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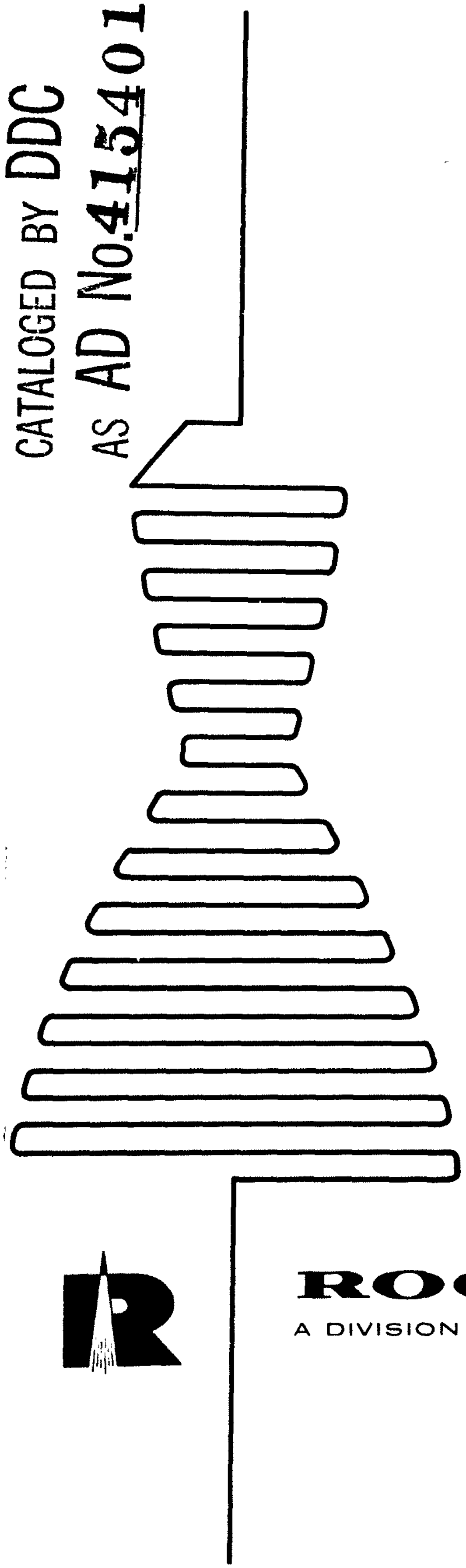

ROCKETDYNE

A DIVISION OF NORTH AMERICAN AVIATION, INC.

CANOGA PARK, CALIFORNIA

R-5304

INVESTIGATION OF ATLAS F-SERIES FLAME DEFLECTOR PRESSURE PULSE

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.
6633 CANOGA AVENUE
CANOGA PARK, CALIFORNIA

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Exhibit B and
Paragraph 4.2.1 of
AFBM Exhibit 58-1

PREPARED BY

Rocketdyne Engineering
Canoga Park, California

APPROVED BY

J. J. Griffin
Atlas/Thor/Jupiter/ Program Manager

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FORM R 18 G PLATE

FOREWORD

This Atlas Engineering Report was prepared under G.O. 8435 and Contract AF04(694)-328, Part I, Item 4 of Exhibit B and Paragraph 4.2.1 of AFBM Exhibit 58-1.

ABSTRACT

Presented are the results of a test program to determine the effects of the pressure pulse that is generated in the flame deflector during initial thrust buildup of the Atlas MA-3 booster engine.

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INTRODUCTION

Certain recent hardware failures on operational E- and F-series Atlas missiles at Pacific Missile Range (PMR) have been attributed to heat shield distortion caused by a pressure pulse generated in the flame deflector during initial thrust buildup of the MA-3 booster engine. An analysis of data from earlier missile launches and R&D static test programs at Sycamore Canyon and Rocketdyne led to the conclusion that the pressure pulse associated with the operational missiles was a product of a set of conditions consisting of restricted exhaust gas dispersion as a result of deflector configuration, cold flame deflector environment created when liquid nitrogen and LOX bleeds were dumped into the deflector, and a static air mass column in the deflector at engine start.

The missile launch success associated with the Atlantic Missile Range (AMR) was attributed to configuration differences that included flame deflector water and nonrestricted buckets (no "Long-Horn" bucket extensions). Further analysis of the data indicated the magnitude of the pressure pulse was a function of the booster engine thrust buildup rate. As a result, an F-series flame deflector, simulated launcher hardware, and missile boattail were installed on Alfa-1 test stand at Rocketdyne Propulsion Field Laboratory to investigate the cause of the pressure pulse during missile simulated start conditions and to determine a means of depressing its magnitude.

OBJECTIVES

The specific objectives of the test program were:

1. To gather comparative and repetitive pressure pulse data from the simulated F-series flame deflector configuration during engine tests employing (1) dry booster jacket, (2) inert fluid fuel lead, and (3) sustainer lead starts
2. To determine the adequacy of propulsion system boot modification under the conditions imposed by dry jacket, inert lead, and sustainer lead starts
3. To obtain data on inert fluid and related portable equipment using emergency procedures for inserting and draining the inert fluid in the booster engine fuel jacket
4. To determine the effects of turbine exhaus flowback on the thrust section and to determine the amount (if any) of possible flow through the heat shield boots
5. To determine the sources and nature of the acoustic environment of the engine prior to and during the start sequence
6. To define the temperature profile of the F-series flame deflector during start
7. To determine the effects of dry jacket and inert lead starts on the temperature of the steel and aluminum launcher grating
8. To determine the effect of start sequence changes on shaft deflection within the sustainer engine LOX pump

SUMMARY

A 17-test program was conducted on test stand Alfa-1 to define the pressure pulse with respect to the simulated F-series flame deflector and launcher configuration. Low-range pressure transducers located at the heat shield and at the flame deflector entrance defined the pressure pulse at these locations. Flame deflector thermocouples recorded ambient conditions through the start sequence, and work platform thermocouples indicated the temperature environment of the platform prior to missile liftoff. Heat shield temperature was measured to determine the amount of heat transmitted through the heat shield as a result of turbine exhaust flowback. Acoustic levels were recorded at six locations during pretest countdown to isolate the source of damaging high-frequency noise. High-speed cameras were used to monitor the movement of the flame shield boots, work platforms, and turbine exhaust flowback.

Tests were conducted utilizing inert fluid fuel leads of 2 and 3 gallons to depress the rates of booster thrust buildup. Dry jacket tests were interspersed to define the base line, or normal buildup rate, with respect to the pressure pulse in the F-series flame deflector. The sustainer engine was deliberately started prior to the booster engines during two tests, contrary to the customary practice of scheduling the booster engine to start first. All tests were conducted without flame deflector water to simulate the operational configuration and were of short (2 seconds) duration to prevent damage to the flame deflector.

CONCLUSIONS

Analysis of test data resulted in the following conclusions:

1. At booster start the pressure pulse at the heat shield and flame deflector entrance is reduced significantly with reduction of the booster initial thrust buildup rate.
2. During a normal start sequence the pressure pulse at sustainer start is unaffected by changes in the booster pressure pulse, and usually is obscured by the pressure disturbances following booster start.
3. The booster pressure pulse is essentially unchanged by starting the sustainer prior to the booster, but the sustainer pressure pulse is significantly increased.
4. The most effective inert fluid fuel lead was not determined because of the limited test sample. It was determined that a 2-gallon solution of sodium nitrite and monoethylene glycol was satisfactory as an interim fluid.
5. The emergency procedures of inert fluid introduction are satisfactory as an interim measure.
6. Attachment of an inert fluid fill check valve to the booster fuel return manifold is feasible and is recommended.
7. Booster boot retention by means of a Camloc ring on the booster thrust chamber is satisfactory, but a cable is necessary to ensure adequate sealing.
8. To the degree tested, the segmented channel configuration booster boot retainer was satisfactory.

9. The sustainer exhausterator clips with reinforcing gussets proved to be capable of withstanding the loads imposed by the sustainer boot, and retained the boot in its proper position.

10. The clamp and bracket kit is satisfactory to the extent of the exposure experienced during the program.

11. No harmful effects were observed as a result of the booster turbine exhaust gas flowback.

12. No rubbing of the sustainer LOX pump impeller and Kel-F liner was experienced; in particular, the sustainer-lead test imposed no unusual loading sufficient to cause rubbing.

13. Temperature conditions of the heat shield and work platform were defined and were not excessive.

14. Temperature conditions within the flame deflector were defined and are presented in the discussion.

Results of the acoustic microphone recordings will be presented by General Dynamics/Astronautics (GD/A).

TEST PROGRAM

Testing during the simulated F-series flame deflector program at test stand Alfa-1 was conducted from 26 February through 9 March 1963. Configuration of the test stand is shown in Fig. 1 through 6. The standard MA-3 (dry jacket) start with a 550-millisecond delay before sustainer engine start was utilized during 7 of the 17 completed tests. Four tests were conducted with 2 gallons of Glydyne-25 as an inert lead in each booster fuel jacket. Three tests were conducted with 3 gallons of Glydyne-25, and one test used 3 gallons of Aquadyne-29.6. The start sequence of each inert lead test simulated the normal missile start. During two of the tests, the sustainer engine was started 1.3 seconds prior to booster engine start. The repetitive testing caused excessive damage to the coolant tubes within the sustainer thrust chamber and prevented all the tests from being full cluster tests; therefore, tests 11 through 17 were double-booster tests only. Table 1 summarizes the test sequencing and pertinent conditions.

INSTRUMENTATION

High-response pressure pulse data were recorded on 15 channels of FM tape from eight Photocon transducers and seven Data Sensor transducers. Two transducers conveyed differential pressure measurements. The measurement locations are shown in Fig. 7. Tape recordings were made from 36-gage iron-constantan thermocouples (0.17-second time constant) at four locations on the flame deflector (Fig. 8). The temperature environment was measured by direct-recording oscillographs at two locations on the heat shield batting and two locations on the access grating.

