	4.23	Supersonic	Engine performance, effect of angle of attack
23	7	520	1500	0	-	-	2.88	-	Purge force
24	7	520	3965	0	-	-	2.34, 2.88 3.24	-	Airflow calibration, effect of altitude
25	7	1000	3840	0	-	-	1.98, 2.88 3.24	-	Airflow calibration, nominal case
26	7	1000	3840	3	-	-	2.34, 2.88 3.24	-	Airflow calibration, effect of angle of attack
27	7	520 & 1000	3965 3840	0	1a, 1b	6	2.88	Supersonic	Inlet-combustor performance, ignition and inlet unstart limits
28	7	1000	3840	0	1a, 1b, 2a, 2c	7	2.88	Supersonic	Inlet-combustor performance, injector optimization
29	7	1000	3840	0	1c, 4, 2a, 2c	7	2.88	Supersonic	Inlet-combustor performance, injector optimization
30	7	1000	3840	0	1a, 1b, 1c, 4	8	2.88	Supersonic	Inlet-combustor performance, injector optimization
31	7	1000	3840	0	TBD	TBD	2.88	Supersonic	Inlet-combustor performance, injector optimization
32	7	522	3965	0	1a, 1b, 2a, 2c	7	2.88	Supersonic	Inlet-combustor performance, effect of altitude
33	7	700	3965	0	1a, 1b, 2a, 2c	7	2.88	Supersonic	Inlet-combustor performance, effect of altitude
34	7	1000	3840	0	1a, 1b, 2a, 2c	7	3.24	Supersonic	Inlet-combustor performance, effect of spike position
35	7	1000	3840	0	1a, 1b, 2a, 2c	7	2.34	Supersonic	Inlet-combustor performance, effect of spike position
36	7	1000	3840	0	1a, 1b, 2a, 2c	7	1.98	Supersonic	Inlet-combustor performance, effect of spike position
37	7	1000	3840	0	1a, 1b, 2a, 2c	7	2.88	Supersonic	Engine performance, nominal case
38	7	522	3965	0	1a, 1b, 2a, 2c	7	2.88	Supersonic	Engine performance, effect of altitude
39	7	1000	3840	3	1a, 1b, 2a, 2c	7	2.88	Supersonic	Engine performance, effect of angle of attack
40	5	445	1500	0	1a, 1b, 2a, 2c	-	4.23	-	Purge force
41	5	206	2210	0	1a, 1b, 2a, 2c	-	4.23	-	Airflow calibration
42	5	415	2210	0	1a, 1b, 2a, 2c	9	4.23	Supersonic	Inlet-combustor performance, nominal case effect of altitude
43	5	415	2210	0	1a, 1b, 2a, 2c	TBD	4.23	Supersonic	Inlet-combustor performance, and ignitor flow rate
44	5	415	2210	0	1a, 1b, 2a, 2c	9	4.23	Supersonic	Engine performance, supersonic combustion
45	5	415	2210	0	3a, 3b	10	4.23	Subsonic	Engine performance, subsonic combustion
46	5	415	2210	3	1a, 1b, 2a, 2c	11	4.23	Subsonic & Supersonic	Engine performance, effect of angle of attack

TABLE 8-2

WIND TUNNEL TEST REQUIREMENTS

RUN 1 TEST I.D. NO. PF6-1 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 466 psia Tot. Temp. 1500 °R

Data Requirements

Visual Code ____ Record Code 1 Red Line Code ____

Data Reduction Code 1 Special Data Req. Oscillograph recording of load cell reading

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ____ psia Special Requirements Temporary cavity thermocouples installed

Test Objectives Determine force correction due to N_2 purge. Operational checkout of instrumentation and D.A.S.

Work Statement Ref. N/A

Critical Observation Requirements Monitor temporary purged cavity thermocouples to detect hot gas entry.

AIM Operating Conditions

PURGED CAVITY PRESSURES

Time, sec.	Inlet, ΔX	α	PAI	PBI
TBD	4.23	0	TBD	TBD

Time, sec.	Inlet, ΔX	α	PAI	PBI
	4.23	0		

TABLE 8-2 (Continued)

RUN 2　　TEST I.D. NO. PF6-2　　Change Ltr. N/C

Facility Requirements

Mach No. 6　　Total Pressure 466 psia　　Tot. Temp. 1500 °R

Data Requirements

Visual Code ______　　Record Code 1　　Red Line Code ______

Data Reduction Code 1　　Special Data Req. ______

Test Model Setup

Air Flow Meter No　　Nozzle Probes: P_T No　　Gas S. No

N_2 Purge Req. ______ psia　　Special Requirements Temporary cavity thermocouples installed

Test Objectives Determine effect of spike position on nitrogen purge force correction

Work Statement Ref. N/A

Critical Observation Requirements Same as PF6-1

AIM Operating Conditions

PURGED CAVITY PRESSURES

Time, sec.	Inlet, ΔX	α	PAI	PBI
	1.90	0		

Time, sec.	Inlet, ΔX	α	PAI	PBI
	1.90	0		

TABLE 8-2 (Continued)

RUN 3 TEST I.D. NO. PF6-3 Change Ltr. N/C

Facility Requirements

Mach No. 6, $\alpha = 3$ Total Pressure 466 psia Tot. Temp. 1500 °R

Data Requirements

Visual Code ____ Record Code 1 Red Line Code ____

Data Reduction Code 1 Special Data Req. ____

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ____ psia Special Requirements Temporary cavity thermocouple installed

Test Objectives Determine effect of angle of attack on nitrogen purge force correction

Work Statement Ref. N/A

Critical Observation Requirements Same as PF6-1

AIM Operating Conditions

PURGED CAVITY PRESSURES

Time, sec.	Inlet, ΔX	α	PA1	PB1
	4.23	3		

Time, sec.	Inlet, ΔX	α	PA1	PB1
	4.23	3		

TABLE 8-2 (Continued)

RUN 4 TEST I.D. NO. OC6-1 Change Ltr. N/C

Facility Requirements

Mach No. 6.0 Total Pressure 466 psia Tot. Temp. 2000 °R

Data Requirements

Visual Code ______ Record Code 1 Red Line Code ______

Data Reduction Code 1 Special Data Req. Temporary cavity thermocouples installed

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ______ psia Special Requirements ______

Test Objectives Checkout test equipment at intermediate temp. Spot check purge force correction. Check effect of ignitor spark on tape control

Work Statement Ref. N/A

Critical Observation Requirements (1) Cooling water pressures (2) Skin temperatures (3) Inlet unstart (4) Cavity temps

AIM Operating Conditions

PURGED CAVITY PRESSURES

Time, sec.	Inlet, ΔX	α	PAI	PBI
	4.23	0		

Time, sec.	Inlet, ΔX	α	PAI	PBI
	4.23	0		

TABLE 8-2 (Continued)

RUN 5 TEST I.D. NO. WC6-1 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 466 psia Tot. Temp. 3000 °R

Data Requirements

Visual Code _____ Record Code 2 Red Line Code _____

Data Reduction Code 2 Special Data Req. _____

See inst. plan - 4 pressures from AFM visual

Test Model Setup

Air Flow Meter Yes Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. _____ psia Special Requirements Retrim innerbody and outerbody cooling circuits (see Section 6.1)

Test Objectives Determine inlet recovery, mass flow, and check airflow meter calibration

Work Statement Ref. 5.2.1.4.2; 5.2.1.4.3(2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Time from Tunnel Start, sec	Inlet, ΔX, in.
0	0
10	1.71
40	2.52
70	4.23
100	Aft stop
120	Shutdown

TABLE 8-2 (Continued)

RUN 6 TEST I.D. NO. WC6-2 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code _____ Record Code 2 Red Line Code _____

Data Reduction Code 2 Special Data Req. _____

See inst. plan

Test Model Setup

Air Flow Meter Yes Nozzle Probes: P_T _____ Gas S. _____

N_2 Purge Req. _____ psia Special Requirements _____

Test Objectives Same as WC6-1 at 930 psia

Work Statement Ref. Same as WC6-1

Critical Observation Requirements Same as WC6-1

Reasons for Initiating Second Schedule Inlet unstart

AIM Operating Conditions

Time From Tunnel Start, sec	Inlet, ΔX, in.
0	0
10	1.71
40	2.52
70	4.23
100	Aft stop
120	Shutdown

TABLE 8-2 (Continued)

RUN 7　　TEST I.D. NO. WC6-3　　Change Ltr. N/C

Facility Requirements

Mach No. 6, $\alpha = 3^0$　Total Pressure 930 psia　Tot. Temp. 2946 °R

Data Requirements

Visual Code ______　Record Code 2　Red Line Code ______

Data Reduction Code 2　Special Data Req. ______

See inst. plan

Test Model Setup

Air Flow Meter Yes　Nozzle Probes: P_T ______　Gas S. ______

N_2 Purge Req. ______ psia　Special Requirements ______

Test Objectives Same as WC6-1 at α= 3 and 930 psia

Work Statement Ref. Same as WC6-1

Critical Observation Requirements Same as WC6-1

Reasons for Initiating Second Schedule Inlet unstart

AIM Operating Conditions

Time From Tunnel Start, sec	Inlet, ΔX, in.
0	0
10	1.71
40	2.52
70	4.23
100	Aft stop
120	Shutdown

TABLE 8-2 (Continued)

RUN 8 TEST I.D. NO. IC6-1 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements Trim nozzle probe cooling circuits. Retrim innerbody and outerbody cooling circuits

Test Objectives Auto-ignition, lean flameout, positive ignition, and inlet unstart limits with first stage supersonic combustion

Work Statement Ref. 5.2.1.4.3(2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 1 on the next page. Injectors 1a and 1b will be used. The wall pressure oscilloscope will be monitored by the AiResearch test conductor during ramp 1-3 to detect a lit condition. When a light is detected a "lit switch" will be manually actuated by the conductor. The switch will hold fuel flow constant at the level existing at the time of actuation until ramp 3-5 is reached.

If an inlet unstart is detected during ramp 1-3 an "unstart switch" will be actuated. This will shut off all fuel, restart the inlet and skip the fuel schedule to point 7.

Ignitors will automatically light at point 7. The test conductor will extinguish the ignitors when a light is detected. Ignitor manifold pressures will be set at 200 psia during ignitor operation.

Inlet $\Delta X = 4.23$.

FUEL SCHEDULE NO. 1

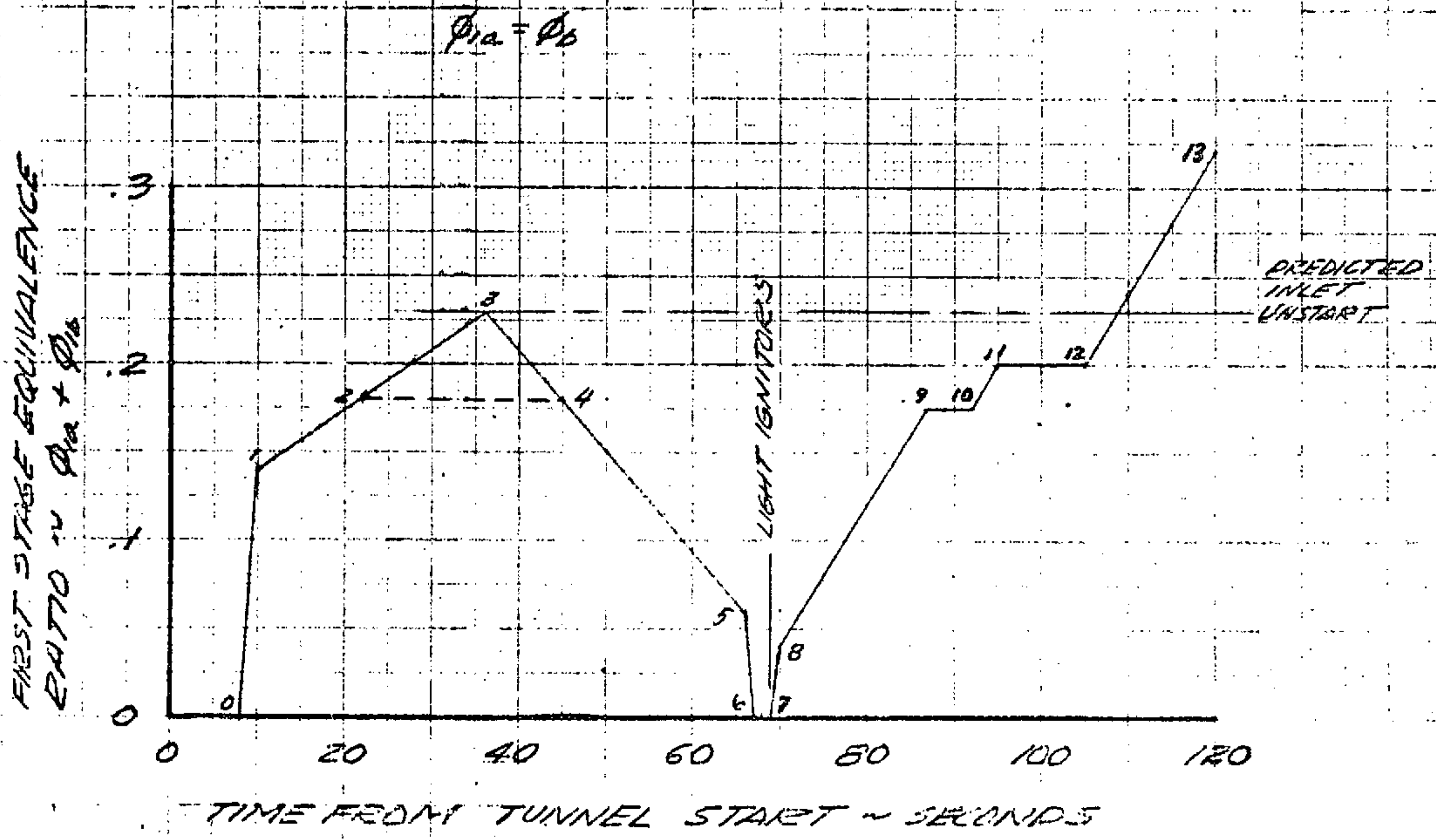


TABLE 8-2 (Continued)

RUN 9 TEST I.D. NO. IC-6-2 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Performance map for injector optimization

Work Statement Ref. 5.2.1.4.3(2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 2 on the next page.

FUEL SCHEDULE NO. 2

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	4.23		0		0		0		0				-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.12		0.11		0		0				-	-	-
25	4.23		0.14		0.12		0		0				-	-	-
30	4.23		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.27		0.27				-	-	-
45	4.23		0.06		0.06		0.44		0.44				-	-	-
50	4.23		0.06		0.06		0.59		0.59				-	-	-
55	4.23		0.06		0.06		0.69		0.69				-	-	-
60	4.23		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.16		0.16				-	-	-
75	4.23		0.09		0.09		0.26		0.26				-	-	-
80	4.23		0.09		0.09		0.33		0.33				-	-	-
85	4.23		0.09		0.09		0.41		0.41				-	-	-
90	4.23		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.12		0.12		0.05		0.05				-	-	-
105	4.23		0.12		0.12		0.10		0.10				-	-	-
110	4.23		0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 10 TEST-I.D. NO. IC6-3 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Performance map for injector optimization

Work Statement Ref. 5.2.1.4.3(2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 2A on the next page.

FUEL SCHEDULE NO. 2A

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1c		4		2a		2c						
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	4.23		0		0		0		0				-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.12		0.11		0		0				-	-	-
25	4.23		0.14		0.12		0		0				-	-	-
30	4.23		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.27		0.27				-	-	-
45	4.23		0.06		0.06		0.44		0.44				-	-	-
50	4.23		0.06		0.06		0.59		0.59				-	-	-
55	4.23		0.06		0.06		0.69		0.69				-	-	-
60	4.23		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.16		0.16				-	-	-
75	4.23		0.09		0.09		0.26		0.26				-	-	-
80	4.23		0.09		0.09		0.33		0.33				-	-	-
85	4.23		0.09		0.09		0.41		0.41				-	-	-
90	4.23		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.12		0.12		0.05		0.05				-	-	-
105	4.23		0.12		0.12		0.10		0.10				-	-	-
110	4.23		0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 11 TEST I.D. NO. IC6-4 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ______ Record Code 3 Red Line Code ______

Data Reduction Code 3 Special Data Req. ______

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ______ psia Special Requirements ______

Test Objectives Performance map for injector optimization

Work Statement Ref. 5.2.1.4.3(4)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 3 on the next page.

FUEL SCHEDULE NO. 3

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		1c		4				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	4.23	TBD	0	TBD	0	TBD	0	TBD	0	TBD			-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.11		0.11		0		0				-	-	-
25	4.23		0.13		0.13		0		0				-	-	-
30	4.23		0.15		0.15		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.19		0.19				-	-	-
45	4.23		0.06		0.06		0.34		0.34				-	-	-
50	4.23		0.06		0.06		0.44		0.44				-	-	-
55	4.23		0.06		0.06		0.52		0.52				-	-	-
60	4.23		0.06		0.06		0.60		0.60				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.09		0.09				-	-	-
75	4.23		0.09		0.09		0.16		0.16				-	-	-
80	4.23		0.09		0.09		0.23		0.23				-	-	-
85	4.23		0.09		0.09		0.29		0.29				-	-	-
90	4.23		0.09		0.09		0.35		0.35				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.11		0.11		0.06		0.06				-	-	-
105	4.23		0.11		0.11		0.10		0.10				-	-	-
110	4.23		0.11		0.11		0.14		0.14				-	-	-
115	4.23	↓	0.11	↓	0.11	↓	0.18	↓	0.18	↓			-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 12 TEST I.D. NO. IC6-5 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code - Record Code 3 Red Line Code

Data Reduction Code 3 Special Data Req.

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. psia Special Requirements

Test Objectives Performance map for injector optimization

Work Statement Ref. Same as OC6-1

Critical Observation Requirements

AIM Operating Conditions

Injector combination and fuel schedule will be determined based on previous tests.

TABLE 8-2 (Continued)

RUN 13 TEST I.D. NO. IC6-6 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 466 psia Tot. Temp. 3000 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Performance map at high altitude

Work Statement Ref. 5.2.1.4.3(4)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 2B on the next page.

FUEL SCHEDULE NO. 2B

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	4.23		0	TBD	0	TBD	0	TBD	0	TBD			-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.12		0.11		0		0				-	-	-
25	4.23		0.14		0.12		0		0				-	-	-
30	4.23		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.27		0.27				-	-	-
45	4.23		0.06		0.06		0.44		0.44				-	-	-
50	4.23		0.06		0.06		0.59		0.59				-	-	-
55	4.23		0.06		0.06		0.69		0.69				-	-	-
60	4.23		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.16		0.16				-	-	-
75	4.23		0.09		0.09		0.26		0.26				-	-	-
80	4.23		0.09		0.09		0.33		0.33				-	-	-
85	4.23		0.09		0.09		0.41		0.41				-	-	-
90	4.23		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.12		0.12		0.05		0.05				-	-	-
105	4.23		0.12		0.12		0.10		0.10				-	-	-
110	4.23		0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12	↓	0.12	↓	0.20	↓	0.20	↓			-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 14 TEST I.D. NO. IC6-7 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 700 psia Tot. Temp. 3000 °R

Data Requirements

Visual Code_____ Record Code 3 Red Line Code_____

Data Reduction Code 3 Special Data Req._____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req._____ psia Special Requirements_____

Test Objectives Performance map at intermediate altitude

Work Statement Ref. 5.2.1.4.3(4)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 2C on the next page.

FUEL SCHEDULE NO. 2C

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		2a		2c				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	4.23		0		0		0		0				-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.12		0.11		0		0				-	-	-
25	4.23		0.14		0.12		0		0				-	-	-
30	4.23		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.27		0.27				-	-	-
45	4.23		0.06		0.06		0.44		0.44				-	-	-
50	4.23		0.06		0.06		0.59		0.59				-	-	-
55	4.23		0.06		0.06		0.69		0.69				-	-	-
60	4.23		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.16		0.16				-	-	-
75	4.23		0.09		0.09		0.26		0.26				-	-	-
80	4.23		0.09		0.09		0.33		0.33				-	-	-
85	4.23		0.09		0.09		0.41		0.41				-	-	-
90	4.23		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.12		0.12		0.05		0.05				-	-	-
105	4.23		0.12		0.12		0.10		0.10				-	-	-
110	4.23		0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 15 TEST I.D. NO. IC6-8 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Performance map with inlet at aft stop

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 2D on the next page.

FUEL SCHEDULE NO. 2D

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		2a		2c				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	Aft Stop		0		0		0		0				-	-	-
10			0.06		0.06		0		0				-	-	-
15			0.09		0.09		0		0				-	-	-
20			0.12		0.11		0		0				-	-	-
25			0.14		0.12		0		0				-	-	-
30			0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	Aft Stop		0.06		0.06		0.27		0.27				-	-	-
45			0.06		0.06		0.44		0.44				-	-	-
50			0.06		0.06		0.59		0.59				-	-	-
55			0.06		0.06		0.69		0.69				-	-	-
60			0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	Aft Stop		0.09		0.09		0.16		0.16				-	-	-
75			0.09		0.09		0.26		0.26				-	-	-
80			0.09		0.09		0.33		0.33				-	-	-
85			0.09		0.09		0.41		0.41				-	-	-
90			0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	Aft Stop		0.12		0.12		0.05		0.05				-	-	-
105			0.12		0.12		0.10		0.10				-	-	-
110			0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 16 TEST I.D. NO. IC6-9 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code______ Record Code 3 Red Line Code______

Data Reduction Code 3 Special Data Req.______

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req.______ psia Special Requirements______

Test Objectives Performance map with inlet at ΔX = 2.52

Work Statement Ref. ______

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 2E on the next page.

FUEL SCHEDULE NO. 2E

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		2a		2c				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	2.52		0		0		0		0				-	-	-
10	2.52		0.06		0.06		0		0				-	-	-
15	2.52		0.09		0.09		0		0				-	-	-
20	2.52		0.12		0.11		0		0				-	-	-
25	2.52		0.14		0.12		0		0				-	-	-
30	2.52		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	2.52		0.06		0.06		0.27		0.27				-	-	-
45	2.52		0.06		0.06		0.44		0.44				-	-	-
50	2.52		0.06		0.06		0.59		0.59				-	-	-
55	2.52		0.06		0.06		0.69		0.69				-	-	-
60	2.52		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	2.52		0.09		0.09		0.16		0.16				-	-	-
75	2.52		0.09		0.09		0.26		0.26				-	-	-
80	2.52		0.09		0.09		0.33		0.33				-	-	-
85	2.52		0.09		0.09		0.41		0.41				-	-	-
90	2.52		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	2.52		0.12		0.12		0.05		0.05				-	-	-
105	2.52		0.12		0.12		0.10		0.10				-	-	-
110	2.52		0.12		0.12		0.15		0.15				-	-	-
115	2.52		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 17 TEST I.D. NO. IC6-10 Change Ltr. N/C

Facility Requirements

Mach No. 6, $\alpha = 3^{\circ}$ Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements 3° angle of attack

Test Objectives Performance map with inlet at $\Delta X = 1.71$

Work Statement Ref. ____

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 2F on the next page.

FUEL SCHEDULE NO. 2F

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	1.71		0		0		0		0				-	-	-
10	1.71		0.06		0.06		0		0				-	-	-
15	1.71		0.09		0.09		0		0				-	-	-
20	1.71		0.12		0.11		0		0				-	-	-
25	1.71		0.14		0.12		0		0				-	-	-
30	1.71		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	1.71		0.06		0.06		0.27		0.27				-	-	-
45	1.71		0.06		0.06		0.44		0.44				-	-	-
50	1.71		0.06		0.06		0.59		0.59				-	-	-
55	1.71		0.06		0.06		0.69		0.69				-	-	-
60	1.71		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	1.71		0.09		0.09		0.16		0.16				-	-	-
75	1.71		0.09		0.09		0.26		0.26				-	-	-
80	1.71		0.09		0.09		0.33		0.33				-	-	-
85	1.71		0.09		0.09		0.41		0.41				-	-	-
90	1.71		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	1.71		0.12		0.12		0.05		0.05				-	-	-
105	1.71		0.12		0.12		0.10		0.10				-	-	-
110	1.71		0.12		0.12		0.15		0.15				-	-	-
115	1.71		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 18 TEST I.D. NO. IC6-11 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Inlet - combustor performance with subsonic combustion and combustion limits.

Work Statement Ref. 5.2.1.4.3 (4)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 4 on the next page. The ignitors will be turned off by the AiResearch test conductor between 10 and 35 sec when a light is detected.

FUEL SCHEDULE NO. 4

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			3a		3b								System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	4.23														Off
10	4.23		0.3		0.3										200
15	4.23		0.4		0.4								Extinguish when light detected		
20	4.23		0.5		0.5										
25	4.23		0.6		0.6										
30	4.23		0.7		0.7										
35	4.23		0.8		0.8										
40	0		0		0										
45	4.23		0.5		0.5										200
50	4.23		0.4		0.4										Off
55	4.23		0.3		0.3										
60	4.23		0.2		0.2										
65	0		0		0										
70	4.23		0.3		0.3										
75	4.23		0		0										
80	4.23		0.4		0.4										
85	4.23		0		0										
90	4.23		0.5		0.5										Off
95		SHUTDOWN													
100															
105															
110															
115															
120															

TABLE 8-2 (Continued)

RUN 19 TEST I.D. NO. ICN6-1 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ____ Record Code 4 Red Line Code ____

Data Reduction Code 4 Special Data Req. ____

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ____ psia Special Requirements pre- and post-test check of load cell

Test Objectives Determine engine and nozzle performance with subsonic combustion and demonstrate transition

Work Statement Ref. 5.2.1.4.3 (6)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Fuel will be admitted in accordance with fuel schedule No. 5 on the next page. The inlet will be set at ΔX = 4.23.

FUEL SCHEDULE NO. 5

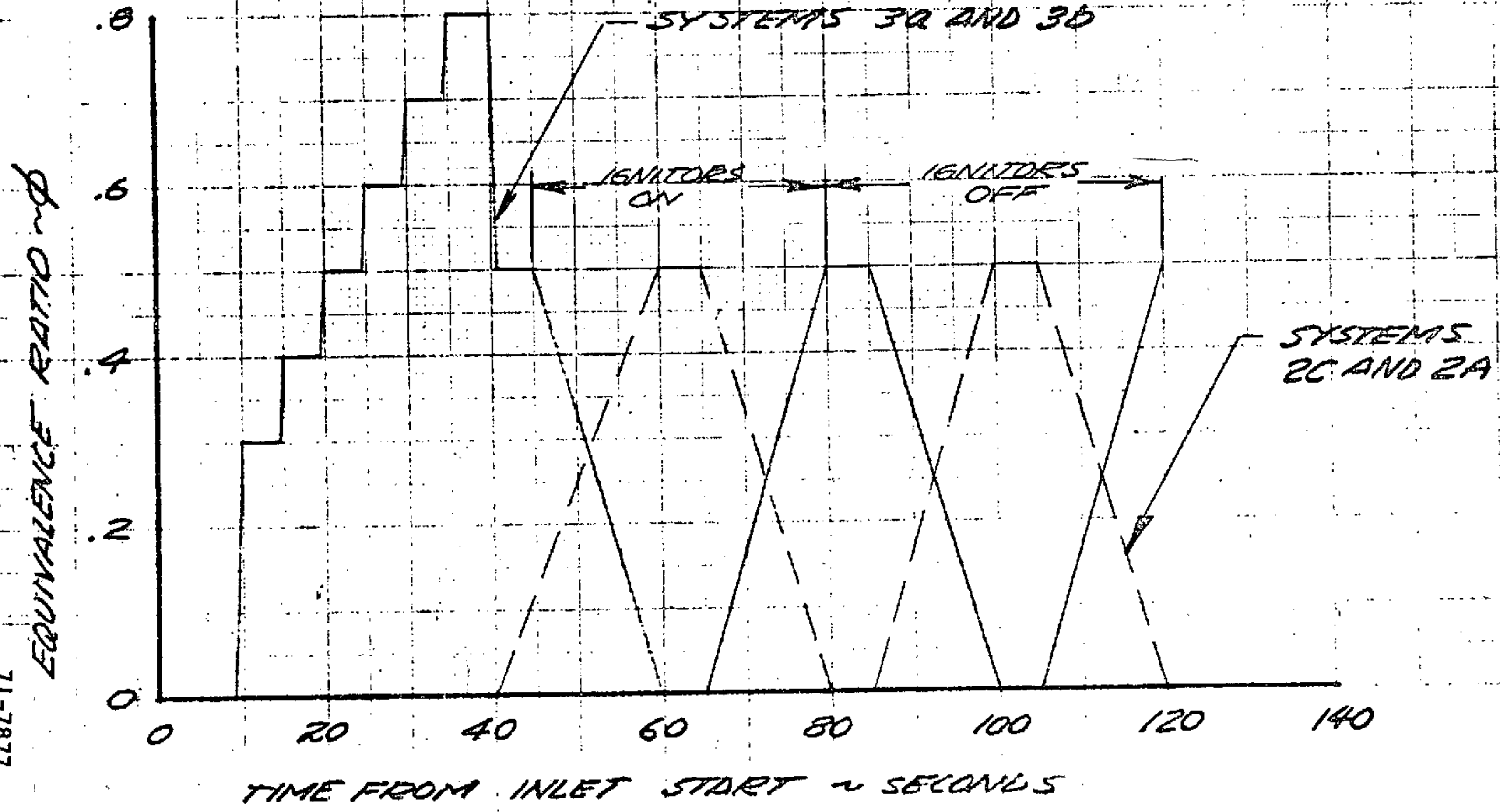


TABLE 8-2 (Continued)

RUN 20 TEST I.D. NO. ICN6-2 Change Ltr. N/C

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ___ Record Code 4 Red Line Code ___

Data Reduction Code 4 Special Data Req. ___

See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ___ psia Special Requirements ___

Test Objectives Determine engine and nozzle performance with supersonic combustion

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 2 on the next page.

FUEL SCHEDULE NO. 2

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	4.23		0		0		0		0				-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.12		0.11		0		0				-	-	-
25	4.23		0.14		0.12		0		0				-	-	-
30	4.23		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.27		0.27				-	-	-
45	4.23		0.06		0.06		0.44		0.44				-	-	-
50	4.23		0.06		0.06		0.59		0.59				-	-	-
55	4.23		0.06		0.06		0.69		0.69				-	-	-
60	4.23		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.16		0.16				-	-	-
75	4.23		0.09		0.09		0.26		0.26				-	-	-
80	4.23		0.09		0.09		0.33		0.33				-	-	-
85	4.23		0.09		0.09		0.41		0.41				-	-	-
90	4.23		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.12		0.12		0.05		0.05				-	-	-
105	4.23		0.12		0.12		0.10		0.10				-	-	-
110	4.23		0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 21 TEST I.D. NO. ICN6-3 Change Ltr.

Facility Requirements

Mach No. 6 Total Pressure 466 psia Tot. Temp. 3000 °R

Data Requirements

Visual Code Record Code Red Line Code

Data Reduction Code 4 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. psia Special Requirements

Test Objectives Determine effect of altitude on engine and nozzle performance with supersonic combustion

Work Statement Ref. 5.2.1.4.3 - (6)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 2B on the next page.

FUEL SCHEDULE NO. 2B

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		2a		2c				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	4.23		0		0		0		0				-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.12		0.11		0		0				-	-	-
25	4.23		0.14		0.12		0		0				-	-	-
30	4.23		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.27		0.27				-	-	-
45	4.23		0.06		0.06		0.44		0.44				-	-	-
50	4.23		0.06		0.06		0.59		0.59				-	-	-
55	4.23		0.06		0.06		0.69		0.69				-	-	-
60	4.23		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.16		0.16				-	-	-
75	4.23		0.09		0.09		0.26		0.26				-	-	-
80	4.23		0.09		0.09		0.33		0.33				-	-	-
85	4.23		0.09		0.09		0.41		0.41				-	-	-
90	4.23		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.12		0.12		0.05		0.05				-	-	-
105	4.23		0.12		0.12		0.10		0.10				-	-	-
110	4.23		0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 22 TEST I.D. NO. ICN6-4 Change Ltr. NC

Facility Requirements

Mach No. 6 Total Pressure 930 psia Tot. Temp. 2946 °R

Data Requirements

Visual Code ___ Record Code 4 Red Line Code ___

Data Reduction Code 4 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter no Nozzle Probes: P_T no Gas S. no

N_2 Purge Req. ___ psia Special Requirements ___

Test Objectives Effect of angle of attack on engine and nozzle performance with supersonic combustion

Work Statement Ref. 5.2.1.4.3-9

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 2G on the next page.

FUEL SCHEDULE NO. 2G

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	4.23		0		0		0		0				-	-	-
10	4.23		0.06		0.06		0		0				-	-	-
15	4.23		0.09		0.09		0		0				-	-	-
20	4.23		0.12		0.11		0		0				-	-	-
25	4.23		0.14		0.12		0		0				-	-	-
30	4.23		0.16		0.12		0		0				-	-	-
35	0		0		0		0		0				-	-	-
40	4.23		0.06		0.06		0.27		0.27				-	-	-
45	4.23		0.06		0.06		0.44		0.44				-	-	-
50	4.23		0.06		0.06		0.59		0.59				-	-	-
55	4.23		0.06		0.06		0.69		0.69				-	-	-
60	4.23		0.06		0.06		0.79		0.79				-	-	-
65	0		0		0		0		0				-	-	-
70	4.23		0.09		0.09		0.16		0.16				-	-	-
75	4.23		0.09		0.09		0.26		0.26				-	-	-
80	4.23		0.09		0.09		0.33		0.33				-	-	-
85	4.23		0.09		0.09		0.41		0.41				-	-	-
90	4.23		0.09		0.09		0.49		0.49				-	-	-
95	0		0		0		0		0				-	-	-
100	4.23		0.12		0.12		0.05		0.05				-	-	-
105	4.23		0.12		0.12		0.10		0.10				-	-	-
110	4.23		0.12		0.12		0.15		0.15				-	-	-
115	4.23		0.12		0.12		0.20		0.20				-	-	-
120		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 23 TEST I.D. NO. PF7-1 Change Ltr.

Facility Requirements

Mach No. 7 Total Pressure 520 psia Tot. Temp. 2500 °R

Data Requirements

Visual Code Record Code 1 Red Line Code

Data Reduction Code 1 Special Data Req.

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. psia Special Requirements Temporary cavity thermocouples installed

Test Objectives Determine force correction due to N_2 purge at Mach 7.0

Work Statement Ref. N/A

Critical Observation Requirements Same as PF6-1

PURGED CAVITY PRESSURES

Inlet, ΔX	Time, sec.	α	PAI	PBI

Time, sec.	Inlet, ΔX	α	PAI	PBI

TABLE 8-2 (Continued)

RUN 24 TEST I.D. NO. WC7-1 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 520 psia Tot. Temp. 3965 °R

Data Requirements

Visual Code______ Record Code 2 Red Line Code______

Data Reduction Code 2 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter Yes Nozzle Probes: P_T No Gas S. No

N_2 Purge Req.______ psia Special Requirements______

Test Objectives Airflow calibration at high altitude

Work Statement Ref. 5.2.1.4.2, 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Time From Tunnel Start, sec	Inlet ΔX, in.
0	0
10	2.34
40	2.88
70	3.24
100	Shutdown

TABLE 8-2 (Continued)

RUN 25 TEST I.D. NO. WC7-2 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code_____ Record Code 2 Red Line Code_____

Data Reduction Code 2 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter Yes Nozzle Probes: P_T No Gas S. No

N_2 Purge Req._____ psia Special Requirements_____

Test Objectives Airflow calibration, nominal case

Work Statement Ref. 5.2.1.4.2, 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Time From Tunnel Start, sec	Inlet ΔX, in.
0	0
10	1.98
40	2.88
70	3.24
100	Shutdown

TABLE 8-2 (Continued)

RUN 26 TEST I.D. NO. WC7-3 Change Ltr. N/C

Facility Requirements

Mach No. 7, $\alpha = 3^{\circ}$ Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code _____ Record Code 2 Red Line Code _____

Data Reduction Code 2 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter Yes Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. _____ psia Special Requirements Retrim innerbody and outerbody cooling circuit

Test Objectives Determine inlet pressure recovery and flow at 3 deg angle of attack

Work Statement Ref. 5.2.1.4.2, 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Time From Tunnel Start, sec	Inlet ΔX, in.
0	0
10	2.34
40	2.88
70	3.24
100	Shutdown

TABLE 8-2 (Continued)

RUN 27 TEST I.D. NO. IC7-1 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 520 and 1000 psia Tot. Temp. 3965 and 3840°R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements Retrim innerbody and outerbody cooling circuits

Test Objectives Inlet - combustor performance, ignition and inlet unstart limits

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 6 on the next page. If an inlet unstart occurs during ramp 1-2, the AiResearch test conductor will actuate an "unstart switch." This will shut off the fuel and shift the schedule to point 3 where the inlet is scheduled for restart. If an unstart is detected during ramp 5-6, the tunnel will be shut down.

Inlet $\Delta X = 2.88$

FIGURE 5 - FUEL SCHEDULE NO 6

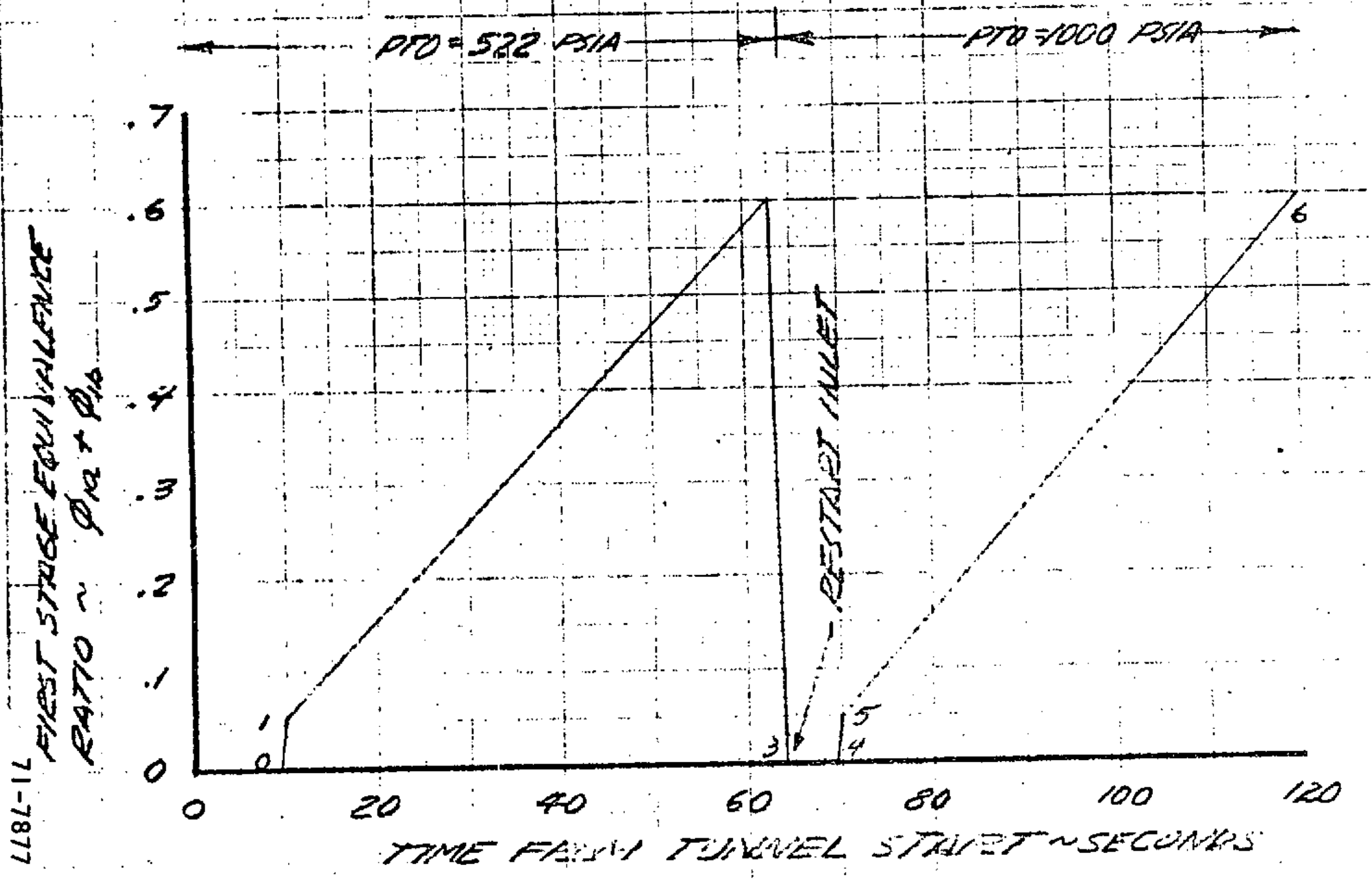


FIGURE 5

TABLE 8-2 (Continued)

RUN 28 TEST I.D. NO. IC7-2 Change Ltr.______

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code______ Record Code 3 Red Line Code______

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req.______ psia Special Requirements______

Test Objectives Inlet - combustor performance, injector optimization

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7 on the next page.

FUEL SCHEDULE NO. 7

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c						
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.14		0.14		0		0						
20	2.88		0.17		0.17		0		0						
25	2.88		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.14		0.14		0.16		0.16						
70	2.88		0.14		0.14		0.26		0.26						
75	2.88		0.14		0.14		0.36		0.36						
80	2.88		0.14		0.14		0.46		0.46						
85	2.88		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.88		0.17		0.17		0.13		0.13						
100	2.88		0.17		0.17		0.23		0.23						
105	2.88		0.17		0.17		0.33		0.33						
110	2.88		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 29 TEST I.D. NO. IC7-3 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Inlet - combustor performance, injector optimization

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7A on the next page.

FUEL SCHEDULE NO. 7A

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1c		4		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.14		0.14		0		0						
20	2.88		0.17		0.17		0		0						
25	2.88		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.14		0.14		0.16		0.16						
70	2.88		0.14		0.14		0.26		0.26						
75	2.88		0.14		0.14		0.36		0.36						
80	2.88		0.14		0.14		0.46		0.46						
85	2.88		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.88		0.17		0.17		0.13		0.13						
100	2.88		0.17		0.17		0.23		0.23						
105	2.88		0.17		0.17		0.33		0.33						
110	2.88		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 30 TEST I.D. NO. IC7-4 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code____ Record Code 3 Red Line Code____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req.____ psia Special Requirements____

Test Objectives Inlet - combustor performance, injector optimization

Work Statement Ref. 5.2.1.4.3 (4)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 8 on the next page.

FUEL SCHEDULE NO. 8

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		1c		4				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.125		0.125		0		0						
20	2.88		0.15		0.15		0		0						
25	2.88		0.175		0.175		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.125		0.125		0.175		0.175						
70	2.88		0.125		0.125		0.275		0.275						
75	2.88		0.125		0.125		0.375		0.375						
80	2.88		0.125		0.125		0.475		0.475						
85	2.88		0.125		0.125		0.625		0.625						
90	0		0		0		0		0						
95	2.88		0.15		0.15		0.15		0.15						
100	2.88		0.15		0.15		0.25		0.25						
105	2.88		0.15		0.15		0.35		0.35						
110	2.88		0.15		0.15		0.45		0.45						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 31 TEST I.D. NO. IC7-5 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Inlet - combustor performance, injector optimization

Work Statement Ref. 5.2.1.4.3 (4)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Fuel schedule to be determined from previous test results.

TABLE 8-2 (Continued)

RUN 32 TEST I.D. NO. IC7-6 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 520 psia Tot. Temp. 3965 °R

Data Requirements

Visual Code ______ Record Code 3 Red Line Code ______

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ______ psia Special Requirements ______

Test Objectives Inlet - combustor performance, effect of altitude

Work Statement Ref. 5.2.1.4.3 (4)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7B on the next page.

FUEL SCHEDULE NO. 7B

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.14		0.14		0		0						
20	2.88		0.17		0.17		0		0						
25	2.88		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.14		0.14		0.16		0.16						
70	2.88		0.14		0.14		0.26		0.26						
75	2.88		0.14		0.14		0.36		0.36						
80	2.88		0.14		0.14		0.46		0.46						
85	2.88		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.88		0.17		0.17		0.13		0.13						
100	2.88		0.17		0.17		0.23		0.23						
105	2.88		0.17		0.17		0.33		0.33						
110	2.88		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 33
TEST I.D. NO. IC7-6
Change Ltr. N/C

Facility Requirements

Mach No. 7
Total Pressure 700 psia
Tot. Temp. 3965 °R

Data Requirements

Visual Code
Record Code 3
Red Line Code
Data Reduction Code 3
Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No
Nozzle Probes: P_T Yes
Gas S. Yes
N_2 Purge Req. psia
Special Requirements

Test Objectives Inlet - combustor performance, effect of altitude

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7C on the next page.

FUEL SCHEDULE NO. 7C

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c						
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.14		0.14		0		0						
20	2.88		0.17		0.17		0		0						
25	2.88		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.14		0.14		0.16		0.16						
70	2.88		0.14		0.14		0.26		0.26						
75	2.88		0.14		0.14		0.36		0.36						
80	2.88		0.14		0.14		0.46		0.46						
85	2.88		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.88		0.17		0.17		0.13		0.13						
100	2.88		0.17		0.17		0.23		0.23						
105	2.88		0.17		0.17		0.33		0.33						
110	2.88		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 34 TEST I.D. NO. IC7-7 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code____ Record Code 3 Red Line Code____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req.____ psia Special Requirements____

Test Objectives Inlet - combustor performance, effect of spike position

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7D on the next page.

FUEL SCHEDULE NO. 7D

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		2a		2c				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	0		0		0		0		0						
10	3.24		0.1		0.1		0		0						
15	3.24		0.14		0.14		0		0						
20	3.24		0.17		0.17		0		0						
25	3.24		0.20		0.20		0		0						
30	0		0		0		0		0						
35	3.24		0.1		0.1		0.2		0.2						
40	3.24		0.1		0.1		0.3		0.3						
45	3.24		0.1		0.1		0.4		0.4						
50	3.24		0.1		0.1		0.5		0.5						
55	3.24		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	3.24		0.14		0.14		0.16		0.16						
70	3.24		0.14		0.14		0.26		0.26						
75	3.24		0.14		0.14		0.36		0.36						
80	3.24		0.14		0.14		0.46		0.46						
85	3.24		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	3.24		0.17		0.17		0.13		0.13						
100	3.24		0.17		0.17		0.23		0.23						
105	3.24		0.17		0.17		0.33		0.33						
110	3.24		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 35 TEST I.D. NO. IC7-8 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code _____ Record Code 3 Red Line Code _____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. _____ psia Special Requirements _____

Test Objectives Inlet - combustor performance, effect of spike position

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7E on the next page.

FUEL SCHEDULE NO. 7E

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	0		0		0		0		0						
10	2.34		0.1		0.1		0		0						
15	2.34		0.14		0.14		0		0						
20	2.34		0.17		0.17		0		0						
25	2.34		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.34		0.1		0.1		0.2		0.2						
40	2.34		0.1		0.1		0.3		0.3						
45	2.34		0.1		0.1		0.4		0.4						
50	2.34		0.1		0.1		0.5		0.5						
55	2.34		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.34		0.14		0.14		0.16		0.16						
70	2.34		0.14		0.14		0.26		0.26						
75	2.34		0.14		0.14		0.36		0.36						
80	2.34		0.14		0.14		0.46		0.46						
85	2.34		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.34		0.17		0.17		0.13		0.13						
100	2.34		0.17		0.17		0.23		0.23						
105	2.34		0.17		0.17		0.33		0.33						
110	2.34		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 36 TEST I.D. NO. IC7-9 Change Ltr. N/C

Facility Requirements

Mach No. 7, Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code______ Record Code 3 Red Line Code______

Data Reduction Code 3 Special Data Req. See inst. list

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req.______ psia Special Requirements______

Test Objectives Inlet - combustor performance, effect of spike position

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7F on the next page.

FUEL SCHEDULE NO. 7F

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	0		0		0		0		0						
10	1.98		0.1		0.1		0		0						
15	1.98		0.14		0.14		0		0						
20	1.98		0.17		0.17		0		0						
25	1.98		0.20		0.20		0		0						
30	0		0		0		0		0						
35	1.98		0.1		0.1		0.2		0.2						
40	1.98		0.1		0.1		0.3		0.3						
45	1.98		0.1		0.1		0.4		0.4						
50	1.98		0.1		0.1		0.5		0.5						
55	1.98		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	1.98		0.14		0.14		0.16		0.16						
70	1.98		0.14		0.14		0.26		0.26						
75	1.98		0.14		0.14		0.36		0.36						
80	1.98		0.14		0.14		0.46		0.46						
85	1.98		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	1.98		0.17		0.17		0.13		0.13						
100	1.98		0.17		0.17		0.23		0.23						
105	1.98		0.17		0.17		0.33		0.33						
110	1.98		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 37   TEST I.D. NO. ICN-1   Change Ltr. N/C

Facility Requirements

Mach No. 7   Total Pressure 1000 psia   Tot. Temp. 3840 °R

Data Requirements

Visual Code ____   Record Code 3   Red Line Code ____

Data Reduction Code 3   Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No   Nozzle Probes: P_T Yes   Gas S. Yes

N_2 Purge Req. ____ psia   Special Requirements ____

Test Objectives Supersonic combustion engine performance

Work Statement Ref. 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7 on the next page.