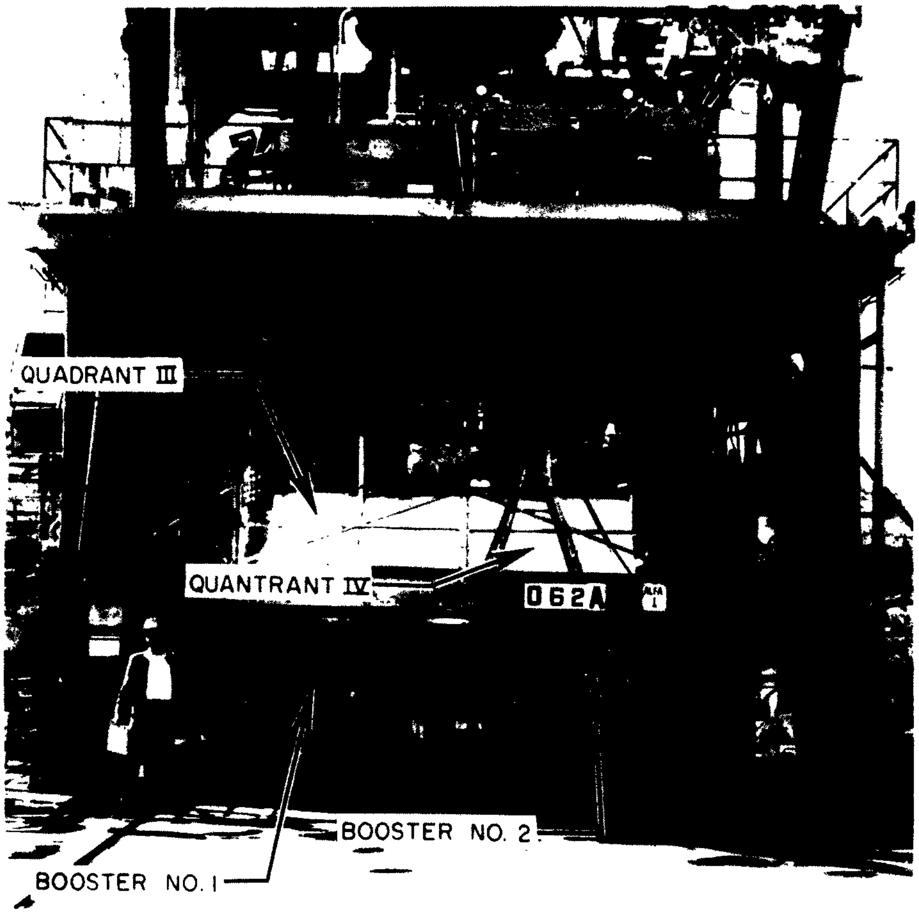

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Figure 1. Simulated Boattail

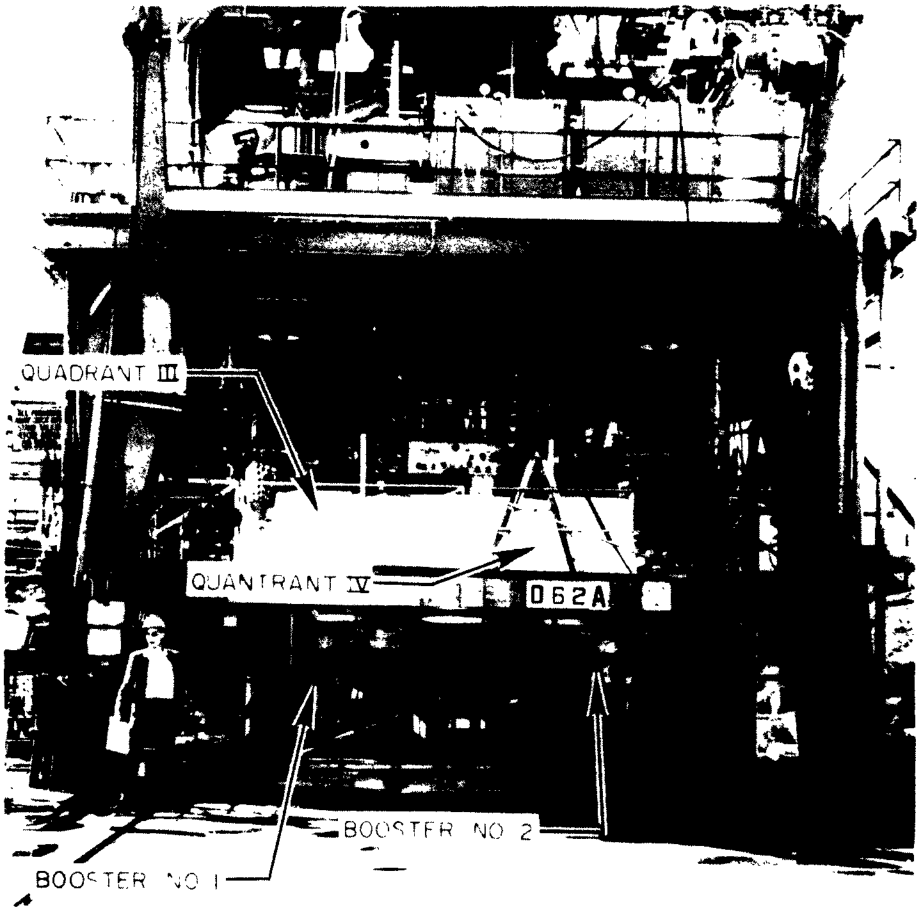

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Figure 1. Simulated Boattail

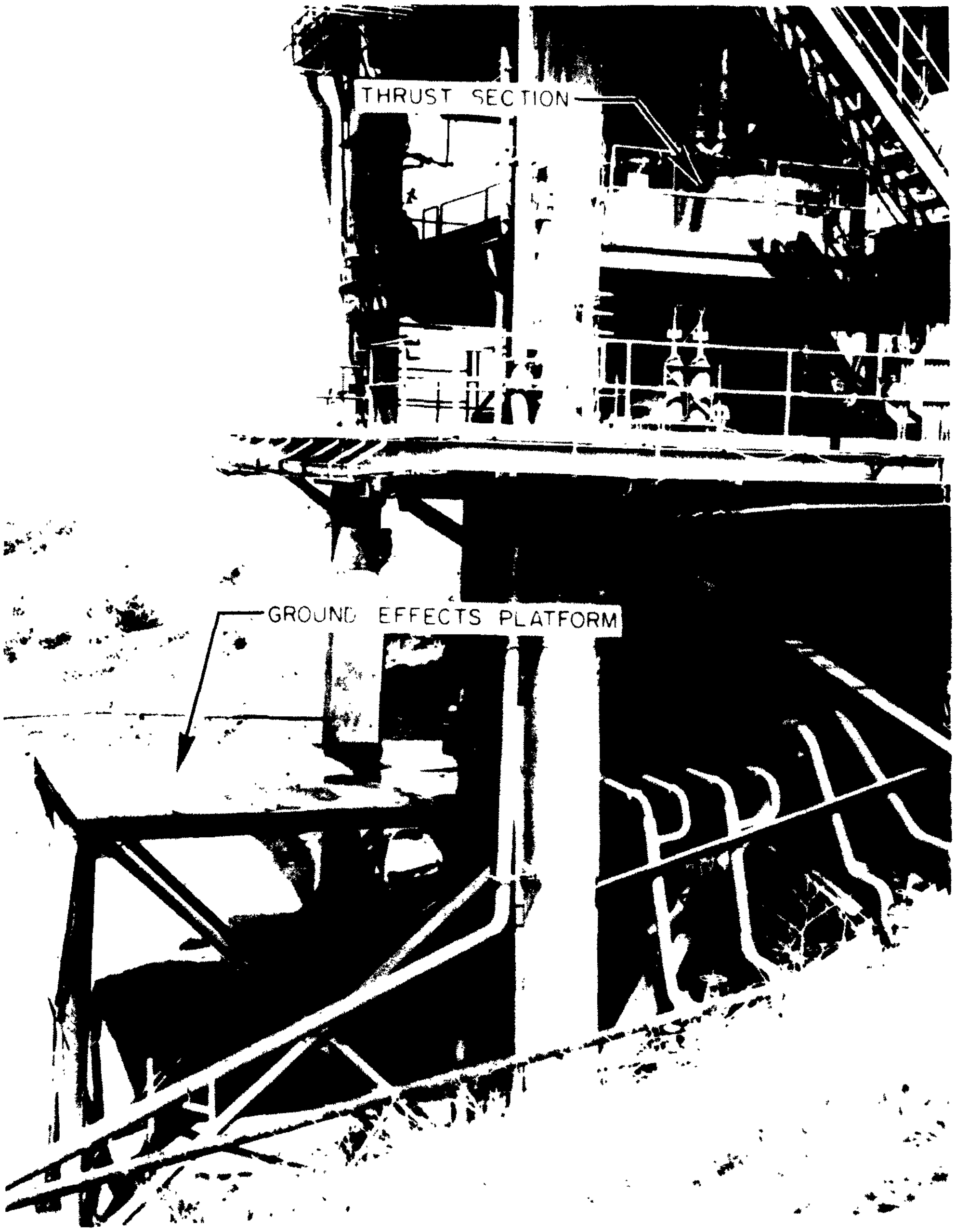

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Figure 2. Simulated Ground Effects Platform

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Figure 3. Fences and Launcher in Simulated Quadrant I

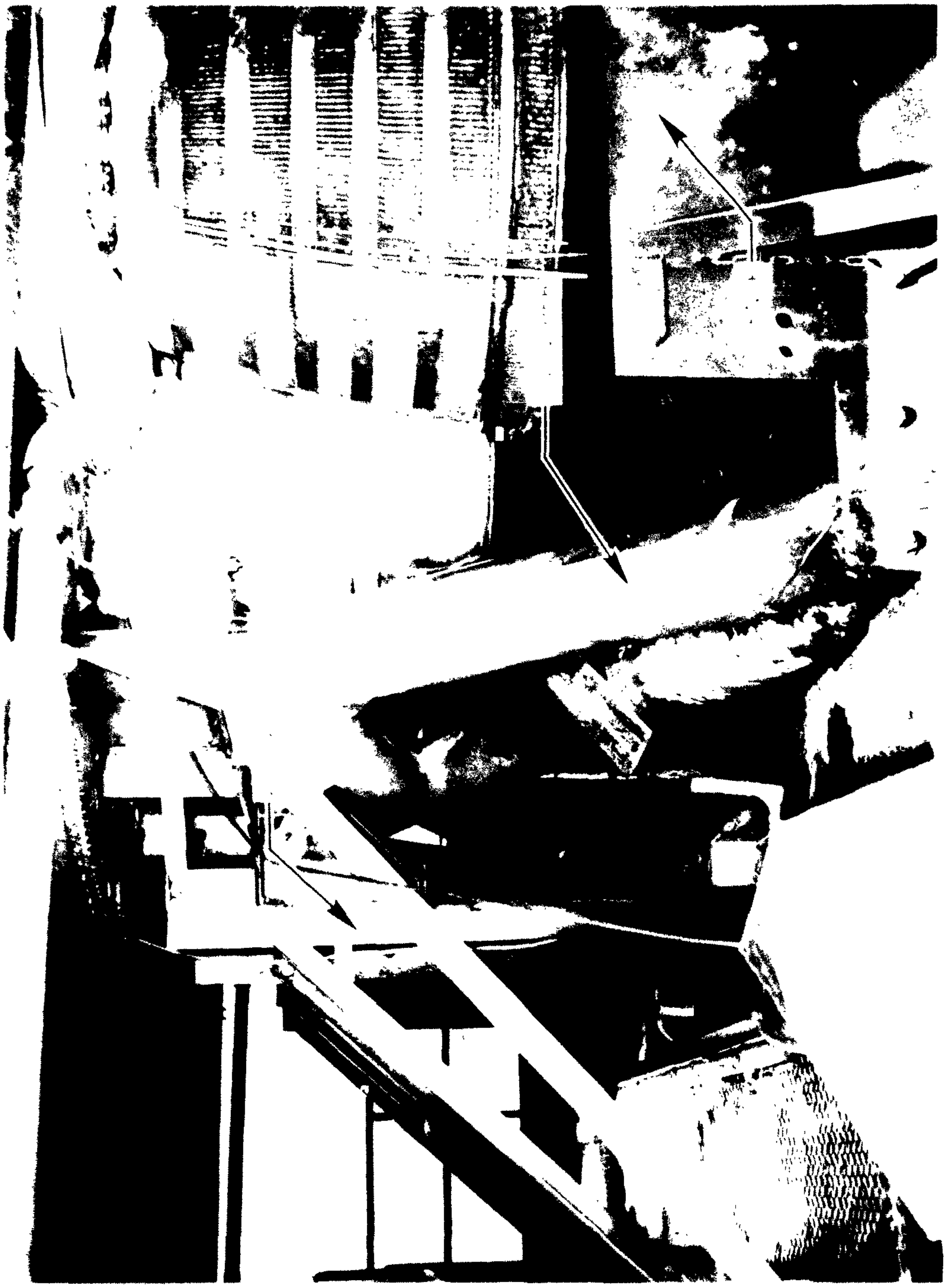

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Figure 4. Fences and Launcher in Simulated Quadrant II

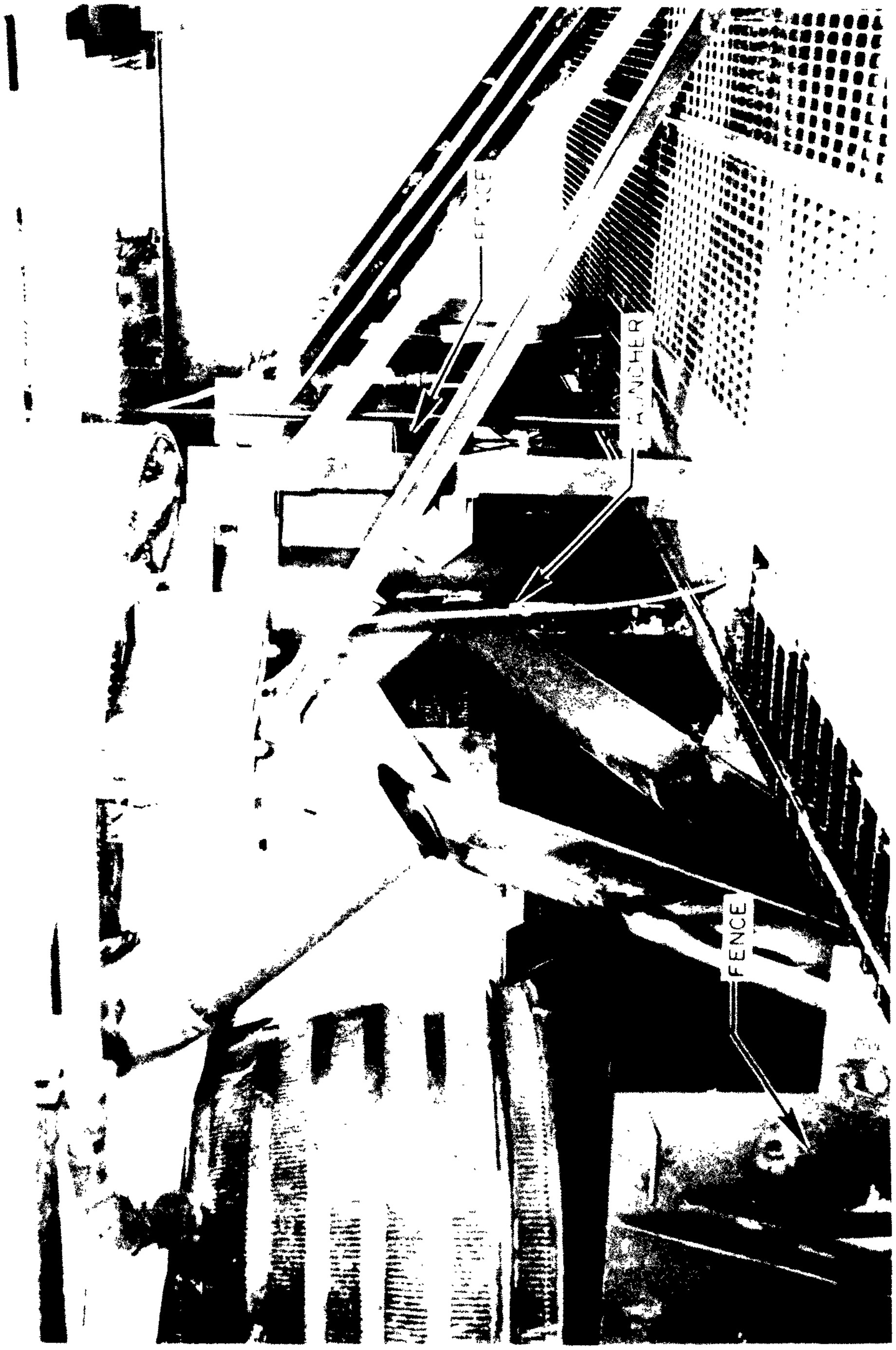

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Figure 5. Fences and Launcher in Simulated Quadrant III

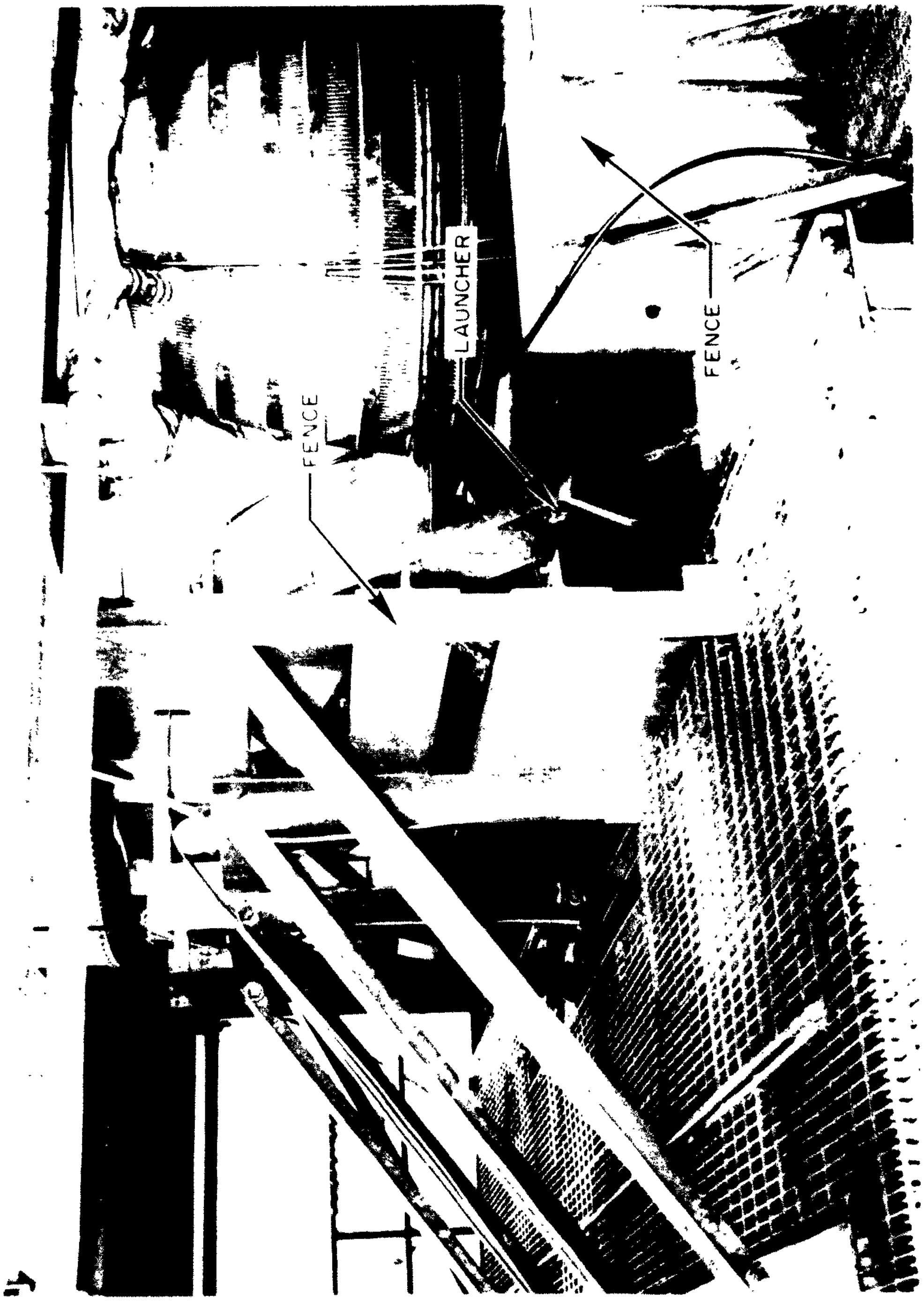

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Figure 6. Fences and Launcher in Simulated Quadrant IV

TABLE 1

TEST SEQUENCE

Test No.	Start Sequence	Booster Jacket Condition	Minimum Mainstage Timer Duration, seconds
1	Normal[a]	Dry	1.8
2	Normal	2 gallons Glydyne-25[c]	1.8
3	Normal	Dry	1.8
4	Normal	2 gallons Glydyne-25	1.8
5	Normal	Dry	1.8
6	Normal	2 gallons Glydyne-25	1.8
7	Normal	Dry	1.8
8	Normal	2 gallons Glydyne-25	1.8
9	Sustainer Lead[b]	Dry	2.5
10	Sustainer Lead	Dry	2.5
11	Booster Only	Dry	1.8
12	Booster Only	3 gallons Glydyne-25	1.8
13	Booster Only	Dry	1.8
14	Booster Only	3 gallons Aquadyne-29.6[d]	1.8
15	Booster Only	Dry	1.8
16	Booster Only	3 gallons Glydyne-25	1.8
17	Booster Only	3 gallons Glydyne-25	1.8

[a] All normal start sequence tests were similar to missile start sequence, i.e., 550-millisecond sustainer delay

[b] The sustainer lead time was 1.3 seconds

[c] Glydyne-25 is a solution consisting of 25%, by weight, monoethylene glycol in a 36% aqueous sodium-nitrite solution.

[d] Aquadyne-29.6 is a 29.6%, by weight, aqueous monoethylene glycol solution.