FUEL SCHEDULE NO. 7

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			ϕ	W_f, lb/sec	ϕ	W_f, lb/sec	ϕ	W_f, lb/sec	ϕ	W_f, lb/sec	ϕ	W_f, lb/sec			
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.14		0.14		0		0						
20	2.88		0.17		0.17		0		0						
25	2.88		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.14		0.14		0.16		0.16						
70	2.88		0.14		0.14		0.26		0.26						
75	2.88		0.14		0.14		0.36		0.36						
80	2.88		0.14		0.14		0.46		0.46						
85	2.88		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.88		0.17		0.17		0.13		0.13						
100	2.88		0.17		0.17		0.23		0.23						
105	2.88		0.17		0.17		0.33		0.33						
110	2.88		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 38 TEST I.D. NO. ICN-2 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 520 psia Tot. Temp. 3965 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Supersonic combustion engine performance, effect of altitude

Work Statement Ref. 5.2.1.4.3(2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7G on the next page.

FUEL SCHEDULE NO. 7G

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			1a		1b		2a		2c				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.14		0.14		0		0						
20	2.88		0.17		0.17		0		0						
25	2.88		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.14		0.14		0.16		0.16						
70	2.88		0.14		0.14		0.26		0.26						
75	2.88		0.14		0.14		0.36		0.36						
80	2.88		0.14		0.14		0.46		0.46						
85	2.88		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.88		0.17		0.17		0.13		0.13						
100	2.88		0.17		0.17		0.23		0.23						
105	2.88		0.17		0.17		0.33		0.33						
110	2.88		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 39 TEST I.D. NO. ICN-3 Change Ltr. N/C

Facility Requirements

Mach No. 7 Total Pressure 1000 psia Tot. Temp. 3840 °R

Data Requirements

Visual Code____ Record Code 3 Red Line Code____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req.____ psia Special Requirements____

Test Objectives Supersonic combustion engine performance, effect of angle of attack

Work Statement Ref. 5.2.1.4.3(2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 7H on the next page.
Angle of attack = 3 deg

FUEL SCHEDULE NO. 7H

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			1a		1b		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	0		0		0		0		0						
10	2.88		0.1		0.1		0		0						
15	2.88		0.14		0.14		0		0						
20	2.88		0.17		0.17		0		0						
25	2.88		0.20		0.20		0		0						
30	0		0		0		0		0						
35	2.88		0.1		0.1		0.2		0.2						
40	2.88		0.1		0.1		0.3		0.3						
45	2.88		0.1		0.1		0.4		0.4						
50	2.88		0.1		0.1		0.5		0.5						
55	2.88		0.1		0.1		0.65		0.65						
60	0		0		0		0		0						
65	2.88		0.14		0.14		0.16		0.16						
70	2.88		0.14		0.14		0.26		0.26						
75	2.88		0.14		0.14		0.36		0.36						
80	2.88		0.14		0.14		0.46		0.46						
85	2.88		0.14		0.14		0.61		0.61						
90	0		0		0		0		0						
95	2.88		0.17		0.17		0.13		0.13						
100	2.88		0.17		0.17		0.23		0.23						
105	2.88		0.17		0.17		0.33		0.33						
110	2.88		0.17		0.17		0.43		0.43						
115		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 40 TEST I.D. NO. PF5-1 Change Ltr. N/C

Facility Requirements

Mach No. 5 Total Pressure 415 psia Tot. Temp. 1500 °R

Data Requirements

Visual Code ______ Record Code 1 Red Line Code ______

Data Reduction Code ______ Special Data Req. Temporary cavity thermocouples installed.

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ______ psia Special Requirements Temporary cavity thermocouples installed.

Test Objectives Determine force correction due to N_2 purge at Mach 5

Work Statement Ref. N/A

Critical Observation Requirements Same as PF6-1

PURGED CAVITY PRESSURES

Time, sec.	Inlet, ΔX	α	PA1	PB1
	4.23	0		

Time, sec.	Inlet, ΔX	α	PA1	PB1
	4.23	0		

TABLE 8-2 (Continued)

RUN 41 TEST I.D. NO. WC5-1 Change Ltr. N/C

Facility Requirements

Mach No. 5 Total Pressure 206-415 psia Tot. Temp. 2210 °R

Data Requirements

Visual Code ______ Record Code 2 Red Line Code ______

Data Reduction Code 2 Special Data Req. See inst. list

Test Model Setup

Air Flow Meter Yes Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ______ psia Special Requirements Retrim innerbody and outerbody cooling circuit.

Test Objectives Airflow calibration

Work Statement Ref. 5.2.1.4.2, 5.2.1.4.3 (2)

Critical Observation Requirements Same as WC6-1

AIM Operating Conditions

Operating conditions are defined on the chart below. If the inlet unstarts between 0 and 70 sec, the alternate schedule will be selected by actuating the "unstart switch."

Schedule	Time From Tunnel Start, sec	Inlet ΔX, in.	PTO, psia
1st	0	0	206
	10	4.23	206
	40	4.23	206
	70	4.23	415
	100	Shutdown	
Alternate	0	0	415
	5	3.68	415
	35	3.25	415
	65	Shutdown	

TABLE 8-2 (Continued)

RUN 42 TEST I.D. NO. ICN5-1 Change Ltr. N/C

Facility Requirements

Mach No. 5 Total Pressure 415 psia Tot. Temp. 2210 °R

Data Requirements

Visual Code _____ Record Code 4 Red Line Code _____

Data Reduction Code 4 Special Data Req. See inst. list

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. _____ psia Special Requirements _____

Test Objectives Engine performance, subsonic combustion

Work Statement Ref. 5.2.1.4.3 (6)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 10 on the next page.

FUEL SCHEDULE NO. 10

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			3a		3b								System		
			ϕ	W_f, lb/sec	ϕ	W_f, lb/sec	ϕ	W_f, lb/sec	ϕ	W_f, lb/sec	ϕ	W_f, lb/sec	1	2	3
0	0		0		0										
10	4.23		0.2		0.2										220
15	4.23		0.3		0.3								Extinguish when combustor lit		
20	4.23		0.4		0.4										
25	4.23		0.5		0.5										
30	4.23		0.6		0.6										
35	4.23		0.7		0.7										
40	4.23		0.8		0.8										
45	0		0		0										
50	4.23		0.5		0.5										220
55	4.23		0.5		0.5										Off
		Linear 20 sec ramp from ϕ = 0.5 to 0.1													Off
75	4.23		0.1		0.1										Off
75		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 43 TEST I.D. NO. ICN-2 Change Ltr. N/C

Facility Requirements

Mach No. 5 Total Pressure 415 psia Tot. Temp. 2210 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. See inst. list

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements Retrim innerbody and outerbody cooling circuit.

Test Objectives Engine performance, subsonic and supersonic combustion - effect of angle of attack

Work Statement Ref. ____

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. II on the next page.

Angle of attack = 5 deg

FUEL SCHEDULE NO. 11

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			3a		3b		4		1c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	0		0		0										
9	4.23		0		0										
10	4.23		0.2		0.2										220
15	4.23		0.3		0.3								Extinguish		
20	4.23		0.4		0.4								when		
25	4.23		0.5		0.5								combustor		
30	4.23		0.6		0.6								lit		
35	4.23		0.7		0.7										
40	4.23		0.8		0.8										
45	0		0		0										
50	4.23		0		0		0.025		0.025				220		
55	4.23		0		0		0.0375		0.0375				220		
60	4.23		0		0		0.05		0.05				220		
65	4.23		0		0		0.0625		0.0625				220		
70	4.23		0		0		0.075		0.075				220		
75	4.23		0		0		0.0875		0.0875				220		
80		SHUTDOWN													

TABLE 8-2 (Continued)

RUN 44 TEST I.D. NO. IC5-1 Change Ltr. N/C

Facility Requirements

Mach No. 5 Total Pressure 415 psia Tot. Temp. 2210 °R

Data Requirements

Visual Code ____ Record Code 3 Red Line Code ____

Data Reduction Code 3 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req. ____ psia Special Requirements ____

Test Objectives Inlet - combustor performance, supersonic combustion

Work Statement Ref. 5.2.1.4.2.1 (2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule No. 9 on the next page.

FUEL SCHEDULE NO. 9

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System												
			4		1c		2a		2c				System		
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	1	2	3
0	4.23		0.025		0.025		0		0						
10	4.23		0.037		0.037		0		0						
15	4.23		0.05		0.05		0		0						
20	4.23		0.062		0.062		0		0						
25	4.23		0.075		0.075		0		0						
30	4.23		0.087		0.087		0		0						
35	0		0		0		0		0						
40	4.23		0.025		0.025		0.0625		0.0625						
45	4.23		0.025		0.025		0.112		0.112						
50	4.23		0.025		0.025		0.162		0.162						
55	4.23		0.025		0.025		0.212		0.212						
60	4.23		0.025		0.025		0.262		0.262						
65	4.23		0.025		0.025		0.312		0.312						
70	0		0		0		0		0						
75	4.23		0.0375		0.0375		0.05		0.05						
80	4.23		0.0375		0.0375		0.10		0.10						
85	4.23		0.0375		0.0375		0.15		0.15						
90	4.23		0.0375		0.0375		0.2		0.2						
95	4.23		0.0375		0.0375		0.25		0.25						
100	0		0		0		0		0						
105	4.23		0.05		0.05		0.05		0.05						
110	4.23		0.05		0.05		0.087		0.087						
115	4.23		0.05		0.05		0.125		0.125						
120	4.23		0.05		0.05		0.162		0.162						
125	4.23		0.05		0.05		0.200		0.200						
130	0		0		0		0		0						
135	4.23		0.0625		0.0625		0.037		0.037						
140	4.23		0.0625		0.0625		0.075		0.075						
145	4.23		0.0625		0.0625		0.112		0.112						
150	4.23		0.0625		0.0625		0.150		0.15						
155	0		0		0		0		0						
160	4.23		0.075		0.075		0.025		0.025						
165	4.23		0.075		0.075		0.05		0.05						
170	4.23		0.075		0.075		0.075		0.075						
175		SHUTDOWN													
180															

TABLE 8-2 (Continued)

RUN 45 TEST I.D. NO. IC5-2 Change Ltr. N/C

Facility Requirements

Mach No. 5 Total Pressure 206 psia Tot. Temp. 2248 °R

Data Requirements

Visual Code____ Record Code 3 Red Line Code____

Data Reduction Code 3 Special Data Req.____

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T Yes Gas S. Yes

N_2 Purge Req.____ psia Special Requirements____

Test Objectives Inlet - combustor performance, supersonic combustion, effect of ignitor pressure. Spot check altitude performance

Work Statement Ref. 5.2.1.4.2.1 (2)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions will be selected based on previous tests. Ignitor pressure will be varied between 50 and 250 psia.

TABLE 8-2 (Continued)

RUN 46 TEST I.D. NO. IC5-3 Change Ltr. N/C

Facility Requirements

Mach No. 5 Total Pressure 415 psia Tot. Temp. 2210 °R

Data Requirements

Visual Code ______ Record Code 4 Red Line Code ______

Data Reduction Code 4 Special Data Req. See inst. plan

Test Model Setup

Air Flow Meter No Nozzle Probes: P_T No Gas S. No

N_2 Purge Req. ______ psia Special Requirements ______

Test Objectives Engine performance, supersonic combustion

Work Statement Ref. 5.2.1.4.3(6)

Critical Observation Requirements Same as OC6-1

AIM Operating Conditions

Operating conditions are defined on fuel schedule 9 on the next page.

FUEL SCHEDULE NO. 9

Time From Inlet Start, sec	Inlet ΔX, in.	Airflow, lb/sec	Fuel Flow										Ignitor Manifolds H_2O & O_2 Press., psia		
			System										System		
			4		1c		2a		2c				1	2	3
			φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec	φ	W_f, lb/sec			
0	4.23		0.025		0.025		0		0						
10	4.23		0.037		0.037		0		0						
15	4.23		0.05		0.05		0		0						
20	4.23		0.062		0.062		0		0						
25	4.23		0.075		0.075		0		0						
30	4.23		0.087		0.087		0		0						
35	0		0		0		0		0						
40	4.23		0.025		0.025		0.0625		0.0625						
45	4.23		0.025		0.025		0.112		0.112						
50	4.23		0.025		0.025		0.162		0.162						
55	4.23		0.025		0.025		0.212		0.212						
60	4.23		0.025		0.025		0.262		0.262						
65	4.23		0.025		0.025		0.312		0.312						
70	0		0		0		0		0						
75	4.23		0.0375		0.0375		0.05		0.05						
80	4.23		0.0375		0.0375		0.10		0.10						
85	4.23		0.0375		0.0375		0.15		0.15						
90	4.23		0.0375		0.0375		0.2		0.2						
95	4.23		0.0375		0.0375		0.25		0.25						
100	0		0		0		0		0						
105	4.23		0.05		0.05		0.05		0.05						
110	4.23		0.05		0.05		0.087		0.087						
115	4.23		0.05		0.05		0.125		0.125						
120	4.23		0.05		0.05		0.162		0.162						
125	4.23		0.05		0.05		0.200		0.200						
130	0		0		0		0		0						
135	4.23		0.0625		0.0625		0.037		0.037						
140	4.23		0.0625		0.0625		0.075		0.075						
145	4.23		0.0625		0.0625		0.112		0.112						
150	4.23		0.0625		0.0625		0.150		0.15						
155	0		0		0		0		0						
160	4.23		0.075		0.075		0.025		0.025						
165	4.23		0.075		0.075		0.05		0.05						
170	4.23		0.075		0.075		0.075		0.075						
175		SHUTDOWN													
180															

ROW	STA	ANGULAR LOCATION, DEG						ORIENTATION OF IGNITOR ℄ IN RESPECT TO UNIT ℄
1	42.0	55	110	165	230	290	350	4° 30' CLOCKWISE LOOKING FROM LEFT SIDE
2	50.98	40	100	220	-	280	240	30° 0' FWD, 30° 0' CLOCKWISE LOOKING FWD FROM AFT
3	54.38	10	70	130	190	250	310	30° 0' AFT, 30° 3' CLOCKWISE LOOKING FWD FROM AFT

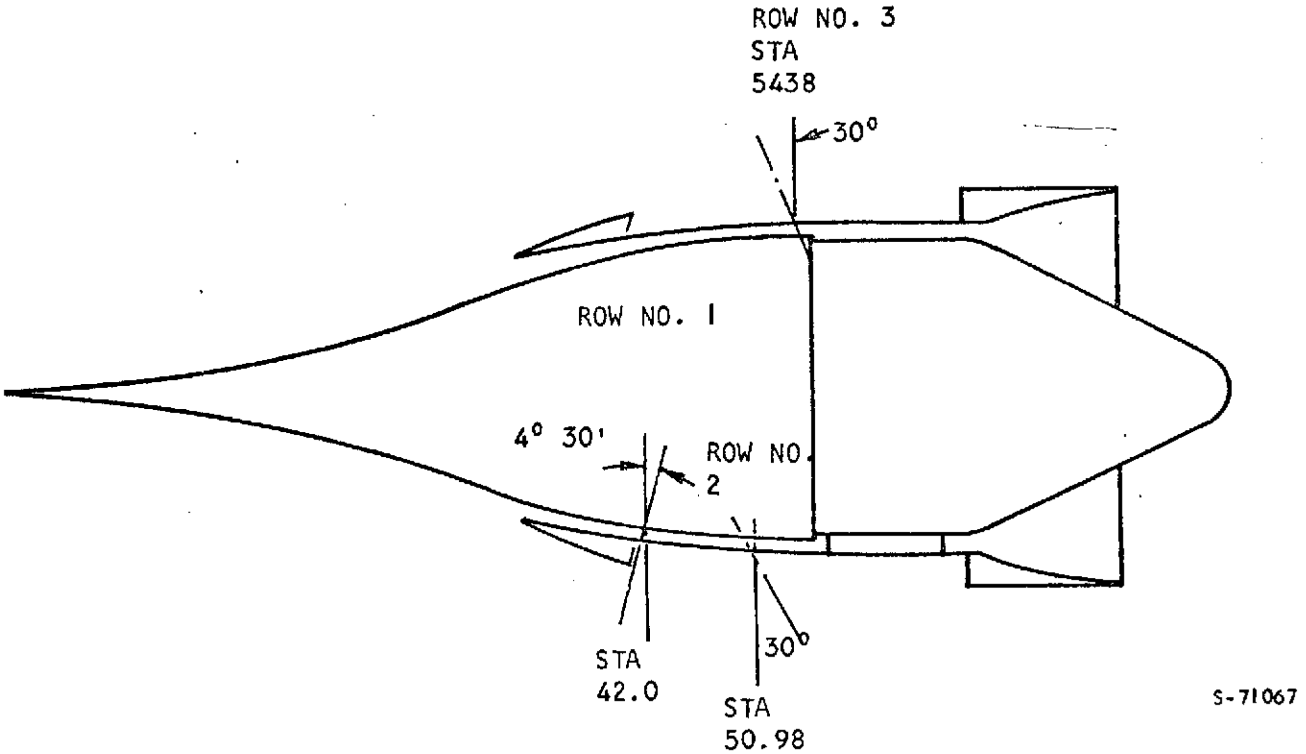


Figure 8-1. Location of Ignitors

(b) Record Code--This code defines the instrumentation to be connected to the SEL data acquisition system and visual readouts in the control room. The instrumentation corresponding to each code number is defined on the instrumentation list given in Table 4-1.

(c) Red Line Code--This code defines the red line conditions for the test. Red line conditions are the same for all tests as they are now defined in Table 8-3. If different red line conditions are found necessary during the course of the tests, an entry made under this heading will define the new conditions.

(d) Data Reduction Code--This code defines the parameters to be printed on the data reduction program printout. The parameters corresponding to each code number are defined on the data listing sheets in Table 1-1, Appendix A.

8.3 TEST MODEL SETUP

The entries under this heading are defined below.

(a) Airflow Meter--A YES entry specified that the AIM exhaust nozzle is replaced by the air metering duct, PN 95804. A NO entry specifies that the exhaust nozzle is installed.

(b) Combustor Exit Rake--A YES entry specifies that the combustor exit rake, PN 950592 is installed.

(c) Nitrogen Purge Code--This code defines the pressures to be set in the purged cavities. The values of pressure corresponding to each code number will be defined after the nitrogen purge calibration tests are performed.

8.4 CRTICAL OBSERVATION REQUIREMENTS

The visual instrumentation displays which require special attention during the test are designated under this heading.

8.5 AIM OPERATING CONDITIONS

The fuel schedule, inlet position, and ignitor manifold pressure schedule are defined. Nitrogen purge pressures are also defined here for the purge system tests.

Fuel schedules are numbered according to equivalence ratio. All fuel schedules having the same designation number have the same equivalence ratio schedule versus time. A suffix letter is added to the number when a different fuel injector combination or a different fuel flow is used. The fuel flow columns will be filled out after the AIM airflow is determined from the airflow meter tests.

The ramp rates during all full control valve closing and opening sequences shall be 50 percent per sec. In cases where the inlet is called for to move from the closed positions and fuel to be admitted simultaneously (see Run 9 at 40 sec for an example) the inlet will be allowed to reach the open position before fuel is admitted.

TABLE 8-3

RED LINE LIMITS

I SYSTEMS

Item No.	Measurement No.	Item	Limits
1	*17-F through 32-F	Fuel injector manifold temp	13°F
2	**1-F through 15-F	Fuel injector manifold press.	See paragraph 6.4.4
	33-F, 35-F, 37-F	Ignitor system H_2, O_2	300 psia
3		Purge system	
	89-F	Pressure	40 psia
	90-F	Temperature	125°F
	85-F	Outer cowl body	20 psia across seal (PA-PB)

*Use the temperature with the odd measurement number in each manifold.
**Use the pressure with the odd measurement number in each manifold.

II SKIN TEMPERATURES

Item No.	Measurement No.	Component	Thermocouple Location, Station	Estimated Temperature, °F	Shutdown Temp, °F	Notes
1	54-C	Cowl leading edge outer surface	37.0	350	700	Monitor CLE
2	5-0	Outer shell	43.8	550	1200	Possible shock impingement area
3	43-0		46.5	1100	1300	Possible shock impingement are
4	49-0		49.0	1100	1300	Combustion zone
5	49-S	Centerbody	40.0	600	1200	Shock impingement
6	51-S		45.0	1000	1200	Combustor zone
7	13-I		60.0	400	1000	

III COOLANT PRESSURES

Item No.	Measurement No.	Component	Maximum Pressure, psia	Minimum Pressure, psia
1	42-F	Centerbody	225	180
2	45-F	Outerbody	240	190
3	43-F	Strut leading edge	425	330
4	44-F	Strut body	350	245
5	41-F	Spike tip	300	205
6	47-F	Outer cowl, forward	200	125
7	48-F	Outer cowl, center	200	100
8	46-F	Outer cowl, leading edge	300	235
9	49-F	Outer cowl, aft	200	120

9. WIND TUNNEL TEST PROCEDURES

9.1 PRE-RUN PROCEDURES

Pre-run procedures related to the facility will be defined by the responsible facility personnel. The procedures directly related to the AIM are defined below. A pretest check list containing both facility and AIM items will be made by a coordinated effort of AiResearch and NASA personnel.

9.1.1 Inlet Spike Position Calibration

The inlet spike position LVDT will be calibrated before each run. The spike position will be detected using a translating optical sighting device which views scribed reference marks on the inlet spike. The spike position will be sighted at six settings, including the latched position. The corresponding voltage readings on the ISACS control will be recorded. The resulting data will be input into the data reduction computer program. A constant 0.383 in. will be added to the measured translation distances to obtain consistency with definitions used in the computer program. The associated relationships are defined in Appendix A. Details of the calibration procedure will be established during test setup. The hydraulic fluid inlet pressure (Measurement No. 64-F) will be verified to be 3000 ±50 psig before testing.

9.1.2 Load Cell Calibration

The thrust balance load cell will be calibrated as defined in Section 6.5.1 before each run. A schedule with less frequent calibrations or spot checks may be adapted if the calibrations prove repeatable. A record will be maintained of load cell readings during the pre-run proceedings. This will provide a measurement of the force increments, if any, due to cell evacuation, heating of fuel lines, introduction of nitrogen purge, and pressurization of the cooling system. A similar post run procedure will be used as the systems are turned off. A "zero reading" with no forces applied must be obtained before and after each run to check for load cell drift.

9.1.3 Fuel Control Valve Check

The fuel control valves will be actuated before each run to check for proper functioning.

9.1.4 Ignitor Purge and System Check

For cases when ignitors are used, dry nitrogen gas shall be supplied through the ignitor hydrogen supply line at 5 psig at a temperature of 100^0 to 125^0F for 1/2 hr within 2 hr before testing. The above conditions pertain to the AIM facility interface station. Nitrogen will be admitted to the oxygen system prior to testing and the manifold pressure monitored to check for proper valve operation. The ignitor spark system will be turned on for three sec to check for an audible noise signal. Prolonged spark bursts with no ignitor flow are to be avoided to prevent overheating the ignitor electrodes.

9.1.5 Fuel System Purge and Preheat

The AIM fuel manifolds to be used during the run will be preheated by flowing nitrogen through the fuel heater bed and downstream piping. The flow rate will be 1 lb/min per manifold for 10 min immediately before testing.

The fuel system purge must be applied up to the time that the hydrogen is admitted during tests. The purge nitrogen will prevent the incoming hydrogen from mixing with air in the fuel system.

A purge will be applied to each system immediately following its use with hydrogen. The water cooling and cavity purge nitrogen systems must be on during fuel system preheating. A reduced water inlet pressure of 25 psig may be applied during this period to conserve the expendable water supply. The innerbody cavity nitrogen pressure will be set at 10 psig and the outerbody cavities at 5 psig during fuel system heating. The innerbody cavity temperature, Measurement No. 90-F in Table 4-1, will be monitored during the preheat. Preheat will be terminated immediately, should this temperature exceed 125°F.

9.1.6 Cooling System Conditions

The water cooling flow will be set and the system inlet and discharge pressures verified to be consistent with the values established in Section 6.1.

9.1.7 Nitrogen Purge System Conditions

The purged cavity nitrogen pressures will be set to the values defined on the test requirement sheets defined in Section 7. Pressures will be set after the cell has been evacuated and before wind tunnel flow has been established.

9.1.8 Data Acquisition Check

The data acquisition system will be recording at the following conditions to provide a cross check on pressure and temperature readings.

(a) Before run with cell at ambient conditions

(b) During and after cell evacuation with no wind tunnel flow

(c) After run with cell evacuated and no tunnel flow

(d) During and after period while the cell is restored to ambient pressure

Further data recording considerations during shutdown are discussed in Section 9.3.1.

9.1.9 Intercom System Tape Recording

Voice communication on the intercom system will be tape recorded during prerun, run, and shutdown operations.

9.2 RUN PROCEDURES

The facility director shall be responsible for establishing the tunnel conditions specified on the test requirement sheet. He shall also verify that the tunnel is started and the target flow conditions set. The tape control system will then be started. This system will automatically set the inlet spike, fuel, and ignitor system conditions specified on the test requirement sheet. The following procedures will be followed during the test.

9.2.1 Inlet Start

The spike will be at the maximum forward position during tunnel start. When the tape control is started, the spike will stroke to the RUN position. The test conductor will then have 10 sec to verify that the inlet has started before fuel is admitted. Cowl and spike pressure distributions, load cell reading, and the Schlieren image will be criteria for a started condition. If the inlet does not start the test conductor will recycle the start procedure using a switch on the tape control panel.

9.2.2 Test Conditions

The tape control will set the AIM operating conditions specified on the test definition sheet. The test conductor will follow the procedures given in the following paragraph depending on the type of run.

9.2.2.1 Nitrogen Purge and Operational Checkout System Tests

The tape control will set the purged cavity pressures defined on the test requirement sheet. The cavity pressures programmed into the tape control will be established based on the results of the static calibration defined in Section 6.5.5.1. The control will set high cavity pressures first and proceed toward lower values. The test conductor will monitor cavity temperatures which will serve as an indication of hot gas entering the purged cavities. If the cavity temperature is seen to increase when low cavity pressure points are set, the tape control will be stepped to the next data point having a higher pressure. The stepping will be accomplished with a switch in the control room. The facility director must be on alert for tunnel unstart during these runs.

9.2.2.2 Runs With Combustion

The tape control will set the fuel/air ratios specified on the first schedule on the test definition sheets. The test conductor will monitor the AIM wall pressures and temperatures for indications of a combustor unlit or inlet unstart condition. Extended operation at the above condition is to be avoided to prevent uneconomical usage of tunnel time. Also, combustion with the inlet unstarted is to be avoided to prevent possible damage to the test equipment. If an undesirable condition is detected, corrective action will be taken with an appropriate input into the tape control. Two switches on the control panel labeled STEP and SKIP are provided for selection of alternate fuel schedules. The STEP switch will select the next higher fuel/air ratio on the existing schedule. This switch is intended to be used in the case where a combustor unlit condition is observed. This is expected to occur at some low fuel/air ratio points. The test conductor will use the switch to select the next highest fuel/air ratio and then recheck for a lit condition. The SKIP switch will be used to select the alternate fuel injection location and schedule. This procedure will be used in the event of an inlet unstart due to an excessively high fuel/air ratio. The alternate fuel injection location will be more favorable from inlet unstart considerations. Actuation of the SKIP switch stops hydrogen flow to the system in use and initiates the automatic transfer procedure to the alternate system. The system in use and the alternate system are both purged with nitrogen. Hydrogen is then admitted to the alternate fuel manifold and the first fuel/air ratio in the alternate fuel schedule is set.

A switch is provided on the control for an unscheduled shutdown should all else fail. Actuation of this switch shuts off all fuel, purges fuel lines, closes the AIM inlet, and shuts off the tunnel flow.

9.2.2.3 Airflow Meter Tests

The tape control will set the inlet spike positions defined on the test definition sheets. If an inlet unstart is detected, the inlet spike will be set at the next position using the STEP switch on the tape control. If a started condition cannot be obtained, the SKIP switch will be used to select an alternate inlet position schedule.

9.2.4 Oscilloscope and Schlieren Pictures

Motion pictures will be taken of the Schlieren screen and the wall pressure distribution oscilloscope during runs. Schlieren pictures will be taken during the full tunnel operating period. Scope pictures will be taken 5 sec prior to and during the time that fuel is admitted.

9.3 POST-RUN PROCEDURES

9.3.1 Data Recording

The data acquisition system will remain operative during shutdown so that appropriate checks can be made on the pressure instrumentation as discussed in Section 9.1.8. The exhaust ejector will remain operative for a sufficient period to stabilize and record all pressure instrumentation at the cell pressure value. Recordings will also be made of load cell readings as the cavity nitrogen purge systems and water cooling systems are shut down. This will provide a comparison of before- and after-run load cell readings to check for drift, as discussed in Section 9.1.8.

9.3.2 Ignitor System Purge

Nitrogen gas shall be supplied through the hydrogen supply line of the ignitor system during and immediately following the test shutdown period at approximately 20 psig (W = 0.03 lb/sec). Purge will continue until the humidity in the tunnel is ambient. The purge will be applied on all runs regardless of ignitor system usage.

9.3.3 Visual Inspection

A visual inspection shall be made of the test equipment following a run. Checks will be made for foreign object or other structural damage and metal discoloration due to hot spots. The inlet spike will be stroked to check for binding or interference within the innerbody cavity. The number of strokes shall not exceed one per test in order that the limited life of the spike support bearing may be prolonged.

9.3.4 Test Log

A test log will be recorded by the Test Conductor (AiResearch Engineering) noting any irregularities or pertinent information immediately after each test.

9.4 DATA LISTING CHECKS

When preliminary data listings are available, the following checks will be included.

9.4.1 Nitrogen Purge Force Calibration Check

The load cell force parameter,

$$\frac{FL}{PTO},$$

and nondimensional cavity pressures

$$\frac{P_A}{PTO} \quad \text{and} \quad \frac{P_B}{PTO}$$

will be read after the inlet has started but before fuel admission. These values will be spotted on the calibration curves generated by the procedures defined in Section 7.1. This will provide a cross check on the validity of the calibration.

9.4.2 Load Cell Drift Check

Before and after run, load cell readings will be compared to check for drift.

9.4.3 Fuel Flow Measurement Check

The fuel injector discharge coefficients will be checked against the values obtained in the calibrations defined in Section 6.4.

9.4.4 Wall Pressure Distribution Check

Wall pressure distributions with no fuel flow will be plotted on curves of previously obtained values at the same inlet spike position.

9.4.5 Skin Temperature Check

Skin temperatures will be checked for hot spots.

REFERENCES

1. Engineering Staff, Hypersonic Research Engine Project - Phase II, Aerothermodynamic Integration Model Measurement Plan (U), Data Item No. 2-1.01, AiResearch Report AP-70-6216, 9 June 1970, CONFIDENTIAL

2. Engineering Staff, Hypersonic Research Engine Project - Phase II, Test Facility Interface Requirements for the Aerothermodynamic Integration Model (AIM), AiResearch Report AP-69-4753, Rev. 1, 9 June 1969

3. Engineering Staff, Hypersonic Research Engine Project, Statement of Work, Experimental Development of the Hypersonic Research Ramjet Engine, NASA Report L-4947-B (Revised), 3 September 1968

APPENDIX A

DATA REDUCTION COMPUTER PROGRAM

1. INTRODUCTION

AIM test data will be tape recorded on the SEL data acquisition system. The tape will be transported to LeRC for reduction on the IBM 360-65 computer immediately after each test. Preliminary abbreviated data listings will then be made on a typewriter printer. The listings will be repeated at remote teletypewriter terminals at NASA LeRC, NASA Plum Brook, and AiResearch Torrance. Complete on-line printer listings and selected plots will be available about three days after the test.

The data reduction program consists of two sections: Engineering Units, Section 2, and Performance Analysis, Section 3. Section 2 lists, versus "time", all recorded measurements and some calculated values such as selected flow rates and wall pressure ratios. Section 3 computes component and cycle performance and various aerodynamic and heat transfer parameters. Section 3 data will be listed only at selected times of interest. All calculations in both sections will be checked by hand with assumed values before the program is put in operation.

2. ENGINEERING UNITS SECTION

2.1 SUMMARY

All AIM measurements recorded on the data acquisition system will be converted to digital output and corrected for instrument calibration. The corrected data will be listed versus "time". Selected parameters will be plotted from the output. The purpose of the listing is to:

(a) Display all measurements to check for error

(b) Determine if and when the desired steady-state operating conditions were achieved

(c) Check for proper system functioning

Some parameters will be calculated and listed, but only those necessary to satisfy the above requirements.

2.2 PROGRAM FUNCTIONS

The program shall perform the following functions:

2.2.1 Averaging

The program will be capable of arithmetically time-averaging all measured and computed parameters for a selected number of scans. The number of scans averaged will be selected by an appropriate flag. The data scan rate will be 5 per second.

2.2.2 Deletion of Data

When an instrumentation channel is known to be in error, the listing for that channel can be left blank. The print format need not change.

2.2.3 Program Heading

The following printout shall precede the data listing for each run.

(a) Test run number and date (tests will be numbered starting with No. 1 as the first run)

(b) Computer run number and date

(c) Test I.D. number (see Section 8.1 in report body)

(d) Tunnel Mach number (record the Mach number determined from tunnel calibration tests)

(e) Angle of attack (program input)

(f) Data samples averaged per printed data point

(g) Definition of units; i.e., all pressures in psia, temperatures in ^{0}R, heat inputs in Btu/sec, weight flows in lb/sec, time in seconds, distance in inches.

(h) Definition of the facility fuel systems connected to the AIM fuel manifolds (see paragraph 2.4.3).

2.2.4 Program Options

For convenience, all program options are listed below.

(a) Data scan rate (now set at 5 per second)

(b) Print rate

(c) Number of points averaged per printed data point

(d) Deletion of errant data channels

(e) Facility fuel systems connected to the AIM fuel manifolds (see paragraph 2.4.3)

(f) Data reduction code (see Section 8 in the body of this report).

2.3 Data Listing Format

The complete engineering units data listing format for the on-line printer and the abbreviated listing for the typewriter printer are defined in the following sections. The program heading defined in Section 2.2.3 will be used for both listings.

2.3.1 On-Line Printer Format

The following paragraphs define the complete engineering units data listing to be performed by the on-line printer.

An example of the data listing is given below:

```
INLET CONDITIONS

        44-T     45-T     IC-I     2C-I     52-T. . . . . . . . . .
TIME    PT01     PT02     PT0      P0       PCEL
XXX     XXX.X    XXX.X    XXX.X    X.XXX    X.XXX
```

The listing code numbers, headings, and symbols are defined in Table A-1. The heading (in this case, INLET CONDITIONS) is printed on the top line, followed by the listing code number, symbols, and the listed data. Time will be listed in the first column of each page. The heading will be repeated on subsequent pages of the same listing. The data listing code numbers for measured parameters correspond to the measurement numbers in the instrumentation list, Table 4-1, given earlier in the body of this report. In cases where a calculated parameter is listed, the listing code number refers to the equation used to make the calculation. The equations are given in Section 2.4. Calculated parameters always have the letter "C" preceding the dash numbers.

When the listing under the first heading is completed, the heading from the next listing, i.e., FORCE SYSTEM will be printed at the top of the page and the same procedure followed as for the first listing as shown below.

```
                   BALANCE SYSTEM
7C-I     8C-I     14C-E     71-T     7C-F. . . . . . . . .
WA       MFR      FC        FLC      FL
```

In cases where wall pressures are listed, both the absolute value of pressure and the ratio of wall pressure to tunnel static pressure are given as shown below.

```
SPIKE PRESS.
1.0.60-0     2 14.4-0     3 14.4-90. . . . . . . . . . .
P      P/PO  P      P/PO  P      P/PO
XX.XX .XXXX XX.XX .XXXX XX.XX .XXXX
```

The first figure in the code number is always the same as the first figure in the measurement number. The second and third numbers are the axial station and angular location of the pressure tap.

Special considerations are given to the fuel system listing. This is discussed in paragraph 2.4.3.

The program will be capable of four different listing formats, depending on run type. The format used for each run is designated by the data reduction code number defined in Section 8.2 in the body of this report. The on-line printer format corresponding to each data reduction code number is defined in Table A-1.

2.3.2 Typewriter Printer Format

The format defined in this section will be used for the typewriter printer output. Execution of the printing will be initiated by a single coded typewriter input into the computer. Additional parameters may be added to the listing by inputing the appropriate data listing code numbers. These code numbers are defined in Table A-1. Four different formats will be used, depending on run type. The format used for each run is designated by the data reduction code number defined in Section 8.2 in the body of this report. The typewriter printer format corresponding to each code number is listed below. The parameters will be listed in vertical columns versus "time". Time will be listed in the first column of all pages.

Format for Data Reduction Code 1

This format will be used for purge force calibration and operational checkout runs.

Time	PTO	TTO	FL	FLPTO	PAPTO	PBPTO
	1C-I	5C-I	7C-B	10C-B	8C-B	9C-B

Format for Data Reduction Code 2

This format will be used for airflow meter runs.

Time	PTO	TTO	X	WAFM	MFR	TPFM	PSAM
	1C-I	5C-I	52-S	6C-I	8C-I	1-EF	5-EF

Format for Data Reduction Code 3

This format will be used for combustor performance runs.

Time	PTO	TTO	FC	ERX*	PMX*	TMX*	PO	PS9C
	1C-I	5C-I	51-T				2-CE	18CE

Format for Data Reduction Code 4

This format will be used for engine performance runs.

Time	PTO	TTO	FC	ERX*	PMX*	TMX*
	1C-I	5C-I	51-T			

*The equivalence ratio and one fuel manifold pressure and temperature in each operative fuel system will be printed as in the following example.

ER1A	PM1A1	TM1A	ER1B	PM1B1	TM1B1
1C-F	1-F	17-F	7C-F	9-F	25-F

The fuel system parameters listed depend on which facility fuel systems are connected to the AIM manifolds. The data listing procedures for the fuel system are described in Section 2.4.3.

TABLE A-1 AIM ENGINEERING UNITS ON-LINE PRINTER DATA LISTING

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
INLET CONDITIONS											
Inlet Total Press. (Upper)		PT01	44-T	44-T			X	X	X	X	
Inlet Total Press. (Lower)		PT02	45-T	45-T			X	X	X	X	
Inlet Total Press. (Average)		PTO	1C-I				X	X	X	X	
Calculated Nozzle Exit Static Press.		PO	2C-I				X	X	X	X	
Measured Nozzle Exit Static Press.		POM	52A-T	52A-T			X	X	X	X	
Cell Press.		PCEL	52-T	52-T			X	X	X	X	
Inlet Total Temp. (Upper)		TT01	3C-I				X	X	X	X	
Inlet Total Temp. (Lower)		TT02	4C-I				X	X	X	X	
Inlet Total Temp. (Average)		TTO	5C-I				X	X	X	X	
Spike Translation		X	52-S	52-S			X	X	X	X	
Airflow Meter Flow		WAFM	6C-I					X			
Airflow		WA	7C-I				X		X	X	
Inlet Mass Flow Ratio		MFR	8C-I				X	X	X	X	
BALANCE SYSTEM											
Load Cell Reading		FLC	14C-B				X	X	X	X	
Corrected Load Cell Reading		FC	71-T	71-T			X	X	X	X	
Intermediate Load Cell Reading		FL	7C-B				X	X	X	X	
Force Parameter		FLPTO	10C-B				X	X	X	X	
Purge Force Correction		DFT	13C-B				X	X	X	X	
Forward Cavity Press. ÷ PTO		PAPTO	8C-B				X	X	X	X	
Aft Cavity Press. ÷ PTO		PBPTO	9C-B				X	X	X	X	
Forward Cavity Press. 1		PA1	85-F	85-F			X	X	X	X	
Forward Cavity Press. 2		PA2	86-F	86-F			X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Aft Cavity Press. 1		PB1	87-F	87-F			X	X	X	X	
Aft Cavity Press. 2		PB2	88-F	88-F			X	X	X	X	
Innerbody Cavity Press.		PIC	89-F	89-F			X	X	X	X	
Innerbody Cavity Temp.		TIC	90-F	90-F			X	X	X	X	
Forward Cavity Temp.		TA1	91-F	91-F			X	X	X	X	
Forward Cavity Temp.		TA2	92-F	92-F			X	X	X	X	
Aft Cavity Temp.		TB1	93-F	93-F			X	X	X	X	
Aft Cavity Temp.		TB2	94-F	94-F			X	X	X	X	
Purge Line Meter Press.		PPM	89-F	89-F			X	X	X	X	
Purge Line Meter ΔP		DPPM	90-F	90-F			X	X	X	X	
Purge Line Meter Temp.		TPM	91-F	91-F			X	X	X	X	
Purge Line Meter Flow Parameter		WPPL	11C-B				X	X	X	X	
Makeup Line Meter Press.		PMM	92-F	92-F			X	X	X	X	
Makeup Line Meter ΔP		DPMM	93-F	93-F			X	X	X	X	
Makeup Line Meter Temp.		TMM	94-F	94-F			X	X	X	X	
Makeup Line Meter Flow Parameter		WPML	12C-B				X	X	X	X	
Fuel System A Force Correction		DFA	1C-F				X	X	X	X	
Fuel System B Force Correction		DFB	2C-B				X	X	X	X	
Fuel System C Force Correction		DFC	3C-B				X	X	X	X	
Fuel System D Force Correction		DFD	4C-B				X	X	X	X	
Fuel System E Force Correction		DFE	5C-B				X	X	X	X	
Cooling System Force Correction		DFW	6C-B				X	X	X	X	

TABLE A-1 (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
FUEL SYSTEM									X	X	
*System A Fuel Flow		WFA	1C-F						X	X	
System B Fuel Flow		WFB	2C-F						X	X	
System C Fuel Flow		WFC	3C-F						X	X	
System D Fuel Flow		WFD	4C-F						X	X	
System E Fuel Flow		WFE	5C-F						X	X	
System A Equiv. Ratio		ERA	6C-F						X	X	
System B Equiv. Ratio		ERB	7C-F						X	X	
System C Equiv. Ratio		ERC	8C-F						X	X	
System D Equiv. Ratio		ERD	9C-F						X	X	
System E Equiv. Ratio		ERE	10C-F						X	X	
Overall Equiv. Ratio		EROA	11C-F						X	X	
System A Venturi Press.		PVA	60-T	60-T					X	X	
System B Venturi Press.		PVB	61-T	61-T					X	X	
System C Venturi Press.		PVC	62-T	62-T					X	X	
System D Venturi Press.		PVD	63-T	63-T					X	X	
System E Venturi Press.		PVE	64-T	64-T					X	X	
System A Venturi ΔP		DPVA	65-T	65-T					X	X	
System B Venturi ΔP		DPVB	66-T	66-T					X	X	
System C Venturi ΔP		DPVC	67-T	67-T					X	X	
System D Venturi ΔP		DPVD	68-T	68-T					X	X	
System E Venturi ΔP		DPVE	69-T	69-T					X	X	
Fuel Venturi Manifold Temp.		TFVM	70-T	70-T					X	X	
Fuel Manifold 1A Press. 1		PM1A1	1-F	1-F		172			X	X	
Fuel Manifold 1A Press. 2		PM1A2	2-F	2-F		25					
Fuel Manifold 1C Press. 1		PM1C1	3-F	3-F		175			X	X	
Fuel Manifold 1C Press. 2		PM1C2	4-F	4-F		25					
Fuel Manifold 2C Press. 1		PM2C1	5-F	5-F		175			X	X	
Fuel Manifold 2C Press. 2		PM2C2	6-F	6-F		25					

*See Section 2.4.3 for fuel system data listing procedure

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASURE-MENT NUMBER	STATION NUMBER	CIRCUMF-ERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Fuel Manifold 3B Press. 1		PM3B1	7-F	7-F		95			X	X	
Fuel Manifold 3B Press. 2		PM3B2	8-F	8-F		275					
Fuel Manifold 1B Press. 1		PM1B1	9-F	9-F		90			X	X	
Fuel Manifold 1B Press. 2		PM2B2	10-F	10-F		270					
Fuel Manifold 4 Press. 1		PM41	11-F	11-F		90			X	X	
Fuel Manifold 4 Press. 2		PM42	12-F	12-F		270					
Fuel Manifold 2A Press. 1		PM2A1	13-F	13-F		90			X	X	
Fuel Manifold 2A Press. 2		PM2A2	14-F	14-F		270					
Fuel Manifold 3A Press. 1		PM3A1	15-F	15-F		90			X	X	
Fuel Manifold 3A Press. 2		PM3A2	16-F	16-F		270					
Fuel Manifold 1A Temp. 1		TM1A1	17-F	17-F		188	X	X	X	X	
Fuel Manifold 1A Temp. 2		TM1A2	18-F	18-F		30					
Fuel Manifold 1C Temp. 1		TM1C1	19-F	19-F		180	X	X	X	X	
Fuel Manifold 1C Temp. 2		TM1C2	20-F	20-F		30					
Fuel Manifold 2C Temp. 1		TM2C1	21-F	21-F		180	X	X	X	X	
Fuel Manifold 2C Temp. 2		TM2C2	22-F	22-F		30					
Fuel Manifold 3B Temp. 1		TM3B1	23-F	23-F		90	X	X	X	X	
Fuel Manifold 3B Temp. 2		TM3B2	24-F	24-F		270					
Fuel Manifold 1B Temp. 1		TM1B1	25-F	25-F		90	X	X	X	X	
Fuel Manifold 1B Temp. 2		TM1B2	26-F	26-F		270					
Fuel Manifold 2A Temp. 1		TM2A1	27-F	27-F		90	X	X	X	X	
Fuel Manifold 2A Temp. 2		TM2A2	28-F	28-F		270					
Fuel Manifold 4 Temp. 1		TM41	29-F	29-F		90	X	X	X	X	
Fuel Manifold 4 Temp. 2		TM42	30-F	30-F		270					
Fuel Manifold 3A Temp. 1		TM3A1	31-F	31-F		90	X	X	X	X	
Fuel Manifold 3A Temp. 2		TM3A2	32-F	32-F		270					

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Fuel Injector Discharge Coeff.		CD1A	12C-F						X	X	
Fuel Injector Discharge Coeff.		CD1C	13C-F						X	X	
Fuel Injector Discharge Coeff.		CD2C	14C-F						X	X	
Fuel Injector Discharge Coeff.		CD3B	15C-F						X	X	
Fuel Injector Discharge Coeff.		CD1B	16C-F						X	X	
Fuel Injector Discharge Coeff.		CD2A	17C-F						X	X	
Fuel Injector Discharge Coeff.		CD4	18C-F						X	X	
Fuel Injector Discharge Coeff.		CD3A	19C-F						X	X	
Fuel Injector Discharge Coeff.		CD3AB	20C-F						X	X	
SPIKE PRESS.											
Spike Wall Press.		PS	1 0.60-0	1-S	0.595	℄	X	X	X	X	
PS/PO		PS/PO	1 0.60-0				X	X	X	X	
Spike Wall Press.		PS	2 14.4-0	2-S	14.49	0.2	X	X	X	X	
PS/PO		PS/PO	2 14.4-0				X	X	X	X	
Spike Wall Press.		PS	3 14.4-271	3-S	14.48	271.1	X	X	X	X	
PS/PO		PS/PU	3 14.4-271				X	X	X	X	
Spike Wall Press.		PS	4 14.4-180	4-S	14.47	180.1	X	X	X	X	
PS/PO		PS/PO	4 14.4-180				X	X	X	X	
Spike Wall Press.		PS	6 30.7-0	6-S	30.70	359.6	X	X	X	X	
PS/PO		PS/PO	6 30.7-0				X	X	X	X	
Spike Wall Press.		PS	7 35.0-0	7-S	35.09	359.6	X	X	X	X	
PS/PO		PS/PO	7 35.0-0				X	X	X	X	
Spike Wall Press.		PS	8 35.0-270	8-S	35.07	269.6	X	X	X	X	
PS/PO		PS/PO	8 35.0-270				X	X	X	X	