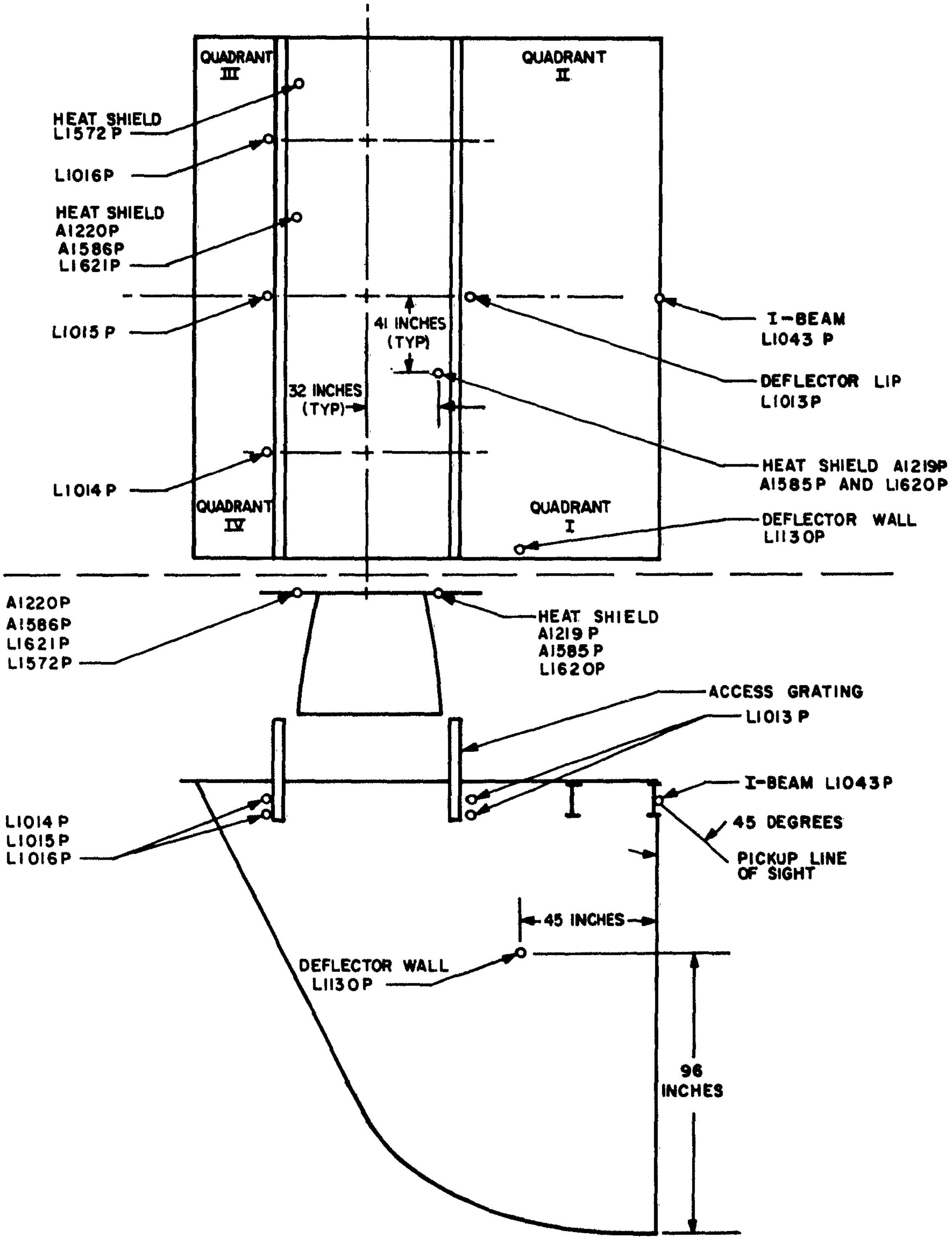

Figure 7 . Pressure Instrumentation Locations

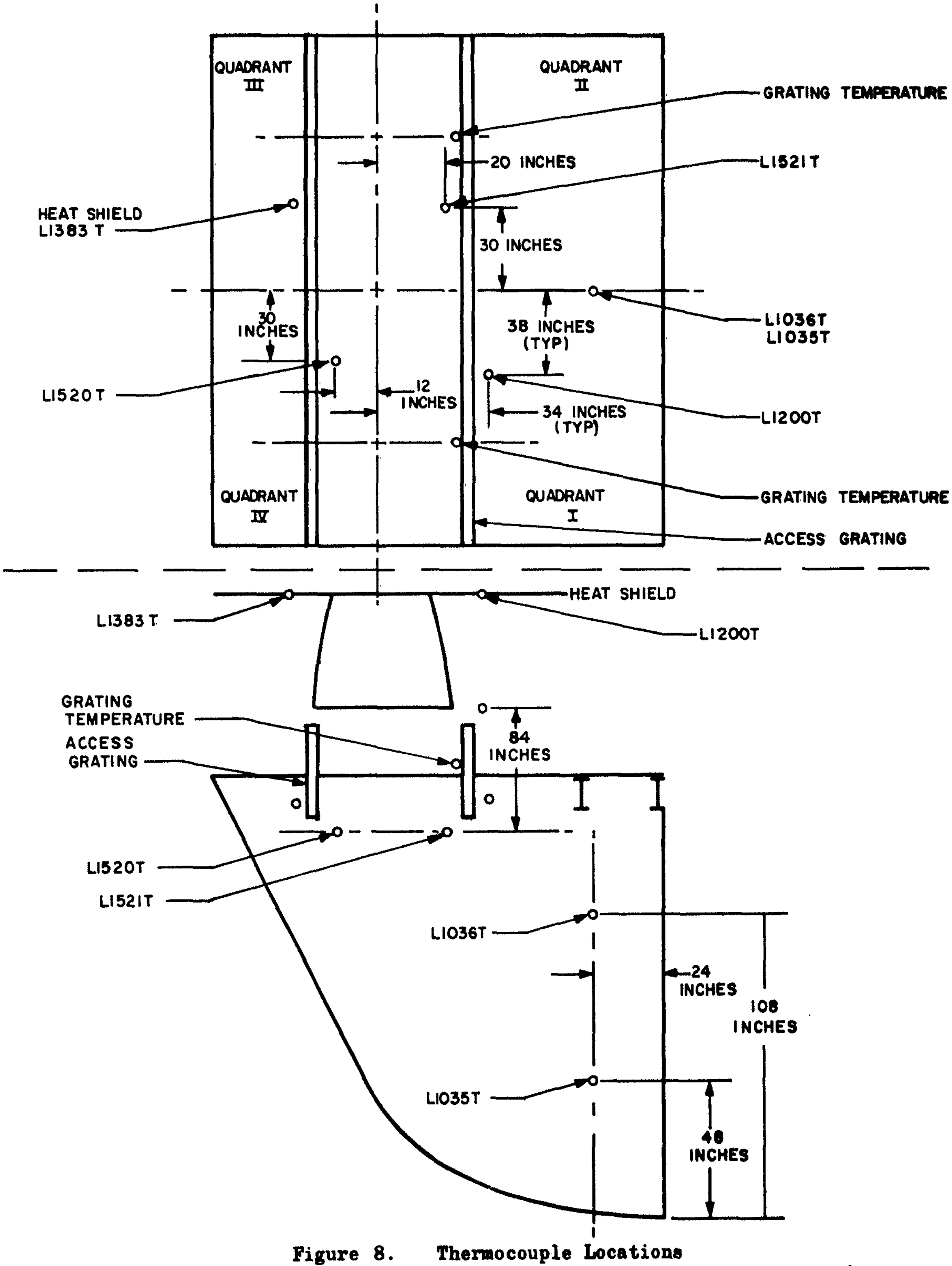

Figure 8. Thermocouple Locations

Tape and direct oscillograph recordings were used to measure chamber pressures from both booster engines and the sustainer engine, and thrust was measured by direct oscillograph recordings from each engine load cell. Duplicate tapes of all tests were provided to GD/A and Space Technology Laboratories (STL). All pressure transducers were periodically subjected to 10-step calibrations to eliminate error introduced by transducer nonlinearity and to increase the reliability of the records by completing the end-to-end check of the instrument system. With these precautions, the pressure pulse data are believed to be accurate within 10% of the reading. The test data were presented at Rocketdyne on Miller oscillograph playbacks at 25 in./sec. For ease of interpretation, the 15 pressure pulse records were filtered at 200 cps (low pass) on the Miller oscillograph. Table 2 lists the special instrumentation recorded during the test program and identifies the measurements with particular transducers Some transducers were moved from test to test; this was done to optimize the data and to provide data comparisons between transducers.

PRESSURE PULSE DATA REVIEW

Dry-Jacket Start

The maximum flame deflector pressure pulse recorded was 10.0 psig (Tables 3 and 4). This was recorded during test 15 at the flame deflector entrance at position L1015P. Accompanying maximum outside and inside heat shield pressures during the test were 4.1 psig and 0.9 psig, respectively. Maximum heat shield differential pressure was 1.6 psid. The thrust buildup rates of the booster engines during the dry-jacket start were 6050 lb/msec and 3066 lb/msec.

TABLE 2

SPECIAL INSTRUMENTATION LIST

Identification No.	Parameter	Transducer S/N*	Tests
L1572P	Outside Heat Shield Pressure	2110095	All
L1572P	Outside Heat Shield Pressure (Duplicate)	1473 1474	1 through 4 5 through 17
L1621P	Outside Heat Shield Pressure	4848 4849 207006	1 through 4; 8 5 through 7 9 through 17
L1620P	Outside Heat Shield Pressure	4849 4848	1 through 4; 8 through 17 5 through 7
L1620P	Outside Heat Shield Pressure (Duplicate)	4848 207006	9 through 13 1 through 8
A1220P	Inside Heat Shield	2100307	All
A1219P	Inside Heat Shield	22200	All
A1585P	Heat Shield Differential Pressure	358	All
A1586P	Heat Shield Differential Pressure	1474 1473	1 through 4 5 through 17
L1013P	Deflector Lip Pressure	4875	All
L1014P	Deflector Lip Pressure	1255	All
L1015P	Deflector Lip Pressure	208009	All
L1016P	Deflector Lip Pressure	1254	All
L1043P	Deflector Side-Wall Pressure	2110141	All
L1130P	Launcher Pressure	1257	All

*Transducers with 4-digit serial numbers are Photocon transducers; all other transducers are Data Sensor transducers.

TABLE 2

(Continued)

Identification No.	Parameter	Transducer S/N*	Tests
Not Assigned	Sustainer Exit Manifold Pressure	4043	14 through 17
L1383T	Heat Shield Batting Temperature	DNA	All
L1200T	Heat Shield Batting Temperature	DNA	All
L1520T	Flame Deflector Entrance Temperature	DNA	1 through 10
L1521T	Flame Deflector Entrance Temperature	DNA	1 through 10
L1035T	Flame Deflector Temperature	DNA	1 through 10
L1036T	Flame Deflector Temperature	DNA	1 through 10
Not Assigned	Access Grating Temperature	DNA	All
Not Assigned	Access Grating Temperature	DNA	All
Not Assigned	Booster No. 1 Chamber Pressure	DNA	All
Not Assigned	Booster No. 2 Chamber Pressure	DNA	All
Not Assigned	Sustainer Chamber Pressure	DNA	All
Not Assigned	Booster No. 1 Main Thrust	DNA	All
Not Assigned	Booster No. 2 Main Thrust	DNA	All
Not Assigned	Sustainer Main Thrust	DNA	All

*Transducers with 4-digit serial numbers are Photocon transducers; all other transducers are Data Sensor transducers.

The maximum outside heat shield pressure pulse recorded during a dry-jacket start was 5.9 psig during test 5. This was accompanied by maximum pulses of 6.1 psig at the flame deflector entrance, 1.1 psig inside the heat shield, and 1.4 psid heat shield differential pressure. Thrust buildup rates of the booster engines during test 5 were 6400 and 3930 lb/msec.

Inert Fluid Lead

The pressure pulses were significantly reduced with reduction of thrust buildup rates during the inert fluid lead tests. The maximum outside heat shield pressure pulse recorded with 2 gallons of Glydyne-25 was 1.6 psig. Accompanying booster engine thrust buildup rates were 3000 and 1600 lb/msec.

With 3 gallons of Glydyne-25, the maximum outside heat shield pressure pulse recorded was 0.7 psig. Accompanying booster engine thrust buildup rates were 2600 and 1100 lb/msec.