TABLE A-1 (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Spike Wall Press.		PS	9 35.0-180	9-S	35.07	179.5	X	X	X	X	
PS/PO		PS/PO	9 35.0-180				X	X	X	X	
Spike Wall Press.		PS	10 35.1-89	10-S	35.08	89.4	X	X	X	X	
PS/PO		PS/PO	10 35.1-89				X	X	X	X	
Spike Wall Press.		PS	11 35.5-0	11-S	35.58	359.5	X	X	X	X	
PS/PO		PS/PO	11 35.5-0				X	X	X	X	
Spike Wall Press.		PS	12 36.1-0	12-S	36.08	359.6	X	X	X	X	
PS/PO		PS/PO	12 36.1-0				X	X	X	X	
Spike Wall Press.		PS	13 36.5-0	13-S	36.49	359.5	X	X	X	X	
PS/PO		PS/PO	13 36.5-0				X	X	X	X	
Spike Wall Press.		PS	14 36.5-269	14-S	36.48	269.5	X	X	X	X	
PS/PO		PS/PO	14 36.5-269				X	X	X	X	
Spike Wall Press.		PS	15 36.5-180	15-S	36.48	179.4	X	X	X	X	
PS/PO		PS/PO	15 36.5-180				X	X	X	X	
Spike Wall Press.		PS	16 36.5-89	16-S	36.48	89.5	X	X	X	X	
PS/PO		PS/PO	16 36.5-89				X	X	X	X	
Spike Wall Press.		PS	17 37.0-0	17-S	36.98	359.5	X	X	X	X	
PS/PO		PS/PO	17 37.0-0				X	X	X	X	
Spike Wall Press.		PS	20 38.0-269	20-S	38.02	269.5		X	X	X	
PS/PO		PS/PO	20 38.0-269					X	X	X	
Spike Wall Press.		PS	24 39.0-0	24-S	39.02	359.4	X	X	X	X	
PS/PO		PS/PO	24 39.0-0				X	X	X	X	
Spike Wall Press.		PS	25 39.0-269	25-S	39.01	269.4		X	X	X	
PS/PO		PS/PO	25 39.0-269					X	X	X	
Spike Wall Press.		PS	26 39.0-179	26-S	39.00	179.4		X	X	X	
PS/PO		PS/PO	26 39.0-179					X	X	X	
Spike Wall Press.		PS	28 39.5-0	28-S	39.50	359.4	X	X	X	X	
PS/PO		PS/PO	28 39.5-0				X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASURE-MENT NUMBER	STATION NUMBER	CIRCUMF-ERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Spike Wall Press.		PS	29 40.0-0	29-S	40.02	359.4	X	X	X	X	
PS/PO		PS/PO	29 40.0-0				X	X	X	X	
Spike Wall Press.		PS	30 40.0-269	30-S	40.02	269.5	X	X	X	X	
PS/PO		PS/PO	30 40.0-269				X	X	X	X	
Spike Wall Press.		PS	31 40.0-180	31-S	40.02	179.4	X	X	X	X	
PS/PO		PS/PO	31 40.0-180				X	X	X	X	
Spike Wall Press.		PS	32 40.0-89	32-S	40.02	89.3	X	X	X	X	
PS/PO		PS/PO	32 40.0-89				X	X	X	X	
Spike Wall Press.		PS	33 41.5-0	33-S	41.50	359.5	X	X	X	X	
PS/PO		PS/PO	33 41.5-0				X	X	X	X	
Spike Wall Press.		PS	34 42.5-0	34-S	42.46	359.5	X	X	X	X	
PS/PO		PS/PO	34 42.5-0				X	X	X	X	
Spike Wall Press.		PS	39 44.8-0	39-S	44.80	359.5	X	X	X	X	
PS/PO		PS/PO	39 44.8-0				X	X	X	X	
Spike Wall Press.		PS	41 47.3-0	41-S	47.32	359.5	X	X	X	X	
PS/PO		PS/PO	41 47.3-0				X	X	X	X	
Spike Wall Press.		PS	42 47.38-269	42-S			X	X	X	X	
PS/PO		PS/PO	42 47.38-269				X	X	X	X	
Spike Wall Press.		PS	43 47.3-180	43-S	47.29	179.2	X	X	X	X	
PS/PO		PS/PO	43 47.3-180				X	X	X	X	
Spike Wall Press.		PS	44 47.3-89	44-S	47.31	89.3	X	X	X	X	
PS/PO		PS/PO	44 47.3-89				X	X	X	X	
Spike Wall Press.		PS	45 48.1-0	45-S	48.11	359.5	X	X	X	X	
PS/PO		PS/PO	45 48.1-0				X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
SPIKE TEMP											
Spike Wall Temp.		TS	47-S	47-S	35.79	354	X	X	X	X	
Spike Wall Temp.		TS	48-S	47-S	38.02	354	X	X	X	X	
Spike Wall Temp.		TS	49-S	49-S	40.02	354	X	X	X	X	
Spike Wall Temp.		TS	50-S	50-S		354	X	X	X	X	
Spike Wall Temp.		TS	51-S	51-S	44.80	354	X	X	X	X	
INNERBODY PRESS.											
Innerbody Wall Press.		PI	1 54.5-0	1-I	54.52	359.8	X	X	X	X	
PI/PO		PI/PO	1 54.5-0				X	X	X	X	
Innerbody Wall Press.		PI	2 54.5-270	2-I	54.53	269.8	X	X	X	X	
PI/PO		PI/PO	2 54.5-270				X	X	X	X	
Innerbody Wall Press.		PI	3 54.5-180	3-I	54.51	179.7	X	X	X	X	
PI/PO		PI/PO	3 54.5-180				X	X	X	X	
Innerbody Wall Press.		PI	4 54.5-90	4-I	54.51	90.0	X	X	X	X	
PI/PO		PI/PO	4 54.5-90				X	X	X	X	
Innerbody Wall Press.		PI	5 56.0-18	5-I	56.00	0.8	X	X	X	X	
PI/PO		PI/PO	5 56.0-18				X	X	X	X	
Innerbody Wall Press.		PI	9 64.8-0	9-I	64.78	359.8	X	X	X	X	
PI/PO		PI/PO	9 64.8-0				X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
INNERBODY TEMP.											
Innerbody Wall Temp.		TI	13-I	13-I	59.98	240.0	X	X	X	X	
Innerbody Wall Temp.		TI	14-I	14-I	60.02	120.0	X	X	X	X	
Innerbody Wall Temp.		TI	15-I	15-I	64.80	355.0	X	X	X	X	
NOZZLE PLUG PRESS.											
Nozzle Plug Wall Press.		PNP	1 66.64-60	1-NP	66.64	59.9	X			X	
PNP/PO		PNP/PO	1 66.64-60				X			X	
Nozzle Plug Wall Press.		PNP	2 68.1-120	2-NP	68.08	119.6	X			X	
PNP/PO		PNP/PO	2 68.1-120				X			X	
Nozzle Plug Wall Press.		PNP	3 69.4-180	3-NP	69.41	180.1	X			X	
PNP/PO		PNP/PO	3 69.4-180				X			X	
Nozzle Plug Wall Press.		PNP	4 70.8-240	4-NP	70.79	240.2	X			X	
PNP/PO		PNP/PO	4 70.8-240				X			X	
Nozzle Plug Wall Press.		PNP	5 72.5-300	5-NP	72.47	300.2	X			X	
PNP/PO		PNP/PO	5 72.5-300				X			X	
Nozzle Plug Wall Press.		PNP	6 74.6-0	6-NP	74.55	0.2	X			X	
PNP/PO		PNP/PO	6 74.6-0				X			X	
Nozzle Plug Wall Press.		PNP	7 77.4-60	7-NP	77.40	60.0	X			X	
PNP/PO		PNP/PO	7 72.4-60				X			X	
Nozzle Plug Wall Press.		PNP	8 81.3-120	8-NP	81.30	120.1	X			X	
PNP/PO		PNP/PO	8 81.3-120				X			X	
Nozzle Plug Wall Press.		PNP	9 84.1-180	9-NP	84.11	180.1	X			X	
PNP/PO		PNP/PO	9 84.1-180				X			X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASURE-MENT NUMBER	STATION NUMBER	CIRCUMF-ERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Nozzle Plug Wall Press.		PNP	10 87.0-0	10-NP	86.97	0	X			X	
PNP/PO		PNP/PO	10 87.0-0				X			X	
NOZZLE PLUG TEMP.											
Nozzle Plug Wall Temp.		TNP	11-NP	11-NP	68.08	124.3	X		X	X	
Nozzle Plug Wall Temp.		TNP	12-NP	12-NP	70.79	245.2	X		X	X	
Nozzle Plug Wall Temp.		TNP	14-NP	14-NP	81.30	125.1	X		X	X	
OUTER COWL PRESS.											
Outer Cowl Wall Press.		POC	1 35.5-83	1-CO	35.53	83.0	X	X		X	
POC/PO		POC/PO	1 35.5-83				X	X		X	
Outer Cowl Wall Press.		POC	2 35.5-173	2-CO	35.51	173.0	X	X		X	
POC/PO		POC/PO	2 35.5-173				X	X		X	
Outer Cowl Wall Press.		POC	3 35.5-263	3-CO	35.54	262.9	X	X		X	
POC/PO		POC/PO	3 35.5-263				X	X		X	
Outer Cowl Wall Press.		POC	4 35.5-353	4-CO	35.52	353.0	X	X		X	
POC/PO		POC/PO	4 35.5-353				X	X		X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Outer Cowl Wall Press.		POC	5 37.0-83	5-CO	37.04	83.1	X	X			
POC/PO		POC/PO	5 37.0-83				X	X			
Outer Cowl Wall Press.		POC	6 37.0-173	6-CO	37.04	173.1	X	X			
POC/PO		POC/PO	6 37.0-173								
Outer Cowl Wall Press.		POC	7 37.0-263	7-CO	37.05	263.1	X	X			
POC/PO		POC/PO	7 37.0-263				X	X			
Outer Cowl Wall Press.		POC	8 37.0-353	8-CO	37.04	353.0	X	X		X	
POC/PO		POC/PO	8 37.0-353				X	X		X	
Outer Cowl Wall Press.		POC	9 39.0-83	9-CO	39.00	83.1	X	X			
POC/PO		POC/PO	9 39.0-83				X	X			
Outer Cowl Wall Press.		POC	10 39.0-173	10-CO	39.00	173.1	X	X			
POC/PO		POC/PO	10 39.0-173				X	X			
Outer Cowl Wall Press.		POC	11 39.0-263	11-CO	39.00	263.0	X	X			
POC/PO		POC/PO	11 39.0-263				X	X			
Outer Cowl Wall Press.		POC	12 39.0-353	12-CO	39.00	353.1	X	X		X	
POC/PO		POC/PO	12 39.0-353				X	X		X	
Outer Cowl Wall Press.		POC	13 40.5-83	13-CO	40.51	83.1	X	X		X	
POC/PO		POC/PO	13 40.5-83				X	X		X	
Outer Cowl Wall Press.		POC	14 40.5-173	14-CO	40.51	173.1	X	X		X	
POC/PO		POC/PO	14 40.5-173				X	X		X	
Outer Cowl Wall Press.		POC	15 40.5-263	15-CO	40.50	263.1	X	X		X	
POC/PO		POC/PO	15 40.5-263				X	X		X	
Outer Cowl Wall Press.		POC	16 40.5-353	16-CO	40.50	353.1	X	X		X	
POC/PO		POC/PO	16 40.5-353				X	X		X	
Outer Cowl Wall Press.		POC	17 40.0-210	17-CO	40.00	210.0	X	X			
POC/PO		POC/PO	17 40.0-210				X	X			
Outer Cowl Wall Press.		POC	18 40.4-210	18-CO	40.36	210.1	X	X			
POC/PO		POC/PO	18 40.4-210				X	X			
Outer Cowl Wall Press.		POC	19 40.7-210	19-CO	40.68	210.1	X	X			
POC/PO		POC/PO	19 40.7-210				X	X			

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Outer Cowl Wall Press.		POC	20 40.3-330	20-CO	40.25	330.0	X	X			
POC/PO		POC/PO	20 40.3-330				X	X			
Outer Cowl Wall Press.		POC	21 40.7-330	21-CO	40.65	330.0	X	X			
POC/PO		POC/PO	21 40.7-330				X	X			
Outer Cowl Wall Press.		POC	22 40.0-0	22-CO	40.00	0.1	X	X	X		
POC/PO		POC/PO	22 40.0-0				X	X	X		
Outer Cowl Wall Press.		POC	23 40.35-0	23-CO	40.36	360.0	X	X	X		
POC/PO		POC/PO	23 40.35-0				X	X	X		
Outer Cowl Wall Press.		POC	24 40.7-0	24-CO	40.66	0.1	X	X			
POC/PO		POC/PO	24 40.7-0				X	X			
Outer Cowl Wall Press.		POC	25 40.3-180	25-CO	40.21	180.2	X	X			
POC/PO		POC/PO	25 40.3-180				X	X			
Outer Cowl Wall Press.		POC	26 40.7-180	26-CO	40.66	180.1	X	X			
POC/PO		POC/PO	26 40.7-180				X	X			
INNER COWL PRESS.											
Inner Cowl Wall Press.		PIC	31 35.5-0	31-C	35.51	360.0	X	X	X	X	
PIC/PO		PIC/PO	31 35.5-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	32 36.0-0	32-C	36.05	0.1	X	X	X	X	
PIC/PO		PIC/PO	32 36.0-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	33 36.5-0	33-C	36.69	0.1	X	X	X	X	
PIC/PO		PIC/PO	33 36.5-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	34 36.5-180	34-C	36.69	180.2	X	X	X	X	
PIC/PO		PIC/PO	34 36.5-180				X	X	X	X	

TABLE A-1 (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Inner Cowl Wall Press.		PIC	35 37.0-0	35-C	37.3	0.1	X	X	X	X	
PIC/PO		PIC/PO	35 37.0-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	36 37.0-90	36-C	37.04	90.2	X	X	X	X	
PIC/PO		PIC/PO	36 37.0-90				X	X	X	X	
Inner Cowl Wall Press.		PIC	37 37.0-180	37-C	37.05	180.1	X	X	X	X	
PIC/PO		PIC/PO	37 37.0-180				X	X	X	X	
Inner Cowl Wall Press.		PIC	38 37.0-180	38-C	37.03	270.1	X	X	X	X	
PIC/PO		PIC/PO	38 37.0-180				X	X	X	X	
Inner Cowl Wall Press.		PIC	39 37.5-0	39-C	37.54	0.2	X	X	X	X	
PIC/PO		PIC/PO	39 37.5-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	40 38.0-0	40-C	38.04	0.2	X	X	X	X	
PIC/PO		PIC/PO	40 38.0-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	41 38.0-90	41-C	38.04	90.2	X	X	X	X	
PIC/PO		PIC/PO	41 38.0-90				X	X	X	X	
Inner Cowl Wall Press.		PIC	42 38.0-180	42-C	38.05	180.1	X	X	X	X	
PIC/PO		PIC/PO	42 38.0-180				X	X	X	X	
Inner Cowl Wall Press.		PIC	43 38.0-270	43-C	38.04	270.1	X	X	X	X	
PIC/PO		PIC/PO	43 38.0-270				X	X	X	X	
Inner Cowl Wall Press.		PIC	44 38.5-94	44-C	38.5	0.1	X	X	X	X	
PIC/PO		PIC/PO	44 38.5-94				X	X	X	X	
Inner Cowl Wall Press.		PIC	45 39.0-0	45-C	39.01	0.1	X	X	X	X	
PIC/PO		PIC/PO	45 39.0-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	46 39.0-90	46-C	39.02	90.1	X	X	X	X	
PIC/PO		PIC/PO	46 39.0-90				X	X	X	X	
Inner Cowl Wall Press.		PIC	49 39.5-359	49-C	39.51	359.1	X	X	X	X	
PIC/PO		PIC/PO	49 39.5-359				X	X	X	X	
Inner Cowl Wall Press.		PIC	50 40.0-0	50-C	40.00	0.1	X	X	X	X	
PIC/PO		PIC/PO	50 40.0-0				X	X	X	X	
Inner Cowl Wall Press.		PIC	51 40.0-90	51-C	40.00	90.1	X	X	X	X	
PIC/PO		PIC/PO	51 40.0-90				X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Inner Cowl Wall Press.		PIC	52 40.0-180	52-C	39.99	180.1	X	X	X	X	
PIC/PO		PIC/PO	52 40.0-180				X	X	X	X	
Inner Cowl Wall Press.		PIC	53 40.0-270	53-C	40.00	270.1	X	X	X	X	
PIC/PO		PIC/PO	53 40.0-270				X	X	X	X	
COWL TEMP.											
Inner Cowl Wall Temp.		TIC	54-C	54-C	37.04	7.2	X	X	X	X	
Inner Cowl Wall Temp.		TIC	55-C	55-C	39.01	7.1	X	X	X	X	
Inner Cowl Wall Temp.		TIC	56-C	56-C	39.99	7.1	X	X	X	X	
Inner Cowl Wall Temp.		TIC	57-C	57-C	40.00	97.2	X	X	X	X	
Inner Cowl Wall Temp.		TIC	58-C	58-C	40.00	187.1	X	X	X	X	
Inner Cowl Wall Temp.		TIC	59-C	59-C	40.00	277.1	X	X	X	X	
Outer Cowl Wall Temp.		TOC	60-CO	60-CO	36.54	353.1	X	X	X	X	
OUTER SHELL PRESS.											
Outer Shell Wall Press.		POS	1 41.1-0	1-0	41.06	0.0	X	X	X	X	
POS/PO		POS/PO	1 41.1-0				X	X	X	X	
Outer Shell Wall Press.		POS	2 41.1-180	2-0	41.06	180.0	X	X	X	X	
POS/PO		POS/PO	2 41.1-180				X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER			
							1	2	3	4
Outer Shell Wall Press.		POS	3 41.1-210	3-0	41.06	210.0		X	X	X
POS/PO		POS/PO	3 41.1-210					X	X	X
Outer Shell Wall Press.		POS	4 41.1-330	4-0	41.06	330.0		X	X	X
POS/PO		POS/PO	4 41.1-330					X	X	X
Outer Shell Wall Press.		POS	5 43.8-1	5-0	43.79	1.0	X	X	X	X
POS/PO		POS/PO	5 43.8-1				X	X	X	X
Outer Shell Wall Press.		POS	6 43.8-90	6-0	43.79	90.0	X	X	X	X
POS/PO		POS/PO	6 43.8-90				X	X	X	X
Outer Shell Wall Press.		POS	7 43.8-180	7-0	43.73	180.0	X	X	X	X
POS/PO		POS/PO	7 43.8-180				X	X	X	X
Outer Shell Wall Press.		POS	8 43.8-270	8-0	43.79	270.0	X	X	X	X
POS/PO		POS/PO	8 43.8-270				X	X	X	X
Outer Shell Wall Press.		POS	9 45.3-1	9-0	45.22	1.0	X	X	X	X
POS/PO		POS/PO	9 45.3-1				X	X	X	X
Outer Shell Wall Press.		POS	10 47.0-1	10-0	47.02	1.0	X	X	X	X
POS/PO		POS/PO	10 47.0-1				X	X	X	X
Outer Shell Wall Press.		POS	11 49.0-1	11-0	49.00	1.0	X	X	X	X
POS/PO		POS/PO	11 49.0-1				X	X	X	X
Outer Shell Wall Press.		POS	12 49.0-90	12-0	49.02	90.0		X	X	X
POS/PO		POS/PO	12 49.0-90					X	X	X
Outer Shell Wall Press.		POS	13 49.0-180	13-0	49.00	180.0		X	X	X
POS/PO		POS/PO	13 49.0-180					X	X	X
Outer Shell Wall Press.		POS	14 49.0-270	14-0	49.00	270.0		X	X	X
POS/PO		POS/PO	14 49.0-270					X	X	X
Outer Shell Wall Press.		POS	15 49.0-270	15-0	49.51	0.0		X	X	X
POS/PO		POS/PO	15 49.0-270					X	X	X
Outer Shell Wall Press.		POS	16 50.4-0	16-0	50.41	0.0	X	X	X	X
POS/PO		POS/PO	16 50.4-0				X	X	X	X

TABLE A-1 (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Outer Shell Wall Press.		POS	17 50.4-90	17-0	50.41	90.0		X	X	X	
POS/PO		POS/PO	17 50.4-90					X	X	X	
Outer Shell Wall Press.		POS	18 50.4-180	18-0	50.41	180.0		X	X	X	
POS/PO		POS/PO	18 50.4-180					X	X	X	
Outer Shell Wall Press.		POS	19 50.4-270	19-0	50.41	270.0		X	X	X	
POS/PO		POS/PO	19 50.4-270					X	X	X	
Outer Shell Wall Press.		POS	20 51.5-1	20-0	51.51	1.0		X	X	X	
POS/PO		POS/PO	20 51.5-1					X	X	X	
Outer Shell Wall Press.		POS	21 52.5-0	21-0	52.51	0.0		X	X	X	
POS/PO		POS/PO	21 52.5-0					X	X	X	
Outer Shell Wall Press.		POS	22 53.0-1	22-0	53.01	1.0	X	X	X	X	
POS/PO		POS/PO	22 53.0-1				X	X	X	X	
Outer Shell Wall Press.		POS	23 53.0-90	23-0	53.01	90.0	X	X	X	X	
POS/PO		POS/PO	23 53.0-90				X	X	X	X	
Outer Shell Wall Press.		POS	24 53.0-180	24-0	53.01	180.0	X	X	X	X	
POS/PO		POS/PO	24 53.0-180				X	X	X	X	
Outer Shell Wall Press.		POS	25 53.0-270	25-0	52.99	270.0	X	X	X	X	
POS/PO		POS/PO	25 53.0-270				X	X	X	X	
Outer Shell Wall Press.		POS	26 54.5-0	26-0	54.51	0.0	X	X	X	X	
POS/PO		POS/PO	26 54.5-0				X	X	X	X	
Outer Shell Wall Press.		POS	27 56.5-0	27-0	56.50	0.0	X	X	X	X	
POS/PO		POS/PO	27 56.5-0				X	X	X	X	
Outer Shell Wall Press.		POS	28 57.5-0	28-0	57.45	0.0		X	X	X	
POS/PO		POS/PO	28 57.5-0					X	X	X	
Outer Shell Wall Press.		POS	29 58.5-0	29-0	58.47	0.0	X	X	X	X	
POS/PO		POS/PO	29 58.5-0				X	X	X	X	
Outer Shell Wall Press.		POS	30 59.5-0	30-0	59.47	0.0		X	X	X	
POS/PO		POS/PO	30 59.5-0					X	X	X	
Outer Shell Wall Press.		POS	31 60.5-0	31-0	60.48	0.0	X	X	X	X	
POS/PO		POS/PO	31 60.5-0				X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASURE-MENT NUMBER	STATION NUMBER	CIRCUMF-ERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Outer Shell Wall Press.		POS	32 61.9-0	32-0	61.87	0.0	X	X	X	X	
POS/PO		POS/PO	32 61.9-0				X	X	X	X	
Outer Shell Wall Press.		POS	33 61.9-110	33-0	61.88	110.0	X	X	X	X	
POS/PO		POS/PO	33 619-110				X	X	X	X	
Outer Shell Wall Press.		POS	34 61.9-180	34-0	61.88	180.0	X	X	X	X	
POS/PO		POS/PO	34 61.9-180				X	X	X	X	
Outer Shell Wall Press.		POS	35 61.9-290	35-0	61.87	290.0	X	X	X	X	
POS/PO		POS/PO	35 61.9-290				X	X	X	X	
Outer Shell Wall Press.		POS	36 63.0-0	36-0	62.98	0		X	X	X	
POS/PO		POS/PO	36 63.0-0					X	X	X	
Outer Shell Wall Press.		POS	37 64.0-0	37-0	63.97	0		X	X	X	
POS/PO		POS/PO	37 64.0-0					X	X	X	
Outer Shell Wall Press.		POS	38 65.0-1	38-0	64.98	1	X	X	X	X	
POS/PO		POS/PO	38 65.0-1				X	X	X	X	
OUTER SHELL TEMP.											
Outer Shell Wall Temp.		TO	39-0	39-0	41.98	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	40-0	40-0	42.58	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	41-0	41-0	43.79	359.0	X	X	X	X	
Outer Shell Wall Temp.		TO	42-0	42-0	45.23	359.0	X	X	X	X	
Outer Shell Wall Temp.		TO	43-0	43-0	46.51	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	44-0	44-0	46.51	90.0	X		X	X	
Outer Shell Wall Temp.		TO	45-0	45-0	46.52	180.0	X		X	X	
Outer Shell Wall Temp.		TO	46-0	46-0	46.49	270.0	X		X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Outer Shell Wall Temp.		TO	47-0	47-0	47.02	359.0	X	X	X	X	
Outer Shell Wall Temp.		TO	49-0	49-0	49.00	359.0	X	X	X	X	
Outer Shell Wall Temp.		TO	50-0	50-0	50.00	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	52-0	52-0	50.01	180.0	X		X	X	
Outer Shell Wall Temp.		TO	54-0	54-0	51.51	359.0	X	X	X	X	
Outer Shell Wall Temp.		TO	55-0	55-0	52.01	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	56-0	56-0	53.00	359.0	X	X	X	X	
Outer Shell Wall Temp.		TO	59-0	59-0	56.00	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	60-0	60-0	56.00	120.0	X		X	X	
Outer Shell Wall Temp.		TO	61-0	61-0	56.00	240.0	X		X	X	
Outer Shell Wall Temp.		TO	62-0	62-0	57.01	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	63-0	63-0	57.47	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	64-0	64-0	58.97	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	65-0	65-0	59.98	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	66-0	66-0	60.97	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	67-0	67-0	62.47	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	68-0	68-0	62.47	120.0	X		X	X	
Outer Shell Wall Temp.		TO	69-0	69-0	62.47	240.0	X	X	X	X	
Outer Shell Wall Temp.		TO	70-0	70-0	63.49	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	71-0	71-0	64.48	0.0	X	X	X	X	
Outer Shell Wall Temp.		TO	72-0	72-0	65.22	359.0	X	X	X	X	

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER			
							1	2	3	4
INNER NOZZLE PRESS.										
Inner Nozzle Shroud Wall Press.		PNI	1 66.7-300	1-N	66.64	298.9	X			X
PNI/PO		PNI/PO	1 66.7-300				X			X
Inner Nozzle Shroud Wall Press.		PNI	2 67.5-240	2-N	67.31	240.0	X			X
PNI/PO		PNI/PO	2 67.5-240				X			X
Inner Nozzle Shroud Wall Press.		PNI	4 69.0-120	4-N	68.80	118.8	X			X
PNI/PO		PNI/PO	4 69.0-120				X			X
Inner Nozzle Shroud Wall Press.		PNI	5 69.8-60	5-N	69.61	58.9	X			X
PNI/PO		PNI/PO	5 69.8-60				X			X
Inner Nozzle Shroud Wall Press.		PNI	6 70.6-0	6-N	70.36	358.1	X			X
PNI/PO		PNI/PO	6 70.6-0				X			X
Inner Nozzle Shroud Wall Press.		PNI	7 71.4-300	7-N	71.23	299.0	X			X
PNI/PO		PNI/PO	7 71.4-300				X			X
Inner Nozzle Shroud Wall Press.		PNI	8 72.4-235	8-N	72.32	235.1	X			X
PNI/PO		PNI/PO	8 72.4-235				X			X
Inner Nozzle Shroud Wall Press.		PNI	9 73.1-178	9-N	73.03	178.3	X			X
PNI/PO		PNI/PO	9 73.1-178				X			X
Inner Nozzle Shroud Wall Press.		PNI	10 73.2-0	10-N	73.22	0.2	X			X
PNI/PO		PNI/PO	10 73.2-0				X			X
Inner Nozzle Shroud Wall Press.		PNI	11 73.2-180	11-N	73.22	180.2	X			X
PNI/PO		PNI/PO	11 73.2-180				X			X

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
INNER NOZZLE TEMP											
Inner Nozzle Shroud Temp.		TNI	12-N	12-N	67.33	238.0	X			X	
Inner Nozzle Shroud Temp.		TNI	13-N	13-N	68.81	113.8	X			X	
Inner Nozzle Shroud Temp.		TNI	14-N	14-N	70.36	354.0	X			X	
Inner Nozzle Shroud Temp.		TNI	15-N	15-N	72.3	240.1	X			X	
OUTER NOZZLE PRESS.											
Outer Nozzle Shroud Press.		PNO	16 70.9-180	16-NO	70.92	180.2	X			X	
PNO/PO		PNO/PO	16 70.9-180				X			X	
Outer Nozzle Shroud Press.		PNO	17 70.9-330	17-NO	70.92	330.1	X			X	
PNO/PO		PNO/PO	17 70.9-330				X			X	
Outer Nozzle Shroud Press.		PNO	18 71.0-134	18-NO	71.04	134.9	X				
PNO/PO		PNO/PO	18 71.0-134				X				
Outer Nozzle Shroud Press.		PNO	19 71.1-150	19-NO	71.05	150.2	X				
PNO/PO		PNO/PO	19 71.1-150				X				
Outer Nozzle Shroud Press.		PNO	20 71.1-155	20-NO	71.05	155.6	X				
PNO/PO		PNO/PO	20 71.1-155				X				
Outer Nozzle Shroud Press.		PNO	21 72.0-0	21-NO	71.98	0.2	X			X	
PNO/PO		PNO/PO	21 72.0-0				X			X	
Outer Nozzle Shroud Press.		PNO	22 72.0-180	22-NO	71.97	180.2	X			X	
PNO/PO		PNO/PO	22 72.0-180				X			X	
Outer Nozzle Shroud Press.		PNO	23 72.0-183	23-NO	71.97	183.7	X				
PNO/PO		PNO/PO	23 72.0-183				X				

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Outer Nozzle Shroud Press.		PNO	24 72.0-192	24-NO	71.96	192.9	X				
PNO/PO		PNO/PO	24 72.0-192				X				
Outer Nozzle Shroud Press.		PNO	25 72.0-201	25-NO	71.96	201.2	X				
PNO/PO		PNO/PO	25 72.0-201				X				
Outer Nozzle Shroud Press.		PNO	26 72.0-210	26-NO	71.95	210.2					
PNO/PO		PNO/PO	26 72.0-210								
Outer Nozzle Shroud Press.		PNO	27 71.9-219	27-NO	71.93	219.1	X				
PNO/PO		PNO/PO	27 71.9-219				X				
Outer Nozzle Shroud Press.		PNO	28 71.9-228	28-NO	71.92	227.9	X				
PNO/PO		PNO/PO	28 71.9-228				X				
Outer Nozzle Shroud Press.		PNO	29 71.9-236	29-NO	71.92	236.7	X			X	
PNO/PO		PNO/PO	29 71.9-236				X			X	
Outer Nozzle Shroud Press.		PNO	30 72.0-330	30-NO	71.96	330.1	X			X	
PNO/PO		PNO/PO	30 72.0-330				X			X	
Outer Nozzle Shroud Press.		PNO	31 72.0-340	31-NO	71.97	340.3	X				
PNO/PO		PNO/PO	31 72.0-340				X				
Outer Nozzle Shroud Press.		PNO	32 72.0-347	32-NO	71.97	346.9	X				
PNO/PO		PNO/PO	32 72.0-347				X				
Outer Nozzle Shroud Press.		PNO	33 72.0-353	33-NO	71.97	353.6	X				
PNO/PO		PNO/PO	33 72.0-353				X				
Outer Nozzle Shroud Press.		PNO	34 72.4-150	34-NO	72.43	150.2	X			X	
PNO/PO		PNO/PO	34 72.4-150				X			X	
Outer Cowl Body Press.		POC/PO	35 66.3-180	35-OC	66.34	180.0	X				

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER 1	2	3	4	
COMBUSTOR PROBES											
0 Deg Probe Total Press.		PT0	1-CE	(Same	66.74	0			X		
*0 Deg Probe Static Press. at 13 Deg		PS13	2-CE	as	67.04	0			X		
0 Deg Probe Static Press. at 109 Deg		PS109	3-CE	listing	67.04	0			X		
0 Deg Probe Static Press. at 193 Deg		PS193	4-CE	code	67.04	0			X		
0 Deg Probe Static Press. at 283 Deg		PS283	5-CE	number)	67.04	0			X		
110 Deg Probe Total Press.		PT110	6-CE		66.74	110			X		
*110 Deg Probe Static Press. at 18 Deg		PS18	7-CE		67.04				X		
110 Deg Probe Static Press. at 108 Deg		PS108	8-CE		67.04				X		
110 Deg Probe Static Press. at 198 Deg		PS198	9-CE		67.04				X		
110 Deg Probe Static Press. at 288 Deg		PS288	10-CE		67.04				X		
180 Deg Probe Total Press.		PT180	11-CE		66.74				X		
*180 Deg Probe Static Press. at 1 Deg		PS1	12-CE		67.04				X		
180 Deg Probe Static Press. at 91 Deg		PS91	13-CE		67.04				X		
180 Deg Probe Static Press. at 181 Deg		PS181	14-CE		67.04				X		
180 Deg Probe Static Press. at 271 Deg		PS271	15-CE		67.04				X		
280 Deg Probe Total Press.		PT280	16-CE		66.74				X		
*280 Deg Probe Static Press at 355 Deg		PS355	17-CE		67.04				X		
280 Deg Probe Static Press. at 85 Deg		PS85	18-CE		67.04				X		
280 Deg Probe Static Press. at 175 Deg		PS175	19-CE		67.04				X		
280 Deg Probe Static Press. at 265 Deg		PS265	20-CE		67.04				X		
330 Deg Probe Total Press.		PT330	21-CE		66.74				X		
*330 Deg Probe Static Press. at 3 Deg		PS3	22-CE		67.04				X		
330 Deg Probe Static Press. at 93 Deg		PS93	23-CE		67.04				X		
330 Deg Probe Static Press. at 183 Deg		PS183	24-CE		67.04				X		
330 Deg Probe Static Press. at 273 Deg		PS273	25-CE		67.04				X		
30 Deg Probe Gas Sample		GS30	26-CE		66.74				X		
30 Deg Probe Total Temp.		TT30	27-CE		66.74				X		

*Cone probe static pressure opposite engine ℄

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
30 Deg Probe Ref. Temp.		TR30	28-CE	(Same	66.74				X		
30 Deg Probe Total Press.		PT30	29-CE	as	66.74				X		
30 Deg Probe Static Press.		PS30	30-CE	listing	66.74				X		
70 Deg Probe Gas Sample		GS70	31-CE	code	66.74				X		
70 Deg Probe Total Temp.		TT70	32-CE	number)	66.74				X		
70 Deg Probe Ref. Temp.		TR70	33-CE		66.74				X		
70 Deg Probe Total Press.		PT70	34-CE		66.74				X		
70 Deg Probe Static Press.		PS70	35-CE		66.74				X		
170 Deg Probe Gas Sample		GS170	36-CE		66.74				X		
170 Deg Probe Total Temp.		TT170	37-CE		66.74				X		
170 Deg Probe Ref. Temp.		TR170	38-CE		66.74				X		
170 Deg Probe Total Press.		PT170	39-CE		66.74				X		
170 Deg Probe Static Press.		PS170	40-CE		66.74				X		
260 Deg Probe Gas Sample		GS260	41-CE						X		
260 Deg Probe Total Temp.		TT260	42-CE						X		
260 Deg Probe Ref. Temp.		TR260	43-CE						X		
260 Deg Probe Total Press.		PT260	44-CE						X		
260 Deg Probe Static Press.		PS260	45-CE						X		
350 Deg Probe Gas Sample		GS350	46-CE						X		
350 Deg Probe Total Temp.		TT350	47-CE						X		
350 Deg Probe Ref. Temp		TR350	48-CE						X		
350 Deg Probe Total Press.		PT350	49-CE						X		
350 Deg Probe Static Press.		PS350	50-CE						X		

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
AFM CL TEMP.											
Air Flowmeter ℄ Probe Temp.		TP	1-EF	1-EF	79.99	45.0		X			
Air Flowmeter ℄ Probe Temp.		TP	2-EF	2-EF	79.99	135.0		X			
Air Flowmeter ℄ Probe Temp.		TP	3-EF	3-EF	79.99	225.0		X			
Air Flowmeter ℄ Probe Temp.		TP	4-EF	4-EF	79.99	315.0		X			
AFM SHROUD PRESS.											
AFM Shroud Wall Press.		PS	5 82.4-0	5-EF	79.45	0.0		X			
PS/PO		PS/PO	5 82.4-0					X			
AFM Shroud Wall Press.		PS	6 82.4-90	6-EF	79.45	90.0		X			
PS/PO		PS/PO	6 82.4-90					X			
AFM Shroud Wall Press.		PS	7 82.4-180	7-EF	79.45	180.0		X			
PS/PO		PS/PO	7 82.4-180					X			
AFM Shroud Wall Press.		PS	8 82.4-270	8-EF	79.45	270.0		X			
PS/PO		PS/PO	8 82.4-270					X			
AFM Shroud Wall Press.		PS	13 85.6-0	13-EF	85.60	0.0		X			
PS/PO		PS/PO	13 85.6-0					X			
AFM Shroud Wall Press.		PS	14 85.6-90	14-EF	85.60	90.0		X			
PS/PO		PS/PO	14 85.6-90					X			
AFM Shroud Wall Press.		PS	15 85.6-180	15-EF	85.60	180.0		X			
PS/PO		PS/PO	15 85.6-180					X			
AFM Shroud Press.		PS	16 85.6-270	16-EF	85.60	270.0		X			
PS/PO		PS/PO	16 85.6-270					X			

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER 1	2	3	4	
AFM PLUG PRESS.											
AFM Plug Wall Press.		PP	9 82.4-0	9-EF	79.45	0.0		X			
PP/PO		PP/PO	9 82.4-0					X			
AFM Plug Wall Press.		PP	10 82.4-90	10-EF	79.45	90.0		X			
PP/PO		PP/PO	10 82.4-90					X			
AFM Plug Wall Press.		PP	11 82.4-180	11-EF	79.45	180.0		X			
PP/PO		PP/PO	11 82.4-180					X			
AFM Plug Wall Press.		PP	12 82.4-270	12-EF	79.45	270.0		X			
PP/PO		PP/PO	12 82.4-270					X			
AFM Plug Wall Press.		PP	17 85.6-0	17-EF	85.6	0.0		X			
PP/PO		PP/PO	17 85.6-0					X			
AFM Plug Wall Press.		PP	18 85.6-90	18-EF	85.6	90.0		X			
PP/PO		PP/PO	18 85.6-90					X			
AFM Plug Wall Press.		PP	19 85.6-180	19-EF	85.6	180.0		X			
PP/PO		PP/PO	19 85.6-180					X			
AFM Plug Wall Press.		PP	20 85.6-270	20-EF	85.6	270.0		X			
PP/PO		PP/PO	20 85.6-270					X			
AFM SHROUD TEMP											
AFM Shroud Wall Temp		TS	21-EF	(Same	85.85	0		X			
AFM Shroud Wall Temp		TS	22-EF	as	85.85	90		X			
AFM Shroud Wall Temp		TS	23-EF	list-	85.85	180		X			
AFM Shroud Wall Temp		TS	24-EF	ing	85.85	270		X			
AFM Shroud Wall Temp.		TR	288-EF	code	77.43	164.5		X			
*Wall Temp. at Rake, $\frac{\Delta R}{h} = 0$		TS	34-EF	number)	78.93	165		X			

*$\frac{\Delta R}{h}$ = plug wall-to-probe spacing as a fraction of duct height

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
AFM PLUG TEMP											
AFM Plug Wall Temp.		TP	25-EF	(Same	85.85	5		X			
AFM Plug Wall Temp.		TP	26-EF	as	85.85	95		X			
AFM Plug Wall Temp.		TP	27-EF	listing	85.85	185		X			
AFM Plug Wall Temp.		TP	28-EF	code	85.85	275		X			
AFM Plug Wall Temp.		TR	28A-EF	number)	77.42	195		X			
*Wall Temp. at Rake $\frac{\Delta R}{h} = 1$		TP	35-EF	↓	78.86	165		X			
AFM RAKE TEMP											
*AFM Rake Temp, $\frac{\Delta R}{h} = 0.9118$		TR	29-EF	(Same	79.31	165		X			
*AFM Rake Temp., $\frac{\Delta R}{h} = 0.7317$		TR	30-EF	as	79.31	165		X			
*AFM Rake Temp., $\frac{\Delta R}{h} = 0.5419$		TR	31-EF	listing	79.31	165		X			
*AFM Rake Temp., $\frac{\Delta R}{h} = 0.3553$		TR	32-EF	code	79.31	165		X			
*AFM Rake Temp., $\frac{\Delta R}{h} = 0.1584$		TR	33-EF	number)	79.31	165		X			

*$\frac{\Delta R}{h}$ = plug wall-to-probe spacing as a fraction of duct height

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER 1	2	3	4
IGNITOR PRESS.										
Ignitor O_2 Press., System 1		PIGO	33-F	33-F					X	X
Ignitor O_2 Press., System 2 and 3		PIGO	35-F	35-F					X	X
Ignitor H_2 Press., System 1		PIGH	37-F	37-F			X	X	X	X
Ignitor H_2 Press. System 2 and 3		PIGH	39-F	39-F			X	X	X	X
H_2O DELTA T										
H_2O ΔT Spike Bulk		DTSP	59-F	(Same as listing code number)			X	X	X	X
H_2O ΔT Innerbody and Nozzle Plug		DTNI	60-F				X	X	X	X
H_2O ΔT Strut Leading Edge		DTSE	61-F				X	X	X	X
H_2O ΔT Strut Body		DTSB	62-F				X	X	X	X
H_2O ΔT Outerbody Assy		DTOB	63-F				X	X	X	X
H_2O ΔT Cowl L.E., 0 Deg		DT1A	66-F				X	X	X	X
H_2O ΔT Cowl L.E., 180 Deg		DT1B	67-F				X	X	X	X
H_2O ΔT Outerbody Fwd., 0 Deg		DT2A	68-F				X	X	X	X
H_2O ΔT Outerbody Fwd., 180 Deg		DT2B	69-F				X	X	X	X
H_2O ΔT Outerbody Aft, 0 Deg		DT3A	70-F				X	X	X	X
H_2O ΔT Outerbody Aft, 180 Deg		DT3B	71-F				X	X	X	X

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
H_2O ΔT Nozzle Shroud 0 Deg		DT4A	72-F	(Same			X	X	X	X	
H_2O ΔT Nozzle Shroud 180 Deg		DT4B	73-F	as			X	X	X	X	
H_2O ΔT Spike Aft 0 Deg		DT5A	74-F	listing			X	X	X	X	
H_2O ΔT Spike Aft 180 Deg		DT5B	75-F	code			X	X	X	X	
H_2O ΔT Spike Assy 0 Deg		DT6A	76-F	number)			X	X	X	X	
H_2O ΔT Spike Assy 180 Deg		DT6B	77-F				X	X	X	X	
H_2O ΔT Innerbody 0 Deg		DT7A	78-F				X	X	X	X	
H_2O ΔT Innerbody 180 Deg		DT7B	79-F				X	X	X	X	
		DTW	80-F				X	X	X	X	
H_2O Temp			83-F				X	X	X	X	
H_2O Temp			84-F				X	X	X	X	
GN_2 HEATER											
Annulus Gas Temp.		TAG	1-T	(Same							
Heater Inlet Press.		PIH	2-T	as							
Annulus-to-Core ΔP		DPAC	3-T	listing							
Port N33-To-Heater-Inlet ΔP		DPHI	4-T	code							
Circumferential (N24-N33) ΔP		DPC	5-T	number)							
Heater In-To-Out ΔP		DPH	6-T								

TABLE A-I (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
GN_2 PIPING											
Venturi 4365 Press.		PVN	7-T	(Same							
Venturi 4365 ΔP 1		DPNV1	8-T	as							
Venturi 4365 ΔP 2		DPNV2	9-T	listing							
Venturi 4365 Temp		TNV	10-T	code							
Orifice 430 Press.		PNO	11-T	number)							
Orifice 430 ΔP		DPNO	12-T								
Orifice 430 Temp.		TNO	13-T								
GO_2 PIPING											
Orifice 102 Press.		POO	14-T	(Same as							
Orifice 102 ΔP		DPOO	15-T	listing							
Orifice 102 Temp.		TOO	16-T	code							
Mixer Press.		PM	17-T	number)							

TABLE A-1 (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
HOT TRAIN											
Heater Exit Temp. 1		THE1	18-T	(Same							
Heater Exit Temp. 2		THE2	19-T	as							
Heater Exit Temp. 3		THE3	20-T	listing							
Radiation Valve Temp. 1		TRV1	21-T	code							
Radiation Valve Temp. 2		TRV2	22-T	number)							
Radiation Valve Temp. 3		TRV3	23-T								
Diluent Inj. Flange Temp. 1		TDF1	24-T								
Diluent Inj. Flange Temp. 2		TDF2	25-T								
Film Cooling Flange Temp. 1		TCF1	26-T								
Film Cooling Flange Temp. 2		TCF2	27-T								
Diluent Inj. Flange Film Cooling Temp.		TFF	28-T								
Mixer Liner Temp. 1		TML1	29-T								
Mixer Liner Temp. 2		TML2	30-T								
Mixer Liner Temp. 3		TML3	31-T								
Mixer Liner Temp. 4		TML4	32-T								
Mixer Liner Temp. 5		TML5	33-T								
Mixer Liner Temp. 6		TML6	34-T								
Mixer Liner Temp. 7		TML7	35-T								
Adapter Exit N Temp.		TAEN	36-T								
Adapter Inlet N Temp.		TAIN	37-T								
Adapter Exit S Temp.		TAES	38-T								
Adapter Inlet S Temp.		TAIS	39-T								
Nozzle Metal Temp. 1		TNM1	40-T								
Nozzle Metal Temp. 2		TNM2	41-T								
Nozzle Metal Temp. 3		TNM3	42-T								
Nozzle Metal Temp. 4		TNM4	43-T								
Nozzle Total Press. 1		PT01	44-T								
Nozzle Total Press. 2		PT02	45-T	↓							

TABLE A-1 (Continued)

DESCRIPTION OR HEADING	ITEM	SYMBOL	LISTING CODE NUMBER	MEASUREMENT NUMBER	STATION NUMBER	CIRCUMFERENTIAL LOCATION	DATA REDUCTION CODE NUMBER				
							1	2	3	4	
Nozzle Thermocouple (UP)		TNT1	46-T	(Same							
Ref. Temp. for Probe 46-T		TNR1	47-T	as							
H_2O Temp. for Probe 46-T		TRW1	48-T	listing							
Nozzle Thermocouple Reading (LOW)		TNT2	49-T	code							
Ref. Temp. for Probe 49-T		TNR2	50-T	number)							
H_2O Temp. for Probe 49-T		TRW2	51-T	↓							
EJECTOR											
Ejector Inlet Temp. 1		TEI1	53-T	(Same							
Ejector Inlet Temp. 2		TEI2	54-T	as							
Ejector Inlet Temp. 3		TEI3	55-T	listing							
Ejector Inlet Temp. 4		TEI4	56-T	code							
Ejector Inlet Temp. 5		TEI5	57-T	number)							
Ejector Inlet Temp. 6		TEI6	58-T								
Sump H_2O Temp.		TSW	59-T	↓							

2.4 CALCULATIONS

2.4.1 Inlet Conditions

The following equations will provide the calculated quantities in the INLET CONDITIONS listing.

Calculation 1C-I - Average Nozzle Total Pressure

$$PT0 = \frac{PT01 + PT02}{2}$$

$$= \left[\frac{(44\text{-}T) + (45\text{-}T)}{2}\right]$$

Calculation 2C-I - Nozzle Exit Static Pressure

PO = f (nozzle gas properties and nozzle area ratio)

This function is to be coordinated with Plum Brook test personnel.

Calculation 3C-I - Nozzle Total Temperature 1

$$TT01 = f\ (TNT1,\ TNR1)$$

$$= f\left[(46\text{-}T),\ (47\text{-}T)\right]$$

This function to be coordinated with Plum Brook test personnel.

Calculation 4C-I - Nozzle Total Temperature 2

$$TT02 = f\left[(TNT2),\ (TNR2)\right]$$

$$= f\left[(49\text{-}T),\ (50\text{-}T)\right]$$

This function to be coordinated with Plum Brook test personnel.

Calculation 5C-I - Average Nozzle Total Temperature

$$TT0 = \frac{TT01 + TT02}{2}$$

$$= \frac{(3C\text{-}I) + (4C\text{-}I)}{2}$$

Calculations 6C-I, 7C-I, and 8C-I Engine and Flowmeter Airflow

For Airflow Meter Runs, the airflow will be determined by two methods. The meter throat flow (WA*, Calculation 6C-I) will be determined assuming a choked throat using the measured average throat static pressure. The calculation is defined in Section 3.2.1.1.3(b). The airflow will be recalculated (WAD, Calculation 7C-I) using the measured duct static pressure upstream of the throat as a check on the throat calculated value. This calculation is defined in Section 3.2.1.1.3(a). For runs without the flowmeter, the inlet flow rate (WA, Calculation 8C-I) will be determined from tunnel conditions and spike position. This calculation is defined in Section 3.2.1.1.4.

Calculation 9C-I Inlet Mass Flow Ratio

The inlet massflow ratio, MFR, will be determined from airflow meter runs and input as defined in Section 3.2.1.1.4. MFR will be calculated for airflow meter runs as follows:

$$MFR = \frac{WA*}{\rho_o V_o A_c}$$

$$= \frac{6C-I}{256.13\ \rho_o V_o}$$

2.4.2 Balance System

The following calculations will provide the calculated quantities for the BALANCE SYSTEM listing.

The load cell readings may be affected by the flexure of the fuel lines connecting the AIM to the facility. For the first cut, the forces will be calculated as shown below. The constants CA through CE will be determined from calibration tests. The final methods of calculation will be determined from the force calibration tests.

Calculation 1C-B - Fuel System A, Force Correction

$$DFA = (PVA - PCEL)\ CA$$

$$= \left[(60-T) - (52-T)\right]\ CA$$

Calculation 2C-B - Fuel System B, Force Correction

$$DFB = (PVB - PCEL)\ CB$$

$$= \left[(61-T) - (52-T)\right]\ CB$$

Calculation 3C-B - Fuel System C, Force Correction

$$DFC = (PVC - (PCEL)\ CC$$

$$= \left[(62-T) - (52-T)\right]\ CB$$

Calculation 4C-B - Fuel System D, Force Correction

$$\text{DFD} = (\text{PVD} - \text{PCEL})\ \text{CD}$$

$$= \left[(63\text{-T}) - (52\text{-T})\right]\ \text{CD}$$

Calculation 5C-B - Fuel System E, Force Correction

$$\text{DFE} = (\text{PVE} - (\text{PCEL})\,\text{CE}$$

$$= \left[(64\text{-T}) - (52\text{-T})\right]\ \text{CE}$$

The force correction for the cooling system will be calculated as follows:

CW will be determined from a calibration test.

Calculation 6C-B - Cooling System Force Correction

$$\text{DFW} = \left[(\text{0-P-H2O-IN}) - \text{PCEL}\right]\ \text{CW}$$

$$= \left[(45\text{-F}) - (52\text{-T})\right]$$

Calculation 7C-B - Intermediate Load Cell Reading

$$\text{FL} = \text{FLC} + \text{DFA} + \text{DFB} + \text{DFC} + \text{DFE} + \text{DFW}$$

$$= (71\text{-T}) + (1\text{C-F}) + (2\text{C-F}) + (3\text{C-F}) + (4\text{C-F}) + (5\text{C-F}) + (6\text{C-F})$$

= Load cell reading corrected for fuel and cooling system forces.

Calculation 8C-B - Average Forward Cavity Pressure

$$\frac{\text{PA}}{\text{PTO}} = \frac{\text{PA1} + \text{PA2}}{2\text{PTO}}$$

$$= \frac{(85\text{-F}) + (86\text{-F})}{2(1\text{C-I})}$$

Calculation 9C-B - Average Aft Cavity Pressure

$$\frac{\text{PB}}{\text{PTO}} = \frac{\text{PB1} + \text{PB2}}{2\text{PTO}}$$

$$= \frac{(87\text{-F}) + (88\text{-F})}{2(1\text{C-I})}$$

Calculation 10C-B - Force Parameter

$$\frac{\text{FL}}{\text{PTO}} = \frac{7\text{C-B}}{(1\text{C-I})}$$

Calculation 11C-B - Purge Line Flow Parameter

$$WPPL = \frac{WPL\sqrt{TPM}}{PPM} = \frac{WPL\sqrt{74\text{-}T}}{72\text{-}T}$$

where

$$WPL = \text{Purge line meter flow rate}$$
$$= f\left[(PPM,\ TPM,\ DPPM,\ K_1)\right]$$
$$= f\left[(72\text{-}T),\ (73\text{-}T),\ (74\text{-}T),\ K_1)\right]$$

This function will be coordinated with Plum Brook test personnel. K_1 is the meter constant.

Calculation 12C-B - Makeup Line Flow Parameter

$$WPML = \frac{WML\sqrt{TPM}}{PPM}$$
$$= \frac{WML\sqrt{74\text{-}T}}{72\text{-}T}$$

where

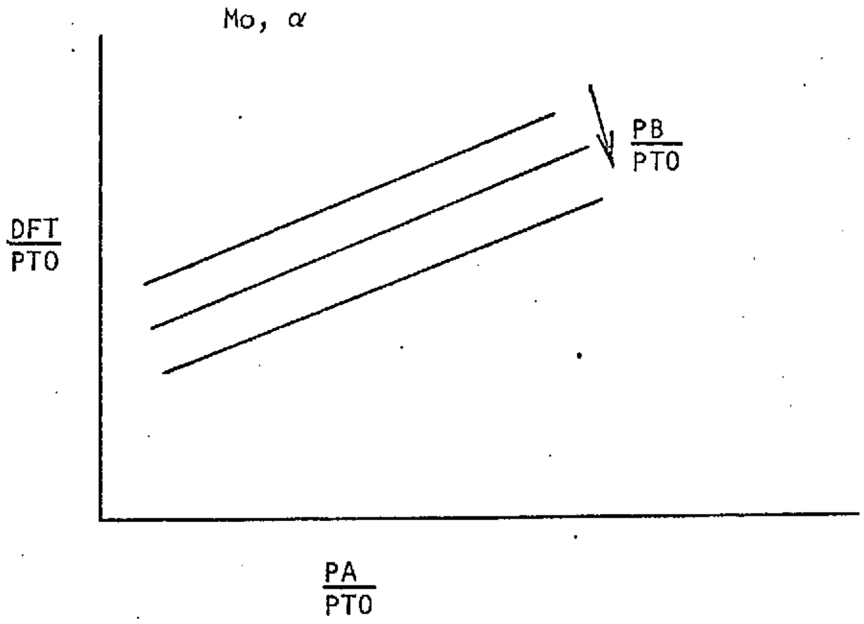
$$WML = \text{Makeup line meter flow rate}$$
$$= f\ (PMM,\ TMM,\ PPMM,\ K_2)$$
$$= f\left[(75\text{-}T),\ (76\text{-}T),\ (77\text{-}T),\ K_2\right]$$

This function will be coordinated with Plum Brook test personnel. K_2 is the meter constant.

Calculation 13C-B - Nitrogen Purge Force Correction

$$DFT = f\left(\frac{PA}{PTO},\ \frac{PB}{PTO},\ PTO,\ Mo,\ \alpha,\ X\right)$$
$$= f\left[(8C\text{-}B),\ (9C\text{-}B),\ (1C\text{-}I),\ Mo,\ \alpha,\ (52\text{-}S)\right]$$

Mo and α are program inputs. This function will be determined from calibration tests and presented in the following form for each Mo and α.



Calibrations will be performed at each Mo and α at the same conditions that the performance and runs will be made. Therefore, no interpolations will be required for these parameters. The program will interpolate between PA, PB, and X.

Calculation 14C-B - Corrected Load Cell Reading

$$FC = FL + DFT$$

$$= (7C-B) + (13C-B)$$

2.4.3 Fuel System Data Listing and Calculations

A total of five facility fuel systems are connected to the AIM. The five systems may be connected to the eight engine fuel manifolds in various combinations. Figure A-1 defines the fuel system and manifold designation numbers. Each fuel system has its own fuel flow measuring venturi which requires a unique calculation of fuel flow. The program must be flagged to designate the facility system to which each AIM fuel manifold is connected. This information will be used by the program to:

(a) Use the correct equations for fuel flow calculation

(b) Use the appropriate symbols for listing the data

The following calculations will provide the calculated quantities in the FUEL SYSTEM listing. The venturi flow equations used will be coordinated with Plum Brook test personnel.

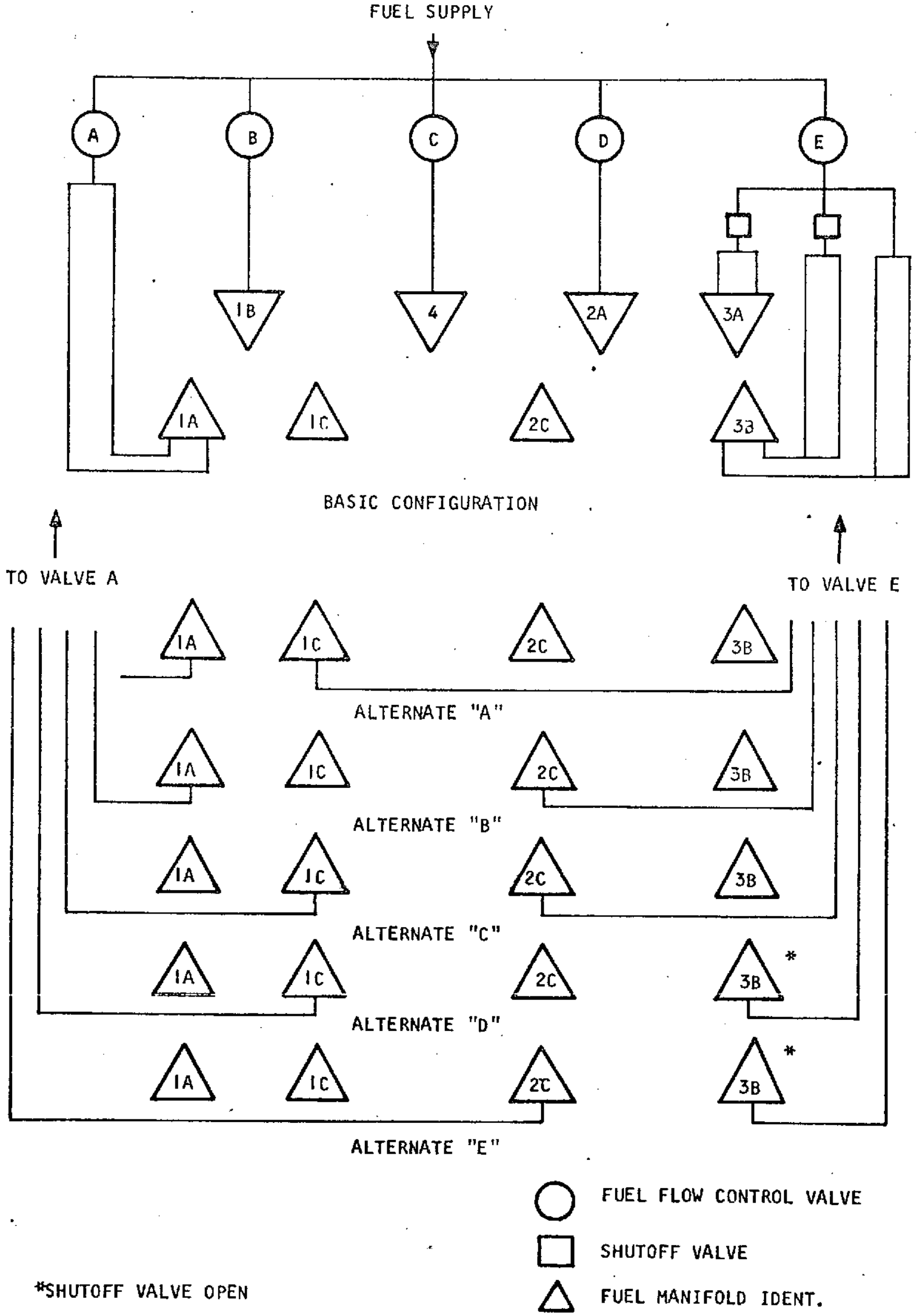


Figure A-1. AIM Fuel System Schematic

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Calculation 1C-F - System A, Fuel Flow

$$\text{WFA} = f\ (\text{PVA, DPVA, TFVM})$$

$$= f\ \left[(60\text{-T}),\ (65\text{-T}),\ (70\text{-T})\right]$$

Calculation 2C-F - System B, Fuel Flow

$$\text{WFB} = f\ (\text{PVB, DPVB, TFVM, venturi areas})$$

$$= f\ \left[(61\text{-T}),\ (66\text{-T}),\ (70\text{-T}),\ \text{venturi areas})\right]$$

Calculation 3C-F - System C, Fuel Flow

$$\text{WFC} = f\ (\text{PVD, DPVD, TFVM})$$

$$= f\ \left[(62\text{-T}),\ (67\text{-T}),\ (70\text{-T})\right]$$

Calculation 4C-F - System D, Fuel Flow

$$\text{WFD} = f\ \left[(63\text{-T}),\ (68\text{-T}),\ (70\text{-T})\right]$$

Calculation 5C-F - System E, Fuel Flow

$$\text{WFE} = f(\text{PVD, DPVD, TFVM})$$

$$= f\left[(63\text{-T}),\ (68\text{-T}),\ (70\text{-T})\right]$$

Calculation 6C-F - System A, Equivalence Ratio

$$\text{ERA} = \frac{\text{WFA}}{.0293\text{WA}}$$

$$= \frac{\text{1C-F}}{0.0293(\text{8C-I})}$$

Calculation 7C-F - System B, Equivalence Ratio

$$\text{ERB} = \frac{\text{WFB}}{0.0293\text{WA}}$$

$$= \frac{\text{2C-F}}{0.0293(\text{8C-I})}$$

Calculation 8C-F - System C, Equivalence Ratio

$$\text{ERC} = \frac{\text{WFC}}{0.0293\text{WA}}$$

$$= \frac{\text{3C-F}}{0.0293(\text{8C-I})}$$

Calculation 9-CF - System D, Equivalence Ratio

$$ERD = \frac{WFD}{0.0293WA}$$

$$= \frac{4C\text{-}F}{0.0293(8C\text{-}I)}$$

Calculation 10C-F - System E, Equivalence Ratio

$$ERE = \frac{WFE}{0.0293WA}$$

$$= \frac{5C\text{-}F}{0.0293(8C\text{-}I)}$$

Calculation 11C-F - Overall Equivalence Ratio

$$EROA = ERA + ERB + ERC + ERD + ERE$$

$$= (6C\text{-}F) + (7C\text{-}F) + (8C\text{-}F) + (9C\text{-}F) + (10C\text{-}F)$$

Calculation 12C-F - Fuel Injector 1A Discharge Coefficient

$$CD1A = \frac{\text{Ideal area required for fuel flow at } M = 1.0}{\text{Measured total fuel injector areas}}$$

$$= \frac{WF1A\sqrt{TM1A1}}{.1402\ (PM1A1)\ (A1A)}$$

$$= \frac{W1A\sqrt{17\text{-}F}}{.1402\ (1\text{-}F)\ (.4255)}$$

Calculation 13C-F - Fuel Injector 1C Discharge Coefficient

$$CD1C = \frac{WF1C\sqrt{TM1C1}}{.1402\ (PM1C1)\ (A1C)}$$

$$= \frac{WF1C\sqrt{19\text{-}F}}{.1402\ (3\text{-}F)\ (.4255)}$$

Calculation 14C-F - Fuel Injector 2C Discharge Coefficient

$$CD2C = \frac{WF2C\sqrt{TM2CI}}{.1402\ (PM2CI)\ (A2C)}$$

$$= \frac{WF2C\sqrt{21\text{-}F}}{.1402\ (5\text{-}F)\ (.4076)}$$

Calculation 15C-F - Fuel Injector 3B Discharge Coefficient

$$CD3B = \frac{WF3B\sqrt{TM3BI}}{.1402\ PM3BI}$$

$$= \frac{WF3B\sqrt{23\text{-}F}}{.1402\ (7\text{-}F)\ .6929}$$

Calculation 16C-F - Fuel Injector 1B Discharge Coefficient

$$CD1B = \frac{WF1B\sqrt{TM1BI}}{.1402\ (PM1BI)\ (A1B)}$$

$$= \frac{WF1B\sqrt{25\text{-}F}}{.1402\ (9\text{-}F)\ .4396}$$

Calculation 17C-F - Fuel Injector 2A Discharge Coefficient

$$CD2A = \frac{WF2A\sqrt{TM2AI}}{.1402\ (PM2AI)\ (A2A)}$$

$$= \frac{WF2A\sqrt{27\text{-}F}}{.1402\ (13\text{-}F)\ (.4526)}$$

Calculation 18C-F - Fuel Injector 4 Discharge Coefficient

$$CD4 = \frac{WF4\sqrt{TM4I}}{.1402\ (PM4I)\ (A4)}$$

$$= \frac{WF4\sqrt{29\text{-}F}}{.1402\ (11\text{-}F)\ (.4396)}$$

Calculation 19C-F - Fuel Injector 3B Discharge Coefficient

$$\mathrm{CD3A} = \frac{\mathrm{WF3A}\sqrt{\mathrm{TM3A1}}}{.1402\ (\mathrm{PM3A1})\ \mathrm{A3}}$$

$$= \frac{\mathrm{WF3A}\sqrt{31\text{-}F}}{.1402\ (15\text{-}F)\ .6929}$$

Calculation 20C-F - Fuel Injector 3A, 3B Discharge Coefficient

The fuel system is trimmed so that WF3A = WF3B as described in Section 6.3 in report body. CD3AB is calculated assuming WF3A = WF3B as follows.

$$\mathrm{CD3AB} = \frac{\dfrac{\mathrm{WFE}}{(2)\ (.1402)}\left(\dfrac{\sqrt{\mathrm{TM3A1}}}{\mathrm{PM3A1}} + \dfrac{\sqrt{\mathrm{TM3B1}}}{\mathrm{PM3B1}}\right)}{\mathrm{A3A} + \mathrm{A3B}}$$

$$= \frac{\dfrac{5C\text{-}F}{.2804}\left(\dfrac{\sqrt{31\text{-}F}}{15\text{-}F} + \dfrac{\sqrt{23\text{-}F}}{7\text{-}F}\right)}{0.7744 + 0.6929}$$

CD3AB will be computed when manifolds 3A and 3B are connected to fuel system E. CD3A and CD3B will not be computed for this case.

The fuel flow listing method will be shown with the following example:

For a given test assume that fuel system A is connected to manifold 1A, fuel system B is connected to manifold 1B, fuel system C is connected to manifold 4, and fuel system E is connected to manifold 1C.

The program heading (see paragraph 2.2.3 g) will read as follows:

```
FUEL SYSTEM A - MANIFOLD 1A

FUEL SYSTEM B - MANIFOLD 1B

FUEL SYSTEM C - MANIFOLD 4

FUEL SYSTEM E - MANIFOLD 1C
```

The fuel system listing will read as follows:

```
FUEL SYSTEM

1-CF 6-CF 12C-F 2-CF 7-CF 16C-F 3-CF 8-CF 18-CF 5-CF 10-CF 13C-F 11-CF
WF1A ER1A CD1A  WF1B ER1B CD1B  WF4  ER4  CD4   WF1C ER1C  CD1C  ER0A
```

The code numbers (i.e., 1C-F) are keyed to the above fuel flow calculation equations. Since a maximum of four manifolds may be operational during a run, then space for four columns of WF's, ER's and CD's will be provided for in the data listing. Note that in the symbols listed, the manifold designation number has replaced the fuel system designation letter in the fuel flow calculation. For example, calculation 1-CF gives the fuel flow in system A, designated WFA. Fuel system A is connected to manifold 1A. The program will replace the A with 1A on the data listing.

For cases where system E is hooked to manifolds 3A and 3B, the symbols will be WF3AB, ER3AB, and CD3AB.

The overall equivalence ratio, EROA, Code No. 11-CF, will always be printed for runs with combustion.

Following the fuel flow listings, the fuel manifold pressures and temperatures will be listed. These will be listed for all manifolds regardless of the fuel systems in operation. The code numbers, headings, and symbols are given in Table A-1.

2.5 DATA PLOTS

Any measured or calculated quantity may be plotted versus time. Also, any time-averaged quantity may be plotted versus any other such quantity at a selected time. A standard set of plots will be made for each run. These plots are defined as follows:

(a) Plot as a function of time

  (1) PTO (1C-I)

  (2) TTO (5C-I)

  (3) Corrected load cell reading (14C-B)

  (4) Spike position 52-S

  (5) Engine airflow (7C-I) or flowmeter airflow (6C-I)

  (6) Equivalence ratio in each operative system

  (7) Ignitor pressure (H_2 pressure in operative system). This may be any of code numbers 37-F through 40-F.

(b) The following ratios of wall pressure to tunnel static pressure will be plotted as a function of axial station for each of the following averaged wall static pressures.

  (1) Average spike wall pressure ratio at Station 40.

$$PR40\text{-}S = \frac{(29\text{-}S) + (30\text{-}S) + (31\text{-}S) + (32\text{-}S)}{4(2C\text{-}I)}$$

(2) Average inner cowl wall pressure at Station 40.

$$\text{PR40-C} = \frac{(50\text{-C}) + (51\text{-C}) + (52\text{-C}) + (53\text{-C})}{4(2\text{C-I})}$$

(3) Average outer shell pressure at Station 43.8.

$$\text{PR43.8} = \frac{(5\text{-0}) + (6\text{-0}) + (7\text{-0}) + (8\text{-0})}{4(2\text{C-I})}$$

(4) Outer shell pressure at Station 49.0.

$$\text{PR47-0} = \frac{(10\text{-0})}{(2\text{C-I})}$$

(5) Average outer shell pressure ratio at Station 49.0.

$$\text{PR49-0} = \frac{(11\text{-0}) + (12\text{-0}) + (13\text{-0}) + (14\text{-0})}{4(2\text{C-I})}$$

(6) Average outer shell pressure ratio at Station 53.

$$\text{PR53-0} = \frac{(22\text{-0}) + (23\text{-0}) + (24\text{-0}) + (25\text{-0})}{4(2\text{C-I})}$$

(7) Average outer shell pressure ratio at Station 61.4.

$$\text{PR61.9-0} = \frac{(32\text{-0}) + (33\text{-0}) + (34\text{-0}) + (35\text{-0})}{4(2\text{C-I})}$$

(8) Inner shell pressure ratio at Station 56.0.

$$\text{PR56-I} = \frac{5\text{-I}}{2\text{C-I}}$$

The pressures will be plotted versus distance (X) from the spike apex. The effect of spike translation on the location of points other than those on the spike will be determined from the relationships given in Figure A-2.

3. PERFORMANCE ANALYSIS SECTION

3.1 SUMMARY

This section defines the calculations of component performance, cycle performance, and selected aerodynamic and heat transfer parameters. Weight-flow calculations are also defined for the airflow meter runs.

Basically, the analysis uses available test information and conservation equations in arriving at performance parameters for the AIM. Equilibrium chemistry is employed throughout the analysis. Non-equilibrium losses are accounted for using the non-reacting hydrogen species.

Analyses for inlet, combustor, nozzle, and engine performance are presented separately in different sections. However, they may use some of the same subroutines in determining heat flux or friction coefficients. Heat transfer data are analyzed to determine the heat flux, heat load, and surface temperatures. Friction coefficients are evaluated analytically using Spalding and Chi's method.

3.2 DATA REDUCTION ANALYSIS

3.2.1 Inlet

3.2.1.1 Flowmeter Calculations

Flowmeter instrumentation includes a five-element T_T rake. This rake will be used to determine a calibration factor to apply to temperature readings taken on four centerline thermocouples for evaluation of stream average total temperature. The five-element T_T rake will be installed for Mach 5 and 6 testing but may be removed for Mach 7 testing; therefore a subroutine must be written to interpret the readings when the probes are in place (M_o = 5 and 6) and to provide extrapolation values for $M_o = 7$.

3.2.1.1.1 Flowmeter Air Total Temperature

The flowmeter air temperature will be measured by four shielded thermocouples located at various circumferential locations on the duct annulus centerline. A five-element temperature rake is installed to determine the radial temperature profile. The rake thermocouples are unshielded and are therefore expected to read a lower temperature than the shielded probe thermocouples for a given gas temperature. The unshielded probe readings require a correction based on the shielded probe readings. Also included in the temperature profile measurement are two thermocouples imbedded in the duct walls at the rake station. Analytical results show that these measurements will read no less than 10 deg below the gas temperature next to the wall; therefore, no correction is required for these readings. Based on the above considerations the average gas temperature entering the flowmeter throat will be computed as follows:

$$\bar{T}_T = 84.918 \Bigg/ \left[\frac{6.8027}{T_{T1}} + \frac{16.987}{T_{T2}} + \frac{18.779}{T_{T3}} + \frac{18.80}{T_{T4}} + \frac{16.84}{T_{T5}} + \frac{6.709}{T_{T6}} \right]$$

where
$$T_{T1} = \frac{1}{2} \left[T_{(34\text{-}EF)} + T_{corr.(29\text{-}EF)} \right]$$

$$T_{T2} = \frac{1}{2} \left[T_{corr.(29\text{-}EF)} + T_{corr.(30\text{-}EF)} \right]$$

$$T_{T3} = \frac{1}{2} \left[T_{corr.(30\text{-}EF)} + T_{corr.(31\text{-}EF)} \right]$$

$$T_{T4} = \frac{1}{2} \left[T_{corr.(31\text{-}EF)} + T_{corr.(32\text{-}EF)} \right]$$

$$T_{T5} = \frac{1}{2} \left[T_{corr.(32\text{-}EF)} + T_{corr.(33\text{-}EF)} \right]$$

$$T_{T6} = \frac{1}{2} \left[T_{corr.(33\text{-}EF)} + T_{(35\text{-}EF)} \right]$$

The constants in the equation are mass-weighting factors. $T_{(34\text{-}EF)}$ and $T_{(35\text{-}EF)}$ are plug wall and shroud wall temperatures respectively; therefore, no radiation correction is required; $T_{(29\text{-}EF)}$ through $T_{(33\text{-}EF)}$ are rake temperatures which may be corrected for radiation as follows:

$$T_{corr.(i\text{-}EF)} = \frac{T^4_{(i\text{-}EF)} - T_w^4}{T^4_{(31\text{-}EF)} - T^4_w} \left[T_{T\mathbb{C}} - T_{(31\text{-}EF)} \right] + T_{(i\text{-}EF)}$$

where $T_w = \frac{1}{2} \left(T_{34\text{-}EF} + T_{35\text{-}EF} \right)$

$T_{T\mathbb{C}}$ = numerical average of the four shielded probe temperatures (measurement numbers 1-EF through 4-EF)

The temperature rake may not be operative at Mach 7. In this case the Machs 5 and 6 rake data will be extrapolated to determine $\bar{T}_T$ from the probe readings at Mach 7. The extrapolation will be performed as follows:

$$\left(\frac{\bar{T}_T}{T_{T℄}}\right)_{M_o=7} = \left(\frac{\bar{T}_T}{T_{T℄}}\right)_{M_o=5} + \frac{\left[\left(\frac{\bar{T}_T}{T_{T℄}}\right)_{M_o=6.0} - \left(\frac{\bar{T}_T}{T_{T℄}}\right)_{M_o=5}\right]\left[(M_c)_{M=7} - (M_c)_{m=5}\right]}{(M_c)_{m=6} - (M_c)_{m=5}}$$

and

$$\bar{T}_{T_{M=7}} = \left(\frac{\bar{T}_T}{T_{T℄}}\right)_{M_o=7} (T_{T℄})_{M_o=7}$$

where M_c is the Mach number determined from wind tunnel calibration at each nominal Mach number.

$$\left(\frac{\bar{T}_T}{T_{T℄}}\right)_{M_o=5} \text{ and } \left(\frac{\bar{T}_T}{T_{T℄}}\right)_{M_o=6} \text{ will be inputs.}$$

If the rake is operative at $M_o = 7$ the extrapolation will not be used.

3.2.1.1.2 Flowmeter Flow Coefficient

The flowmeter discharge coefficient, C_D, will be a program input. It's value will be determined from flowmeter tests with zero external spillage. Then the inlet flow captured can be calculated and used to calibrate the flowmeter discharge coefficient. The flowmeter discharge coefficient determined by this procedure is defined as follows.

$$C_D' = \frac{\rho_o V_o A_c \sqrt{\bar{T}_T}}{A^* \bar{P}^* \left[\frac{W\sqrt{T_T}}{AP}\right]^*}$$

where

$$\bar{P}^* = \frac{1}{8} \sum_{13-EF}^{20-EF} P_{measured},$$

$$\left[\frac{W\sqrt{T_T}}{AP}\right]^* = \text{Weight flow parameter for } M = 1 \text{ evaluated for equilibrium air at}$$

$$P = \bar{P}^* \text{ and } T_T = \bar{T}_T$$

3.2.1.1.3 Flowmeter Weightflow

Weightflow will be calculated from measurements of the flowmeter pressure and temperature in two ways, as follows:

(a) Weightflow based on duct pressure

$$W_{AD} = M_{DOT} \frac{\overline{P}_D}{\sqrt{\overline{T}_T}} A_D$$

where all properties are evaluated at $\overline{T}_T$ and $\overline{P}_D$
where $\overline{T}_T$ is defined in Section 3.2.1.1.1.

Symbols defined above,

$M_{DOT} = \frac{W\sqrt{T_T}}{AP}$; this parameter is based on a subsonic Mach number whose isentropic area ratio, A/A*, is 2.0639

$$\overline{P}_D = \frac{1}{8} \sum_{5-EF}^{12-EF} P_{measured}$$

$$A_D = 103.2388 \text{ in.}^2$$

(b) Weightflow based on throat conditions

$$W_A = (M_{DOT})^* \frac{\overline{P}^*}{\sqrt{\overline{T}_T}} C_D A^*$$

Where $(M_{DOT})^*$ is evaluated at M = 1

$$\overline{P}^* = \frac{1}{8} \sum_{13-EF}^{20-EF} P_{measured},$$

C_D = Throat discharge coefficient

$$A^* = 50.0203 \text{ in.}^2$$

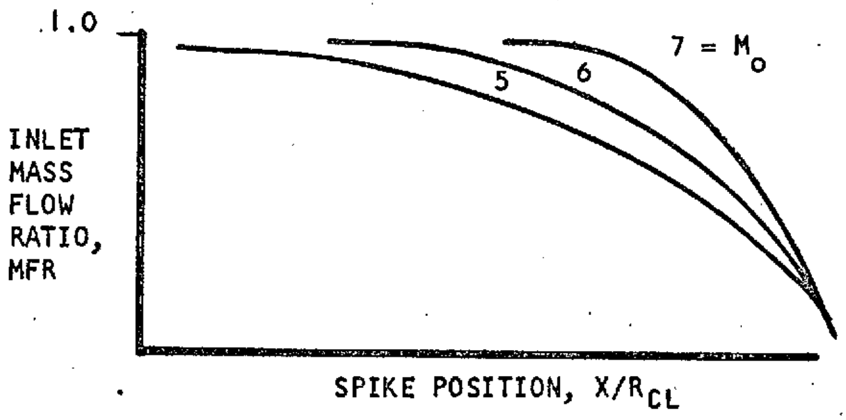
3.2.1.1.4 Engine Weightflow

For combustor and engine performance runs, the weightflow will be determined as follows:

$$WA = MFR\ Ac\ \frac{W}{A}$$

$$= 256.13\ MFR\ \rho_o\ V_o$$

MFR will be determined from the airflow meter runs and will be input into the computer in the following form:



Method for Calculating Properties at Inlet Station

I. Momentum Equation

$$\frac{W_2V_2}{g} + p_2A_2 = \frac{W_oV_o}{g} + p_oA_o + \sum_{Q=1}^{4} \int_{\substack{\text{spike}\\ \text{\& cowl}}} pdA + \int_{\substack{\text{spillage}\\ \text{streamline}}} pdA$$

$$- \sum_{Q=1}^{4} \int_{\substack{\text{spike}\\ \text{\& cowl}}} C_f\ q\ dA_s \cos \delta_s - C_{D_{\substack{\text{spike}\\ \text{tip}}}}\ q_oA_{\substack{\text{spike}\\ \text{tip}}}$$

$$- C_{D_{\substack{\text{cowl}\\ \text{lip}}}}\ q_oA_{\substack{\text{cowl}\\ \text{lip}}}$$

II. Energy Equation

$$H_{T_2} = H_{T_o} + Q_{o_2}$$

$$H_2 = H_{T_2} - V_2^{\,2}/2gJ$$

III. Continuity Equation

$$W_o = \left(\frac{W}{A}\right)_o \frac{A_o}{A_c} A_c$$

$$W_2 = W_o$$

When flowmeter is utilized, make side calculations

$$\frac{A_o}{A_c} = \frac{W_a}{(W/A)_o A_c}$$

and

$$W_2 = W_a$$

IV. Skin Friction Drag

Calculate spike conical shock to obtain total pressure (p_{TC}) and entropy (S_C). With local measured or interpolated static pressures $p_{X,Q}$ and S_C, solve SP problem for local static conditions and obtain local dynamic pressures from

$$q_{X,Q} = \left(\frac{W}{A}\right)_{X,Q} \frac{V_{X,Q}}{2g}$$

and local skin friction coefficients $C_{fX,Q}$ from the local transport properties using the method of Spalding and Chi. With these quantities, integrate the skin friction term in the momentum equation over the four quadrants on the spike up to the position where the wedge shock from the cowl lip impinges on the centerbody. The entropy level inside the cowl and downstream of the shock impingement point on the spike is determined by taking a nominal 10-deg wedge shock off the cowl lip at the flow conditions downstream of the spike conical shock and a normal shock wave to account for the effect of cowl-lip bluntness. The entropy level is assumed constant up to the inlet throat. With the local measured or interpolated static pressures and entropy, the SP problem is solved for dynamic pressures and skin friction coefficients as described above, and the skin friction term in the momentum equation is integrated over the four quadrants inside the cowl and spike up to the inlet throat. The wedge angle should be made variable.

V. Flow Properties at Inlet Station

Evaluate V_2, H_{T_2}, H_2 and W_2 from the above equations. With H_2 and measured p_2, solve HP problem to obtain static properties at inlet throat and evaluate area blockage from

$$1 - \frac{W_2/(W/A)_2}{A_2}.$$

Obtain estimate of total pressure from

$$p_{T2}^{(1)} = p_2 \left(1 + \frac{\gamma_2 - 1}{2} M_2{}^2\right)^{\frac{\gamma_2}{\gamma_2 - 1}}$$

and with S_2 and $p_{T2}^{(n)}$ solve SP problem for total conditions. Iterate on $p_{T2}^{(n)}$ until

$$\left| \frac{H_{T2} - H_{T2}^{(n)}}{H_{T2}} \right| < \epsilon$$

The pressure integral along the entering streamline is to be evaluated from the theoretical additive drag for this inlet

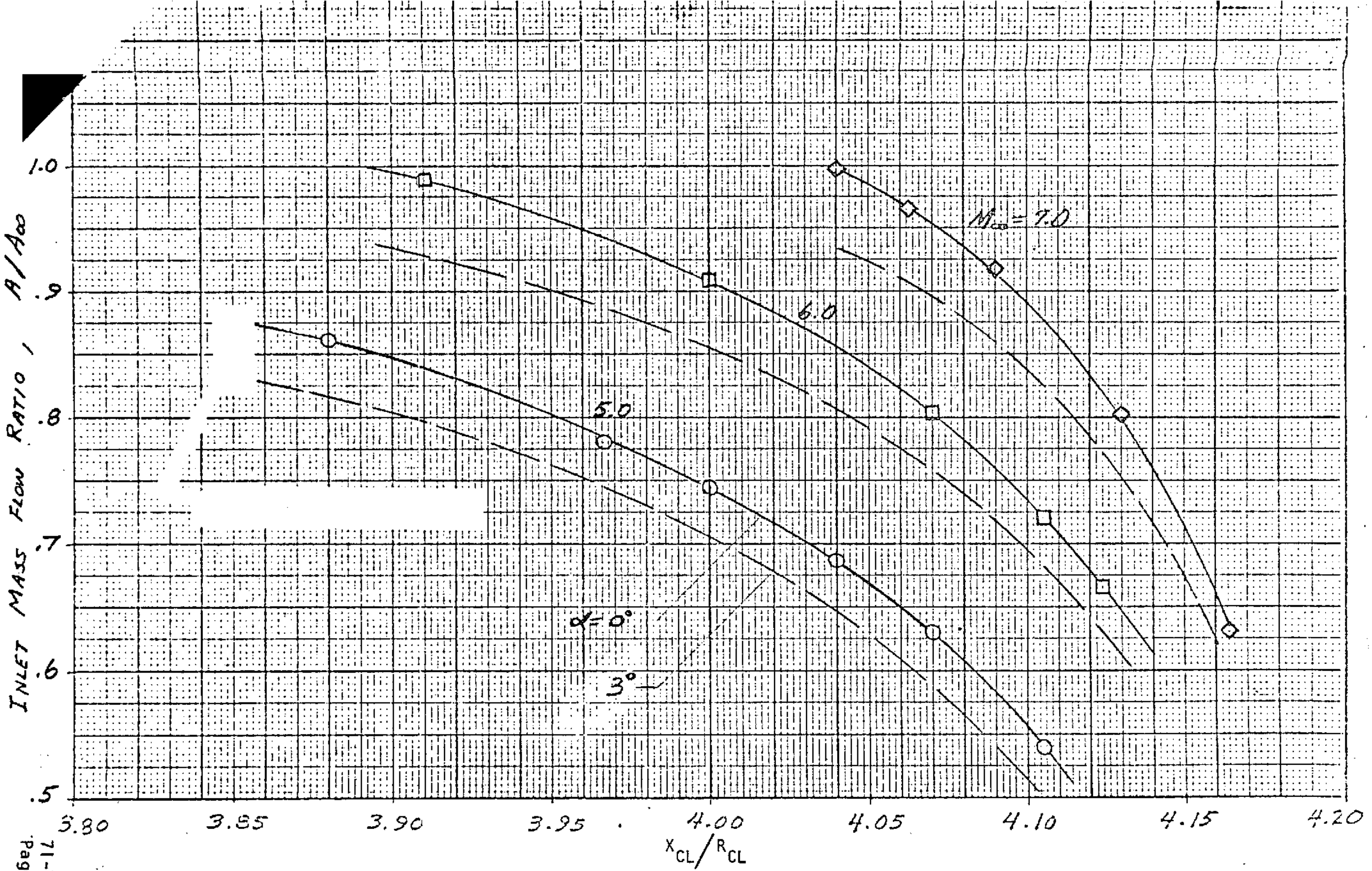
$$\int_{\substack{\text{SPILLAGE}\\ \text{STREAMLINE}}} PdA = q_o A_c C_{DA} + P_o A_c \; (1 - A_o/A_c)$$

Inlet mass flow ratio, A_o/A_c, and additive drag coefficient, C_{DA}, are presented in curve form (Figure A-2) as functions of M_o, α and spike position; however, provisions should be made to accommodate changes during the course of the test program.

Spike Static Pressures

The hemispherical spike tip will be included in the calculations by means of a drag coefficient

$$C_{D_{\substack{\text{SPIKE}\\ \text{TIP}}}} = \frac{\int (P - P_o)\; dA}{q_o \; A_T}, \qquad A_T = \frac{\pi}{64} \text{ in.}^2$$



(a) MASS FLOW RATIOS

Figure A-2. Corrections to Mass Flow Ratio and Additive Drag Coefficient Schedules to Account for Angle of Attack; HREPO Computations

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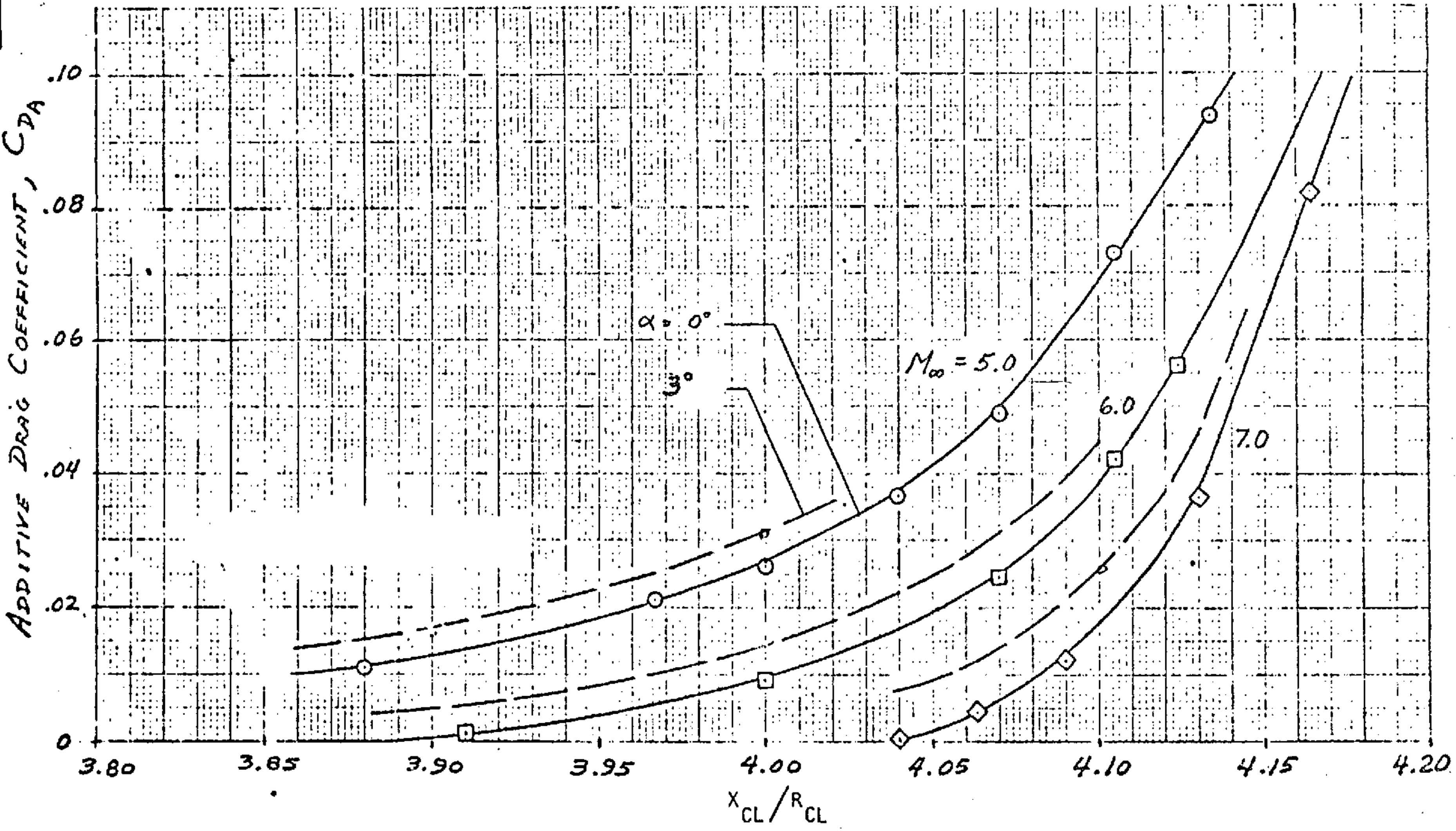


(b) ADDITIVE DRAG COEFFICIENT

Figure A-2 (Continued)

$$C_{D_{\substack{SPIKE\\TIP}}} = 0.4843\ Cp_{TIP},\ \text{where}\ Cp_{TIP} = \frac{P_{1-s} - P_o}{q_o} \qquad (1\text{-}s = \text{TAP NO.})$$

$$F_{ST} = \int \frac{P}{P_o}\, dA = \frac{\gamma_o}{2}\ M_o^2\ A \left(C_D + \frac{1.94}{\gamma_o M_o^2}\right)$$

The remainder of the spike is divided into 4 quadrants to account for angle-of-attack variations and imperfect geometry.

The quadrants and the static pressure taps contained within each are defined in the table below.

Quadrant	Included Angle, deg	Station										
		14.4	30.6	35.0	35.5	36.0	36.5	37.0	38.0	39.0	39.5	40.0
		Tap Number										
I	315-45	2-S	6-S	7-S	11-S	12-S	13-S	17-S	19-S	24-S	28-S	29-S
II	45-135	3-S		8-S			14-S		20-S	25-S		30-S
III	135-225	4-S		9-S			15-S		21-S	26-S		31-S
IV	225-315	5-S		10-S			16-S		22-S			32-S

Pressure Interpolation

(a) X = 0.69814 in. to 18.36 in.

Quadrant	Pressure Obtained From Pressure Tap No.
I	2-S
II	3-S
III	4-S
IV	5-S

(b) X = 18.36 in. to 35 in.

$Cp_x = K_1 \sin^2 \sigma_x$, $\quad Cp$ = pressure coeff = $\frac{P - P_o}{q_o}$

σ = surface angle = f(x)

$$K_1 = \frac{Cp_n}{\sin^2 \sigma_n} + \left[\frac{Cp_{n+1}}{\sin^2 \sigma_{n+1}} - \frac{Cp_n}{\sin^2 \sigma_n} \right] \Big/ \sigma_{n+1} - \sigma_n$$

subscripts n, n+1 refer to pressure taps

Quadrant	Pressure Tap No.			
	X = 18.36 in. to 29 in.		X = 29 in. to 35 in.	
	n	n+1	n	n+1
I	2-S	6-S	6-S	7-S
II	3-S	8-S	3-S	8-S
III	4-S	9-S	4-S	9-S
IV	5-S	10-S	5-S	10-S

(c) X = 35 in. to 40.5 in.

$Cp_X = KCp_{REF}$

Cp_{REF} is press. coeff. based on pressure tap listed in the following table.

X	Quadrant	K	Pressure Tap No. for Cp_{ref}
35.5	I	1.0	Cp_{11-5}
	II	Cp_{11-S}/Cp_{7-S}	Cp_{8-S}
	III	Cp_{11-S}/Cp_{7-S}	Cp_{9-S}
	IV	Cp_{11-S}/Cp_{7-S}	Cp_{10-S}
36.0	I	1.0	Cp_{12-S}
	II	Cp_{12-S}/Cp_{11-S}	$Cp_{35.5}$, II*
	III	Cp_{12-S}/Cp_{11-S}	$Cp_{35.5}$, III
	IV	Cp_{12-S}/Cp_{11-S}	$Cp_{35.5}$, IV
36.5	I	1.0	Cp_{13-S}
	II	1.0	Cp_{14-S}
	III	1.0	Cp_{15-S}
	IV	1.0	Cp_{16-S}
37.0	I	1.0	Cp_{17-S}
	II	Cp_{17-S}/Cp_{13-S}	Cp_{14-S}
	III	Cp_{17-S}/Cp_{13-S}	Cp_{15-S}
	IV	Cp_{17-S}/Cp_{13-S}	Cp_{16-S}

*Definition: $Cp_{35.5}$, II = pressure coefficient from previous calculation at Station 35.5 in Quadrant II.

X	Quadrant	K	Pressure Tap No. for Cp_{ref}
38.0	I	1.0	Cp_{19-S}
	II	1.0	Cp_{20-S}
	III	1.0	Cp_{21-S}
	IV	1.0	Cp_{22-S}
39.0	I	1.0	Cp_{24-S}
	II	1.0	Cp_{25-S}
	III	1.0	Cp_{26-S}
	IV	Cp_{24-S}/Cp_{19-S}	Cp_{22-S}
39.5	I	1.0	Cp_{28-S}
	II	Cp_{28-S}/Cp_{24-S}	Cp_{25-S}
	III	Cp_{28-S}/Cp_{24-S}	Cp_{26-S}
	IV	Cp_{28-S}/Cp_{24-S}	Cp_{39}, IV
40.0	I	1.0	Cp_{29-S}
TO	II	1.0	Cp_{30-S}
40.4	III	1.0	Cp_{31-S}
	IV	1.0	Cp_{32-S}

For all wall pressure integrations, the incremental distance, ΔX, between the points at which pressures are calculated will be a program input. The maximum ΔX that can be input to yield an accurate force integration will be determined experimentally. To do this, the program will be run with data from the first AIM tests at various values of ΔX. The results will reveal the upper limit of ΔX yielding constant calculated wall forces. The selected ΔX will be used for subsequent calculations.

Cowl Static Pressure (Figure A-3)

Cowl internal pressures will be included in the inlet calculations to Station 40.4 inches. Station callouts for the taps in the instrumentation list are based on X_{CL} = 34.884. The wall pressure integral for the inlet of the cowl taps is defined as follows:

$$F = \int_{x_{CL} - .006 \text{ in.}}^{x = 40.4 \text{ in.}} (P - P_o)dA$$

As with the spike, the blunted leading edge FORCE, F_{CL}, will be handled separately as follows:

$$C_{D\ LIP} = \frac{\int (P - P_o)dA}{q_o A_L} \quad , A_L = 1.718 \text{ in.}^2$$

$$C_{D\ LIP} = 2.943 \text{ for all test conditions}$$

The remainder of the cowl portion of the inlet will be divided into four quadrants as was done with the spike.

Following is a list of pertinent instrumentation on the cowl for inlet analysis.

Quadrant	Included Angle, deg	Station 35.5	 36.0	 36.5	 37.0	 37.5	 38.0	 38.5	 39.0	 39.5	 40.0
		Tap Number									
I	315-45	31-C	32-C	33-C	35-C	39-C	40-C	44-C	45-C	49-C	50-C
II	45-135				36-C		41-C		46-C		51-C
III	135-225			34-C	37-C		42-C		47-C		52-C
IV	225-315				38-C		43-C		48-C		53-C

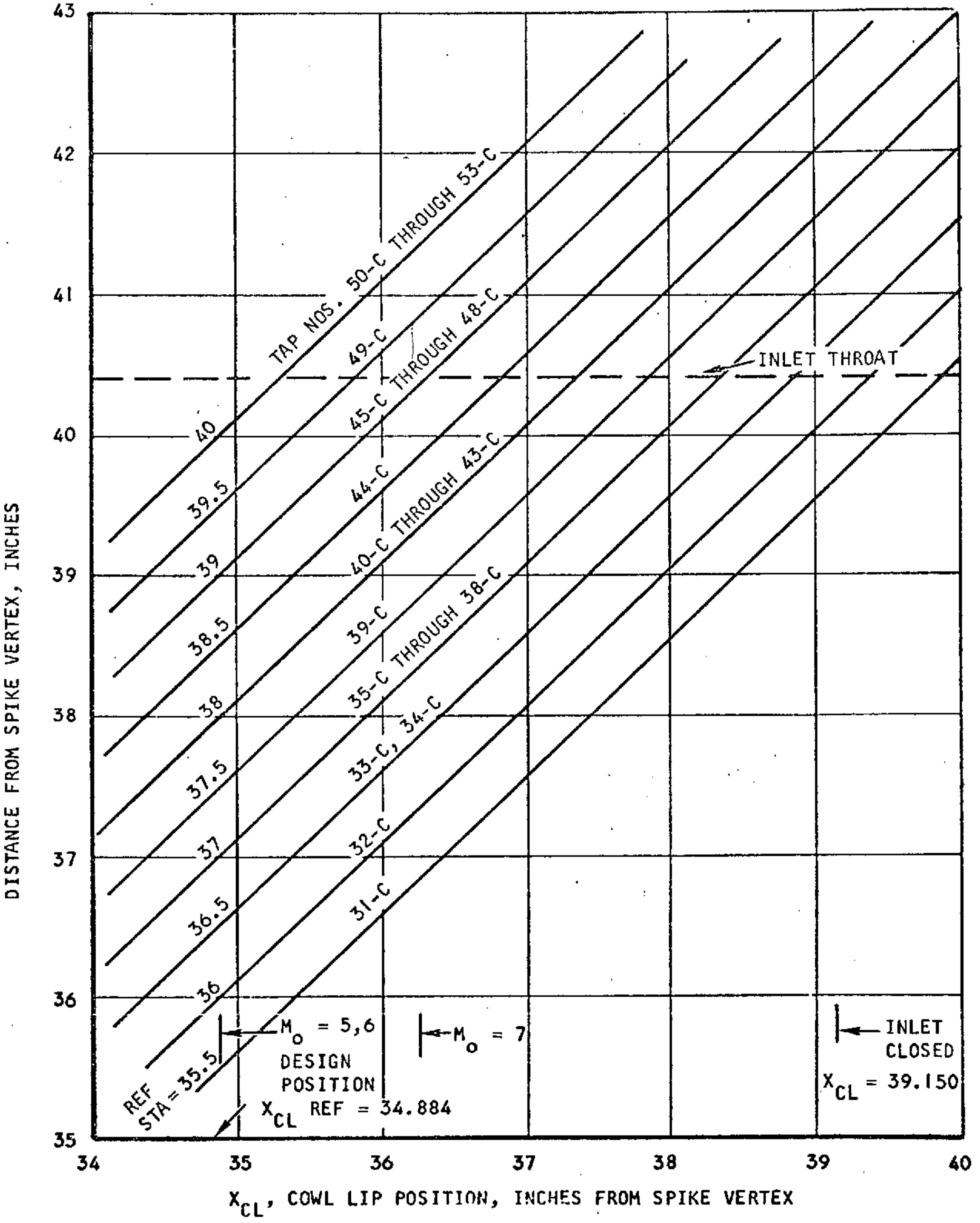


Figure A-3. Cowl Static Pressure Tap Stations for Inlet Analysis

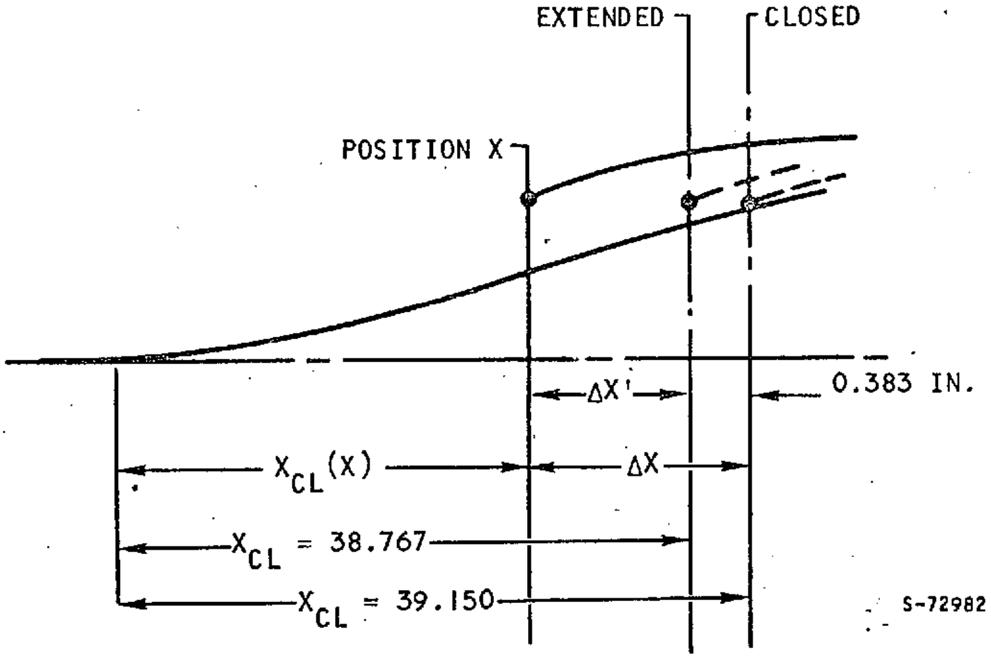
The effect of spike translation on the axial location of a point on the cowl will be determined as follows. The axial location is the distance (X) from the spike apex as shown in Figure A-4, and

$$X = \text{Ref. Sta.} + (X_{CL} - 34.884)$$

This relation is plotted for cowl pressure tap locations in Figure A-5. X_{CL} is defined in Figure A-4 and is determined from the following relationship.