The test conducted with 3 gallons of Aquadyne-29.6 produced a pressure pulse of 0.8 psig outside the heat shield. Accompanying booster engine buildup rates were 1800 and 1350 lb/msec.

Sustainer Lead With Dry Jacket

The maximum outside heat shield pressure pulse recorded when the sustainer was started before the booster (sustainer lead) was 6.7 psig. This pulse occurred at sustainer start, and was followed by a pressure pulse of 3.0 psig (a normal value) when the booster engine started

TABLE

SUMMARY OF PRESSURE PULSE DATA WITH S

Test No.	Jacket Condition	Thrust Buildup Rate, lb/msec		Main Propellan Ignition Differential Time (Booster No. 2 Minus Booster No. 1), milliseconds
		Booster No. 1	Booster No. 2	
1	Dry	7250	3800	-70
3	Dry	6400	4200	-70
5	Dry	6400	3930	-53
7	Dry	6350	3250	-56
11	Dry	6500	3900	-50
13	Dry	8400	3400	-92
15	Dry	6050	3066	-65
2	2 Gallons of Glydyne-25	3600	1650	-70
4	2 Gallons of Glydyne-25	3000	1600	-85
6	2 Gallons of Glydyne-25	3160	1530	+10
8	2 Gallons of Glydyne-25	3330	1600	-70
12	3 Gallons of Glydyne-25	2600	1100	-60
16	3 Gallons of Glydyne-25	2250	925	+40
17	3 Gallons of Glydyne-25	2500	925	+130
14	3 Gallons of Aquadyne-29.6	1800	1350	-100
9*	Sustainer Pulse Booster Pulse (Dry)	6200	3070	-82
10*	Sustainer Pulse Booster Pulse (Dry)	7400	3300	-70

*Sustainer Lead Test

1

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TABLE 3

' PRESSURE PULSE DATA WITH SIMULATED F-SERIES FLAME DEFLECTOR

st Buildup , lb/msec		Main Propellant Ignition Differential Time (Booster No. 2 Minus Booster No. 1), milliseconds	Positive Pressure Pulse Outside Heat Shield, psig		Positive Heat Shield Differential Pressure, psi		Positive Deflector Lip Pressure, psig	
er 1	Booster No. 2		Maximum	Average	Maximum	Average	Maximum	Average
0	3800	-70	2.6	1.6	0.7	0.5	4.6	3.7
0	4200	-70	1.8	1.0	0.7	0.5	5.0	4.5
0	3930	-53	5.9	3.9	1.4	1.2	6.1	5.4
0	3250	-56	2.9	1.8	0.8	0.7	6.9	4.5
0	3900	-50	2.8	2.6	1.0	1.0	6.1	4.8
0	3400	-92	4.1	2.7	1.2	1.0	8.0	6.4
0	3066	-65	4.1	3.1	1.6	1.5	10.0	7.4
0	1650	-70	1.4	0.6	0.3	0.3	2.7	2.1
0	1600	-85	1.6	0.9	0.5	0.5	3.0	2.3
0	1530	+10	1.4	0.9	0.2	0.2	3.3	2.4
0	1600	-70	1.4	0.9	0.3	0.4	5.0	2.7
0	1100	-60	0.7	0.5	0.2	0.1	1.9	1.3
0	925	+40	0.5	0.4	0.3	0.3	2.0	1.3
0	925	+130	0.6	0.4	0.6	0.4	1.6	1.2
0	1350	-100	0.8	0.4	0.3	0.2	1.6	1.2
0	3070	-82	6.7 3.0	3.7 2.5	0.7 0.8	0.5 0.7	3.1 6.9	2.8 4.9
0	3300	-70	2.9 3.1	1.6 1.7	0.6 0.2	0.4 0.2	5.4 8.4	4.3 5.0

2

TABLE 4

DETAILED PRESSURE PULSE DATA WITH SIMULAT

Test No.	Thrust Buildup Rate, lb/msec		Main Propellant Ignition Differential Time (Booster No. 2 Minus Booster No. 1), milliseconds	Flame Deflector Pressure (Maximum/Minimum), psig					Launcher Pressure, psig	
	Booster No. 1	Booster No. 2		L1013P	L1014P	L1015P	L1016P	L1130P	L1043P	L1620P
Dry-Jacket Star										
1	7250	3800	-70	4.6/1.9	2.9/1.9	3.5/0.9	3.9/1.6	4.4/2.4	3.7/2.7	2.6/1.
3	6400	4200	-70	4.8/2.4	3.8/2.9	4.4/3.8	5.0/4.0	4.5/4.0	3.6/2.0	1.8/1.
5	6400	3930	-53	4.6/1.0	6.1/3.6	Invalid	5.5/5.5	8.5/3.2	Invalid	3.4/2.
7	6350	3250	-56	2.7/5.4	3.8/4.3	6.9/4.5	Invalid	7.3/3.7	Invalid	2.9/2.
11	6500	3900	-50	3.5/4.0	6.1/4.6	No Data	No Data	4.5/3.9	2.4/3.9	2.8/2.
13	8400	3400	-92	5.3/3.5	8.0/3.8	5.8/3.0	6.6/3.8	5.7/2.6	4.1/2.9	2.8/2.
15	6050	3066	-65	6.4/3.7	6.0/3.8	10.0/3.6	7.3/4.0	9.7/3.8	5.8/4.3	4.1/3.
2-Gallon Glydyne-25										
2	3600	1650	-70	1.4/0.9	2.7/1.4	2.3/1.6	2.0/2.4	1.5/0.9	1.4/0	No Dat
4	3000	1600	-85	1.9/1.3	2.4/2.4	3.0/1.6	1.9/1.6	1.8/4.4	1.0/1.7	1.6/0.
6	3160	1530	+10	0.9/1.4	3.3/2.8	No Data	2.9/2.5	3.2/5.8	Invalid	0.8/1.
8	3330	1600	-70	0.9/2.4	1.9/1.9	3.1/2.8	5.0/2.5	2.0/2.4	0.6/0.4	1.4/1.
3-Gallon Glydyne-25										
12	2600	1100	-60	0.8/1.5	1.9/2.1	1.5/1.3	1.1/0.9	1.9/0.9	0.9/0.9	0.7/0.
16	2250	925	+40	0.6/1.0	Invalid	1.8/0.8	1.5/0.9	2.0/1.2	1.4/0.6	0.5/0.
17	2500	925	+130	0.7/1.0	Invalid	1.5/1.7	1.4/1.7	1.6/1.8	0.6/0.3	0.3/0.
3-Gallon Aquadyne-29.										
14	1800	1350	-100	1.0/1.4	1.5/1.8	1.6/1.4	0.8/0.7	1.8/2.3	1.1/1.7	0.8/0.
Dry Jacket (Sustainer										
9**				No Data	2.5/2.5	Invalid	3.1/0.8	6.3/5.6	3.4/2.2	4.6/0.
9	6200	3070	-82	No Data	4.9/5.6	2.8/2.2	6.9/2.3	4.6/7.0	8.7/5.7	2.7/3.
10**				3.1/1.7	5.4/1.9	4.2/1.5	4.6/2.9	2.4/2.2	1.5/2.0	1.9/1.
10	7400	3300	-70	2.5/4.2	4.2/2.6	3.2/2.5	8.4/2.3	2.8/2.8	2.4/2.0	2.1/2.

*Photocon transducer and Data Sensor transducer were used. See Table 2 for detailed informati

**Sustainer pulse data

TABLE 4

PULSE DATA WITH SIMULATED F-SERIES FLAME DEFLECTOR

	Launcher Pressure, psig	Outside Heat Shield Pressure (Maximum/Minimum), psig					Inside Heat Shield Pressure (Maximum/Minimum), psig		Heat Shield Differential Pressure (Maximum/Minimum), psi		Sustainer Flame Exit Pressure, psig
L1130P	L1043P	L1620P*	L1620P*	L1621P	L1572P*	L1572P*	A1585P	A1586P	A1219P	A1220P	
Dry-Jacket Start											
4.4/2.4	3.7/2.7	2.6/1.4	1.8/1.2	1.8/1.1	0.4/0.8	1.3/0.9	0.2/0.6	Invalid	0.7/0.7	0.3/0.9	
4.5/4.0	3.6/2.0	1.8/1.2	1.6/2.4	Invalid	0.3/0.9	0.5/2.3	0.5/1.6	Invalid	0.2/1.2	0.7/1.5	
8.5/3.2	Invalid	3.4/2.9	2.2/2.2	4.2/2.6	Invalid	5.9/2.9	1.1/0.9	0.8/0.4	1.0/1.5	1.4/1.2	
7.3/3.7	Invalid	2.9/2.0	1.8/2.8	1.2/2.6	Invalid	1.4/1.6	1.4/1.4	0.7/0.6	0.8/1.5	0.6/0.9	
4.5/3.9	2.4/3.9	2.8/2.3	3.6/3.4	2.7/2.7	Invalid	1.4/1.5	1.1/1.2	0.8/0.6	1.0/1.0	1.0/0.9	
5.7/2.6	4.1/2.9	2.8/2.0	4.1/3.5	2.3/1.8	Invalid	1.6/1.5	1.2/1.8	0.7/0.8	1.2/1.4	0.8/0.8	
9.7/3.8	5.8/4.3	4.1/3.6	Not Recorded	3.3/2.3	Invalid	2.1/1.2	0.9/0.9	0.5/0.8	1.6/1.5	1.3/0.9	4.8/4.0
2-Gallon Glydyne-25 Lead											
1.5/0.9	1.4/0	No Data	0.5/0.7	1.4/0.2	0.3/0.2	0.2/0.5	0.2/0.0	Invalid	0.3/0.2	0.3/0.1	
1.8/4.4	1.0/1.7	1.6/0.8	1.4/0.2	Invalid	0.3/0.2	0.5/0.5	0.3/0.2	Invalid	0.5/0.4	0.4/0.2	
3.2/5.8	Invalid	0.8/1.1	0.5/1.3	1.4/0.4	Invalid	0.9/0.5	0.2/0.4	0.2/0.0	0.2/0.6	0.2/0.5	
2.0/2.4	0.6/0.4	1.4/1.4	0.8/1.0	0.6/1.2	No Data	0.7/1.0	0.5/0.2	0.4/0.2	0.2/0.6	0.3/0.5	
3-Gallon Glydyne-25 Lead											
1.9/0.9	0.9/0.9	0.7/0.6	0.4/0.7	0.3/0.5	No Data	0.5/0.4	0.2/0.2	0.2/1.0	0.2/0.2	0.0/0.2	
2.0/1.2	1.4/0.6	0.5/0.6	Not Recorded	0.4/0.4	No Data	0.4/0.2	0.2/0.2	0.15/0.15	0.3/0.2	0.2/0.1	0.5/0.4
1.6/1.8	0.6/0.3	0.3/0.7	Not Recorded	0.6/0.4	No Data	0.4/0.2	Invalid	0.1/0.0	0.6/0.6	0.3/0.4	0.8/1.4
3-Gallon Aquadyne-29.6 Lead											
1.8/2.3	1.1/1.7	0.8/0.7	Not Recorded	0.3/0.7	No Data	0.1/0.3	0.4/0.3	No Data	0.3/0.3	0.1/0.3	0.5/0.3
Dry Jacket (Sustainer Lead)											
6.3/5.6	3.4/2.2	4.6/0.8	6.7/2.2	1.3/0.3	No Data	2.1/1.5	2.0/0.9	0.6/0.5	0.7/0.8	0.3/1.1	
4.6/7.0	8.7/5.7	2.7/3.5	2.5/0.5	3.0/1.7	No Data	2.0/1.3	2.0/0.7	1.0/0.7	0.8/1.3	0.6/0.9	
2.4/2.2	1.5/2.0	1.9/1.3	2.9/2.0	0.8/1.5	No Data	0.7/0.6	0.8/0.6	0.2/0.3	0.6/0.4	0.2/0.5	
2.8/2.8	2.4/2.0	2.1/2.1	3.1/3.1	0.8/2.1	No Data	0.8/1.3	0.8/0.9	0.4/0.1	0.2/0.9	0.2/0.5	

2 for detailed information concerning transducer types.