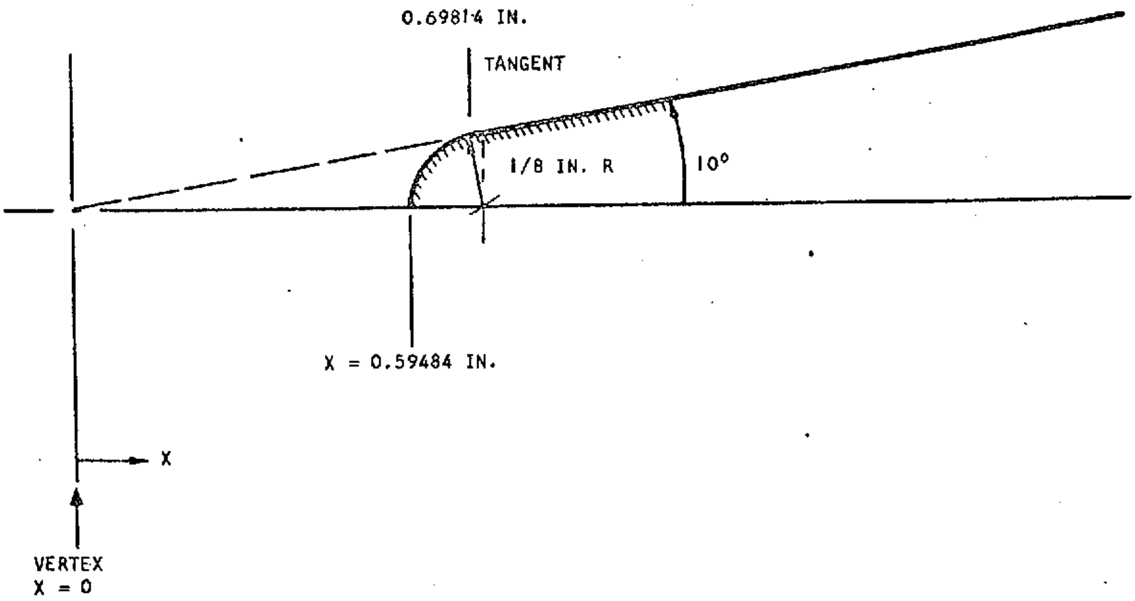
$$X_{CL} = 39.150 - \Delta X$$

This relationship is derived referring to the following sketch.

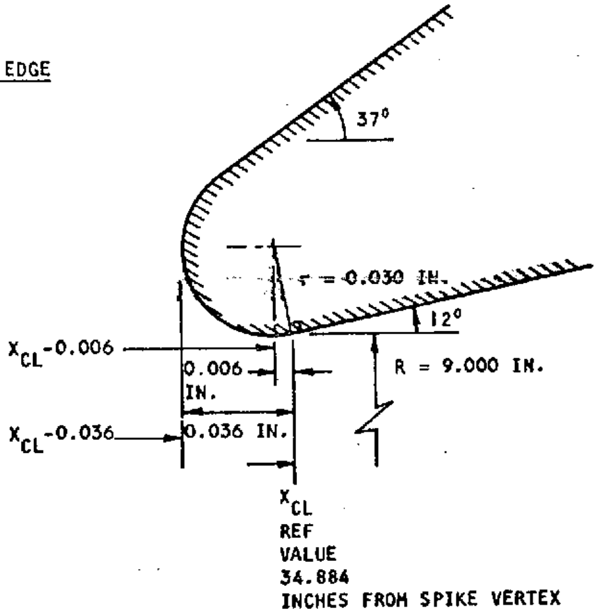


When the spike is fully extended an axial gap between the spike and the cowl of 0.383 in. is allowed to prevent mechanical interference during testing. The movement of the spike, ΔX', is determined from a linear motion transducer during testing. The constant, 0.383 in., is included in the transducer calibration so that ΔX is read directly from the output.

SPIKE TIP



COWL LEADING EDGE



X, STA, IN.	R, RADIUS, IN.
X_{CL} - 0.036	9.029
X_{CL} - 0.006	8.999
X_{CL}	9.000

S-71100

Figure A-4. AIM Spike Tip and Cowl Leading Edge

THE AIM SPIKE TIP POSITIONS RELATIVE TO THE OUTERBODY "HIGHLIGHT", OR LEADING EDGE ARE LISTED BELOW TO SIMPLIFY MEASUREMENTS DURING CALIBRATION OF SPIKE POSITION

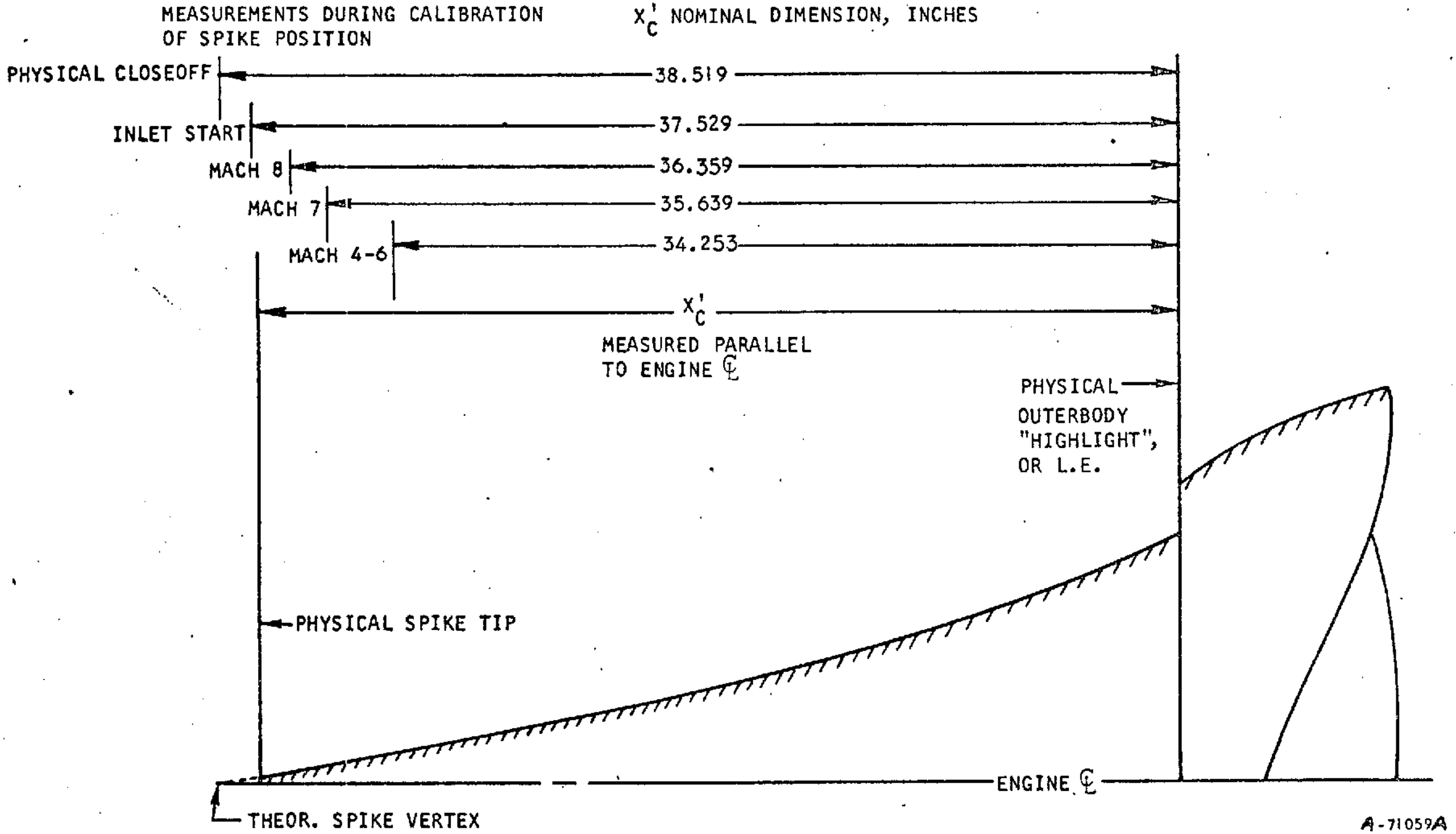
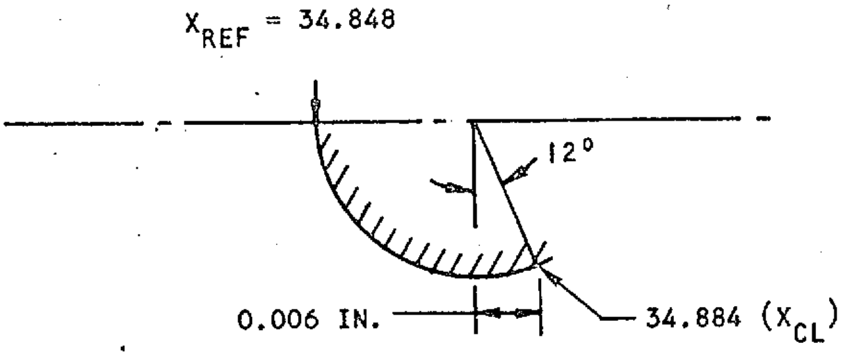


Figure A-5. AIM Spike Tip Positions



Equation for Pressure Coefficients is $Cp_x = K\ Cp_{(ref)}$

X	Quadrant	K	Cp_{ref}
34.878	I	1.0	0.4687
	II	1.0	0.4687
	III	1.0	0.4687
	IV	1.0	0.4687
35.5	I	1.0	Cp_{31-C}
	II	Cp_{36-C}/Cp_{35-C}	Cp_{31-C}
	III	Cp_{37-C}/Cp_{35-C}	Cp_{31-C}
	IV	Cp_{38-C}/Cp_{35-C}	Cp_{31-C}
36.0	I	1.0	Cp_{32-C}
	II	Cp_{36-C}/Cp_{35-C}	Cp_{32-C}
	III	Cp_{37-C}/Cp_{35-C}	Cp_{32-C}
	IV	Cp_{38-C}/Cp_{35-C}	Cp_{32-C}
36.5	I	1.0	Cp_{33-C}
	II	Cp_{36-C}/Cp_{35-C}	Cp_{33-C}

X	Quadrant	K	Cp_{ref}
	III	1.0	Cp_{34-C}
	IV	Cp_{38-C}/Cp_{35-C}	Cp_{33-C}
37.0	I	1.0	Cp_{35-C}
	II	1.0	Cp_{36-C}
	III	1.0	Cp_{37-C}
	IV	1.0	Cp_{38-C}
37.5	I	1.0	Cp_{39-C}
	II	Cp_{39-C}/Cp_{35-C}	Cp_{36-C}
	III	Cp_{39-C}/Cp_{35-C}	Cp_{37-C}
	IV	Cp_{39-C}/Cp_{35-C}	Cp_{38-C}

X_{ref}	Quadrant	K	Cp_{ref}
38.0	I	1.0	Cp_{40-C}
	II	1.0	Cp_{41-C}
	III	1.0	Cp_{42-C}
	IV	1.0	Cp_{43-C}
38.5	I	1.0	Cp_{44-C}
	II	Cp_{44-C}/Cp_{40-C}	Cp_{41-C}
	III	Cp_{44-C}/Cp_{40-C}	Cp_{42-C}
	IV	Cp_{44-C}/Cp_{40-C}	Cp_{43-C}

X_{ref}	Quadrant	K	$C_{p_{ref}}$
39.0	I	1.0	$C_{p_{45-C}}$
	II	1.0	$C_{p_{46-C}}$
	III	1.0	$C_{p_{47-C}}$
	IV	1.0	$C_{p_{48-C}}$
39.5	I	1.0	$C_{p_{49-C}}$
	II	$C_{p_{49-C}}/C_{p_{45-C}}$	$C_{p_{46-C}}$
	III	$C_{p_{49-C}}/C_{p_{45-C}}$	$C_{p_{47-C}}$
	IV	$C_{p_{49-C}}/C_{p_{45-C}}$	$C_{p_{48-C}}$
40.0	I	1.0	$C_{p_{50-C}}$
TO	II	1.0	$C_{p_{51-C}}$
40.4	III	1.0	$C_{p_{52-C}}$
	IV	1.0	$C_{p_{53-C}}$

With the static pressures defined at discrete stations on the foregoing pages, it remains to assign areas for these pressures to act on, and/or a method of interpolation. A linear interpolation of Cp with X will be used on spike and cowl except for $X < 35$ in. on the spike where $Cp_x = f(\sin^2 \sigma_x)$ has already been given.

The absolute pressure datum has been selected for momentum evaluation. The absolute pressures will be obtained from the Cp values from $P_{x,Q} = P_o + q_o Cp_{x,Q}$ where the subscripts x and Q refer to station and quadrants respectively, as previously defined.

In Equation (A-1) the $\int_{\substack{\text{aft}\\\text{face}}}$ PdA includes all of the cowl integral from (X_{CL} - 0.006 in.) to X = 40.4 in. The integral $\int_{\substack{\text{fwd}\\\text{face}}}$ PdA includes all of the spike pressures (including the spike tip plus the internal lip drag as defined previously.

The equivalent $\int$PdA is computed from the given drag coefficients from:

$$\int_{\substack{\text{SPIKE}\\\text{TIP}}} PdA = \frac{\pi}{64} \left[0.4843 \ (P_{1-S} - P_o) + 0.97 \ P_o \right] \ lb_f$$

and $$\int_{\text{LIP}} PdA = 1.699 \ (2.976 \ q_o + P_o) \ , \ lb_f, \ q_o \text{ and } P_o \text{ in psia.}$$

Final expression for combustor entrance momentum in lb_f is:

$$F_2 = \frac{W_2 V_2}{g} + p_2 A_2 = \frac{W_o V_o}{g} + p_o A_o - \frac{\pi}{64}\left[0.4843\ (p_{1-S} - p_o) + 0.97\ p_o\right] +$$

$$- 1.699\ (2.976\ q_o + p_o) + C_{DA}\ q_o A_c + p_o A_c\ (1 - A_o/A_c) +$$

$$- \sum_{Q=1}^{4} \int_{\substack{X = 0.69814 \\ \text{SPIKE}}}^{X = 40.4} pdA - \sum_{Q=1}^{4} \int_{\substack{X = 0.69814 \\ \text{SPIKE}}}^{X = 40.4} C_f\ q\ dA_S \cos \delta_S + \sum_{Q=1}^{4} \int_{\substack{X_{CL} - 0.006 \\ \text{COWL}}}^{X = 40.4} pdA +$$

$$- \sum_{Q=1}^{4} \int_{\substack{X_{CL} - 0.006 \\ \text{COWL}}}^{X = 40.4} C_f\ q\ dA_S \cos \delta_S$$

VI. Kinetic Energy and Process Efficiencies

With S_2 and p_o, solve SP problem to obtain $H_o^{'}$. Evaluate efficiencies from

$$\eta_{KE} = \frac{H_{T2} - H_o^{'}}{H_{To} - H_o}$$

and

$$K_D = \frac{H_2 - H_o^{'}}{H_2 - H_o}$$

VII. Limiting Inlet Pressure Recovery

A. Expansion of flow to $A_{2'}$, evaluate $A_{2'} = 1.1\ A_2$ and

$$p_{2'}^{(1)} = 0.9\ p_2$$

With S_2 and $p_{2'}^{(n)}$, solve SP problem and obtain

$$A_{2'}^{(n)} = W_2/(W/A)_{2'}^{(n)}$$

Iterate on $p_{2'}^{(n)}$ until

$$\left| \frac{A_{2'} - A_{2'}^{(n)}}{A_{2'}} \right| < \epsilon$$

B. Normal shock at $A_{2'}$

1. Obtain estimate for static pressure downstream of normal shock from

$$p_{2''}^{(1)} = p_{2'} \left[1 + \frac{2\gamma}{\gamma + 1} \left(M_1{}^2 - 1 \right) \right]$$

2. Calculate downstream velocity and static enthalpy from

$$V_{2''}^{(n)} = \frac{g}{(W/A)_{2'}} \left(p_{2'} - p_{2''}^{(n)} \right) + V_{2'}$$

and

$$H_{2''}^{(n)} = H_{T2} - \frac{{V_{2''}^{(n)}}^2}{2gj}$$

3. With $p_{2''}^{(n)}$ and $H_{2''}^{(n)}$, solve HP problem and obtain $(W/A)_{2''}^{(n)}$.

4. Iterate on $p_{2''}^{(n)}$ repeating steps 2 and 3, above, with the constraint $S_{2''} > S_{2'}$ until

$$\left| \frac{(W/A_{2'} - (W/A_{2''}^{(n)}}{(W/A)_{2'}} \right| < \epsilon$$

5. Obtain estimate of total pressure from

$$p_{T2''}^{(1)} = p_{2''} \left(1 + \frac{\gamma_{2''} - 1}{2} M_{2''}^2 \right)^{\frac{\gamma_{2''}}{\gamma_{2''} - 1}}$$

6. With $S_{2''}$ and $p_{T2''}^{(n)}$, solve SP problem for total conditions behind normal shock. Iterate on $p_{T2''}^{(n)}$ until

$$\left| \frac{H_{T2} - H_{T2''}^{(n)}}{H_{T2}} \right| < \epsilon$$

C. Limiting Inlet Pressure Recovery Efficiency

Evaluate

$$\Delta p_{T2} = 0.10 \; (p_{T2''} - p_{2''})$$

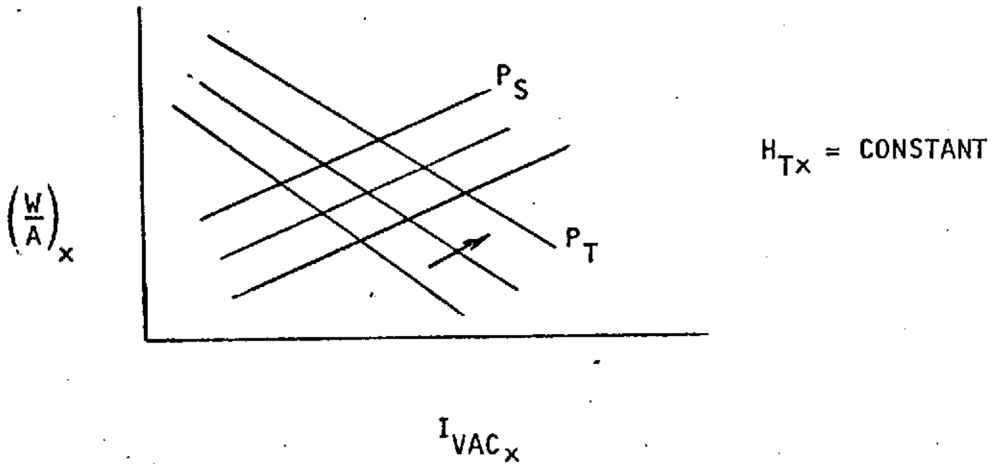
and

$$\eta_{p_{T2}} = \frac{p_{T2''} - \Delta p_{T2}}{p_{To}}$$

3.2.2 Combustor

3.2.2.1 Combustor Performance

The main objectives of this program are to determine the combustor efficiency, pressure loss, and other flow parameters inside the combustor from experimental data. This is accomplished by the one-dimensional analysis using the concept of a continuity-momentum diagram (I_{VAC} chart). The I_{VAC} chart below presents the end equilibrium states of the reaction in the combustor for a given energy level of the system. The thermodynamic state is completely defined if any two parameters are known.



In a combustor where the gas is not in equilibrium state and the composition of gas is not known, the use of I_{VAC} chart must be modified. This is achieved by defining the chemical efficiency as the equivalent mass fraction of ingested fuel reacted in equilibrium with other species.

$$\text{Combustor chemical efficiency} = \frac{\text{Equivalent } W_{H_2} \text{ reacted}}{W_{H_2} \text{ injected}}$$

The efficiency is obtained by matching the combustor wall pressure using an inert hydrogen, HZ_2, which replaces a portion of ingested active hydrogen, H_2. This inert hydrogen exhibits the same properties as the active hydrogen, but does not enter into reactions with any other species and which may participate in dissociation and recombination reactions. Thus, the I_{VAC} chart can be constructed for a given energy level and combustor efficiency. If at any station, $\left(\frac{W}{A}\right)_x$, I_{VAC}, and H_{Tx} are known, then the combustor efficiency, η_c, may be obtained by iteration process to match the measured value of P_x. In general, for a given energy level of the system, three flow parameters are required to define the non-equilibrium equivalent thermodynamic state.

3.2.2.1.1 Determination of $\left(\frac{W}{A}\right)_x$

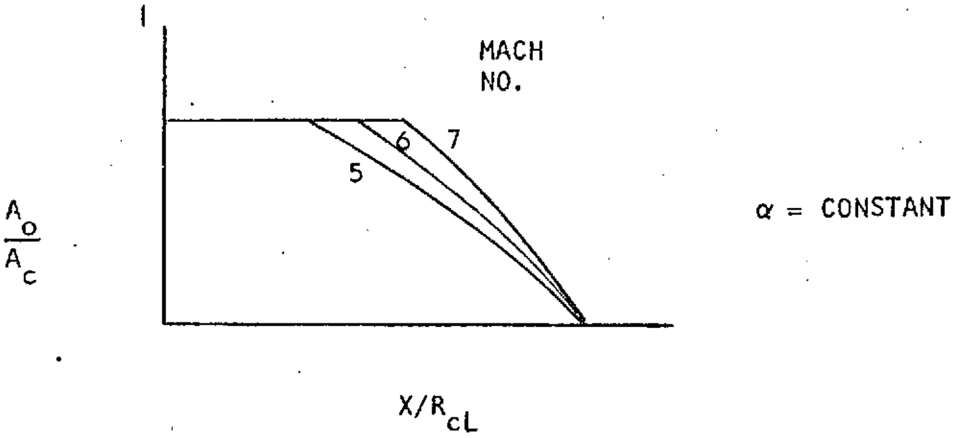
$$\left(\frac{W}{A}\right)_x = \frac{W_x}{A_x}$$

(a) Determination of combustor flow, W_x

The combustor flow is calculated by the following equation

$$W_x = W_{x-1} + W_{H_2 inj} + W_{H_2 ign.} + W_{O_2 ign.}$$

where W_{x-1} is the combustor flow at previous station. Starting from the combustor inlet prior to fuel injection (Station 40.4), the combustor flow is equal to the inlet flow, W_2. The inlet flow is obtained from calibration curve using flow meter test data. The inlet flow data will be presented in the following form for a given angle of attack.



$W_2 = \rho_o V_o \, (A_o/A_c) \, A_c$; R_{cL}= 9.0 in.

X_c = cowl position, in.

The hydrogen fuel, $W_{H_2 inj.}$ at each injector is determined by NASA instrumentation. The ignitor flows are determined by the following equations:*

1st IGN.

$$W_{H_2 ign} = 0.69 \times 10^{-4} \, P_{34-F}, \text{ lb/sec}$$

$$W_{O_2 ign} = 0.499 \times 10^{-3} \, P_{33-F}, \text{ lb/sec}$$

2nd IGN.

$$W_{H_2 ign} = 0.69 \times 10^{-4} \, P_{39-F}, \text{ lb/sec}$$

$$W_{O_2 ign} = 0.499 \times 10^{-3} \, P_{35-F}, \text{ lb/sec}$$

3rd IGN.

$$W_{H_2 ign} = 0.69 \times 10^{-4} \, P_{39-F}, \text{ lb/sec}$$

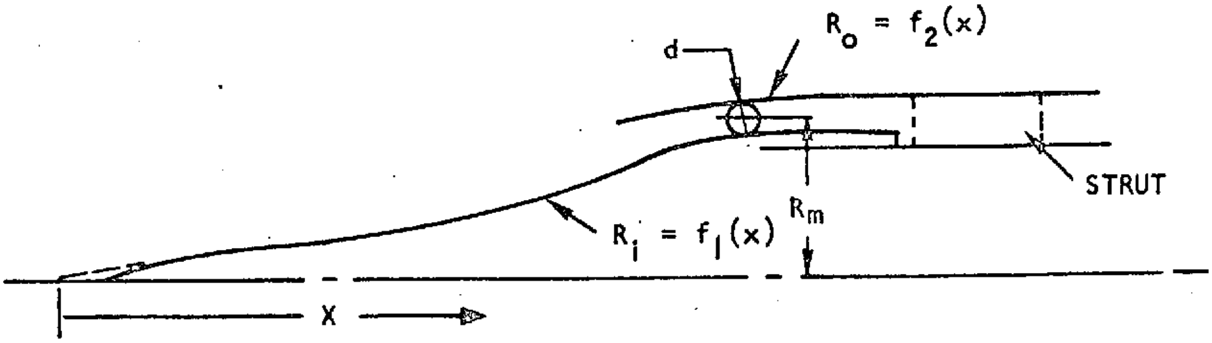
$$W_{O_2 ign} = 0.499 \times 10^{-3} \, P_{35-F}, \text{ lb/sec}$$

---

*Do not calculate ign. flow when ign. is not on.

(b) Determination of flow area, A_x.

The flow area, A_x, is the net geometrical area between the annulus and the strut blockage. The annular area is determined from given inner and outer radii (Table A-2) as shown below:



The flow area is determined by the minimum distance from the spike to outerbody for a given spike translation ($A = 2\pi R_m d$). The strut blockage versus axial location is tabulated below.

Use as linear blockage between stations

Station	Blockage, in.^{2}
56.14	0
56.22	1.436
56.726	3.279
61.9 (Combustor throat)	12.268
64.364	7.264
64.74	0

Net flow area at Station 61.9 = 91.016 in.^{2}

The stations are based on Mach 6 spike position X_c = 34.844 in. from spike vertex to cowl leading edge tangent point (R_c = 9 in.). Proper correction must be made if other spike positions are used.

TABLE A-2

FLOW AREA INNER AND OUTER RADII

Station	R_1	Station	R_1	Station	R_2	Station	R_2	Station	R_3

Coordinates given in AiResearch

Report No. AP-68-3895, (Drawing SK50941)

Data Item 55-4.01, 9 July 1968

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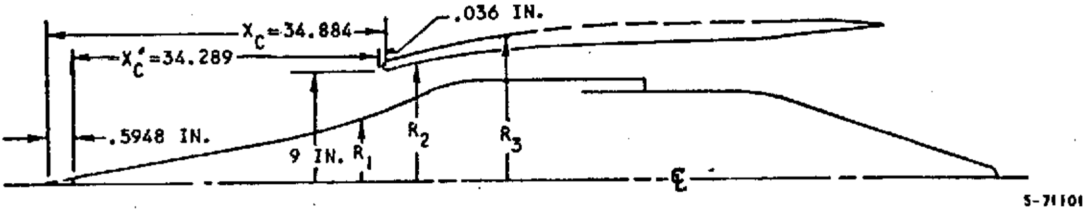


3.2.2.1.2 Determination of H_{Tx} - Use JANAF Base

$$H_{Tx} = (W_{x-1} H_{Tx-1} + W_{H2inj} H_{T_{H2inj}} + W_{H2ign} H_{T_{H2ign}} + W_{O2ign} H_{T_{O2ign}}) \frac{1}{W_x}$$

$$- \frac{\int_{\Delta x} q_{loss} \, dA}{W_x}$$

x = any axial location

The first x-1 station is at the combustor inlet (Station 40.4). Thus the first H_{Tx-1} is H_{T2} which will be calculated previously in the first part of data reduction (inlet section) - $H_{T_{H2inj}}$ is determined from measured temperatures using JANAF base.

Injector	T_T - Convert to ^0R
1a	1/2 (17-F + 18-F)
1b	1/2 (25-F + 26-F)
1c	1/2 (19-F + 20-F)
4	1/2 (29-F + 30-F)
2a	1/2 (27-F + 28-F)
2c	1/2 (21-F + 22-F)
3a	1/2 (31-F + 32-F)
3b	1/2 (23-F + 24-F)

The hydrogen flows are determined from NASA instrumentation.

Ignitors - The ignitor flows will be determined from similar equations in paragraph 3.2.2.1.1. The enthalpy of ignitor gases (H_2 and O_2) is estimated based on ambient temperature using JANAF base. Q_{LOSS} will be determined in Section 3.3.2.

3.2.2.1.3 Determination of $I_{VAC\ x}$

The vacuum specific impulse of the stream is determined from total momentum considerations. The total stream momentum at any station will be computed as follows:

$$F_x = \left(\frac{WV}{g} + PA\right)_x = \left(\frac{WV}{g} + PA\right)_{x-1} + \int_{x-1}^{x} PdA$$

$$-C_f\ \bar{q}_{x,x-1}\ \Delta A_{wx,x-1}\ \cos\alpha + \Delta \dot{W}_{Fx,x-1}\ I_{VAC\ F}\ \cos\beta_F$$

$$-\text{STRUT DRAG}$$

Each term in the above equation is discussed below.

(a) $\left(\frac{WV}{g} + PA\right)_{x-1}$

This term is the total momentum of the stream computed from previous station. The starting value will be the total momentum at the combustor inlet or Station 2 (40.4), which is determined from inlet calculation (Section 3.2.1.2).

(b) $\int_{x-1}^{x} PdA$

The static pressure distribution will be obtained from a curve-fit of test data (see Section 3.2.7). The pressure readings which will be curve-fitted are, shown in Table A-3. The total pressure force may be computed separately for the spike and the outerbody.

The forces along the outerbody are continuous, while the forces acting on the spike are discontinuous at the spike step.

$$\int_{x-1}^{x} PdA = \left(\int_{x-1}^{x} PdA\right)_{\text{outerbody}} - \left(\int_{x-1}^{x} PdA\right)_{\text{innerbody}} + \left[\int PdA\right]_{\text{at step}}$$

$$= 2\pi\left[\int_{x-1}^{x} PRdR_{O.B.} - \int_{x-1}^{x} PRdR_{I.B.}\right] + \left(\int PdA\right)_{\text{at step}}$$

where dA = positive (+) when dR is INCREASING and negative (-) when dR is decreasing. The values of (R) vs (X) are tabulated in Table A-2.

TABLE A-3

STATIC PRESSURE CURVE-FIT DATA

Spike		Outerbody	
Station	Pressure to be Curve-Fit	Station	Pressure to be Curve-Fit
40.0	$\left(\frac{\sum_{29-S}^{34-S} P_{meas}}{4}\right)$	40.0	$\left(\frac{\sum_{50-C}^{53-C} P_{meas}}{4}\right)$
41.5	P_{33-S}	41.06	$\left(\frac{\sum_{1-0}^{4-0} P_{meas}}{4}\right)$
42.5	P_{34-S}	43.81	$\left(\frac{\sum_{5-0}^{8-0} P_{meas}}{4}\right)$
44.85	P_{39-S}	45.25	P_{9-0}
47.375	$\left(\frac{\sum_{41-S}^{44-S} P_{meas}}{4}\right)$	47.0	P_{10-0}
48.17	P_{45-S}	49.0	$\left(\frac{\sum_{11-0}^{14-0} P_{meas}}{4}\right)$
54.5	$\left(\frac{\sum_{1-I}^{4-I} P_{meas}}{4}\right)$	49.5	P_{15-0}
56.0	P_{5-I}	50.4	$\left(\frac{\sum_{16.0}^{19-0} P_{meas}}{4}\right)$
64.8	P_{9-I}	51.5	P_{20-0}
		52.5	P_{21-0}
		53	$\left(\frac{\sum_{22-0}^{25-0} P_{meas}}{4}\right)$
		54.5	P_{26-0}
		56.5	P_{27-0}
		57.5	P_{28-0}
		58.5	P_{29-0}
		59.5	P_{30-0}
		60.5	P_{31-0}
		61.9	$\left(\frac{\sum_{32-0}^{35-0} P_{meas}}{4}\right)$

Provision must be made to delete bad readings in computing performance.

The value of $\left(\int PdA\right)_{\text{at step}}$ may be calculated as

$$\left(\int PdA\right)_{\text{step}} = 15.931 \times \frac{\sum_{I-I}^{5-I} P_{\text{measured}}}{5}, \text{ (Mach 5 and 6), } lb_f$$

$$\text{OR} = 15.931 \times \frac{\sum_{I-I}^{4-I} P_{\text{measured}}}{4}, \text{ (Mach 7), } lb_f$$

Thus, at the step, a positive force is always used, the magnitude of which depends on the spike position for the proper pressure measurements.

(c) Friction force $C_f \, \bar{q}_{x,x-1} \, A_{Wx,x-1} \cos \bar{\alpha}$

The friction force will be computed from the theory based on Spalding and Chi's analysis in determining C_f. See Section 3.2.6

(1) $$\bar{q}_{x,x-1} = \frac{1}{4g}\left[\left(\frac{WV}{A}\right)_x + \left(\frac{WV}{A}\right)_{x-1}\right] \frac{lb_f}{in.^2}$$

(2) $$\Delta A_{Wx,x-1} = 2\pi\,(\bar{R}_o + \bar{R}_i)\,\Delta X;\ in.^2$$

$$\bar{R}_o = \left(\frac{R_{ox} + R_{ox-1}}{2}\right)_{O.B.}$$

$$\bar{R}_i = \left(\frac{R_{ix} + R_{ix-1}}{2}\right)_{I.B.}$$

(3) The value of $\cos \bar{\alpha}$ is tabulated below

Station	Cos $\bar{\alpha}$
40-45	0.99619
45-48.4	0.99756
48.4-57	0.99905
57-58.7	0.99996
58.7-61.9	1.0

(d) Fuel momentum, $W_{Fx,x-1} I_{VAC_F} \cos \beta_F$

The I_{VAC} of fuel may be calculated using the following equation

$$I_{VAC_{Fx,x-1}} = \left[\frac{\sqrt{T_T}\ (1 + \gamma M^2)}{M\left(1 + \frac{\gamma-1}{2} M^2\right)^{1/2} \sqrt{\frac{g\ \gamma\ MW}{R_o}}} \right] \cos \beta, [\text{sec}]$$

$M.W. = 2.016, \quad \gamma = 1.4$

Injectors 1a, 1b, 4, and 3b have zero momentum, since they are injected at 90° ($\cos \beta = 0$).

For the others:

Injector	Cos β
1c	-0.27564
2a	-0.39073
2c	-0.48481
3a	-0.42262

The fuel temperatures are measured values (listing code numbers 17-F through 32-F).

The Mach numbers are determined from the fuel manifold and combustor pressure ratios.

$$M = f(\gamma, P/P_t)$$

$$(P/P_t) = \left(1 + \frac{\gamma-1}{2} M^2\right)^{\frac{\gamma}{1-\gamma}}$$; For injectors, use $\gamma = 1.4$

For P and P_T,

Injector	P	P_T
*1a	$\left[\left(\sum_{29-s}^{32-s} P_{meas}\right)/4 + P_{33-s}\right]/2$	1/2(1·F + 2·F)
*1b	$\left[\left(\sum_{50-c}^{53-c} P_{meas}\right)/4 + \left(\sum_{1-0}^{4-0} P_{meas}\right)/4\right]/2$	1/2(9·F + 20·F)

Note: *Values have zero momentum but calculate M_{H_2} to compare with other injectors.

1c	P_{39-s}	1/2(3·F + 4·F)
*4	$\left[\left(\sum_{5-0}^{8-0} P_{meas}\right)/4 + P_{9-0}\right]/2$	1/2(11·F +12·F)
2a	$\left(\sum_{11-0}^{14-0} P_{meas}\right)/4$	1/2(13·F + 14·F)
2c	P_{10-0}	1/2(5·F + 6·F)
3a	$\left[\left(\sum_{22-0}^{25-0} P_{meas}\right)/4 + P_{26-0}\right]/2$	1/2(15·F + 16·F)
*3b	$\left(\sum_{5-I}^{8-I} P_{meas}\right)/4$	1/2(7·F + 8·F)

Note: *Values have zero momentum but calculate M_{H_2} to compare with other injectors

Once P is obtained, calculate (P/Pt) and determine Mach number.

If Mach number ≥1.0, set equal to 1.0 and check injector discharge coefficients.

$$C_D = \frac{W\sqrt{T_T}}{P_T\, A\, D\sqrt{\frac{\gamma\, g\, MW}{Ro}}}$$

$$D = M\left(1 + \frac{\gamma-1}{2}\; M^2\right)^{\left(\frac{-(1+\gamma)}{2(\gamma-1)}\right)}$$

Injector	A, in.^{2}
1a	0.4115
1b	0.4220
1c	0.4115
4	0.4220
2a	0.4298
2c	0.4298
3a	0.7414
3b	0.7306

(e) Strut Drag

Strut Drag = $F_D = C_{DS} \cdot q \cdot Ap$

$Ap = 12.268 \text{ in.}^2$

q = dynamic pressure at strut leading edge, psia

Mach Number at Strut Leading Edge	C_{DS}
0.8	0.17
0.9	0.375
0.98	0.525
1.0	0.540
1.02	0.535
1.1	0.48
1.2	0.43
1.3	0.385
1.4	0.35
1.5	0.315
1.6	0.29
1.8	0.25
2.0	0.225
2.4	0.190
2.8	0.170

For an approximation, 1/2 of the strut drag is assigned to the combustor and the other 1/2 is assigned to the nozzle. It is further assumed that the combustor strut drag is uniformly distributed from the strut leading edge (56.14) to the combustor throat (61.9).

3.2.2.1.4 Conditions at any Station Downstream of Inlet

Velocity

From the momentum equation

$$\frac{W_x V_x}{g} + p_x A_x = \frac{W_{x-1} V_{x-1}}{g} + p_{x-1} A_{x-1} + \int_{x-1}^{x} pdA +$$

$$+ \sum_i \left(W_{F_i} \cdot I_{VAC\ F_i} \cos \beta_i \right)_{x-1,x}$$

$$- \frac{1}{4} \left(\frac{W_x V_x}{A_x g} + \frac{W_{x-1} V_{x-1}}{A_{x-1}\, g} \right) C_{f_{x-1,x}} A_{W_{x-1,x}}$$

$$- \sum_j C_{D_j} q_j A_j$$

$$\frac{W_x V_x}{g} \left(1 + \frac{C_{f_{x-1,x}} A_{W_{x-1,x}}}{4 A_x} \right) = \frac{W_{x-1} V_{x-1}}{g} \left(1 - \frac{C_{f_{x-1,x}} A_{W_{x-1,x}}}{4 A_{x-1}} \right) +$$

$$+ \int_{x-1}^{x} pdA + p_{x-1} A_{x-1} - p_x A_x +$$

$$\sum_i \left(W_{F_i} \cdot I_{VAC\ F_i} \cdot \cos \beta_i \right)_{x-1,x} -$$

$$\sum_j \left(C_{D_j} q_j A_j \right)_{x-1,x}$$

$$V_x = \frac{g}{W_x} \left\{ \left(1 - \frac{C_{f_{x-1,x}} A_{W_{x-1,x}}}{4 A_{x-1}} \right) \frac{W_{x-1} V_{x-1}}{g} + \int_{x-1}^{x} pdA + p_{x-1} A_{x-1} - p_x A_x + \right.$$

$$\left. + \sum_i \left(W_{F_i} \cdot I_{VAC\ F_i} \cdot \cos \beta_i \right)_{x-1,x} - \sum_j \left(C_{D_j} q_j A_j \right)_{x-1,x} \right\} \Bigg/$$

$$\left(1 + \frac{C_{f_{x-1,x}} A_{W_{x-1,x}}}{4 A_x} \right)$$

Enthalpies

From energy considerations

$$H_{Tx} = \left\{ W_o H_{To} + \sum_i \left[W_{Fi} H_{TFi} + W_{oi} H_{Toi} \right]_{o,x} + Q_{o,x} \right\} \Big/ W_x$$

$$H_x = H_{Tx} - V_x^2/2gJ$$

Massflow Per Unit Area

From the continuity equation

$$W_x = W_o + \sum_i \left(W_{Fi} \right)_{o,x} + \sum_i \left(W_{oi} \right)_{o,x}$$

$$\left(\frac{W}{A} \right)_x = \frac{W_x}{A_x}$$

$$\left(\frac{W}{A} \right)_x = \frac{p_x}{\eta_x R T_x} \quad V_x$$

where η_x is the reciprocal of the molecular weight

Conditions Upstream of Fuel Injectors

(1) Calculate V_x, H_{Tx}, H_x and W_x from above equations

(2) With H_x and measured p_x, solve HP* problem to obtain static conditions at station x and obtain area blockage from

$$1 - \frac{(W/A)_x}{(W/A)_{x'}}$$

(3) Obtain estimate of total pressure from

$$p_{Tx}^{(1)} = p_x \left(1 + \frac{\gamma_x - 1}{2} M_x^2 \right)^{\frac{\gamma_x}{\gamma_x - 1}}$$

---

*HP denotes chemical equilibrium calculation with enthalpy and pressure as the state variables.

and with S_x and $p_{Tx}^{(n)}$ solve SP* problem for total conditions at station x. Iterate on $p_{Tx}^{(n)}$ until

$$\left| \frac{H_{Tx} - H_{Tx}^{(n)}}{H_{Tx}} \right| < \epsilon$$

Stations at or Downstream of Fuel Injectors

(1) Calculate V_x, H_{Tx}, H_x and W_x from above equations.

(2) Obtain estimate of combustor efficiency from

1. Supersonic Combustion: $\eta_{Cx}^{(1)} = 0.50$

2. Subsonic Combustion: $\eta_{Cx}^{(1)} = 0.97$

or

$$\eta_{Cx}^{(1)} = \eta_{Cx-1}^{(n)}$$

(3) Set the weight fraction of reacting fuel equal to $\eta_C^{(n)}$ and of unreacting fuel to $1 - \eta_C^{(n)}$.

(4) Calculate the specific formula numbers of elements contained in the fuel and in the total mixture.

(5) With H_x and measured p_x, solve HP problem to obtain static properties at station x. Iterate on $\eta_{Cx}^{(n)}$ repeating (3) and (4), above, until

$$\left| \frac{(W/A)_x - (W/A)_x^{(n)}}{(W/A)_x} \right|$$

---

*SP denotes chemical equilibrium calculation with entropy and pressure as the state variables.

(6) Obtain estimate of total pressure from

$$p_{Tx}^{(1)} = p_x \left(1 + \frac{\gamma_x - 1}{2} M_x^2\right)^{\frac{\gamma_x}{\gamma_x - 1}}$$

and with S_x and $p_{Tx}^{(n)}$ solve SP problem for total conditions at station X. Iterate on $p_{Tx}^{(n)}$ until

$$\left| \frac{H_{Tx} - H_{Tx}^{(n)}}{H_{Tx}} \right| < \epsilon$$

Recommended Procedure

Assume $C_{fx} = C_{fx-1}$. Calculate flow properties at x and compute C_{fx} by method of Spalding and Chi. Using calculated value of C_{fx}, recalculate flow properties at x.

3.2.2.1.5 Combustor Flow Parameters

Knowing the values of $\frac{W}{A}$, I_{VAC}, H_T and measured value of static pressure, p, the combustor efficiency can be determined through iteration process. Once the combustor efficiency is known, the following flow parameters and fluid properties can be determined from thermodynamic subroutine:

T_T, T, P_T, M, V,

ρ, μ, Prandtl No., Cp, N_{Re}/ft

3.2.2.1.6 Combustor Effectiveness

Combustor effectiveness is defined as

$$\eta_{CE} = \frac{(1 + f/a)\, I_{VAC_{am}} - I_{VAC_2}}{(1 + f/a)\, I'_{VAC_{am}} - I_{VAC_2}}$$

where I_{VAC_2} = combustor entrance vacuum specific impulse

$I_{VAC_{am}}$ = actual combustor exit vacuum specific impulse expanded isentropically to ambient pressure

$I_{VAC'_{am}}$ = combustor exit vacuum specific impulse for constant pressure, zero velocity-combustion expanded isentropically to ambient pressure.

3.2.2.1.7 Inlet Combustor Interaction

It is requested that a special calculation be made at the inlet throat to determine the approximate flow blockage. This is accomplished by knowing the total momentum at the inlet throat, the mass flow, and the averaged static pressure, assuming no combustion takes place upstream of injector(1a) (Station 40.4). The inlet total momentum and mass flow are obtained from inlet calculations. The averaging static pressure is computed from

29-S, 30-S, 31-S, 32-S, 50-C, 51-C, 52-C, 53-C

$$\text{Flow blockage} = 1 - \frac{A_{calculated}}{A_{geometric}} = \frac{dA}{A}$$

3.2.2.1.8 Subsonic Combustion

For subsonic combustion, the computation procedure is the same as that for supersonic combustion. However, an additional check may be performed at the combustor throat (Station 61.9) where the flow Mach number is unity. This calculation may be accomplished by iterating the combustion efficiency knowing H_T, $\frac{W}{A}$, Mach number (=1), and static pressure at the throat. The static pressure is determined by averaging four static pressures.

$$\overline{P}_{throat} = \frac{P_{32-0} + P_{33-0} + P_{34-0} + P_{35-0}}{4}, \text{ psia}$$

3.2.2.2 Combustor Exit Flow Measurements

There are five conical pitot static probes and five total temperature probes at the combustor exit. The pitot static probe consists of one pitot pressure and four cone static pressures. The following is a list of their designations.

Designation	Description	Designation	Description
1-CE	CE-PT-0-000	11-CE	CE-PT-180-000
2-CE	CE-PS-0-0	12-CE	CE-PS-180-0
3-CE	CE-PS-0-90	13-CE	CE-PS-180-90
4-CE	CE-PS-0-180	14-CE	CE-PS-180-180
5-CE	CE-PS-0-270	15-CE	CE-PS-180-270
39-CE	CE-G-TT-350	33-CE	CE-G-TT-170
6-CE	CE-PT-110-000	16-CE	CE-PT-280-000
7-CE	CE-PS-110-0	17-CE	CE-PS-280-0
8-CE	CE-PS-110-90	18-CE	CE-PS-280-90
9-CE	CE-PS-110-180	19-CE	CE-PS-280-180
10-CE	CE-PS-110-270	20-CE	CE-PS-280-270
30-CE	CE-G-77-70	36-CE	CE-G-TT-260
21-CE	CE-PT-330-000		
22-CE	CE-PS-330-0		
23-CE	CE-PS-330-90		
24-CE	CE-PS-330-180		
25-CE	CE-PS-330-270		
39-CE	CE-G-TT-350		

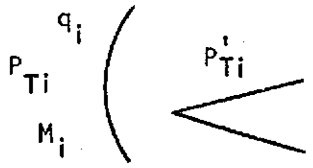
(1) Calculate the arithmetic mean of the four cone static pressures

$$\overline{P}_{i-CE} = \frac{1}{4}\left[P_{(i+1)-CE} + P_{(i+2)-CE} + P_{(i+3)-CE} + P_{(i+4)-CE}\right]$$

$$i = 1, 6, 11, 16, 21$$

(2) Calculate

$\overline{P}_{i-CE}/P'_{Ti-CE}$



(3) From Figure A-6, obtain Mach number M_i

(4) Use real-gas equilibrium program; calculate normal shock total pressure ratio using nearest measured total temperature (T_{Ti-CE}; i = 1, 6, 11, 16, 21).

$$\frac{P'_{Ti}}{P_{Ti}} \text{ and } P_{Ti-CE} \quad (i = 1, 6, 11, 16, 21)$$

(5) Expand flow isentropically from P_{Ti} to M_i and obtain $q_i = \frac{1}{2} \rho V^2$ (i = 1, 6, 11, 16, 21).

(6) Obtain

$$\left(\frac{\Delta P}{q_1}\right)_\epsilon = \frac{P_{4-CE} - P_{2-CE}}{q_1}, \left(\frac{\Delta P}{q_6}\right)_\epsilon = \frac{P_{9-CE} - P_{7-CE}}{q_6}$$

$$\left(\frac{\Delta P}{q_{11}}\right)_\epsilon = \frac{P_{14-CE} - P_{12-CE}}{q_{11}}, \left(\frac{\Delta P}{q_{16}}\right)_\epsilon = \frac{P_{19-CE} - P_{17-CE}}{q_{16}}$$

$$\left(\frac{\Delta P}{q_{21}}\right)_\epsilon = \frac{P_{24-CE} - P_{22-CE}}{q_{21}}$$

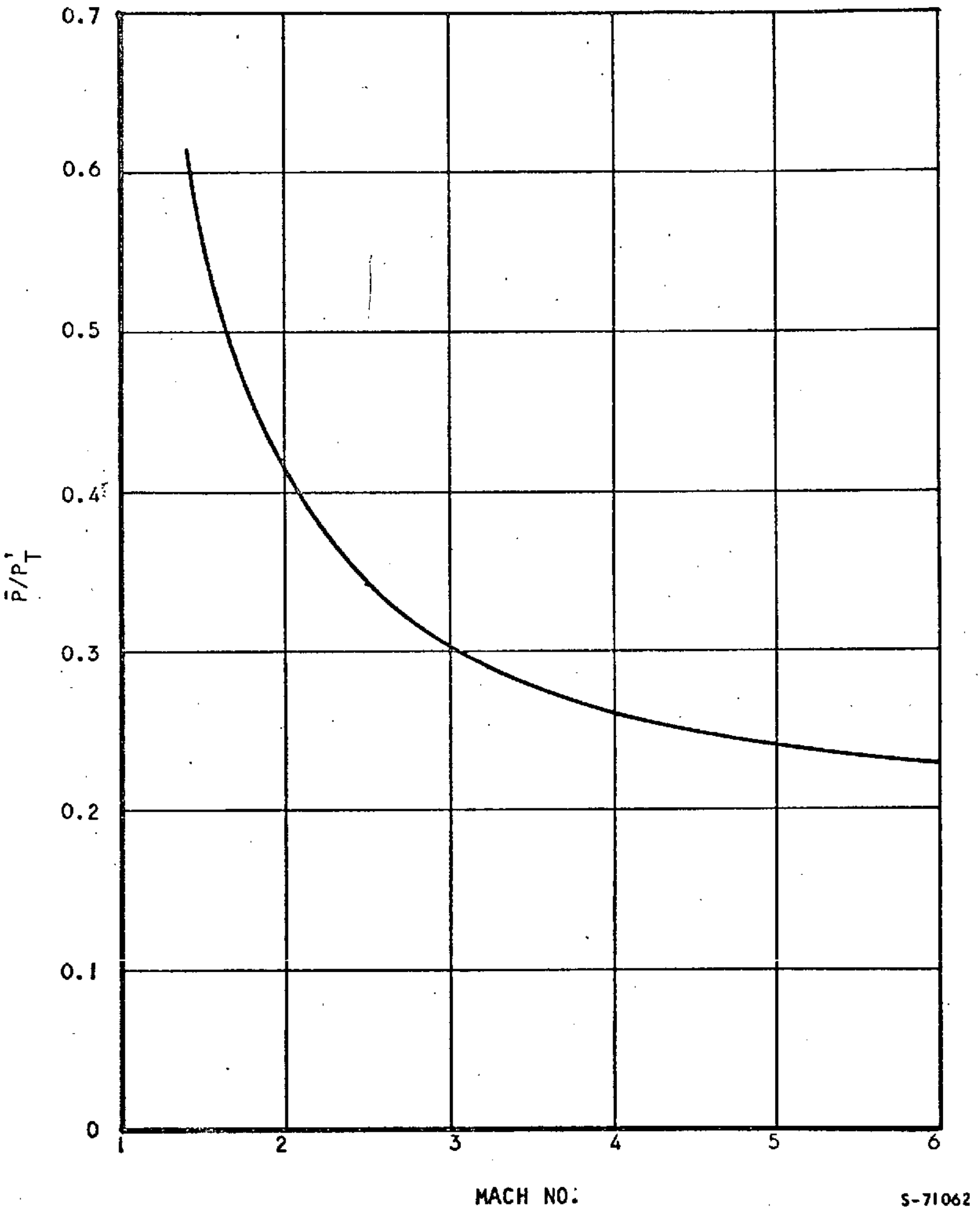


Figure A-6. Mach Number Versus $\bar{P}/P_T'$

and

$$\left(\frac{\Delta P}{q_1}\right)_\sigma = \frac{P_{5-CE} - P_{3-CE}}{q_1},\ \left(\frac{\Delta P}{q_6}\right)_\sigma = \frac{P_{10-CE} - P_{8-CE}}{q_6}$$

$$\left(\frac{\Delta P}{q_{11}}\right)_\sigma = \frac{P_{15-CE} - P_{13-CE}}{q_{11}},\ \left(\frac{\Delta P}{q_{16}}\right)_\sigma = \frac{P_{20-CE} - P_{18-CE}}{q_{16}}$$

$$\left(\frac{\Delta P}{q_{21}}\right)_\sigma = \frac{P_{25-CE} - P_{23-CE}}{Q_{21}}$$

(7) From Figure A-7, obtain ϕ and θ from

$\left(\frac{\Delta P}{qi}\right)_\epsilon$ and $\left(\frac{\Delta P}{qi}\right)_\sigma$ (see Figure A-8)

(8) Determine the sign convention for ϕ and θ

(9) Use θ, M find

$\left(\frac{\overline{P}_i}{PT'_i}\right)_\theta \Big/ \left(\frac{\overline{P}_i}{PT'_i}\right)_{\theta = 0}$ from Figure A-9

(10) Find $\left(\overline{P}_i/P_{T'_i}\right)_{\theta = 0}$

(11) From Figure A-4, find Mach number using $\left(\overline{P}_i/P_{T'_i}\right)_{\theta = 0}$

(12) Repeat Steps 4 to 8

(13) Print out M_i, P_{T_i}, q_i, θ_i, ϕ_i, σ_i, ϵ_i

Figure A-6 is the notation and designation for the probe

3.2.2.3 Gas Sample Probes

Analysis of the gas sample probe data will be performed by NASA LeRC

3.2.3 Nozzle Performance

Nozzle vacuum stream thrust coefficient, C_S, can be written:

$$C_S = \frac{F_4}{F_{6_I}} + \frac{\int PdA}{F_{6_I}} - \frac{F_f}{F_{6_I}} - \frac{1/2\ D_{STRUTS}}{F_{6_I}}$$

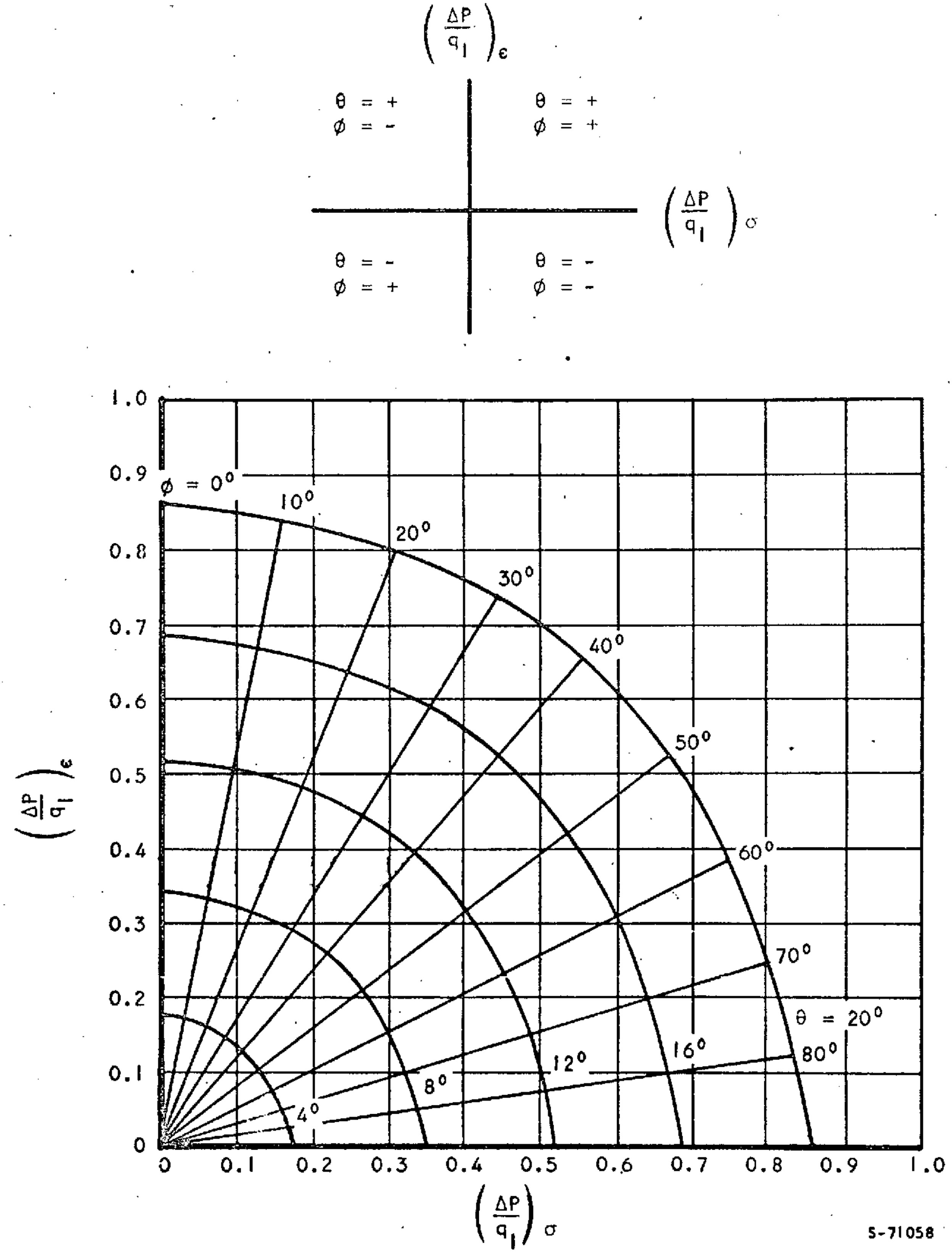


Figure A-7. $\left(\frac{\Delta P}{q}\right)_\sigma$ Versus $\left(\frac{\Delta P}{q_1}\right)_\epsilon$

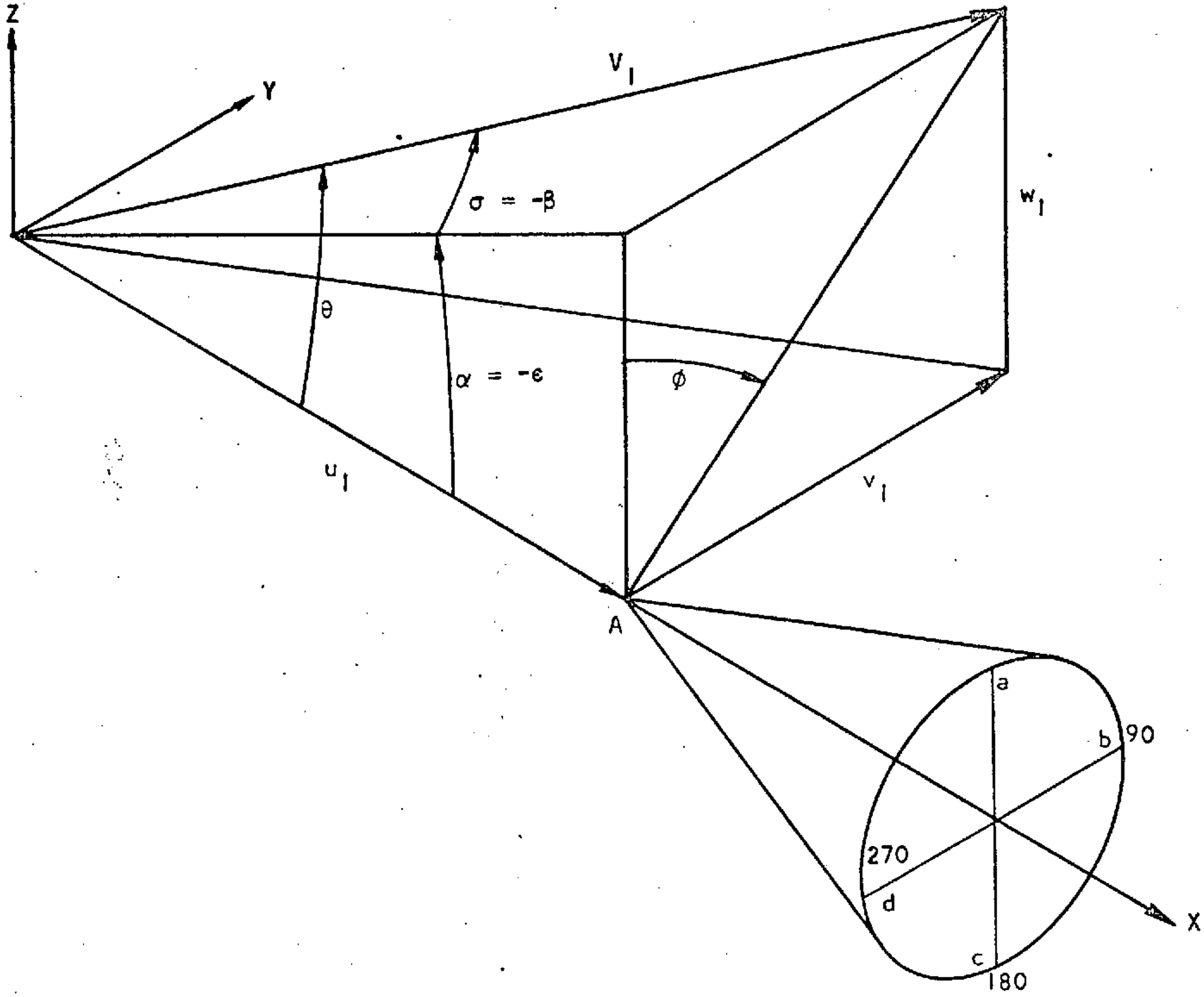


Figure A-8. Orifice Designation and Angle Notation

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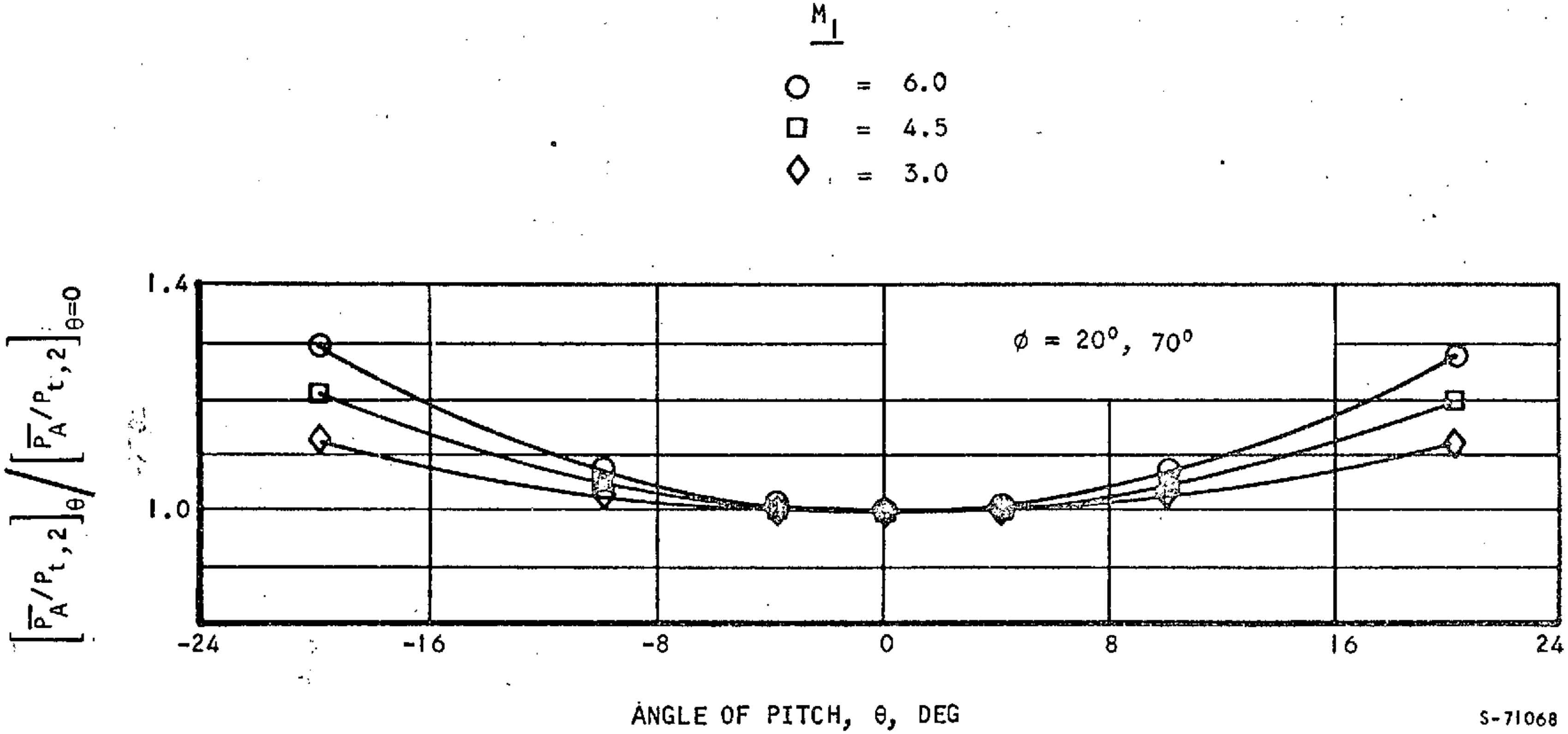


Figure A-9. Effect of Angle of Pitch on Ratio of Average Static Pressure to Pitot Pressure. Probe 1.

F_4 is obtained from combustor (3.2.2.1.3) exit calculations, F_{6I} is obtained from equilibrium, isentropic expansion of the exhaust gases from the combustor exit (Station 61.9) to a nozzle exit area of 512.389 in.^{2}. The pressure-area term is calculated for areas projected perpendicular to the engine centerline and the friction force is that component parallel to the engine centerline. Gas properties are to be evaluated at the strut trailing edge station, X = 64.740. The vacuum stream thrust at that station is given by

$$F_{X = 64.74} = F_{X = 61.9} - 1/2\ D_{STRUT}$$

All gas properties are evaluated at X = 64.74 from this value of stream thrust, together with enthalpy, gas weightflow and geometric flow area at X = 64.74. From this station aft, the wall forces are to be accounted for by integration of wall forces. Note that the nozzle shroud TE pressure is taken as the average of two at that station;

$$P_{X = 73.224} = \frac{1}{2}\left[(10\text{-}N) + (11\text{-}N)\right]$$

The pressures and corresponding stations for the curve-fit procedure are listed below:

Plug

$P_{No.}$	38-0	1-NP	2-NP	3-NP	4-NP	5-NP	6-NP	7-NP	8-NP	9-NP	10-NP
Sta	65.0	66.64	67.94	69.29	70.67	72.36	74.45	77.34	81.24	84.04	86.97

Shroud

$P_{No.}$	38-0	1-N	2-N	3-N	4-N	5-N	6-N	7-N	8-N	9-N	(10-N, 11-N)
Sta	65.00	66.68	67.46	68.18	69.00	69.81	70.63	71.44	72.36	73.06	73.22

Note that the area of the shroud for the force integration includes, by definition, a somewhat fictitious strip on the outside of the nozzle. The shroud and the plug forces integration thus takes the form

$$F_S = \int_{X = 65.74}^{X = 73.22} P\, dA + \left(\frac{P_{10-N} + P_{11-N}}{2}\right)(16.239), \text{pressures in psia}$$

$$F_P = \int_{X = 65.74}^{X = 86.97} P\, dA$$

The nozzle friction calculation will be based on isentropic flow outside the boundary layer. Gas properties will be evaluated from the local static pressures, local stagnation enthalpy and total pressure equal to the mass-energy-momentum value at Station 64.74. The friction analysis uses the Spalding and Chi correlations for C_f (see Section 3.2.6). There is an additional section of nozzle wall to be included in the friction calculation which has no area projection for the wall pressure integral. This lies between Stations 64.740 and 65.740. The friction on these cylindrical walls will be estimated using the previously determined gas properties at Station 65.74 and assuming these properties constant over the inverval $64.74 \leq X \leq 65.74$.

3.2.3.1 Nozzle Performance Coefficients

The following nozzle coefficients are to be evaluated in addition to the stream thrust coefficient, C_S, previously defined;

$$C_T = \frac{C_S\, W_{gas}\, IVAC_I - P_o A_e}{F_{g_I}}$$

where W_{gas} = actual gas flow

I_{VAC_I} = I_{VAC} based on isentropic expansion from conditions at Station 61.9 to A_e = 512.389 in.^{2}

F_{g_I} = gross thrust obtained by isentropic expansion from conditions at Station 61.9 to $P = P_o$

$$\eta_N = \frac{H_{T,6} - H_6}{H_{T,4} - H_{4'}}$$

where the numerator, (Station 6) nozzle exit enthalpy is based on the computed actual value of I_{VAC_6}, Station 4 is the nozzle entrance station (X = 61.9) and Station 4' corresponds to isentropic expansion from X = 61.9 to $P = P_6$.

$$K_N = \frac{H_4 - H_6}{H_4 - H_{4'}}$$

with stations as above.

3.2.4 Engine Performance

3.2.4.1 Internal Performance

(a) Internal specific impulse

$$I_{si} = \frac{T_i}{W_f} \text{ sec}$$

$$W_f = (W_f)_{1a} + (W_f)_{1b} + (W_f)_{1c} + (W_f)_4 + (W_f)_{2a} + (W_f)_{2c}$$

$$+ (W_f)_{3a} + (W_f)_{3b} \text{ lb/sec}$$

All fuel flow measurements will be determined by NASA.

$$T_i = FC/\cos\alpha + D_{ext}$$

FC = corrected load cell thrust reading, lb_f, see calculation 14C-B in Section 2.4.2.

For external drag, D_{ext}, see Section 3.2.4.2.

(b) Internal thrust coefficient

$$C_T = \frac{T_i}{q_o A_c}$$

$$q_o = 1/2\ \rho_o V_o^2 \text{ psi}$$

$$A_c = 256.13 \text{ in.}^2$$

(c) Internal Thrust From Momentum

The internal engine performance can be calculated from thrust measurements as outlined in (a), or the performance can be determined from total momentum considerations. The total momentum at the engine exit can be computed as follows:

$$F_6 = C_S\ F_{6_I}$$

where C_S and F_{6_I} have been previously calculated (see section 3.2.3)

The internal thrust T_i is thus $T_i = F_6 - F_o - q_o A_c\ C_{D_A} - P_o\ (A_c - A_o)$ where C_{D_A} is the additive drag coefficient and F_o is the freestream momentum $= P_o A_o + \frac{W_o V_o}{g}$. As in sections (a) and (b) $I_{S_I} = \frac{Ti}{W_f}$ and $C_T = \frac{Ti}{A_c q_o}$. .

3.2.4.2 External Drag

The external drag will be calculated from Station A = X_{CL} - 0.036 in. to B = X_{CL} + 6.366 in. and from Station C = X_{CL} + 32.096 in. to D = X_{CL} + 38.340 in. There is no external drag correction from Station X_{CL} + 6.366 in. to X_{CL}+ 32.096 in.

External drag = Σ pressure forces + Σ friction drag

Summation of forces acting on load cell (F_{pI}) calculated from pressure integrals

$$F_{pI} = F_{P_{inlet}} + F_{P_{comb}} + F_{P_{nozzle}} - F_{P_{ext}} - F_{P_{cavity}}$$

$$F_{P_{inlet}} = F_2 - P_o \; (1 + Y_o M_o^2) \frac{Wa}{g \, P_o \, V_o} - C_{DA} \, q_o A_c - P_o A_c (1 - A_o/A_c)$$

(see Section 3.2.1.2)

$F_{P_{comb}}$ = combustor exit flow momentum. ($F_{comb\ exit}$) -

combustor inlet flow momentum (F_2)

= F_X at 61.9 (Section 3.2.2.1.3) - F_2 (Section 3.2.1.2)

$F_{P_{nozzle}} = C_S \cdot F_{6I} - F_4$ (Section 3.2.3)

$F_4 = F_X$ at 61.9

$F_{P_{ext}}$ = Σ pressure forces + Σ friction drag (Section 3.2.4.2)

$F_{P_{cavity}}$ = DFT (Section 2.4.2)

(a) Pressure forces

(1) From Station A to Station B the pressure forces produce a drag or negative force.

(2) From Station C to C' = X_{CL} + 35.214 in. there is a zero pressure force at zero angle of attack. Up to 3 deg angle of attack, the estimated force is about 0.1 percent of the total external drag. Thus from 0 to +3 deg angle of attack, a zero pressure force will be assumed between these two stations.

(3) From Station C' to D the pressure forces will produce a thrust or positive force.

Therefore,

$$\text{External drag due to pressure forces} = \sum_{X_{CL} - 0.036}^{X_{CL} + 6.366} P\Delta A - \sum_{X_{CL} + 35.214}^{X_{CL} + 38.1619} P\Delta A$$

In general, the value of ΔA versus station (ΔA = projected area) will be obtained from the table of outside cowl dimensions and p versus station will be obtained from measured wall static pressures.

There are however, no pressure measurements forward of station X_{CL} + 0.616. Thus for the pressure force (PΔA) prior to this station inlet test results will be used as follows:

$$\sum_{X_{CL} - 0.036}^{X_{CL} + 0.553} P\Delta A = C_D \, q_o \, A_{ref}$$

where C_D = 0.11006 at all test Mach numbers

A_{ref} = 256.13 in.^{2}

q_o = freestream dynamic pressure ~ psia.

For $\sum_{X_{CL} + 0.553}^{X_{CL} + 6.366}$ PΔA, use the following values for P:

$Sta = X_{CL} +$	P
0.616	$1/4\left(\sum_{1-CO}^{4-CO} P_{meas}\right)$
2.116	$1/4\left(\sum_{5-CO}^{8-CO} P_{meas}\right)$
4.116	$1/4\left(\sum_{9-CO}^{12-CO} P_{meas}\right)$
5.116	$1/2\ (P_{17-CO} + P_{22-CO})$
5.366	$1/2\ (P_{20-CO} + P_{25-CO})$
5.466	$1/2\ (P_{18-CO} + P_{23-CO})$
5.616	$1/4\left(\sum_{13-CO}^{16-CO} P_{meas}\right)$
5.766	$1/4\ (P_{19-CO} + P_{21-CO} + P_{24-CO} + P_{26-CO})$

The ΔA versus station is obtained from Table A-2

$$\sum_{X_{CL}+35.214}^{X_{CL}+38.340} P\Delta A = P_{meas}\left(\frac{X}{360}\right) A$$

where $A = 75.769079 \text{ in.}^2$

P_{meas}	X
P_{21-NO}	6
$1/5\ (P_{26-NO} + P_{18-NO} + P_{19-NO} + P_{34-NO} + P_{20-NO})$	28
P_{24-NO}	14
P_{25-NO}	14

P_{27-NO}	14
P_{28-NO}	14
P_{32-NO}	14
$1/3\ (P_{22-NO} + P_{16-NO} + P_{23-NO})$	18
$1/3\ (P_{29-NO} + P_{30-NO} + P_{17-NO})$	208
P_{31-NO}	18
P_{33-NO}	12
	$\Sigma X = 360$

Thus the force on the aft portion of the outer cowl has been broken down into sectors of the aft annulus. The magnitude of the sector was estimated as that region on which the outer cowl measured pressures would be acting.

(b) Friction Drag

$$\Sigma \text{ friction drag} = \Sigma\, C_{f\ \text{Local}} \cdot q_{L\ \text{Local}}\ A_{\text{wetted}}$$

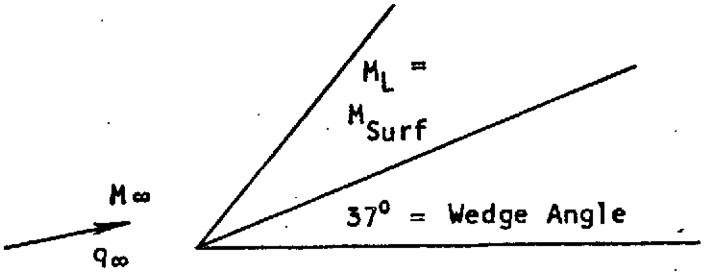
C_{f_L} = func (M_L, Re_L) obtained from Spalding and Chi's analysis, see Section 3.2.6.

$$q_L = (\gamma/2) M_L^2\ P_L$$

$A_{\text{wetted}} = 2\ \pi\ R_{\text{outer cowl}}\ \Delta X$, where ΔX = axial length

In general, wedge flow analysis is used to obtain M_L (surface Mach number) and thus q_L and Re_L.

From station X_{CL} -0.036 in. to X_{CL} + 0.553, M_L and q_L are obtained using the freestream conditions taken through a shock produced by a 37-deg wedge, i.e.,



From station $X_{CL} + 0.553$ to $X_{CL} + 6.366$, use the previously calculated flow behind the 37° wedge and expand isentropically to the measured local static pressure in obtaining the local flow parameters.

For Reynolds number start from station $X_{CL} - 0.036$ when length = zero.

From station $X_{CL} + 32.096$ to $X_{CL} + 35.214$ use the surface condition computed at station 41.25 since there are no static measurements in this region.

From station $X_{CL} + 35.214$ to $X_{CL} + 38.340$, use the measured static pressures together with the total pressure corresponding to the flow computed at station $X_{CL} + 6.366$.

For use in calculating the friction coefficients, use $T_W = 1000°F$ for all test conditions.

(c) Calculate Drag Coefficients

$$C_D = C_{D_p} + C_{D_f}$$

$$C_{D_p} = \frac{\Sigma \text{ Pressure Force}}{q_o A_{ref}} \qquad A_{ref} = 256.13 \text{ in.}^2$$

$$C_{D_f} = \frac{\Sigma \text{ Friction Drag}}{q_o A_{ref}}$$

For the wetted area calculations involving the friction drag term, that area located under the external support struts will not be included as contributing to friction drag.

Thus from the calculated A_{wetted} subtract the following:

$$A_{W\ NET} = A_{wetted} - C\ \Delta L$$

Station	C
$X_{CL} + 32.096$	9.4
$X_{CL} + 37.116$	4.4
$X_{CL} + 37.716$	0

Use straight line interpolation between stations

$$\Delta L = Sta_x - Sta_{x-1}$$

3.2.5 Heat Transfer

3.2.5.1 Summary

Presented herein are calculation procedures for hot gas heat flux and hot wall temperature distributions required for the HRE/AIM data reduction. Axial heat flux distributions are estimated from the water heat loads and local hot wall insert thermocouple measurements. Where insert thermocouples are sparsely spaced along a flow route (spike, innerbody and strut sides), the use of an average constant heat flux is recommended. Linear interpolation between measured hot wall insert thermocouples is recommended to obtain hot wall temperature distribution.

Transient temperature analyses results indicate that approximately 15 seconds are required for the mainstream boundary metal temperatures to reach steady state values. The heat load correlations presented in this memo should only be applied, then, after 15 sec of operation at steady state inlet and injection conditions.

3.2.5.2 Calculation of Heat Flux

Heat flux distributions on the engine routes are divided into two groups as denoted by the heat flux equations below. Distributions on the spike, innerbody, and strut sides are treated separately from the remainder of the engine routes because the reduced number of operative hot wall insert thermocouplets on these routes (five on the spike, one on the inner shell, and none on the strut sides) allows only a constant heat flux distribution with axial length. Insert thermocouples on the outerbody (32 axial locations) and on the nozzle plug (four axial locations) are frequent enough so that incremented heat flux distributions can be formulated.

The general heat flux equations are presented below for the centerbody, internal surface of the outerbody and strut sides. Equation (A-4) represents the heat flux distributions for the spike, innerbody, and strut sides and Equation (A-5) represents the distributions for the outerbody and nozzle plug.

$$q(i) = \frac{W_{H_2O}(j)\ \Delta T_{H_2O}\ (k)}{A(i)}, \quad \frac{\text{Btu}}{\text{sec-ft}^2} \qquad \text{(A-4)}$$

$$q(i) = \frac{W_{H_2O}(j)\ \Delta T_{H_2O}(k)}{\sum\limits_{i=1}^{N(k)} q'(i) \times A(i)} \times q'(i), \quad \frac{\text{Btu}}{\text{sec-ft}^2} \qquad \text{(A-5)}$$

where

$$q'(i) = \frac{W_{H_2O}(j) \times \Delta T_{H_2O}(k)}{\sum\limits_{i=1}^{N(k)} A(i)} \times F_G(i) \times \frac{T_W(i) - \bar{T}_{H_2O}\ (\ell)}{\bar{T}_W(k) - \bar{T}_{H_2O}(\ell)} \qquad \text{(A-6a)}$$

F_G is the geometric factor which accounts for the change of hydraulic diameter along the cooling passage as shown in Table A-4.

i denotes thermocouple location

j denotes coolant manifold

k denotes coolant ΔT corresponding to i grouping and

$$\overline{T}_W(k) = \sum_{i=1}^{N(k)} \frac{T_W(i) \times A(i)}{\sum_{i=1}^{N} A(i)} \qquad (A\text{-}6b)$$

where i is summed over each ΔT_{H_2O} (see Table A-4).

Definition of the integers and physical constants for use in these equations and their axial limits are presented in Table A-4. Definitions of the terms in relation to the test instrumentation are presented in Table A-5 as well as in Table A-4.

Equations in Tables A-4 and A-5 yield a step function array (heat flux constant over the indicated axial limits versus engine axial length. It is recommended that three arrays be established for computation: one each for the centerbody, outerbody, and strut sides. As data reduction calculations progress along the engine, up to three table hookups per axial station can be performed so that surface heat fluxes can be found individually or summed. It is noted with emphasis that the axial reference locations used in this analysis are taken from Drawing L-950501 sheet 2 of 5, Reference A-1, where the spike is in the fully open position. When the spike translation distance has been experimentally calibrated with respect to the cowl tip, all axial coordinates presented in Table A-4 (except on the spike) must have a term X TRANS added to it so that they correspond to the distance from the spike apex for all spike translations. X TRANS as used herein is defined in Table A-5.

3.2.5.3 Calculation of Heat Load

The thermocouple pairs used for measuring coolant water temperature rise are located at approximately 0 and 180 deg at each section as described in Figure A-8. The average of the two temperature rises should be used for heat load calculations as shown in Table A-5. Where specific section coolant water temperature rises are not measured, the section values were computed from the available measurements as defined in Figure A-8 and Table A-4.

3.2.5.4 Calculation of Wall Temperature

Metal temperature distributions on the centerbody and outerbody surfaces can be approximated by using linear interpolation of measured hot wall insert thermocouples. The axial locations and T/C designations for the entire outer body are given in Table A-4. Between the cowl tip and Station 37 use a constant value of T(54-C). Between Station 72.26 and the end of the nozzle shroud use a constant value equal to T(15-N). Metal insert thermocouples on the spike and inner shell are given in Table A-6 with the associated axial locations. Nozzle plug thermocouples are given in Table A-4. Since there are no insert thermocouples between the spike tip and Station 35.70, assume a forever constant value of 700°R at the spike tip. Between Station 81.24 and the nozzle cap use constant value equal to T(14-NP). There are hot wall insert thermocouples on the strut sides.

TABLE A-4

PARAMETERS REQUIRED FOR HEAT FLUX CALCULATIONS

Component	Metal Insert T/C Axial Location, in.	Axial Limits, in.		Heat Flux Equation	Insert T/C Integer, i	Metal Insert T/C $T_W(i)$, °R	Surface Area $A(i)$, ft^2	Geometric Factor, $F_G(i)$	Water Flow Rate $W_{H_2O}(j)$, lb/sec	Water Temp Rise $\Delta T_{H_2O}(k)$, °R	Av. Water Temp $\bar{T}_{H_2O}$, °R
		From	To								
Forward spike	-	0.0	39.79	A-4	-	-	6.65	-	W_{CB}	$(\Delta T_6-\Delta T_5$	-
Aft spike	-	39.79	55.97	A-4	-	-	6.60	-	↓	ΔT_5	-
Innerbody	-	55.97	66.39*	A-4	-	-	[0.41(11.42-XTRANS)-.42]	-	↓	ΔT_7	-
Nozzle plug	67.94*	66.33*	69.36	A-5	1	T(11-NP)**	1.70	2.64	↓	ΔT_{NP}	T_{H_2O} in. - $\frac{\Delta T(60-F)^{**}}{2.0}$
66.89-87 in.	70.67	69.36	72.60	A-5	2	T(12-NP)	1.20	1.65	↓	↓	↓
Summation integer N = 4	74.45	72.60	77.88	A-5	3	T(13-NP)	1.60	1.02	↓	↓	↓
	81.24	77.88	87.00	A-5	4	T(14-NP)	1.51	0.97	W_{CB}	ΔT_{NP}	T_{H_2O} in. + $\frac{\Delta T(60-F)^{**}}{2.0}$
Cowl leading edge	37.0	34.848	38.05	A-5	1	T(54-C)	1.31	1.3	W_o	ΔT_1	T_{H_2O} in. - $\frac{\Delta T(63-F}{2.0}$
34.848-40.5 in.	39.0	38.05	39.56	A-5	2	T(55-C)	0.635	0.865	↓	↓	↓
Summation integer N = 3	40.0	39.56	40.5	A-5	3	T(56-C)	0.42	0.865	↓	ΔT_1	↓
Outer shell	42.0	40.5	42.3	A-5	1	T(39-0)	0.705	1.00	↓	ΔT_2	↓
40.5-56.0 in.	42.6	42.3	43.12	A-5	2	T(40-0)	0.366	↓	↓	↓	↓
Summation integer	43.01	43.12	44.4	A-5	3	T(41-0)	0.581	↓	↓	↓	↓
N = 15	45.25	44.4	45.8	A-5	4	T(42-0)	0.588	↓	↓	↓	↓
	46.5	45.8	46.86	A-5	5	T(43-0)	0.474	↓	↓	↓	↓
	47.0	46.86	47.5	A-5	6	T(47-0)	0.302	↓	↓	↓	↓
	48.0	47.5	48.52	A-5	7	T(48-0)	0.447	↓	↓	↓	↓
	49.0	48.52	49.52	A-5	8	T(49-0)	0.450	↓	↓	↓	↓
	50.0	49.52	50.76	A-5	9	T(50-0)	0.571	↓	↓	↓	↓
Outer shell	51.5	50.76	51.75	A-5	10	T(54-0)	0.443	↓	↓	↓	↓
40.5-56 in.	52.0	51.75	52.45	A-5	11	T(55-0)	0.330	↓	↓	↓	↓
Summation integer N = 15	53.0	52.45	53.5	A-5	12	T(56-0)	0.481	↓	↓	↓	↓
	54.0	53.5	54.5	A-5	13	T(57-0)	0.467	↓	↓	↓	↓
	55.0	54.5	55.46	A-5	14	T(58-0)	0.450	↓	↓	↓	↓
	56.0	55.46	56.0	A-5	15	T(59-0)	0.331	1.00	W_o	ΔT_2	T_{H_2O} in. - $\frac{\Delta T(63-F)}{2.0}$

TABLE A-4 (Continued)

Component	Metal Insert T/C Axial Location, in.	Axial Limits, In. From	To	Heat Flux Equation	Insert T/C Integer, i	Metal Insert T/C $T_W(i)$, °R	Surface Area $A(i)$, ft^2	Geometric Factor, $F_G(i)$	Water Flow Rate $W_{H_2O}(j)$, lb/sec	Water Temp Rise $T_{H_2O}(k)$, °R	Avg Water Temp $\bar{T}_{H_2O}$, °R
Outer shell	57.0	56.0	57.54	A-5	1	T(62-0)	0.640	1.00	W_o	ΔT_3	T_{H_2O} in. - $\frac{\Delta T/63-F}{2.0}$
56.0-66.395 In.	58.0	57.54	58.52	A-5	2	T(63-0)	0.455	↓	↓	↓	↓
Summation Integer N = 10	59.0	58.52	59.55	A-5	3	T(64-0)	0.474	↓	↓	↓	↓
	60.0	59.55	60.5	A-5	4	T(65-0)	0.456	↓	↓	↓	↓
	61.0	60.5	61.76	A-5	5	T(66-0)	0.593	↓	↓	↓	↓
	62.5	61.76	63.0	A-5	6	T(67-0)	0.594	↓	↓	↓	↓
	63.5	63.0	64.0	A-5	7	T(70-0)	0.477	↓	↓	↓	↓
	64.5	64.0	64.88	A-5	8	T(71-0)	0.420	↓	↓	↓	↓
	65.25	64.88	65.64	A-5	9	T(72-0)	0.368	↓	↓	↓	↓
	66.0	65.64	66.395	A-5	10	T(73-0)	0.408	1.00	W_o	ΔT_3	↓
Nozzle shroud	67.46	65.395	68.2	A-5	1	T(12-N)	0.890	0.825	0.88 x W_o	ΔT_4	↓
65.395-73.2	69.0	68.2	69.82	A-5	2	T(13-N)	0.845	0.973	↓	↓	↓
Summation Integer	70.63	69.82	71.46	A-5	3	T(14-N)	0.869	0.948	↓	↓	↓
N = 4	72.26	71.46	73.2	A-5	4	T(15-N)	0.963	1.847	0.88 x W_o	ΔT_4	T_{H_2O} in. - $\frac{\Delta T(63-F}{2.0}$
Strut sides	-	56.15	64.70	A-4	-	-	1.089	-	W_{ST}	1.5 x $\Delta T(62-F)$*	-

---

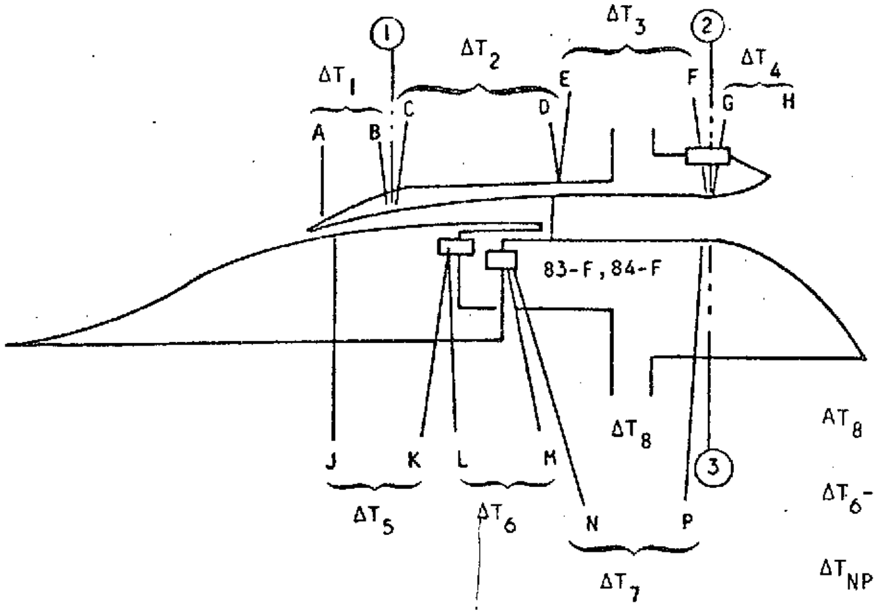
*All axial stations at and beneath that indicated must have a term X TRANS added to it. X TRANS is indicated in Table A-5.

**Instrumentation defined in Table A-1 under heading "H_2O Delta T". Also see Table A-5.

TABLE A-5

NOMENCLATURE

Symbol	Definition
ΔT_1	$\frac{\Delta T(66\text{-}F) + \Delta T(67\text{-}F)}{2}$, ${}^{\circ}R$
ΔT_2	$\frac{\Delta T(68\text{-}F) + \Delta T(69\text{-}F)}{2}$, ${}^{\circ}R$
ΔT_3	$\frac{\Delta T(70\text{-}F) + \Delta T(71\text{-}F)}{2}$, ${}^{\circ}R$
ΔT_4	$\frac{\Delta T(72\text{-}F) + \Delta T(73\text{-}F)}{2}$, ${}^{\circ}R$
ΔT_5	$\frac{\Delta T(74\text{-}F) + \Delta T(75\text{-}F)}{2}$, ${}^{\circ}R$
ΔT_6	$\frac{\Delta T(76\text{-}F) + \Delta T(77\text{-}F)}{2}$, ${}^{\circ}R$
ΔT_7	$\frac{\Delta T(78\text{-}F) + \Delta T(79\text{-}F)}{2}$, ${}^{\circ}R$
ΔT_8	$\Delta T(60\text{-}F)$
ΔT_{NP}	$\Delta T_8 - \Delta T_6 - \Delta T_7 - \frac{\Delta T(62\text{-}F)}{2}$
$T_{H_2O\ IN}$	inlet manifold coolant water temp, ${}^{\circ}R$. (to be supplied by NASA/LeRC)
W_{CB}	centerbody water flow rate, lb/sec (to be supplied by NASA/LeRC)
W_O	outerbody water flow rate, lb/sec) (to be supplied by NASA/LeRC)
W_{ST}	strut-sides water flow rate, lb/sec (to be supplied by NASA/LeRC)
X TRANS	the positive translation of the spike from the position shown in Reference 1, inches



ΔT_8 = INNERBODY OVERALL

ΔT_6-ΔT_5 = FORWARD SPIKE

ΔT_{NP} = NOZZLE PLUG ΔT AS DEFINED IN TABLE A-5

Location	Axial Station	Clockwise Forward Position, deg	Ref Drawing
ΔT_1 COWL L.E. A	35.75	176 356	950554
B	40.50	178.5 356.24	610
ΔT_2 OUTER SHELL C	40.50	181.16 353.53	610
D	55.63	179 355	610
ΔT_3 OUTER SHELL E	55.63	175 357	610
F	66.19	176 356	610
ΔT_4 NOZZLE SHROUD G	66.68	176 356	609
H	72.21	176 356	506
ΔT_5 SPIKE J	39.79	176 356	512
K	47.34	176 356	512
ΔT_6 SPIKE L	48.58	176 356	512
M	50.94	174 354	553
ΔT_7 INNER SHELL N	50.94	178 358	553
P	66.10	176 356	950537

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Figure A-10. Coolant Water Systems Thermocouple Locations

TABLE A-6

SPIKE AND INNERBODY WALL INSERT THERMOCOUPLE

Axial Station (ref. coord), in.	Thermocouple Designation
Spike Tip	700^0R - (Constant for all tests)
35.7	T(47-S)
38.0	T(48-S)
40.0	T(49-S)
42.0	T(50-S)
45.0	T(51-S)
60.0*	T(13-I)
64.8*	T(15-I

---

* Add the term X TRANS to these axial coordinates.

3.2.6 Evaluation of Friction Coefficient

The friction coefficients along the engine surfaces are basically determined using Spalding and Chi's turbulent boundary analysis (Ref. A-2). However, due to different flow conditions, the calculating procedures and equations are varied somewhat for different engine surfaces. They may be divided into three groups.

(1) Flat plate analysis--This analysis is used for all engine external surfaces, all nozzle internal surfaces and cowl internal surfaces.

(2) Flat plate analysis corrected for cone surface--This analysis is used for inlet spike only.

(3) Duct flow analysis--This analysis is used for all combustor surfaces

3.2.6.1 Flat Plate Analysis

The method used for this analysis is presented in Reference A-3. The following are the recommended steps.

(1) Flow Mach number, pressure, and flow properties are known from main program.