Other Pressure Pulse and Inert Lead Characteristics

During all the dry-jacket starts, the maximum pressure pulse was associated with the high booster thrust buildup rate.

During the inert fluid lead tests, with substantially moderated thrust buildup rates, the maximum pulse did not always accompany the most rapid thrust buildup rate.

With the exception of the sustainer-lead starts, the pulse associated with sustainer start was nearly obscured by the noise of the booster engine firing.

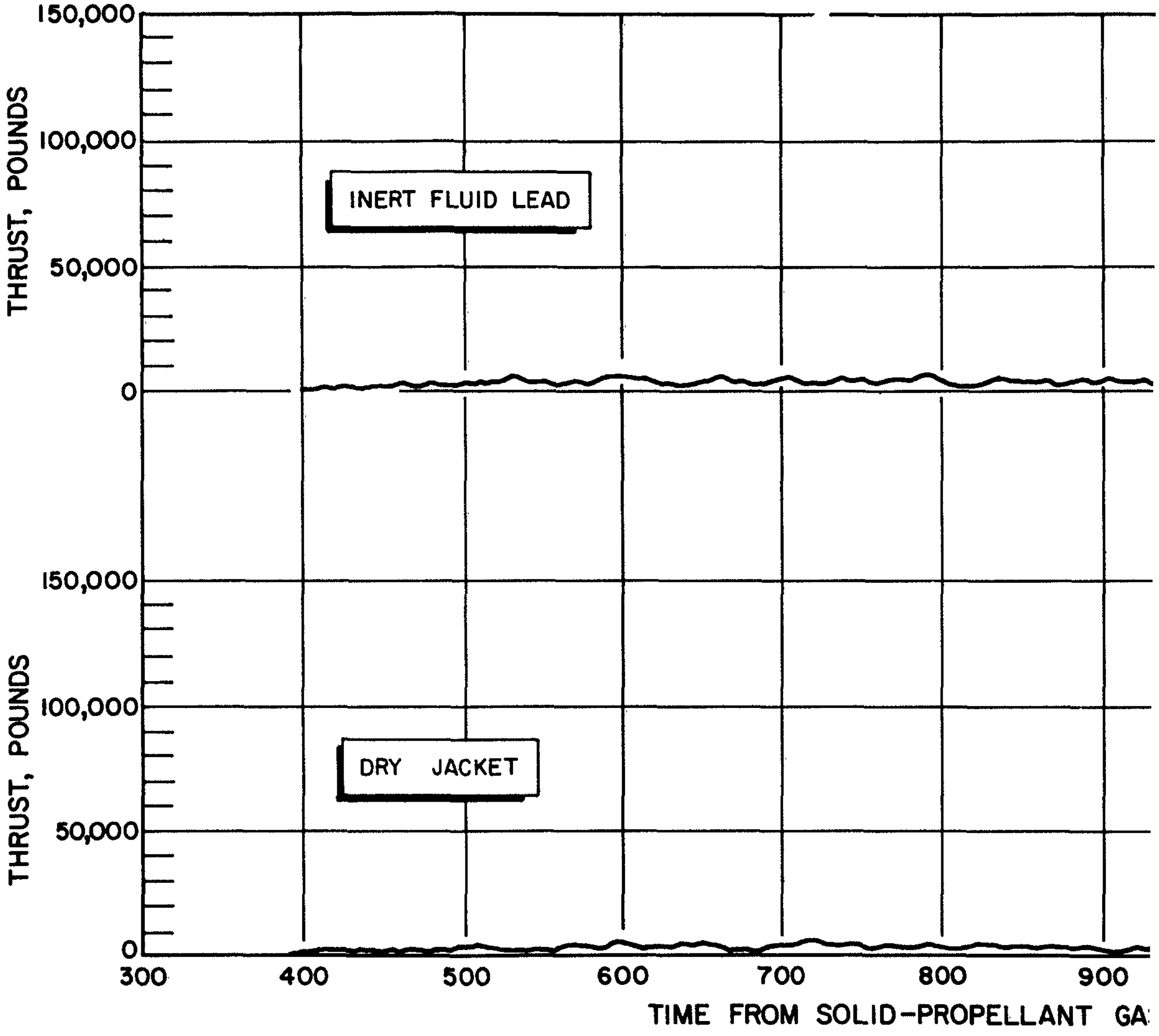
Figure 9 compares a typical booster thrust buildup rate during dry-jacket start with a typical buildup rate that occurs when an inert fluid lead is used.

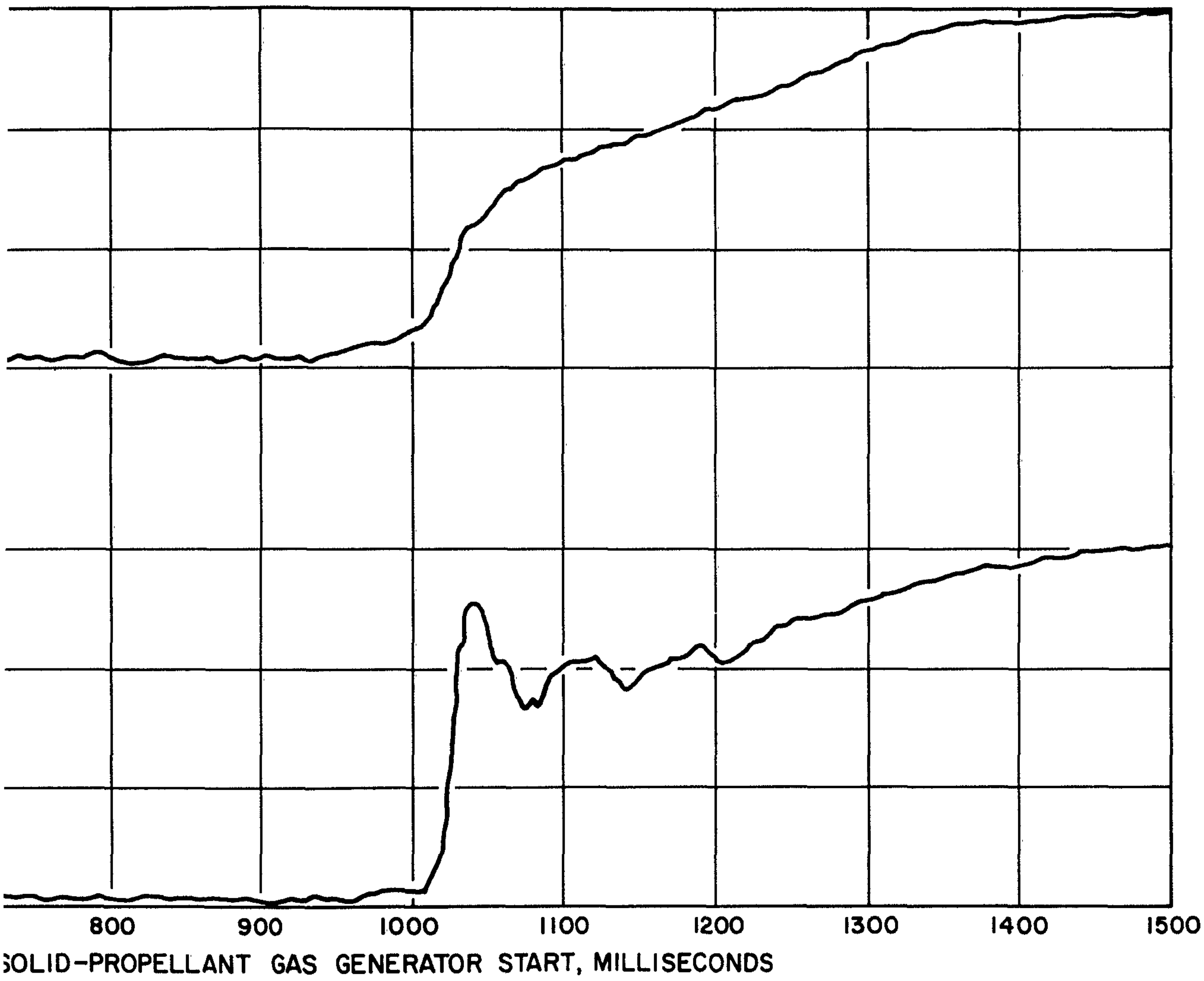
BOOT MODIFICATION

Several engine and missile modification kits were installed on the engines and simulated boattail for verification during the test series. Following is a brief summary of this phase of the program.

Booster Radiation Boot Retention With Camloc Fasteners

This method of boot retention, presented in GD/A engineering change proposal 8122 and Rocketdyne engineering change proposal MA3-339, features clips welded to the lowest of the three reinforcing bands on the bell


THRUST, POUNDS
150,000
100,000
50,000
0
INERT FLUID LEAD
THRUST, POUNDS
150,000
100,000
50,000
0
DRY JACKET
300
400
500
600
700
800
900
TIME FROM SOLID-PROPELLANT GA



2

Figure 9. Typical Booster Thrust Buildup

portion of the booster thrust chamber. Camloc fasteners attach the boot to the clips and the flame shield, and a cable is looped through the boot under the clips to provide additional sealing.

The first 13 tests were conducted without the retaining cable, but the cable was installed during the last 4 tests. The cable provides continuous support of the boot around the thrust chamber, and lack of a cable could result in hot gas aspiration into the boattail between thrust chamber Camloc fasteners. No evidence existed to indicate that the boot could break free from the clips, and there was no evidence of damage or overstressing of the boot or clips after exposure to eight tests where the pressure pulse ranged in magnitude from 2.5 to 5.9 psig.

Booster Radiation Boot Retention With Channels

One set of segmented channels were installed on booster No. 1 during the final five tests of the program. The design incorporates bolting the channel set to the middle reinforcing band on the booster thrust chamber. No difficulties with the channels were encountered. Additional tests are scheduled with the boots installed on the channels, and duration testing is anticipated upon completion of a follow-on program.

Sustainer Exhausterator Clip and Boot Retention

Reinforcing gussets were installed on the sustainer engine thrust chamber boot retention clips prior to the first test of the program. The gussets were designed to give additional support to the clips and thereby increase the load capability of the sustainer boot. Hardware inspection upon completion of the 17-test program revealed slight distortion of the exhausterator and certain clips (Fig. 10), but the gussets had not distorted and the clips had held the boot in position throughout the program. The sustainer boot had been cut by the exhausterator clips (Fig. 11) at each supporting edge as a result of repetitive testing which would not occur with an operational missile; the damage is not considered to be a serious condition.

INERT FLUID LEAD

Emergency Prefill Procedure

During tests utilizing an inert fluid prefill, the fluid was introduced into the thrust chambers by implementing the procedures recommended by Rocketdyne for field application. An associated ground equipment (AGE) kit of the type sent to field sites were used to accomplish the prefill (Fig. 12).

Operational Automatic Prefill System Check Valve

The check valve assembly at the drain screw is planned to be a part of the final operational automatic prefill system, so this valve configuration was tested by welding dummy blocks (to simulate the check valves) to two of the four drain screw bosses of each booster thrust chamber. This attachment remained on the booster thrust chambers throughout the program. In addition, a prototype check valve was welded to one of the

1BL95-3/14/63-S1F

Figure 10. Sustainer Aspirator Clip Distortion

1BL95-3/14/63-S1D

Figure 11. Sustainer Boot Damage

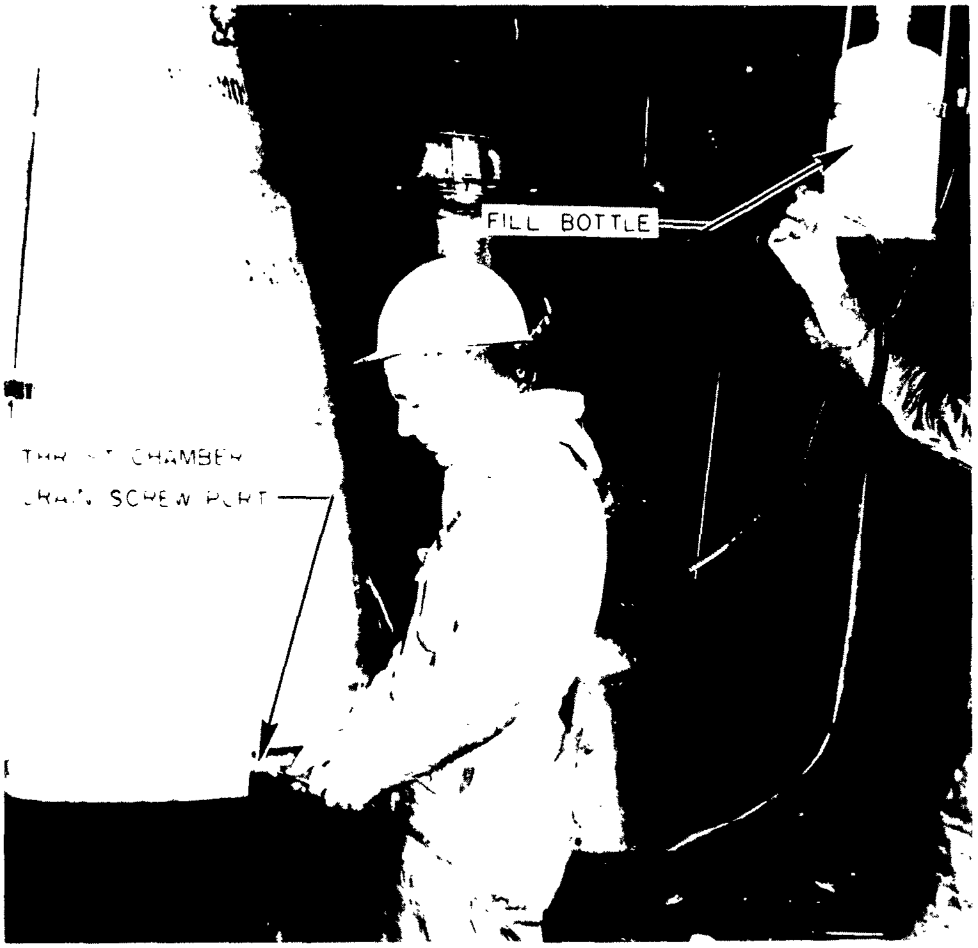


Figure 12. Inert Fluid Emergency Fill Equipment

remaining drain screw bosses on each booster thrust chamber prior to test 13. These valves remained on the chambers for the last five tests of the program.

No leakage occurred at the welds to the drain screw boss on either the dummy blocks or the actual check valves, and no other evidence of weld failure or deterioration was noted. Some leakage occurred through one of the check valves upon installation, but this was analyzed as warpage of the body caused by the welding process. The leak was eliminated by using a new gasket and higher torque on the threaded portion of the assembly.

A refinement of the welding procedure was made to eliminate the possibility of check valve body warpage during the welding process.

Engine Hardening Clamp and Bracket Kit

An engine hardening study resulted in the decision to augment the support to engine control lines in selected locations, and pertinent hardware was installed on engines on test stand Alfa-1 prior to the first test. The hardware remained on the engines during all tests, and is listed below:

1. Clamp between sustainer LOX and fuel bootstrap lines (Fig. 13)
2. Clamp between sustainer propellant utilization open control line and mixture ratio controller LOX sensing line (Fig. 14)
3. Clamps between sustainer gas generator open and close control lines (Fig. 15).
4. Clamps between sustainer gas generator close control line and fuel bootstrap line (Fig. 15)