(2) Calculate Reynolds number

$$R_x = \frac{\rho_x V_x X}{\mu}$$

- For external and cowl internal surfaces, X is the surface distance computed from cowl leading edge (Station 34.848)
- For nozzle surfaces, X_v is the surface distance from the virtual origin which is computed from the following equations:

$$X = X_v + X_s$$

$$\theta(X_{61.9}) = .036 X_v \left(\frac{\rho_x V_x X_v}{\mu} \right)^{-\frac{1}{5}}, \qquad X_v = \text{Virtual Origin for } \theta_x = 61.9$$

where $\theta_{(x = 61.9)}$ is calculated from (4), p. A-114

(3) $$T_{ad} = T \cdot \left[1 + \sqrt[3]{P_R} \left(\frac{\gamma-1}{2} M^2 \right) \right], \quad P_R = \frac{C_p \mu}{k}$$

(4) $$t_w = \frac{T_W}{T}, \quad t_{ad} = \frac{T_{ad}}{T}$$

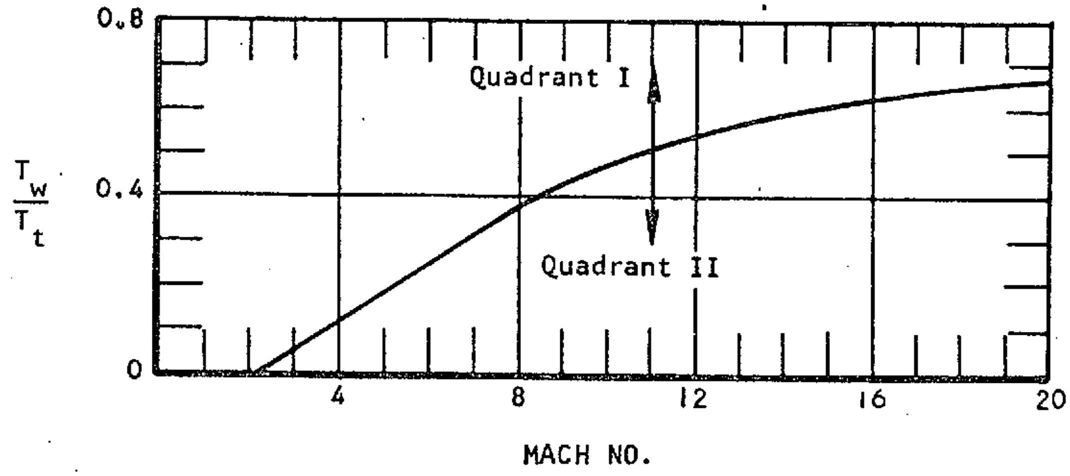
T_W is obtained from Section 3.3 for all internal surfaces

T_W is assumed to be 1000°R for all external surfaces

(5) $F_{R\theta} = t_w^{-1.474} \; t_{aw}^{.772}$

(6) $F_c = (t_{aw}-1) \left\{ \sin^{-1} 2 \frac{\sqrt{t_{aw}-1} \left[t_{aw}-t_w - \sqrt{t_w} \, (2-t_{aw}-t_w) \right]}{(t_{aw}+t_w)^2 - 4 \, t_w} \right\}^{-2}$

The proper quadrant in which to evaluate the inverse sine is shown in the following sketch:



(7) Calculate $F_{RX} = \frac{F_{R\theta}}{F_c}$

(8) Calculate $F_{RX} \; R_X$

(9) Find $F_c \; C_f$ from Table 7 of Ref. A-2.

(10) Find $C_f = \frac{F_c \; C_f}{F_c}$

(11) $\frac{2 \; S_t}{C_f} = \left[1 + 5 \sqrt{\frac{F_c C_f}{2}} \left(P_R - 1 + \log e \, \frac{5 \; Pr + 1}{6} \right) \right]^{-1}$

Find S_t

(12) Find $h = S_t \cdot C_p \cdot V \cdot \rho$ Btu/sec ft^2 °F

3.2.6.2 Flat Plate Analysis Corrected for Cone Surface

This calculation is for inlet spike only (from Station 0 to 40.4). The method of computation is same as paragraph 3.2.6.1 for flat plate except in Step (2) where the Reynolds number of the spike is taken as one-half of the Reynolds number based on linear distance.

$$R_x = \frac{1}{2} \frac{\rho_x V_x X}{\mu}$$

3.2.6.3 Duct Flow Analysis

The duct flow analysis is applicable to combustor surfaces (from Station 40.4 to 61.9). The flow is assumed to be completely established with boundary layer thickness equal to one-half of duct height. The following procedure is then used for this calculation.

(1) Flow Mach number, pressure and flow properties are known from main program.

(2) Given: n = Boundary layer profile exponent = 7.0

(3) $\delta = \frac{1}{2}(R_o - R_i)$ ft; Boundary layer thickness = $\frac{1}{2}$ height

(4) $\theta = \delta \frac{n}{(n+1)(n+2)}$ ft, Momentum thickness

(5) $R_\theta = \frac{\rho V \theta}{\mu}$, Reynolds No. based on momentum thickness

(6) $T_{ad} = T \cdot \left[1 + \sqrt[3]{P_R}\left(\frac{r-1}{2} M^2\right)\right]$

$$P_R = \frac{C_p \mu}{k}$$

(7) $t_w = \frac{T_w}{T}$, $t_{ad} = \frac{T_{ad}}{T}$

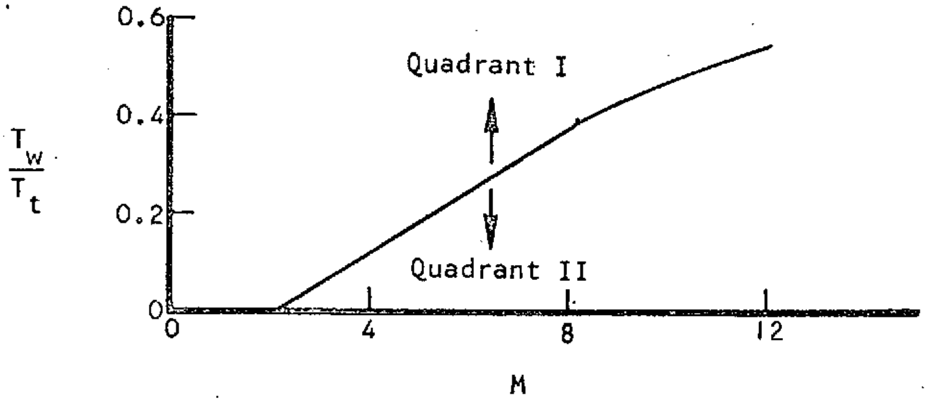
(8) $F_{R\theta} = (t_w)^{-1.474} (t_{ad})^{0.772}$

(9) $F_{R\theta} R_\theta$ - Same as $F_{R\delta} R_\delta$

(10) From Table 7, Reference A-2, Find $F_c C_f$

$$(11)\ F_c = (t_{aw}-1)\left\{\sin^{-1}\frac{2\sqrt{t_{aw}-1}\ \left[t_{aw}-t_w-\sqrt{t_w}\left(2-t_{aw}-t_w\right)\right]}{(t_{aw}+t_w)^2-4\ t_w}\right\}^{-2}$$

The proper gradiant in which to evaluate the inverse sine is shown in the following sketch.



(12) Find C_f

$$(13)\ \frac{2\ S_t}{C_f} = \left[1 + 5\sqrt{\frac{F_c C_f}{2}}\left(P_R - 1 + \log_e \frac{5\ Pr + 1}{6}\right)\right]^{-1}$$

Find S_t

$$(14)\ h = S_t \cdot C_p \cdot V \cdot \rho$$

3.2.7 Curve-Fitting Method

The HRE/AIM Data Reduction Program will perform axial interpolation and all integrations by using cubic splines. This means that for either of the above operations, all relevant measurements in an interval about the interpolant or covering the range of integration are fit to a function F with the following properties:

1. F passes through all the measured points
2. F, F' and F'' are continuous over the specified interval
3. F is a cubic polynomial between each interior pair of measurements
4. F is a quadratic polynomial between the first pair of measurements and also between the last pair of measurements

Having obtained the cubic spline function F, interpolation is performed by evaluating F at the desired point. Integration is performed by integrating F in closed form over the desired range.

Circumferential interpolation will be performed by using periodic cubic splines. A cubic spline F is periodic with period P if

1. F(X+) = F((X+P)-)
2. F'(X+) = F'((X+P)-)
3. F''(X+) = F''((X+P)-)

Reference: ''The Theory of Splines and Their Applications'' by Ahlberg, Nilson, and Walsh Academic Press, 1967, pp. 9-16.

3.3 DATA LISTING

An abbreviated typewriter listing of Engineering Units Data defined in Section 2.3.2 will be made immediately after the data has been reduced. This data will be examined to identify the times during the run at which the test conditions have stabilized at the target values. These times will be input into the computer to request listings of the Performance Analysis data. An abbreviated typewriter listing will be made for each time input. A complete listing of all Performance Analysis data at selected times will be made later on the on-line printer. The formats for each type of listing are defined in the following sections.

3.3.1 Program Heading

The program heading for the on-line printer listing will be identical to the Engineering Units section heading defined in Section 2.3.2.

3.3.2 On-Line Printer Format

The data listing and headings for the on-line printer format are defined in Section 3.3.3. Four formats are to be used depending on run type. The format used for each run is defined by the record code number given on the Test Requirement sheets. This is discussed in Section 8.2 in the body of this report. The format corresponding to each code number is defined in Table A-7.

In some cases all data cannot be listed due to disconnected instrumentation. The readings will remain blank for these cases.

Data will be listed in blocks as shown in the following examples. For cases where wall pressures are listed, a code number is listed to identify the tap number and the axial station and circumferential location. The code number is the same as that used in the engineering units listing defined in Section 2.3. An example is shown in the inlet wall pressure listing below. In cases where interpolated values of P/PO and M are listed, the letter C (designating calculated value) replaces the tap listing number. Other special cases of the format are given in the following paragraphs.

```
TUNNEL                    INLET
Time PTO PO TTO HTO HO QO MFR WA -------------------------------

50.2
52.6
54.0
67.8
68.4

70.6
74.8
```

TABLE A-7

ON-LINE PRINTER HEADINGS

Heading	Data Reduction Code Number*			
	1	2	3	4
TUNNEL	X	X	X	X
INLET	X	X	X	X
INLET WALL PRESSURES	X	X	X	X
INLET FORCES	X	X	X	X
INLET THROAT	X	X	X	X
INLET PERFORMANCE (SUBSONIC COMBUSTION)	X	X	X	X
INLET PERFORMANCE (SUPERSONIC COMBUSTION)	X	X	X	X
FUEL INJECTORS			X	X
IGNITORS			X	X
COMBUSTOR HEAT BALANCE	X		X	X
COMBUSTOR FORCES	X		X	X
COMBUSTOR PARAMETERS VS. X	X		X	X
CONE PROBES			X	
GAS SAMPLE PROBES			X	
NOZZLE INLET (STA. 4)	X		X	X
NOZZLE INLET (STA. 5)	X		X	X
NOZZLE WALL PRESSURE	X		X	X
NOZZLE FORCES	X		X	X
NOZZLE EXIT	X		X	X
IDEAL NOZZLE EXIT	X		X	X
NOZZLE PERFORMANCE	X		X	X
ENGINE PERFORMANCE			X	X
OUTER COWL PS/PO		X	X	X
WALL TEMPERATURES	X	X	X	X
COOLING SYSTEM	X	X	X	X
FLOW METER WALL PRESSURE		X		
FLOW METER WALL TEMPERATURE		X		
FLOW METER PROBE TEMPERATURE		X		
FLOW METER RAKE TEMPERATURE		X		
FLOW METER PARAMETERS		X		

*Data Reduction Code No. 1 Designates operational checkout and purge force run
" " " " 2 Airflow meter run
" " " " 3 Combustor performance run
" " " " 4 Engine performance run

```
INLET WALL PRESSURE
TIME I-0.60-0   C-0.80-0 --------------------------------
     P/PO   M   P/PO   M

50.2
52.6
54.0
67.8
68.4

70.6
74.8
```

3.3.2.1 Fuel Injector Listing Format

The fuel injector listings will be made as shown below for all eight fuel manifolds. WF, ER, and Cd will remain blank for manifolds not in use. Fuel manifold pressure, PM, and fuel manifold temperature, TM, will be listed for all manifolds.

```
WFIA ERIA CDIA PMIAI TMIAI WFIB ERIB CDIB PMIBI TMIBI - - - - - - - - -
```

The symbols and instrumentation code numbers for the fuel manifold pressures and temperatures are defined in Table A-I under FUEL SYSTEM.

3.3.2.2 Combustor Parameters Versus X Format

Various parameters such as total temperature and pressure, friction coefficient, heat transfer coefficient, etc., are listed versus axial station in the combustor at each tap location and at all points where interpolated values are calculated. The listing format is defined below.

```
TIME  I-41.06-0                C-41.9-0
      CF     H      Q/A ------A CF     H     Q/A ----------A
```

In cases where interpolated values are listed, the same code number technique is used as described for the wall pressure ratio and Mach number listing in Section 3.3.2.

3.3.2.3 Cone Probe Format

The cone probe data will be listed as shown below

```
CONE PROBES (0 DEG.)
TIME A     PT   M    Q     THTA PHI  SI6  EPS
```

The listing shown is for the probe at an engine circumferential location of 0°. This format will be used to list data at circumferential locations of 0°, 100°, 150°, 180°, 290°.

3.3.2.4 Outer Cowl Pressure Format

Outer cowl pressures divided by tunnel static pressure will be listed by code number as follows:

OUTER COWL P/PO
TIME 5-CO 7-CO 8-CO - - - - - - - - -

3.3.2.5 Wall Temperatures

Wall temperatures will be listed by data listing code number as follows:

WALL TEMPERATURES
TIME 5-CO 7-CO 8-CO ----- - - - - - - ---- - - - - - - - -

NOTE:

In some cases a different calculation technique for the same parameter is used for subsonic and supersonic combustion. Both calculations will be made and the results listed. An example of this is in Section 3.2.1.2 where different inlet performance calculation procedures are defined for subsonic and supersonic combustion. The print format provides a listing of both subsonic and supersonic combustion inlet performance. Both sets of parameters will be listed regardless of type of combustion.

3.3.3 Listed Data and Symbols

The data listed by the on-line printer is defined below. This list is intended to define the desired format and to serve as a list of symbols when reading the data listing. The notes inserted are directed to the listing reader and are not to be included in the print format.

TUNNEL

Total pressure	PTO
Exit static pressure	PO
Total temperature	TTO
Total enthalpy	HTO
Static enthalpy	HO
Exit dynamic pressure, $\frac{1}{2}(\rho V^2)_o$	QO
Weight flow per unit area	W/A
Exit velocity	VO

INLET

Spike translation, $\frac{X}{R}$ (R = 9.0")	X/R
Angle of attack	AOA
Airflow	WA
Mass flow ratio	MFR

INLET WALL PRESSURES

Spike wall pressure over PO	PS/PO
Inner cowl wall pressure over PO	PIC/PO
(see Section 3.3.2 for format)	
Average Mach number	M

INLET FORCES

Spke tip force, F_{ST}	FST
$FST/\frac{1}{2}(\rho V^2)_o$	FSTQ
Cowl lip force, F_{CL}	FCL
$FCL/\frac{1}{2}(\rho V^2)_o$	FCLQ
Force on all forward-facing areas	FFF
$FFF/\frac{1}{2}(\rho V^2)_o$	FFFQ
Force on all aft-facing areas	FAF
$FAF/\frac{1}{2}(\rho V^2)_o$	FAFQ
Force on dividing streamline	FSL
$FSL/\frac{1}{2}(\rho V^2)_o$	FSLQ
Spike friction force	FSF
$FSF/\frac{1}{2}(\rho V^2)_o$	FSFQ
Cowl friction force	FCF
$FCF/\frac{1}{2}(\rho V^2)_o$	FCFQ

INLET THROAT

NOTE: The following inlet throat properties are based on the calculated stream thrust at the throat.

Throat vacuum specific impulse	IVAC2
Throat Mach number	M2
Throat velocity	V2
Throat total pressure	PT2
Throat static pressure	P2
Throat total temperature	TT2
Throat static temperature	T2
Throat total enthalpy	HT2
Throat static density	RHO2
Throat gamma	GAM2
Flow blockage	DA/A

INLET PERFORMANCE, SUPERSONIC COMBUSTION

Total pressure recovery, PT2/PT0	TPR2
Kinetic energy efficiency, η_{KE}	KEE2
Process efficiency, K_D	KD
H_0' (see Section 3.2.1.2 for definition of supersonic value)	HOI2
Heat rejected to Sta 40.4	Q40.4

INLET PERFORMANCE, SUBSONIC COMBUSTION

Total pressure recovery, PT crit/P_{T0}	TPRC
Kinetic energy efficiency, η_{KE} (subsonic)	KEEC
Process efficiency, K_D (subsonic)	KDC
H_0' (see Section 3.2.1.2 for definition of subsonic value)	HOIC

FUEL INJECTORS

(See Section 3.3.2.1 for format)

Fuel flow	WF
Equivalence ratio	ER
Injector discharge coefficient (see Section 3.2.1.2 for definition)	CD
Fuel manifold pressure	PM
Fuel manifold temperature	TM

IGNITORS

Ignitor oxygen flow	
System 1	WIO1
System 2	WIO2
System 3	WIO3
Ignitor hydrogen flow	
System 1	WIH1
System 2	WIH2
System 3	WIH3

COMBUSTOR HEAT BALANCE

Combustor inlet total enthalpy	HT3
Total injected enthalpy	HTF
Heat rejected to coolant (combustor only)	QREJ
Combustor exit total enthalpy	HT4

COMBUSTOR FORCES

Combustor inlet stream thrust	FS3
Combustor inlet vacuum specific impulse	IVAC3

Combustor exit stream thrust	FS4
Total wall pressure integral, PdA	FWC
Total friction force	FFC
Total fuel axial momentum	FINJ
Total strut drag	FSD
$FSD/\frac{1}{2}(\rho V^2)_o$	FSDQ

COMBUSTOR PARAMETERS VS X

(See Section 3.3.2.2 for format)

Friction coefficient	CF
Heat transfer coefficient	H
Heat flux	Q/A
Combustion efficiency	NC
Total temperature	TT
Static temperature	T
Total pressure	PT
Spike static pressure	PS
Outer shell static pressure	POS
Static temperature	T
Dynamic pressure	Q
Velocity	V
Mach number	M
Unit Reynolds number	RE/L
Geometric flow area	A

SUBSONIC COMBUSTION

Combustor efficiency	NC*
Throat total pressure, when Mach No. = 1.0 (see Section 3.2.2.1.7 for definition)	PT*

CONE PROBES

(See Section 3.3.2.3 for format)

Angular location of probe, deg	A
Total pressure upstream of probe shock	PT
Mach number upstream of probe shock	M
$\frac{1}{2}\rho V^2$ upstream of probe shock	Q
Probe pitch angle, θ	THTA
Probe roll angle, ϕ	PHI
Probe side-wash angle, σ	SIQ
Probe down-wash angle, ϵ	EPS

GAS SAMPLE PROBES

Gas sample probe analysis to be defined by NASA.

NOZZLE INLET (STA 4) 1,2,3

NOTE: The following section is for Station K_a + 27.016

Stream thrust	FS4
Vacuum specific impulse	IVAC4
Gas flow rate	WG4
Mach number	M4
Velocity	V4
Total pressure	PT4
Static pressure	P4
Total temperature	TT4
Static temperature	T4
Total enthalpy	HT4
Static enthalpy	H4

Gamma	GAM4
Nozzle pressure ratio	PT4/PO

NOZZLE INLET (STA 5)

NOTE: The following section is for Station X_{CL} + 29.856

Stream thrust	FS5
Vacuum specific impulse	IVAC5
Gas flow rate	WG5
Mach number	M5
Velocity	V5
Total pressure	PT5
Static pressure	P5
Total temperature	TT5
Static temperature	T5
Total enthalpy	HT5
Static enthalpy	H5
Gamma	GAM5
Nozzle pressure ratio	PT5/PO

NOZZLE WALL PRESSURE

Plug wall pressure over PO	PNP/PO
Nozzle shroud pressure over PO (see Section 3.3.2 for format)	PNI/PO
Mach number	M

NOZZLE FORCES

Plug friction force	FFP
FFP $\frac{1}{2}(\rho V^2)_o$	FFPQ
Shroud friction force	FFS

$FFS/\frac{1}{2}(\rho V^2)_o$	FFSQ
Strut drag	DS
$DS/\frac{1}{2}(\rho V^2)_o$	DSQ
Plug wall pressure integral $\int_{PLUG} PdA$	FNPI
$FNPI/\frac{1}{2}(\rho V^2)_o$	FNPIQ
Shroud wall pressure integral $\int_{29.86}^{38.16} PdA$	FNSI
$FNSI/\frac{1}{2}(\rho V^2)_o$	FNSIQ
Shroud wall pressure integral $\int_{38.16}^{38.34} Pda$	FNS2
$FNS2/\frac{1}{2}(\rho V^2)_o$	FNS2Q

NOZZLE EXIT

Stream thrust	FS6
Vacuum specific impulse	IVAC6
Mach number	M6
Velocity	V6
Total pressure	PT6
Static pressure	P6
Total temperature	TT6
Static temperature	T6

WALL TEMPERATURES

47-S 48-S 49-S 50-S 51-S 13-I 14-I 15-I 11-NP 12-NP 14-NP 54-C

55-C 56-C 58-C 59-C 60-C 60-CO 39-0 40-0 41-0 42-0 43-0 44-0

45-0 46-0 47-0 49-0 50-0 52-0 54-0 55-0 56-0 59-0 60-0 61-0

62-0 63-0 64-0 65-0 66-0 67-0 68-0 69-0 70-0 71-0 72-0

12-N 13-N 14-N 15-N

NOTE: Location of these taps is defined in Table A-1.
See Section 3.3.2.5 for format.

COOLING SYSTEM

Spike cooling flow rate	WS
Spike assembly water ΔT at 0°	DT6A
Spike assembly water ΔT at 180°	DT6B
Spike assembly heat input	QSP
Aft spike water ΔT at 0°	DT5A
Aft spike water ΔT at 180°	DT5B
Aft spike heat input	QAS
Forward spike heat input, QSP-QAS	QFS
Innerbody water ΔT at 0°	DT7A
Innerbody water ΔT at 180°	DT7B
Innerbody heat input	QIB
Innerbody and nozzle plug ΔT	DTNI
Nozzle plug heat input, (WS)(DTNI)-QIB	QNP
Outerbody cooling flowrate	WO
Cowl leading edge water ΔT at 0°	DT1A
Total enthalpy	HT6
Static enthalpy	H6
Static density	RHO6
Gamma	GAM6

IDEAL NOZZLE EXIT

Stream thrust	FSI

Vacuum specific impulse	IVACI
Ideal gross thrust	F6I
Static enthalpy	H4I

NOZZLE PERFORMANCE

Stream thrust coefficient, C_S	CS
Nozzle thrust coefficient, C_T	CT
Nozzle kinetic energy efficiency, η_{KE}	KEEN
Nozzle process efficiency, K_N	KN

ENGINE PERFORMANCE

Corrected load cell reading	FC
Force acting on load cell calculated from pressure integrals (See Section 3.2.4.2)	FPI
External drag $(\int PdA + F_f)$	DEXT
Nitrogen purge force correction	DFT
Internal thrust	FI
Specific impulse	ISI
Thrust coefficient	CTI

NOTE: FC and DFT are defined in Section 2.3.2.

OUTER COWL P/PO

5-CO 7-CO THROUGH 26-CO

NOTE: P/PO will be listed for each tap per the format defined in Section 3.3.2.4. Location of these taps is defined in Table A-1.

Cowl leading edge water ΔT at 180°	DTIB
Cowl leading edge heat input	QLE

Forward outerbody water ΔT at 0^0	DT2A
Forward outerbody water ΔT at 180^0	DT2B
Forward outerbody water heat input	QFOB
Aft outerbody water ΔT at 0^0	DT3A
Aft outerbody water ΔT at 180^0	DT3B
Aft outerbody heat input	QAOB
Strut cooling flow rate (4 of 6 struts)	WST
Strut body water ΔT (4 of 6 struts)	DTSB
Strut heat input (6 struts)	QST
Total heat input = QSP+QAS+QFS +QIB+QNP+QLE+QFOB+QAOB+QST	QSUM

FLOWMETER WALL PRESSURE

5-EF THROUGH 20-EF

NOTE: The location of the pressure taps are defined in Table A-I.

FLOWMETER WALL TEMPERATURE

21-EF THROUGH 28-EF

NOTE: See Section 3.3.2.5 for format. The location of the thermocouples is defined in Table A-I.

FLOWMETER PROBE TEMPERATURES

I-EF THROUGH 4-EF

NOTE: See Section 3.3.2.5 for format. The location of the thermocouples is defined in Table A-I.

FLOWMETER RAKE

35-EF	29-EF	30-EF	31-EF	32-EF	33-EF	34-EF
1.000	.9118	.7317	.5149	.3553	.1584	0
TEFR F(R)	TEFR F(R)	TEFR F(R)	TEFR F(R)	TEFR F(R)	TEFR F(R)	TEFR F(R)

NOTE: 35-EF is the shroud wall temperature, T_{WO}. 34-EF is the plug wall temperature T_{Wi}. The numbers 0.9118 through 0.158 are the probe immersion depths measured from the plug wall as a fraction of duct height. The duct height is 1.62 in. Use the format shown above and list the temperatures under the "T" column headings and the f(R) values under (FR). The calculations are defined in Section 3.2.1.1.1. If the extrapolation technique defined in this section is used, the Mach 5 and 6 values of f(R) will be input. The Mach 7 values of f(R) and temperatures listed will then be extrapolated values as defined in the calculations.

FLOWMETER PARAMETERS

Average wall temperature at rake	TWBAR
Average duct total temperature T_T	TTBAR
Nozzle flow coefficient (input)	CD
Nozzle flow coefficient based on captured inlet flow, C_D'	CDP
Average throat static pressure, $\overline{P}*$	P*BAR
Weightflow based on throat pressure, W_A	WA*
Average duct static pressure, $\overline{P}_D$	PDBAR
Weightflow based on duct pressure	WAD
Throat total pressure	PT*
Throat velocity	V*
Throat static density	RHO*
Throat static temperature	T*
Throat static enthalpy	H*
Throat total enthalpy	HT*
Throat gamma	GAM*

N2 PURGE FORCE

Corrected load cell reading	FC
Load cell reading	FLC
Intermediate load cell reading	FL
Force parameter	FLPTO
Forward cavity pressure ÷ PTO	PAPTO
Aft cavity pressure ÷ PTO	PBPTO

NOTE: The above parameters are defined in Section 2.4.2.

3.3.4 Typewriter Printer Format

The program heading defined in Section 2.2.3 will be used for the typewriter printer format. The data will be printed in blocks at selected times as defined for the on-line printer format defined in Section 3.3.2. The headings and listed data are defined below. The symbols are defined in Section 3.3.3. Additional parameters may be printed by inputing their symbols or equivalent.

TUNNEL

PTO PO TTO HTO HO QO VO

INLET

X/R AOA X/R WA MFR P/S P13S P15S P205 P295 P315 FSTQ FC1Q
FFFQ FAFQ FSLQ FFSQ FCFQ FOQ F2Q TPR2 NKE2 KD2 TPRC NKEC
KDC IVAC2 IVAC3

COMBUSTOR

WF ER CD P1G P29S P39S P41S P45S P1I P5I P9I P10 P50 P200
P220 P290 P320 PT3 TT3 M3 IVAC3 PT4 TT4 M4 W4 NC NC* NC53
PT53 FSD FWC

QREJ

NOTE: NC53 and PT53 are the combustor efficiency and total pressure at Station 53.0 respectively. These will be determined from the "Combustor Parameters vs X" relationship defined in Section 3.3.2.2.

NOZZLE

FS4 IVAC4 F5 IVAC5 F6 IVAC6 FFP FFS DS FNPI FNSI FNS2 C_S

C_5 CT NKE KN

ENGINE PERFORMANCE

FC DEXT DFT FI ISI CTI

FLOWMETER

List flowmeter rake and probe temperatures as defined in Section 3.3.2.1.

PT* P*BAR TTBAR WA WAD

N2 PURGE FORCE

FC FLC FL FLPTO DAPTO PBPTO PIC PA1 PA2 PB1 PB2 WPPL WPML

DFA DFB DFC DFD DFE DFW

NOTE: The above parameters are defined in Section 2.3.2

CONE PROBES

Use format defined in Section 3.3.2.3.

GAS SAMPLE PROBES

To be defined by NASA LeRC.

The headings to be listed for each data reduction code number are defined below:

Heading	Data Reduction Code Number 1	2	3	4
TUNNEL	X	X	X	X
INLET	X	X	X	X
COMBUSTOR	X	X*	X	X
NOZZLE	X		X	X
ENGINE PERFORMANCE			X	X
FLOWMETER		X		

*Wall pressures only

Heading (Continued)	Data Reduction Code Number 1	2	3	4
N2 PURGE FORCE	X	X	X	X
CONE PROBES			X	
GAS SAMPLE PROBES			X	

3.4 DATA PLOTS

The following plots will be made at the same test times that were selected for on-line printer performance data listings. Some parameters are plotted versus distance (X) from the spike apex. The effect of spike translation on the location of points other than on the spike will be determined from the relationships given earlier.

3.4.1 Flowmeter

$$T_{T(i)} \text{ vs } \frac{R - R_i}{R_o - R_i}$$

Including T_{W_i} and T_{W_o}

3.4.2 Inlet

(Separate plots for spike and cowl)

(a) P/P_o vs X, using different symbols for measured and calculated pressures

(b) Surface Mach number vs X

3.4.3 Combustor

Total temperature vs X

Total pressure ratio $(P_T/P_{T_o}$ vs X

Combustor efficiency (η_c) vs X

Combustor pressure ratio (P/P_{T_o}) vs X

Wall surface temperature vs X

3.4.4 Nozzle

P/P_o, Mach No. vs X for plug and shroud

3.6.5 External Wall Pressures

P/P_o vs X using symbols to denote circumferential location of pressure taps.

4. IDENTIFICATION OF LISTED PARAMETERS

The data will be listed in four basic formats defined below:

(a) On-Line Printer

  (1) Engineering Units Listing

  (2) Performance Analysis Listing

(b) Typewriter Printer

  (1) Engineering Units Listing

  (2) Performance Analysis Listing

The on-line printer listings are a complete listing of all measured and calculated parameters. The typewriter printer listings are an abbreviated listing used for planning the succeeding test. Engineering Units listings list measured values versus test time. Performance Analysis listings list calculated performance parameters and some selected measured values at selected test times.

This section defines where each format and the corresponding symbols are defined in the report. Also defined is the code system used to define instrumentation locations and locate equations used for the calculated parameters listed.

4.1 ON-LINE PRINTER LISTINGS

4.1.1 Engineering Units Listing

The format and all symbols for the on-line printer engineering units listing are defined in Table A-1. The format is discussed in Section 2.3, which defines code numbers and the procedures used in the special case of the fuel system.

All symbols listed in Table A-1 are not listed for each run. The symbols listed for each run are defined by the record code number given in Table A-1. The record code number is defined in Section 8.2 of the report body.

4.1.2 Performance Analysis Listing

The on-line printer performance analysis listing headings and symbols are defined in Section 3.3.3. Special cases of the data listing such as the fuel system parameters are discussed in Section 3.3.2. Equations used to calculate the listed parameters are defined in Section 3.2. In some cases calculations methods are loosely defined to give the programming engineer freedom to select a preferred technique. Coordination between the engineer and the interested parties will be required to ensure proper identification of parameters.

4.2 TYPEWRITER PRINTER LISTING

4.2.1 Engineering Units Listing

The engineering units typewriter printer listing format is defined in Section 2.3.2. The symbols may be identified by referring to Table A-I. The special case of the fuel system parameters is discussed in Section 2.3.3. The format shown will be printed when requested by a single coded input into the computer. Additional parameters may be added by inputing their data listing code numbers defined in Table A-I.

4.2.2 Performance Analysis Listing

The typewriter printer format for the Performance Analysis listing is defined in Section 3.3.4.

The symbols used for this listing may be identified by referring to the on-line printer listing defined in Section 3.3.3. The format shown will be printed when requested by a single coded input into the computer. Additional parameters may be printed by requesting them individually. The format procedures for the additional data will be the same as for the original listing.

5. NOMENCLATURE

The following is a list of symbols used throughout Appendix A

Symbol	Description	
A	area	in.^{2}
C_D	drag coefficient or discharge coefficient	
C_F	flow coefficient	
C_f	friction coefficient	
C_p	specific heat at constant pressure or pressure coefficient, $(P/P_o)q_o$	Btu/lbm-^{o}R
C_S	nozzle vacuum stream thrust coefficient	--
C_T	nozzle velocity coefficient	--
C_v	specific heat at constant volume	Btu/lbm-^{o}R
C_R	contraction ratio (A_c/A_2)	--
D	drag	lb_f
F	force or stream thrust	lb_f
F_g	gross thrust	lb_f
g	acceleration of gravity (32.174)	$\frac{lb_m}{lb_f}\ \frac{ft}{sec^2}$
H	enthalpy	Btu/lb_m
I_{VAC}	vacuum specific impulse	$\frac{lb_f}{lb_m}$ sec
I_{VAC}	vacuum impulse	sec
J	energy conversion factor (778.26)	lb_f-ft/Btu

Symbol	Description	
K_D	process efficiency	--
K_{N_M}	nozzle process efficiency	--
MFR	mass flow ratio (A_o/A_c)	--
MW	molecular weight	--
m	mass flow, slugs/sec	--
P	pressure	psia
Q	heat transferred into or out of engine	Btu/sec
q	dynamic pressure or heat flux	$lb_f/in.^2$ or $\frac{Btu}{sec\text{-}ft^2}$
R	radius	in.
R	gas constant $= \frac{R_o}{MW}$	
Re_D	Reynold's number based on hydraulic dia	--
R_o	gas constant (1545.33)	$\frac{ft\text{-}lb_f}{mole\ ^{o}R}$
S	entropy	$Btu/lb_m\text{-}^{o}R$
T	temperature	^{o}R
V	velocity	ft/sec
WF	weight fraction	--
w	weight flow	lb_m/sec
X	axial station, distance from spike apex	in.
α	angle of attack	degrees
β_F	fuel injection angle with respect to engine axis	degrees
γ	ratio of specific heats $= C_p/C_v$	
δ	local surface angle	degrees

Symbol	Description	
η_c	combustor efficiency	--
η_{KE}	kinetic energy efficiency	--
η_N	nozzle kinetic energy efficient	--
η_{P_T}	total pressure recovery	--
K	constant	
ρ	density	lb_m/ft^3
σ	cone angle	degrees
ϕ	equivalence ratio	--

Subscripts	Description
A/A*	isentropic area ratio
a	airflow
C	cowl
CL	denotes station on cowl where leading edge radius (0.030 in) becomes tangent to 12-deg inner cowl surface
c	capture
ca	cavity
D	flowmeter duct
D	airflow parameter based on total pressure
F	denotes conditions relating to fuels as flow
FZ	frozen composition
f	friction
g	gas flow
i	inner wall of annulus
j	jth unit
L	lip, local
MDOT	airflow parameter based on static pressure
n	nth station
O	denotes conditions relating to oxidents; conditions in pressure field
o	outer wall of annulus
P	pressure, plug
Q	quadrant
S	strut, stroud
w	wall
X	denotes conditions at Station X

Subscripts	Description
2	denotes conditions at inlet throat
3	denotes conditions at combustor inlet
4	denotes conditions at combustor exit
5	denotes conditions at nozzle entrance, aft of struts
6	denotes conditions at nozzle exit

Superscript	Description
$(^{n})$	nth iteration
$(')$	denotes pitot pressures or as indicated
$(^{-})$	average properties for uniform stream or average of specific quantities
$*$	sonic conditions

REFERENCES

Appendix A

1. AiResearch Drawing L-95051, Sheet 2 of 5.

2. Spalding, D.B., and S.W. Chi, "Drag of a Compressible Turbulent Boundary Layer on a Smooth Flat Plate With and Without Heat Transfer", Table 7.

3. Neal, Luther, Jr., and Bertram, Mitchel H., NASA TND 3969.

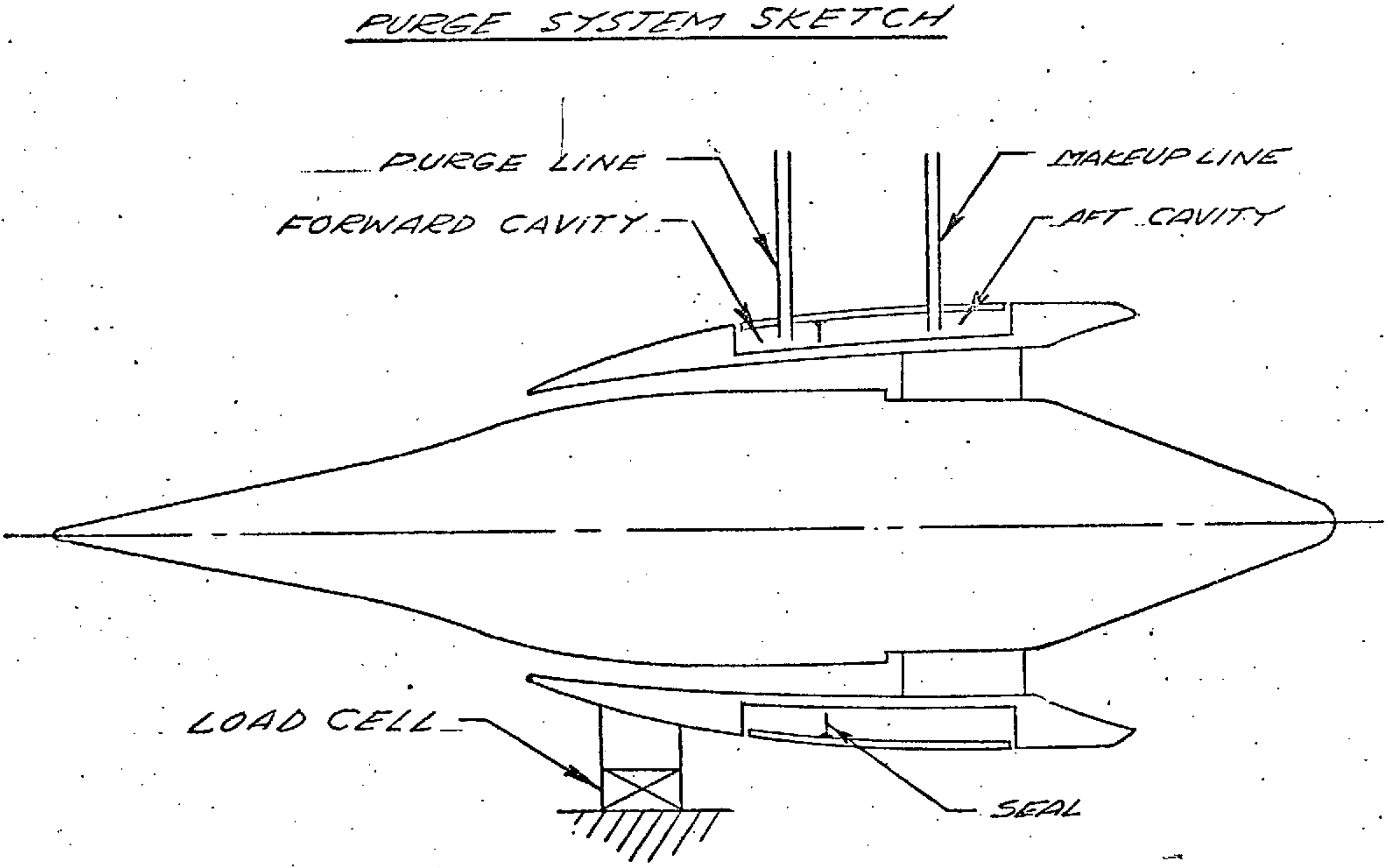
APPENDIX B

AIM THRUST MEASUREMENT CORRECTION DUE TO NITROGEN PURGE

FOREWORD

This appendix is a reproduction of AiResearch Memo EWLA-1071-0303 "AIM Thrust Correction Due to Nitrogen Purge". This memo presents an analysis of the purge force correction and is directly related to the purge force calibration tests described in Sections 6.5 and 7.1. The method of calculating the correction from wind tunnel test results is defined. An error analysis is also presented.

Introduction



Purge nitrogen must be fed into the cavity between the AIM hot shroud and the outerbody to prevent entry of the hot tunnel flow. When the cavities are pressurized, a tare force is applied to the load cell. This force must be known so that the necessary correction can be applied to the load cell reading to determine thrust. The purge nitrogen is discharged from the cavity through slots at the leading and trailing edges of the hot shroud and through the legs. Because of static pressure variations on the AIM surfaces the forward slot requires about three times the pressure as the aft slot to prevent entry of the hot flow.

A seal will be installed dividing the cavity into two compartments as shown in the above sketch. The seal has been positioned so that the front cavity has a larger projected area in the thrust direction than the aft cavity by a factor of about three. Without the seal the entire cavity would operate at the pressure required by the front slot resulting in a higher tare force. A simple calculation using a factor of three on both the pressures and the projected areas described above shows that the absolute value of the tare force is reduced by a factor of two when the seal is installed. This will result in a corresponding reduction in thrust measurement uncertainty.

Referring to the above sketch, the nitrogen is supplied into the forward cavity by the purge line. The nitrogen flow rate is controlled by an Annin valve to set the cavity pressure at the desired value. Some of the nitrogen leaks through the seal to pressurize the aft cavity. The leakage rate is insufficient to obtain the desired aft cavity pressure. The makeup line supplies the remaining nitrogen to set the pressure. The design flow rate and pressure for the purge line is 4.5 pounds per second at 700 PSIA at the AIM inlet flange. The corresponding values for the makeup line are 1.5 pounds per second and 700 PSIA. The detail design requirements for the system are described in Reference 3.

The tare force depends on the front and rear cavity pressures and the tunnel Mach number and total pressure. Also some effects are expected to be encountered due to the interaction of nitrogen flow and the external flow. The nitrogen jet leaving the front cavity will cause a shock wave to stand on the engine cowl and an associated increase in cowl drag. Also, the pressure on the cavity walls near the exit may be affected by interaction with the external flow. If the tunnel Mach number distribution varies with inlet flow properties, the tare may be influenced. Accurate calculation of the tare force thrust correction is difficult because of the complex nature of the problem. Integration of the tare force using pressure tap data is unattractive because of insufficient instrumentation.

This memo presents an analytical estimate of the tare forces and a method for calibrating the tare force by direct load cell measurement while the tunnel is in operation. The major problem here is that during a calibration run, the load cell measures the engine drag plus the tare force. The unknown drag must be evaluated and subtracted from the load cell reading to determine the tare.

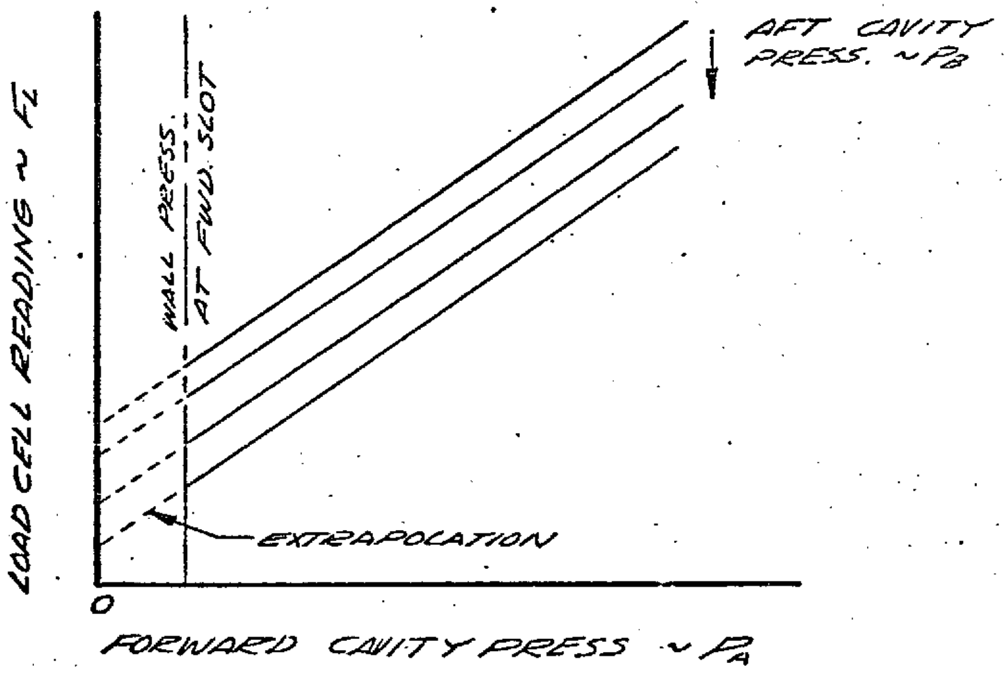
Calibration Tests

It is proposed that force calibration runs first be made with the engine installed in the tunnel with no external flow. The purpose of the tests is to determine flow rates and supply pressures and provide a system checkout. The forward and aft cavity pressures will be varied to determine their effect on load cell reading. The data will serve as a cross check on similar tests with external flow. The external flow tests will be performed at each tunnel Mach number to determine the effect of the cavity pressures including the interactions with the external flow.

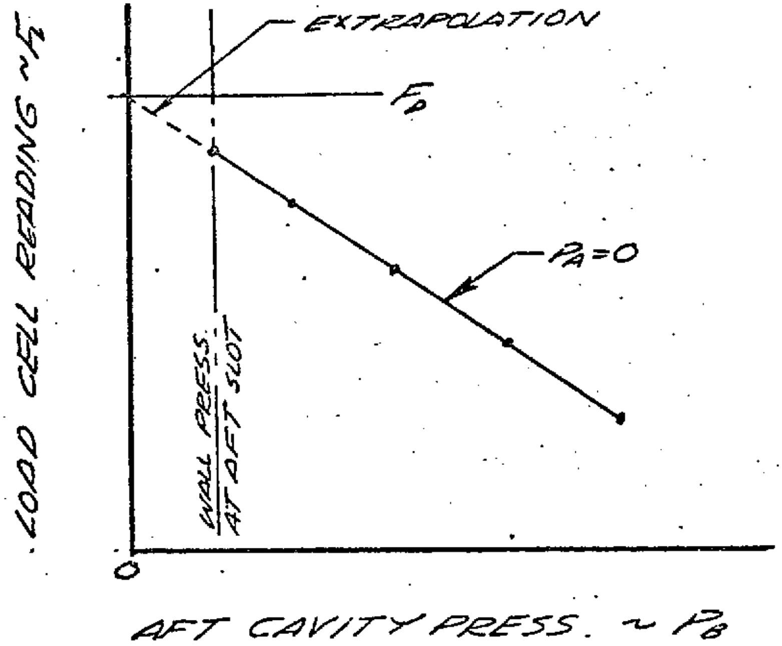
The effect of tunnel total pressure on the calibration must be spot checked. This is discussed further in the "Thrust Calibration Curve" section. Also, the spike position must be varied to investigate a possible effect on the calibration. The spike position may affect the front slot approach Mach number, thereby affecting the cowl drag increment due to shock from the nitrogen jet. A wide range of cavity pressures must be investigated including those approaching the no purge flow condition. Therefore the tests should be performed at as low a tunnel temperature as possible. This will prevent damage to the AIM in case external flow inadvertently enters the cavities. An orifice meter should be placed in each purge line to show when the purge flow is at a minimum allowable value. Pressure regulators should also be installed in the two supply lines so that one pressure can be varied while the other is held constant. Otherwise the data cannot be plotted in a comprehensive manner.

Determination of Engine Drag

The calibration data will be plotted as shown below.



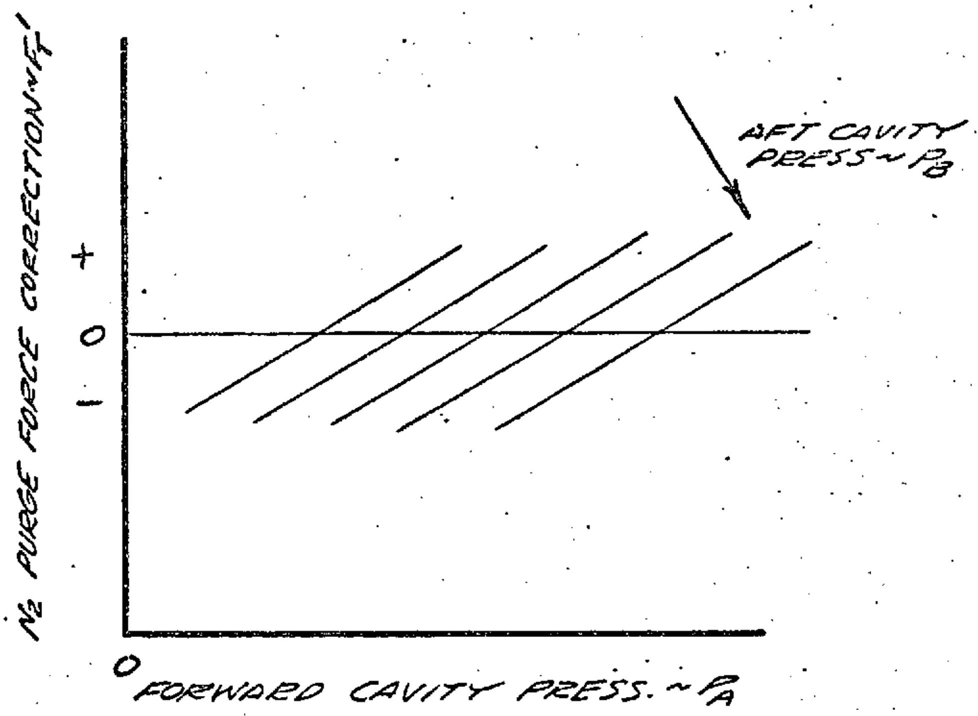
The lines of constant P_B will be extrapolated to $P_A = 0$. The $P_A = 0$ intercepts will then be cross plotted as shown below.



The $P_B = 0$ intercept of this plot gives the load cell reading, F_D, when both the forward and aft cavity pressures are zero. F_D is then the sum of all drag forces acting on the engine other than the forces caused by the introduction of the purge nitrogen including the effect of interactions with the external flow. F_D is defined in detail in the Force Analysis Section.

Thrust Calibration Curve

F_D can be subtracted from F_L to obtain the force, F_T, exerted on the AIM due to nitrogen purge. Included in F_T is the increment in cowl drag, ΔF_S, due to the shock. It is inconvenient to include ΔF_S in F_T for the thrust correction. Therefore, ΔF_S will be evaluated using the cowl pressure taps during the calibrations and subtracted from F_T to obtain the net correction factor $F_T{}'$. $F_T{}'$ will be plotted as shown below.



Curves of this type will be input into the data analysis computer program to correct the load cell reading. It can be shown that this curve may be put in parametric form as

$$\frac{F_T{}'}{P_{T0}} = f\left(\frac{P_A}{P_{T0}}, \frac{P_B}{P_{T0}}\right).$$

This will provide a convenient means of accounting for variation in the tunnel total pressure. The use of this method must be varified experimentally by spot checking the calibration at various values of P_{T0}.

The uncertainty in the determination of the calibration by this method depends on the following variables.

1. The amount of scatter and accuracy of the load cell reading and pressure data taken.
2. The amount of extrapolation required to reach the zero pressure intercepts.
3. The linearity of the calibration data.

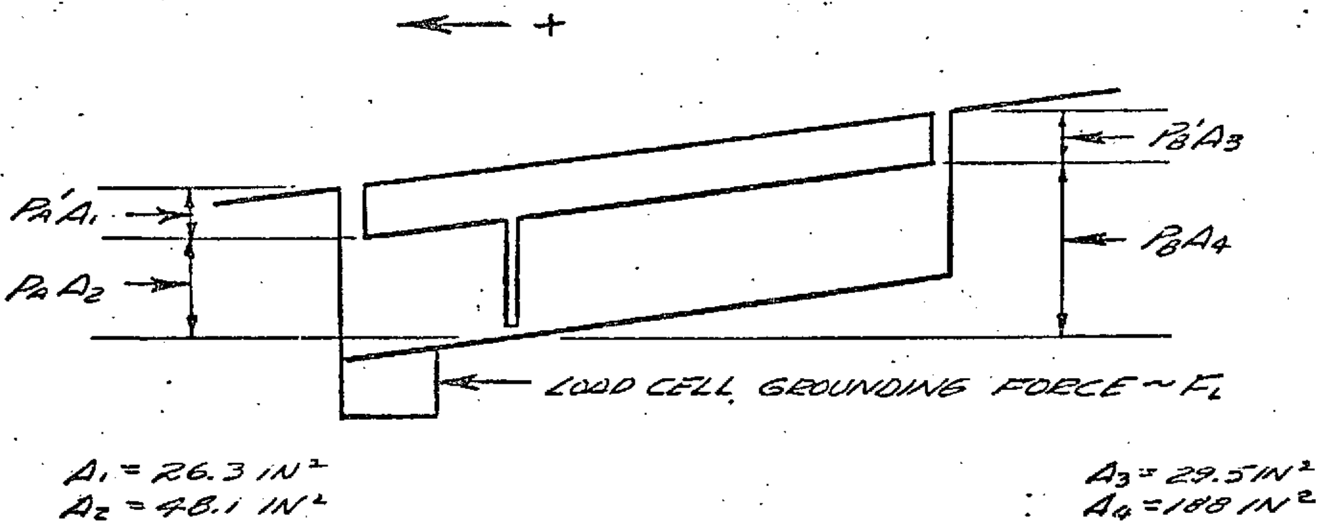
The final evaluation of the accuracy of this method can only be made after the data has been taken and analyzed. The accuracy is further discussed in the "Error Analysis" section.

Force Analysis

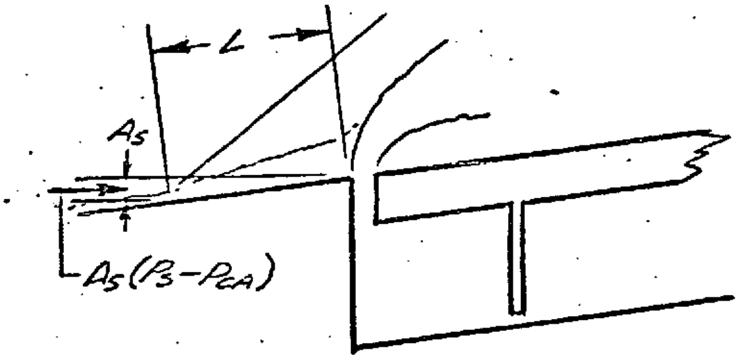
To obtain a feel for the validity of the proposed calibration method, the calibration curves have been analytically predicted. The tunnel conditions selected for the analysis are Mach 5 at 415 PSIA and Mach 7.0 at 1000 PSIA. The analysis may prove useful for interpreting the test results. It is also possible that the data may be analytically extrapolated using the equations derived in the analysis and constants obtained from data reduction.

Analytical Model

The following model is used to analyze the forces exerted on the load cell due to the cavity pressures.



CAVITY FORCES



SHOCK FORCE

P_{CA} = Cowl pressure with no shock

P_S = Cowl pressure with shock

Force increment due to shock = $A_S(P_S-P_{CA}) = \Delta F_S$

The load cell grounding force, F_L, is given by a summation of forces in the thrust direction.

$$\Sigma F_X = 0$$

$$F_L = -F_D - A_S \left(P_S - P_{CA}\right) + P'_A A_1 + P_A A_2 - \left(P'_B A_3 + P_B A_4\right)$$

(Equation 1)

F_D is the sum of internal and external drag forces on the engine and is composed of the following elements.

1. The change in stream thrust of the internal flow
2. Inlet addative drag
3. Cowl drag with no shock due to the nitrogen jet
4. Boattail force

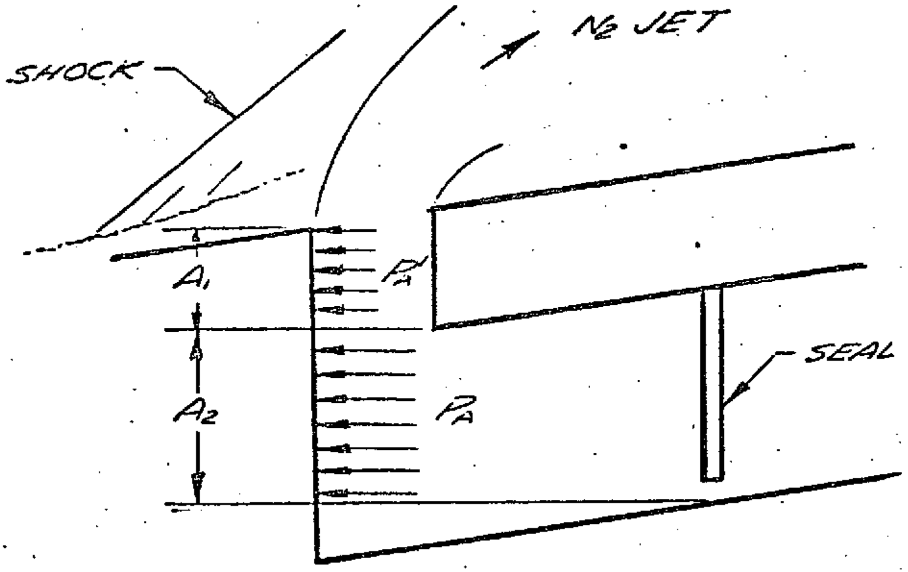
F_D has an estimated value of -1450 pounds at Mach 5, and -770 pounds at Mach 7. These values were obtained from Reference 2, Figure 1.

The assumptions and procedures for evaluating the pressures used in Equation 1 are discussed in the following paragraphs.

Cavity Pressures

The pressures P_A and P_B in the cavities are assumed to act on the projected areas A_2 and A_3 at full value. No attempt was made to account for the small pressure drops as the purge flow passes the manifolds and other obstructions in the cavities.

Slot Flow Characteristics



The pressures acting on the area A1 are less than the pressures on A2 because of the reduction in static pressure when flow is established. The aerodynamics of this process require special attention because of the interaction with the external flow.

Reference 2 presents the flow characteristics of a rectangular duct discharging into a Mach 3.85 stream. This report was used to

1. Predict the static pressures P_A' and P_B' on the slot w lls contributing to the load cell forces.
2. Predict the slot choking pressure ratios.
3. Predict the pressure required to establish flow in the slots.

Figure 1 is a curve from Reference 1 showing the sonic flow coefficient, K_S, as a function of $P_{T,0}/P_0$. This ratio is the total pressure in the slot divided by the static pressure in the undisturbed flow upstream of the slot. The sonic flow coefficient is defined as follows.

$$K_S = \frac{\text{measured slot flow}}{\text{theoretical slot flow at sonic velocity}}$$

$$= \frac{W}{\frac{0.532\ P_{T,0} A_{slot}}{\sqrt{T_{T,0}}}}$$

Figure 1 shows that

1. A pressure ratio of 1.57 is required to establish flow in the slot at $M_0 = 3.25$.
2. A pressure ratio of approximately 3.0 is required to choke the slot at $M_0 = 3.25$.
3. The relationships in 1 and 2 above depend on slot approach mach number.

Since the intent of this analysis is to show trends only, the Mach 3.25 data was used directly for both the front and rear slots. The actual slot approach mach numbers probably lie between 2.5 and 3.5 for both M_0 = 5 and 7 which are analyzed herein.

Reference 2 presents data which shows that the slot start flow and choking pressure ratios depend on aspect ratio for outlets through a thin plate. These relationships are not known for outlets with an approach duct as encountered in the AIM. It is not felt that this uncertainty will effect the trends shown in the analysis. It is conservative to assume that the start flow and choking pressure ratios are high because this increases the extrapolation distance required to reach the zero pressure intercepts.

Slot Wall Pressures

The pressures P'_A and P'_B were estimated using the data from Figure 1 as follows: To calculate the slot mach numbers the relationship

$$\left(\frac{A}{A^*}\right)_{SLOT} = \frac{K_{SMAX}}{K_S}$$

and

$$P_{SLOT} = P' = \left(\frac{P_S}{P_T}\right)_{SLOT} P_{T\ SLOT}$$

$$= f\left(\frac{A}{A^*}\right)_{SLOT} P_{T\ SLOT}$$

This relationship was used to plot the curve presented in Figure 2 which was used to obtain the slot wall pressures P_A' and P_B'.

Outer Skin Pressures

The AIM wall static pressures just upstream of the slots with no purge flow were taken from measured values from the Langley tunnel starting tests using configuration IV-shroud $4X_1$. These data were taken at Mach 5. The measured front slot pressure ratio, $\frac{P_{CA}}{P_O}$, was 7.0. The aft slot pressure ratio, $\frac{P_{CB}}{P_O}$ was 2.0. To convert these pressure ratios to Mach 7 values $\frac{\Delta P}{q_0}$ was assumed to be the same for the two Mach numbers.

Shock Force

The force due to the impingement of the shock generated by the N_2 jet at the front slot is done as follows. The separation distance, L, was determined from an analysis presented in Reference 4, Figure 5.34. Figure 3 which is derived from this reference presents L as a function of forward, cavity pressure, P_A, divided by cowl static pressure, P_{CA}, in the undisturbed flow. It was assumed for this analysis that the separation distance is independent of free stream Mach number.

The static pressure acting on the effected area was assumed to be 2.5 times higher than the undisturbed pressure. Thus $P_S = 2.5\ P_{CA}$.

Results

Figures 4 and 5 show the computed load cell readings from equation 1 for a range of assumed cavity pressures.

The internal plus external drag of the AIM, F_D, assumed for each Mach number is spotted on the curves. The extrapolations to $P_A = 0$ are also shown. The extrapolations were performed by extending the linear portion of the curves above the slot choking pressure.

It can be shown that theoretically both the linear and nonlinear portions of the curves extrapolate to the same point. This provides a cross check when the calibration data is analyzed. If a discrepancy occurs, a judgment will be made based on inspection of the data. If the choked portion of the curves proves to be truly linear, the intercepts may be determined analytically using $Y = mx + b$.

The FL at $P_A = 0$ values determined by the extrapolations are cross plotted in Figures 6 and 7. These curves provide the final solution for the AIM drag, F_D, at zero cavity pressure.

The drag assumed in the analysis is spotted on the curves so that the alignment of the plotted curve with the known solution can be observed. The target area for a one percent thrust error is spotted on the curves. Under the ideal conditions of plotting analytical results a reasonably accurate extrapolation appears to be feasible.

Error Analysis

The tare force due to purge is given by the following equation:

$$F_T = A_S (P_S - P_{CA}) + P'_A A_1 + P_A A_2 - (P'_B A_3 + P_B A_4) \qquad \text{(Eq. 2)}$$

It is planned to run the AIM tests with P_A and P_B set so that F_T has a net value of zero. The pressures required to do this will be determined from the calibration tests.

However the thrust uncertainty due to the purge system is independent of the net value of F_T. The uncertainty depends on the total force exerted on the AIM by the purge system. This can be evaluated by taking the absolute value of equation (2).

$$|F_T| = A_S (P_{CS} - P_{CA}) + P'_A A_1 + P_A A_2 + P'_B A_3 + P_B A_4 \qquad \text{(Eq. 3)}$$

$|F_T|$ from Equation (3) is plotted versus P_A at a value of $F_T = 0$ in Figure 8. The values of P_A and P_B required to hold $F_T = 0$ can be read from Figures 4 and 5 at the intersections of the P_B lines with $F_L = F_D$.

$|F_T|$ is seen to be nearly linear with P_A. With the assumption that $|F_T|$ is linear with cavity pressures, the effects of pressure and force measurement uncertainties were evaluted with the following ground rules.

1. ±1 percent uncertainity in P_A and P_B pressure measurements during performance tests. This gives a ±1 percent uncertainity in $|F_T|$.

2. ±1 percent uncertainity in P_A and P_B during calibration tests. This gives an additional ±1 percent uncertainity in $|F_T|$.

3. ±1 percent uncertainity in load cell reading during calibration tests. Since the error analysis is done at a net tare force of 0, the load cell reading will be equal to the AIM drag at zero cavity pressure, F_D. F_D' has a predicted value of 770 lb at Mach 7 and 1450 lb at Mach 5.

4. The AIM thrust was taken from Reference 2 at the minimum values for the thrust loads presented.

5. No attempt was made to evaluate the error due to the extrapolated solution for F_D. The uncertainity due to the extrapolation will be evaluated when the calibration data is reduced and the various methods of extrapolation cross checked.

Figure 9 presents the thrust uncertainity with the above ground rules and assumptions. The error is seen to increase with P_A. This implies that the cavity pressures should be set as low as possible to reduce the error. The point can be made that the pressure should be sufficiently high to choke the slots. This could minimize the interactions between the cavity pressures and the external flow and thereby reduce the error. The values of P_A and P_B used for the AIM performance tests will be selected when the calibration test data have been analyzed.

W. L. Andersen

W. L. Andersen

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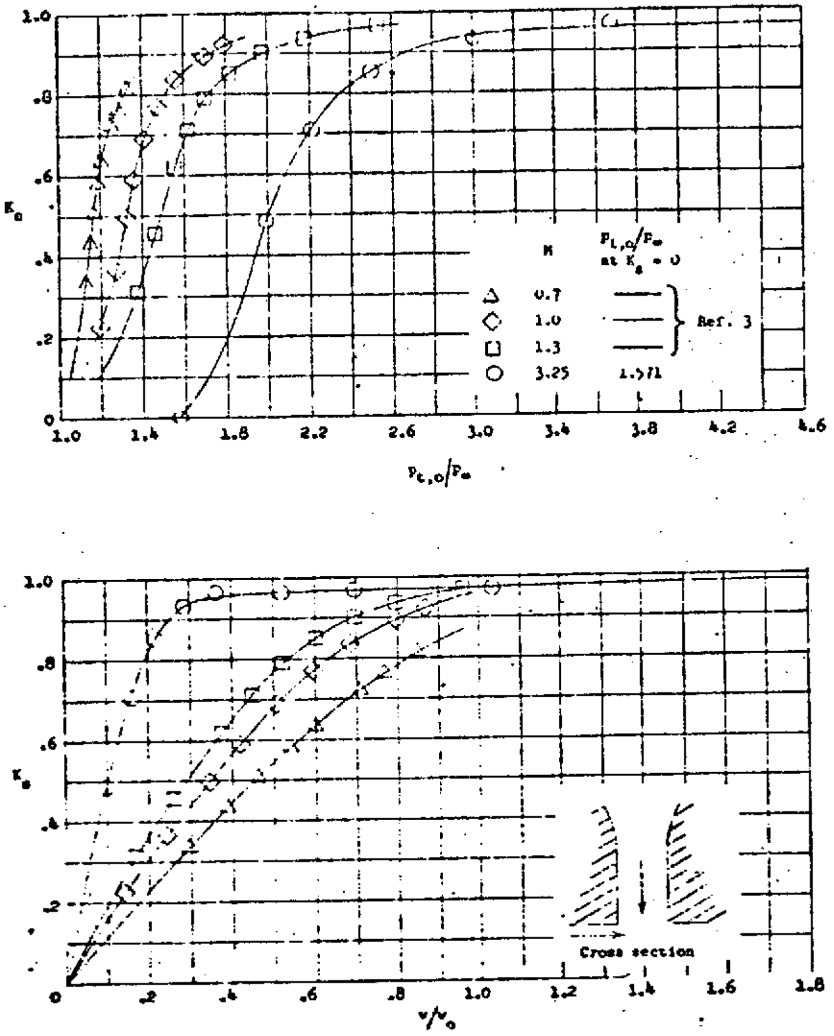

(a) Square ducted outlet 9. A = 1.0; β = 90°.

Figure 1.- Discharge characteristics of ducted outlets.

FIGURE 2

EFFECT OF SLOT PRESSURE RATIO ON SLOT WALL PRESSURE

COMPUTED FROM TND 1478, FIG 9

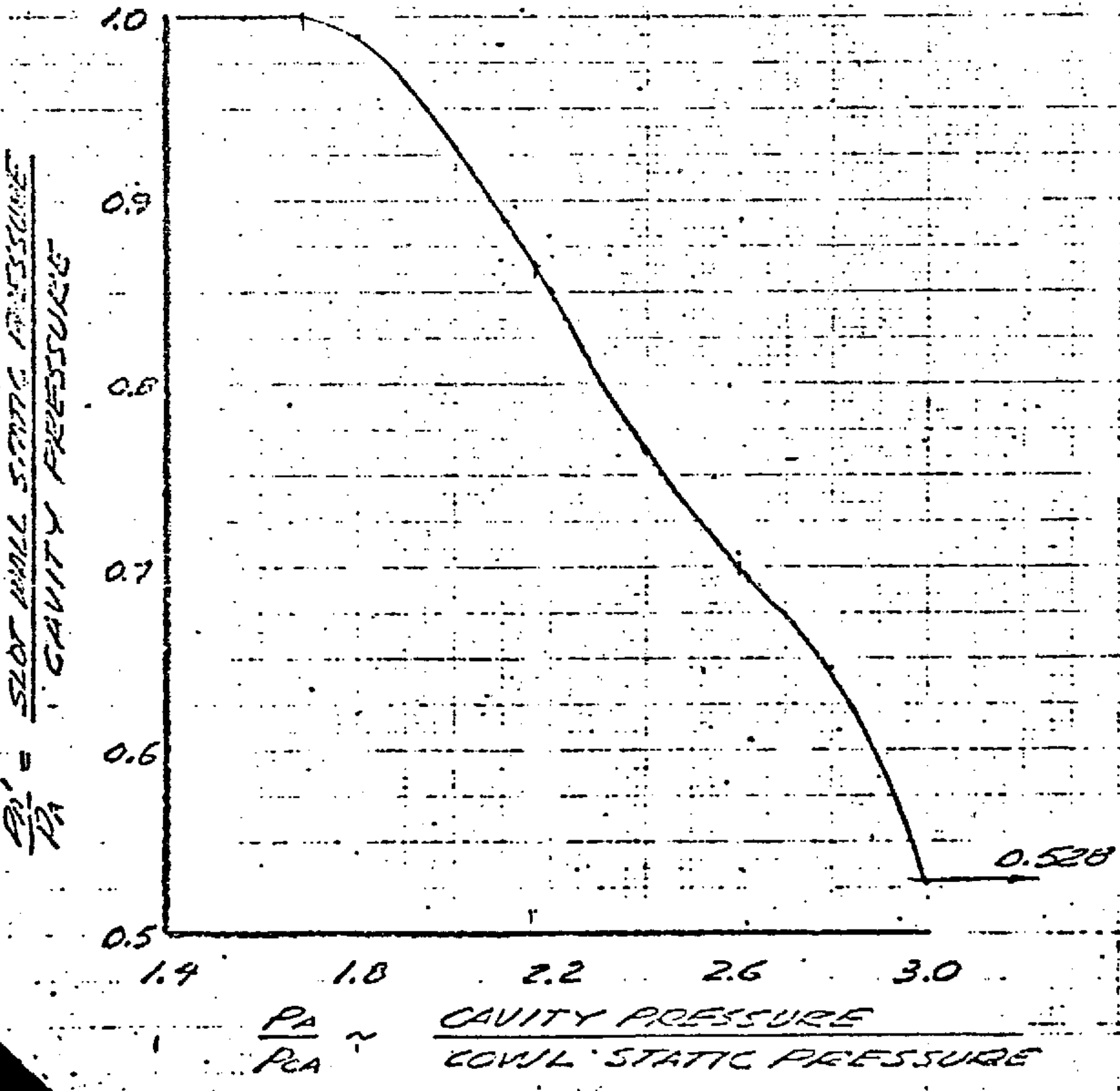

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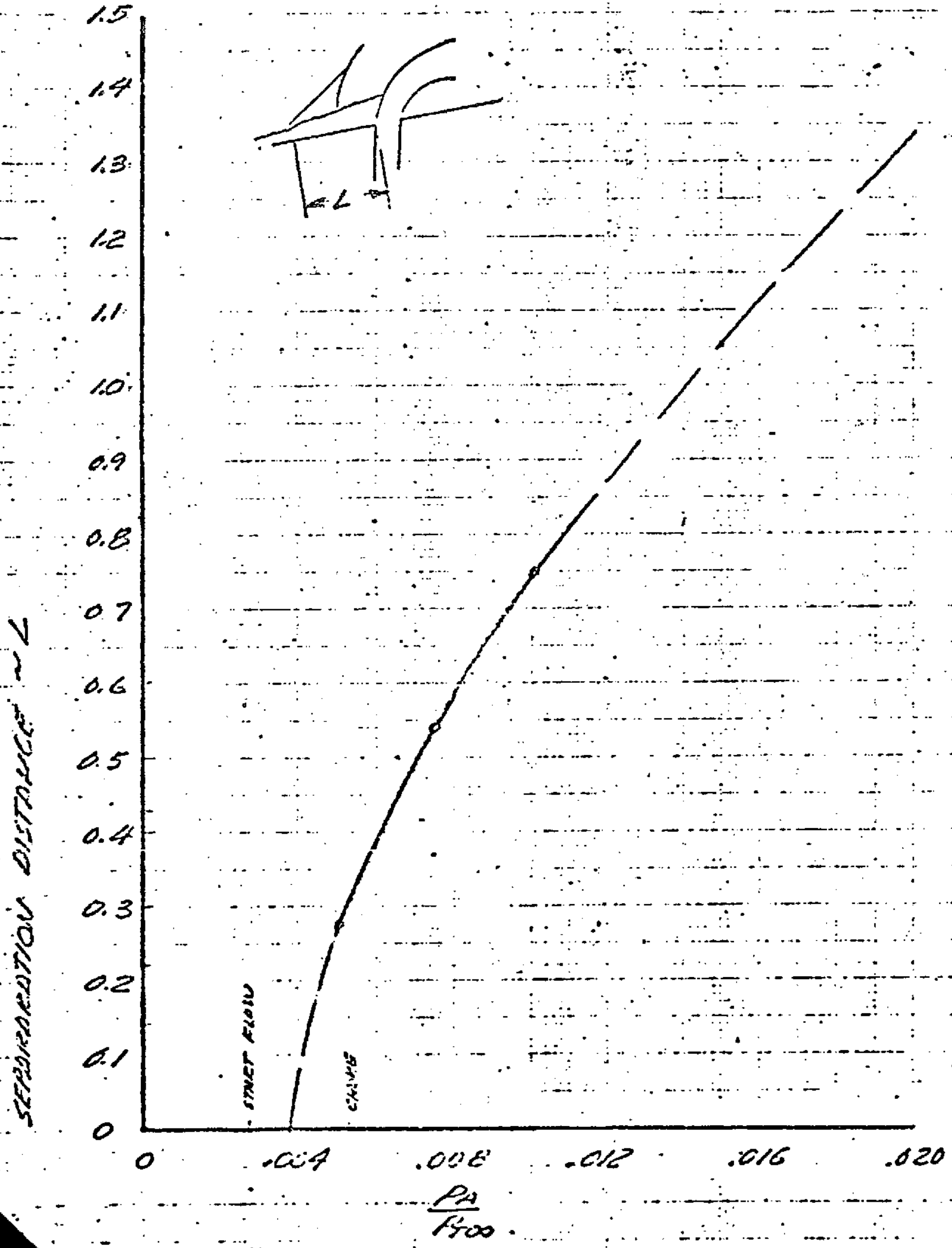
FIGURE 3

EFFECT OF SLOT PRESSURE ON SEPARATION DISTANCE



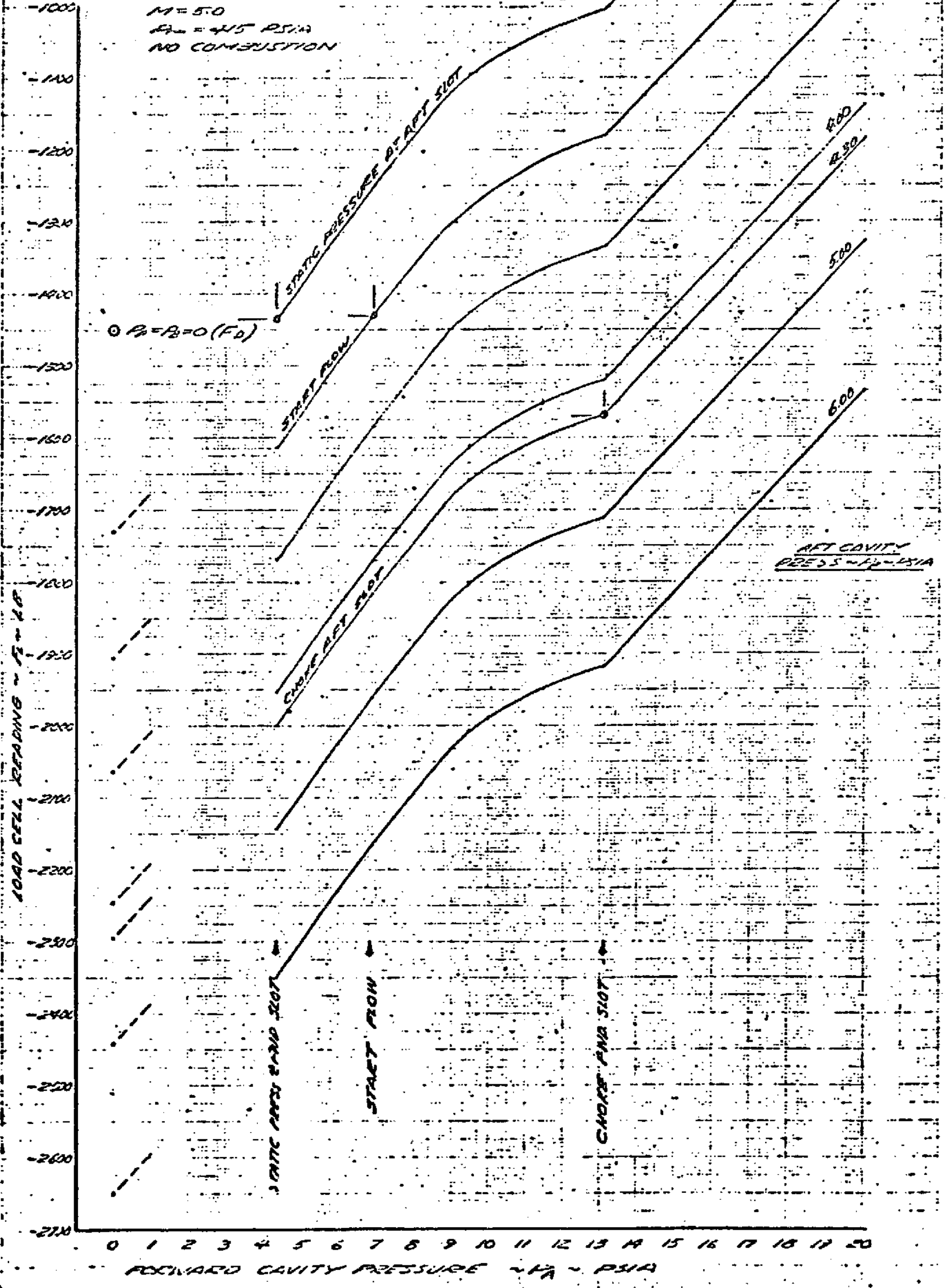


FIGURE 4
EFFECT OF CAVITY PRESSURES ON LOAD CELL READING

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FIGURE 5
EFFECT OF CAVITY PRESSURES ON LOAD CELL READING

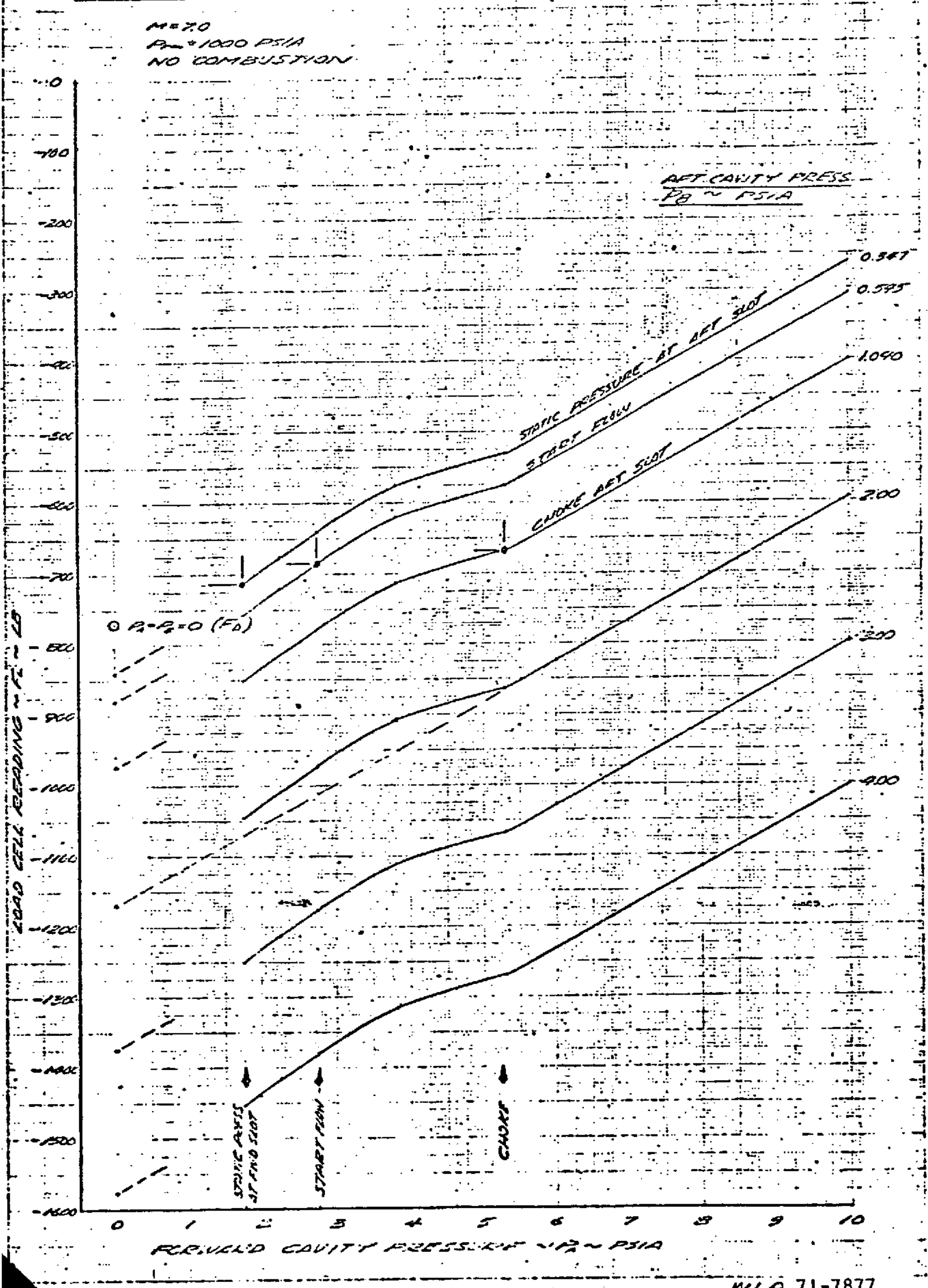


FIGURE 6
GRAPHICAL SOLUTION FOR ENGINE DRAG WITH ZERO CAVITY PRESSURE

$M_\infty = 5.0$
$P_{T\infty} = 415$
NO COMBUSTION
CROSS PLOT OF EXTRAPOLATED POINTS FROM FIGURE 4

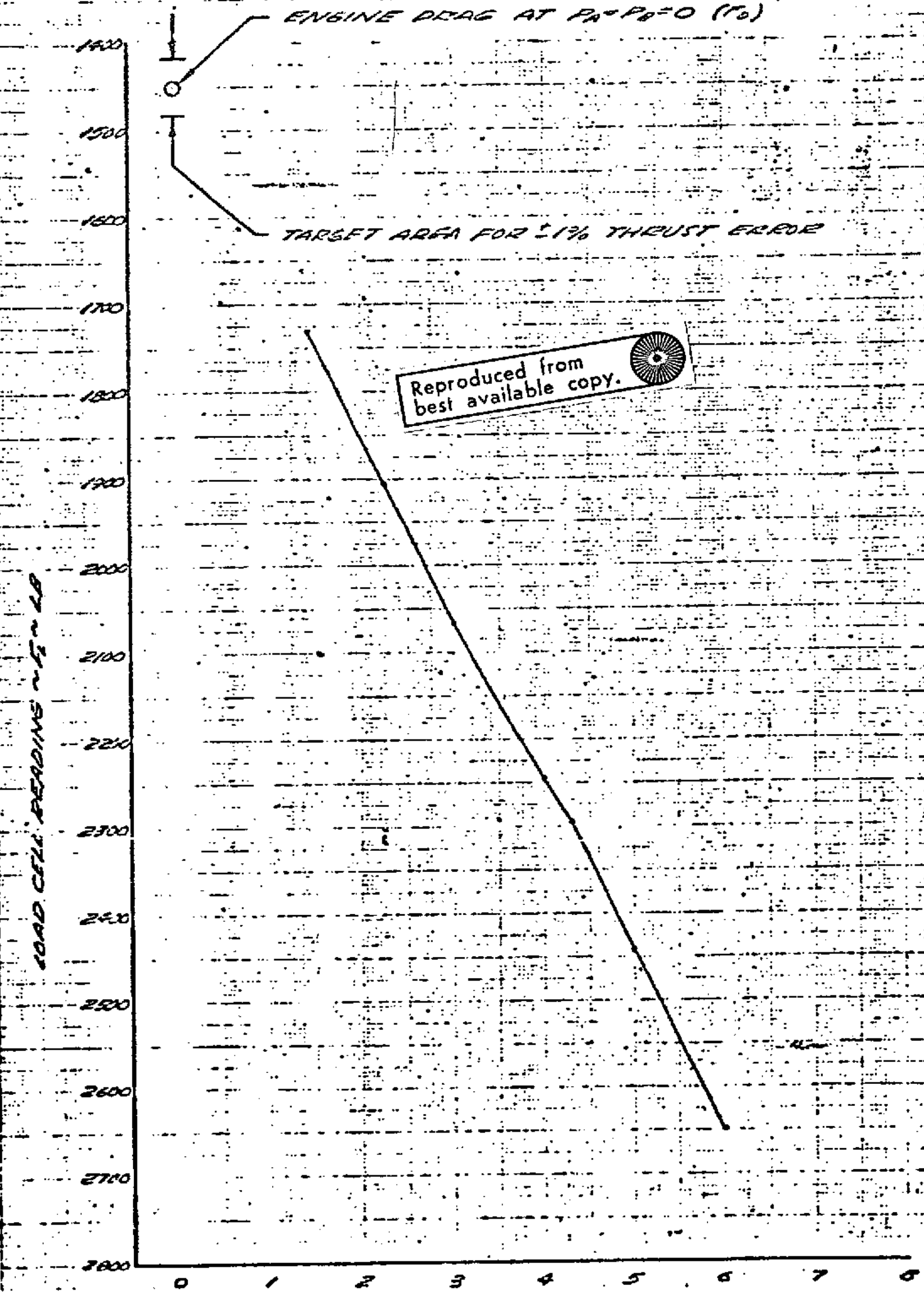


FIGURE 7
GRAPHICAL SOLUTION FOR ENGINE DRAG
WITH ZERO CAVITY PRESSURE

$M_0 = 7.0$
$P_{T0} = 315$
NO COMBUSTION
CROSS PLOT OF EXTRAPOLATED POINTS FROM FIGURE 5

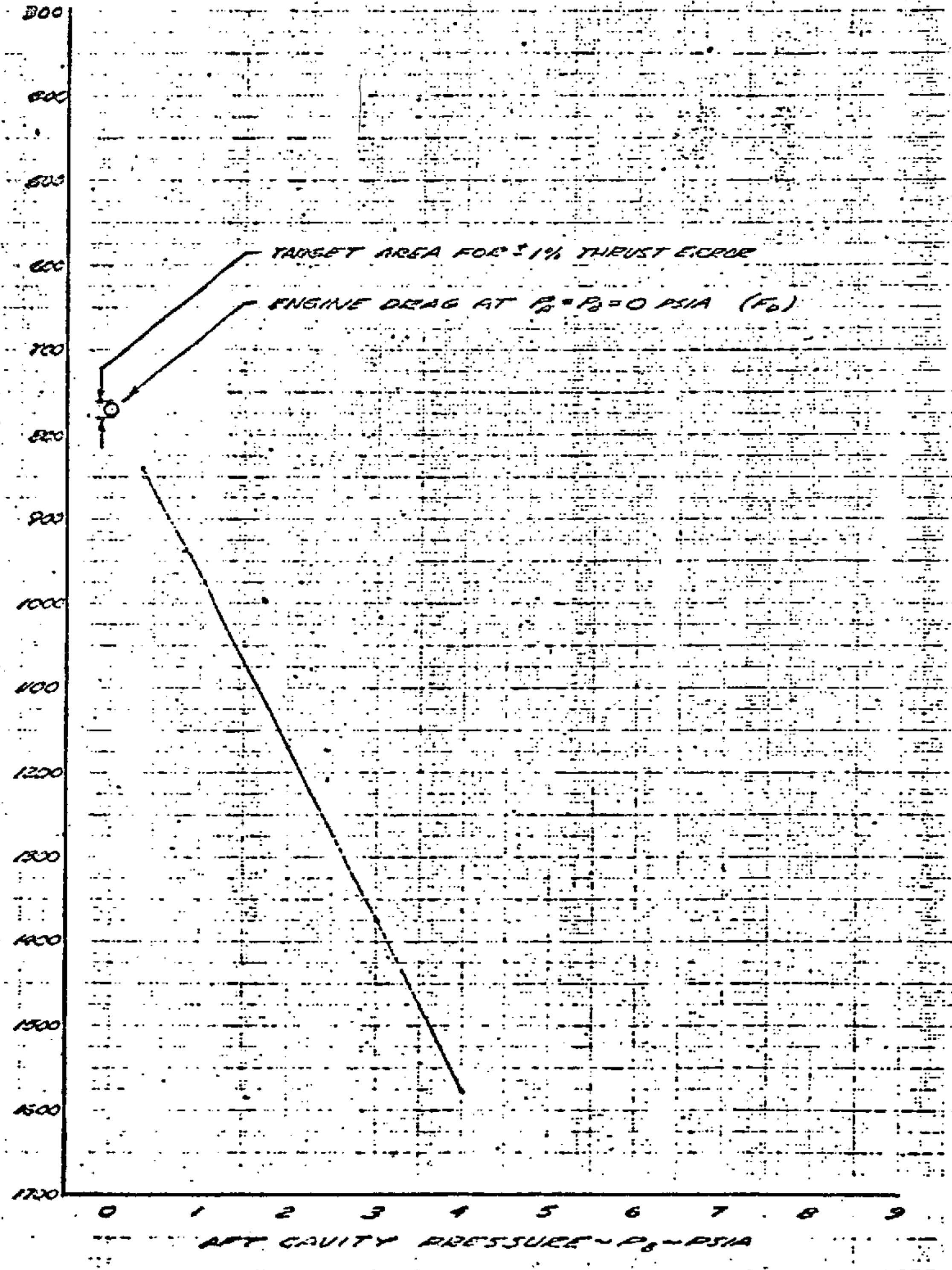


FIGURE 8
EFFECT OF CAVITY PRESSURE ON ABSOLUTE TARE FORCE

NET TARE FORCE = 0

◊ FORWARD SLOT CHOKED

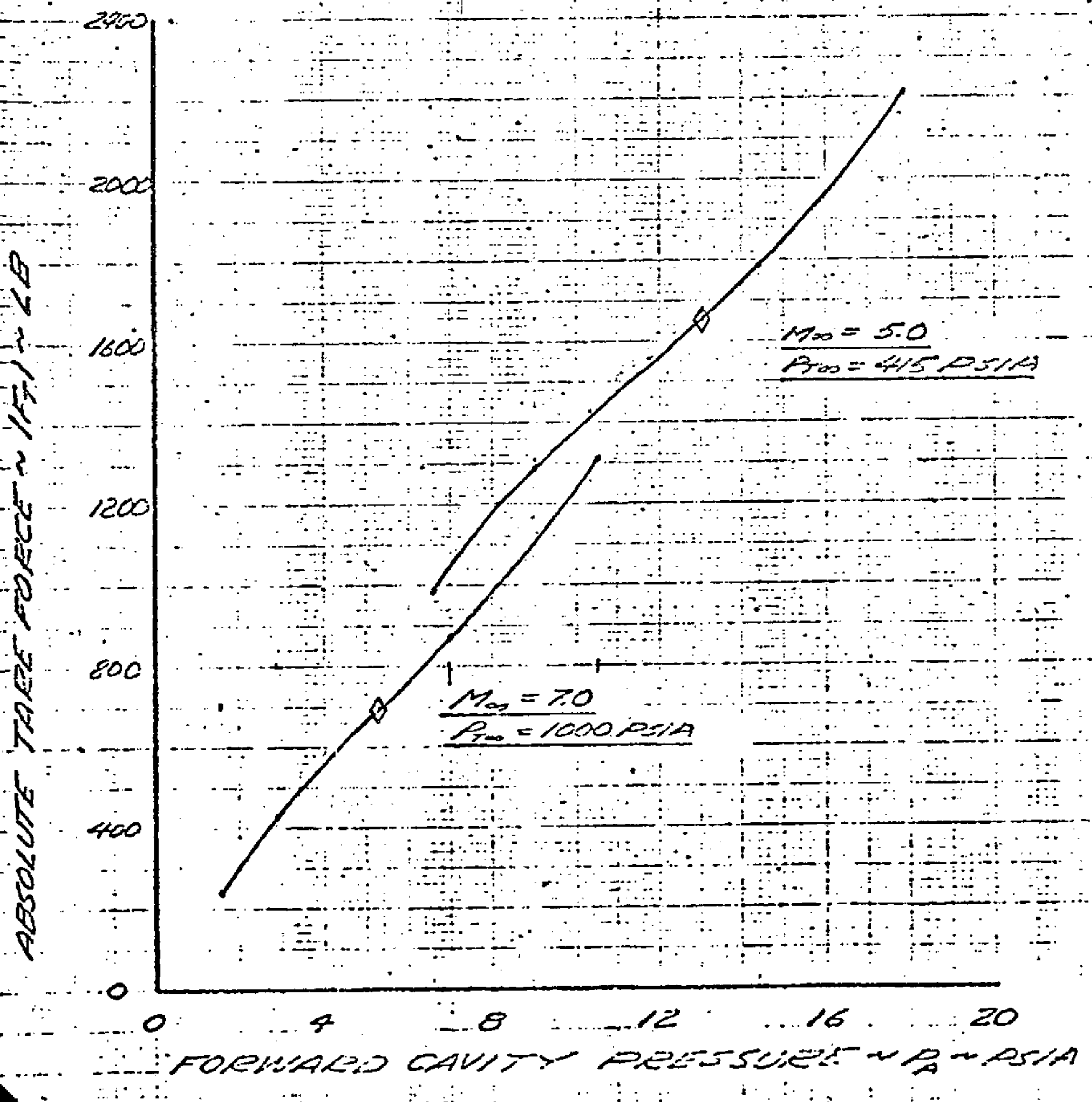
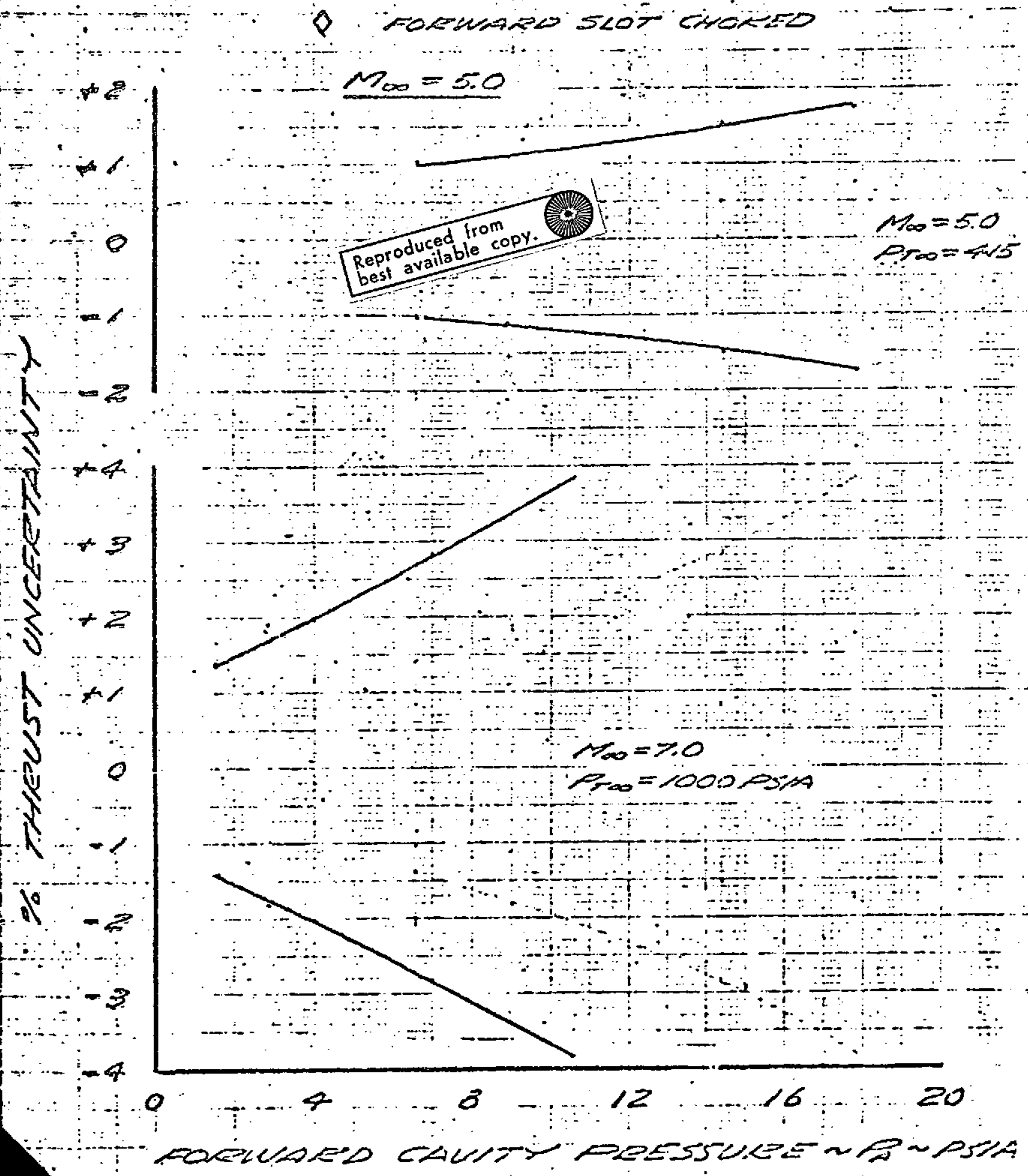


FIGURE 9
THRUST MEASUREMENT UNCERTAINTY DUE TO PURGE SYSTEM THRUST CORRECTION

- NET TARE FORCE = 0
- EXTRAPOLATION ERROR NOT INCLUDED
- 1% THRUST BALANCE AND CAVITY PRESSURE MEASUREMENT UNCERTAINTY



REFERENCES

Appendix B

1. Vick, Allen R., "An Investigation to Determine the Discharge and Thrust Characteristics of Auxiliary-Air Outlets for a Free Stream Mach Number of 3.25," NASA TND 1478, October 1962.

2. Sainio, W. C., "Estimated Accuracy of AIM Performance as Determined from Thrust Measurements," Memo EWCS-0076-0310, March 10, 1970.

3. Andersen, W. L., "HRE N_2 Purge System," Memo EWLA-0483-1204, December 4, 1970.

4. Engineering Staff, Hypersonic Research Engine Project - Phase II Aerothermodynamic Integration Model Development, Seventh Interim Technical Data Report (U), AiResearch Report No. AP-69-5899, January 16, 1970.