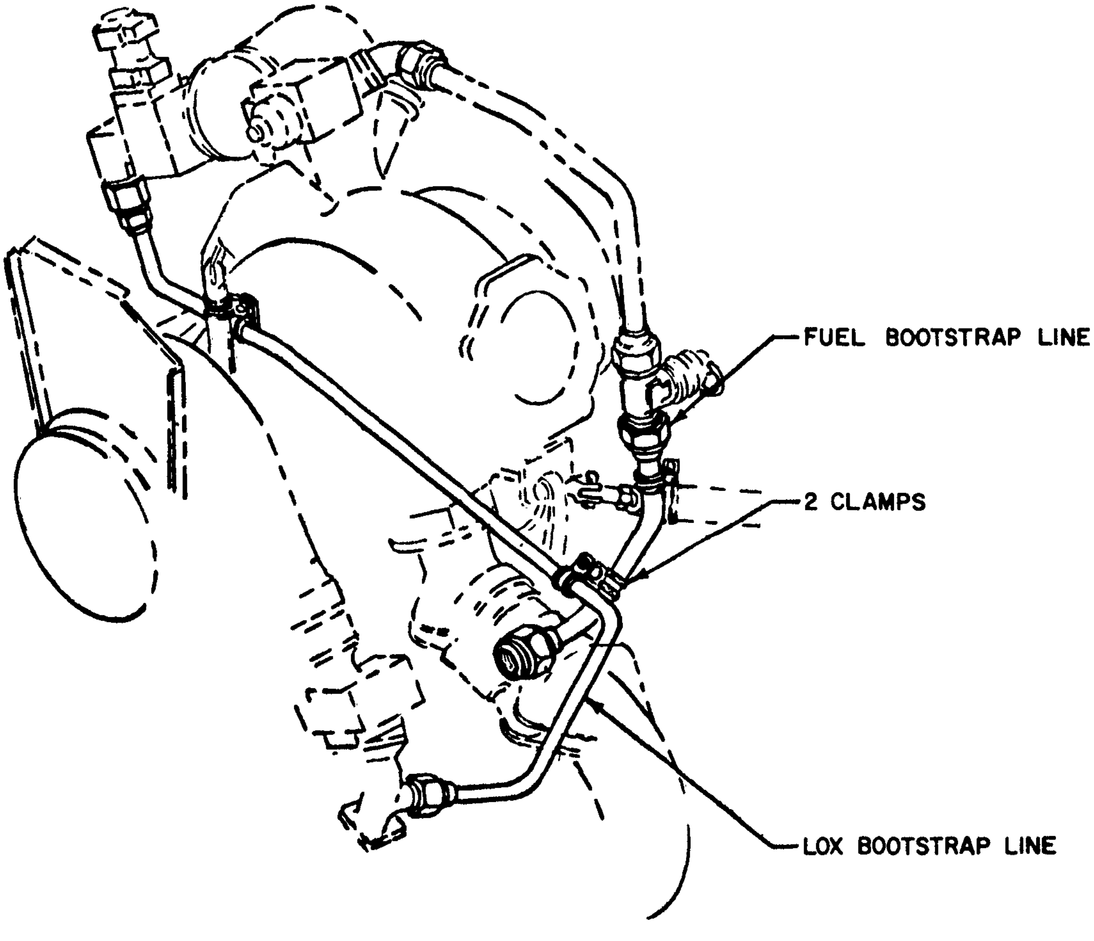


Figure 13. Bootstrap Line Clamp

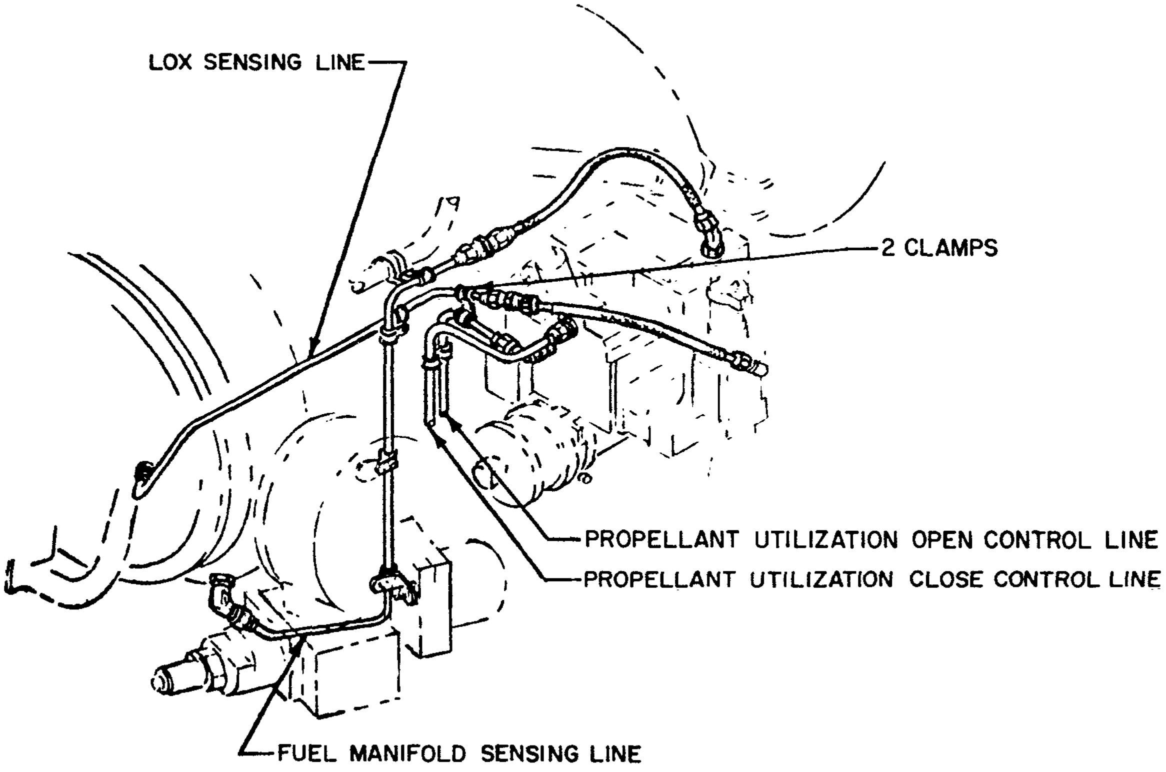


Figure 14. Control Line Clamp, Mixture Ratio Controller

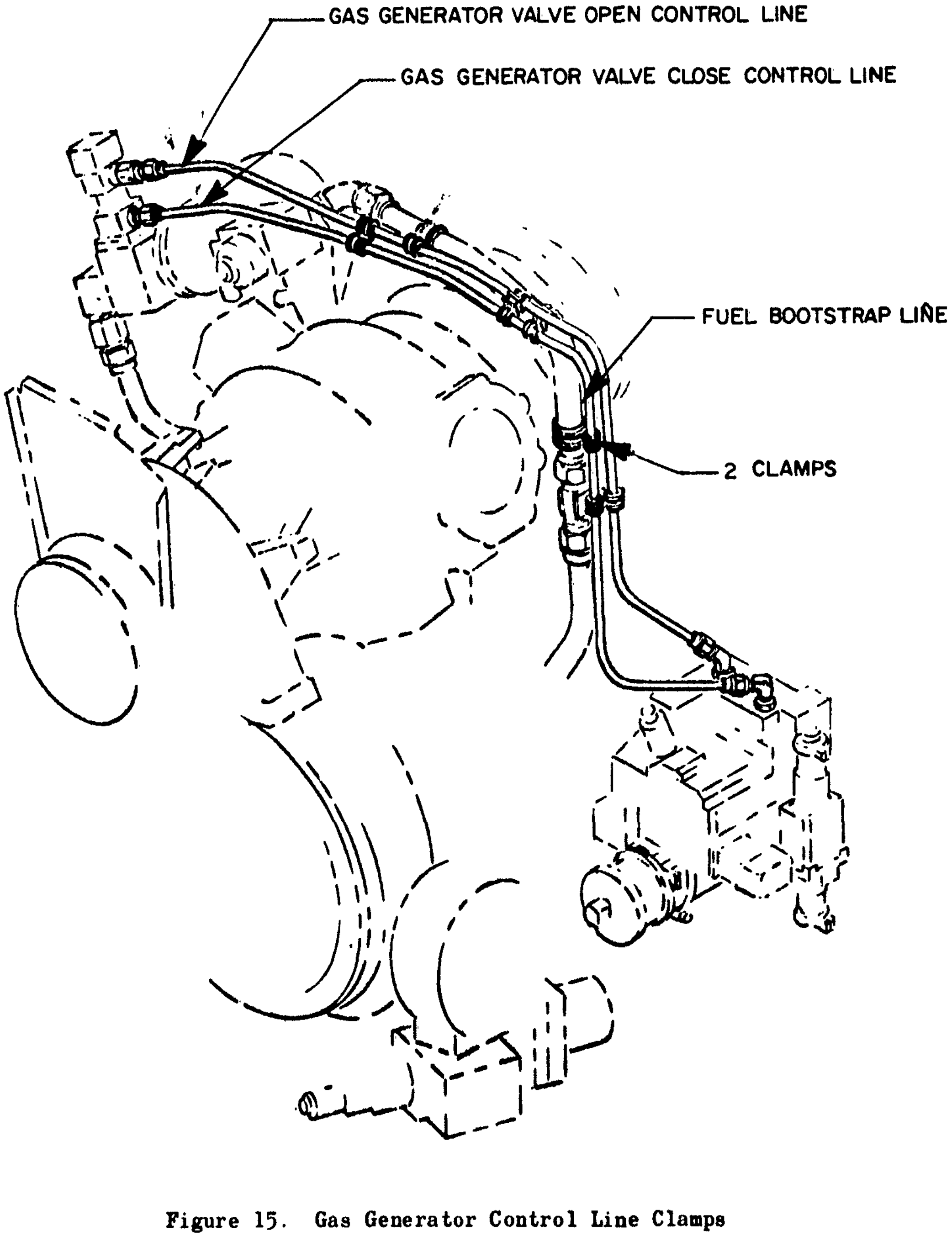
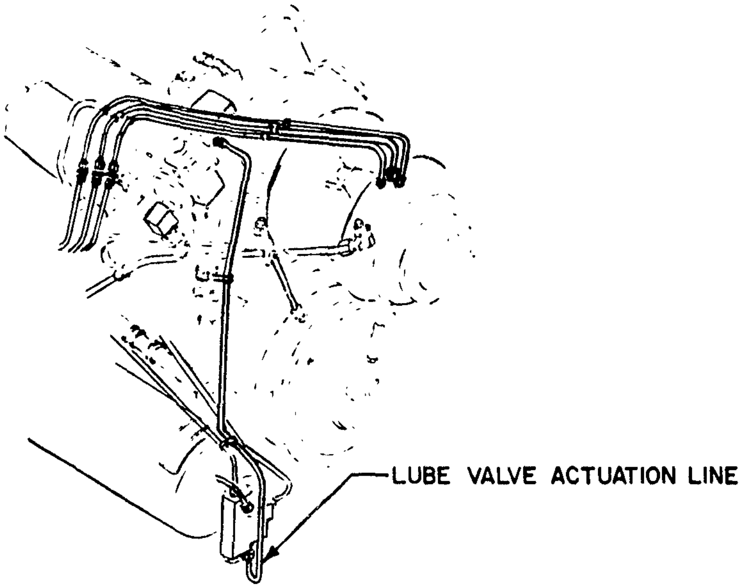


Figure 15. Gas Generator Control Line Clamps

5. Rerouting of lube valve actuation line; engineering change proposal MA3-341 (Fig. 16)
6. Additional clamping of rerouted sustainer lube valve actuation line (Fig. 16)
7. Clamp between lube tank drain line and sustainer lube oil supply line (Fig. 16)
8. Clamp between fuel coolant line to turbine bearing and high-pressure lube line to No. 1 bearing on sustainer (Fig. 17)
9. Clamping between head suppression valve open and closing control lines, modified after addition of insulation to closing control lines (Fig. 18)
10. Support bracket and line between booster exhaust duct and lube oil drain line (Fig. 19)
11. Fuel control line insulation; engineering change proposal MA3-338 (Fig. 20)
12. Clamp between turbopump strut assembly and No. 2 bearing manifold overboard drain line (Fig. 21)

None of the clamps, brackets, or lines loosened during the program, and there was no evidence of detrimental action to the lines caused by the addition of the clamps and brackets. Examination of the sustainer engine after removal from the stand revealed some wear on the rubber lining from the sustainer LOX bootstrap line clamp. A change from rubber to Teflon lining was made on all clamps on LOX lines.



EXISTING

PROPOSED

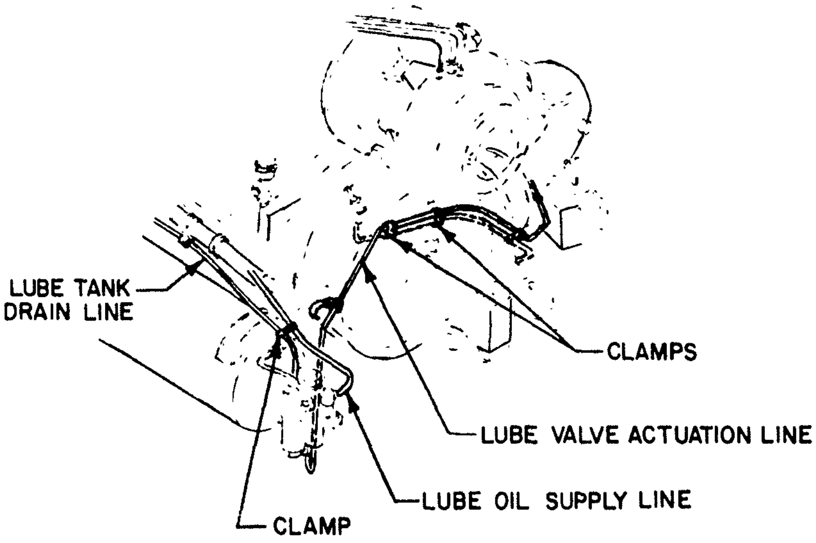


Figure 16. Lube Valve Control Line Installation

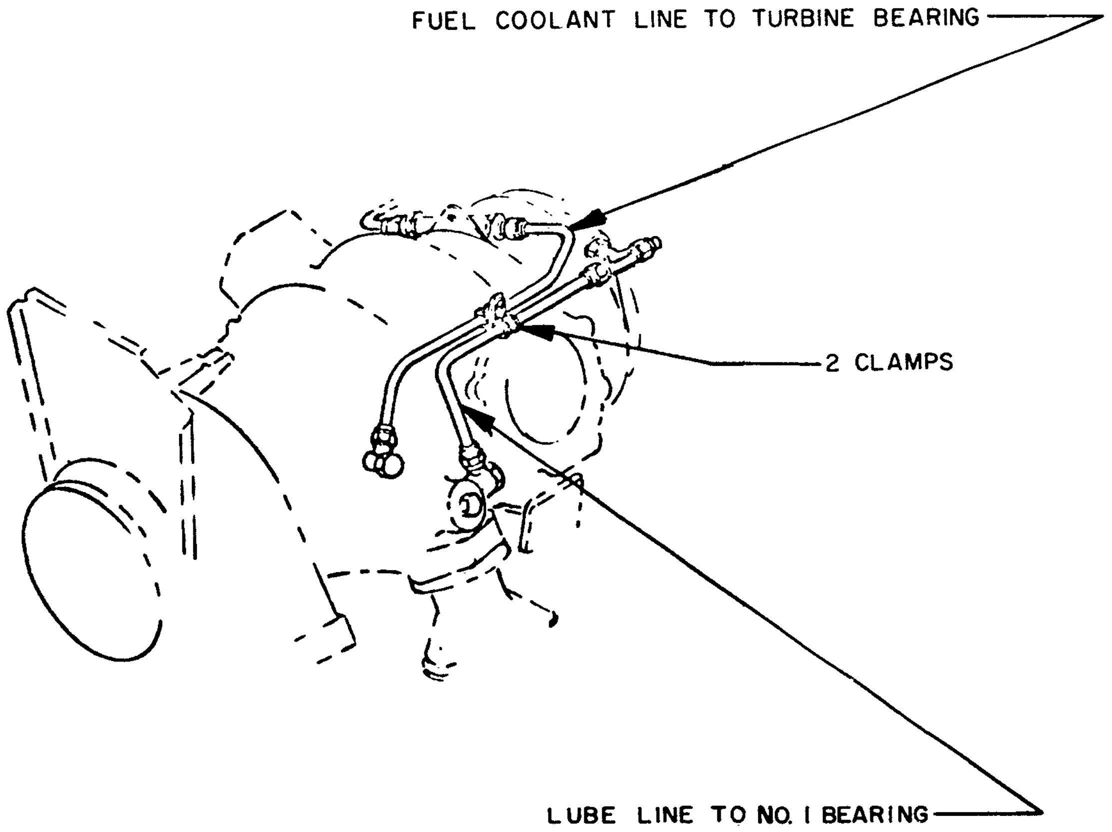


Figure 17. Fuel Coolant and Lube Supply Line Clamp

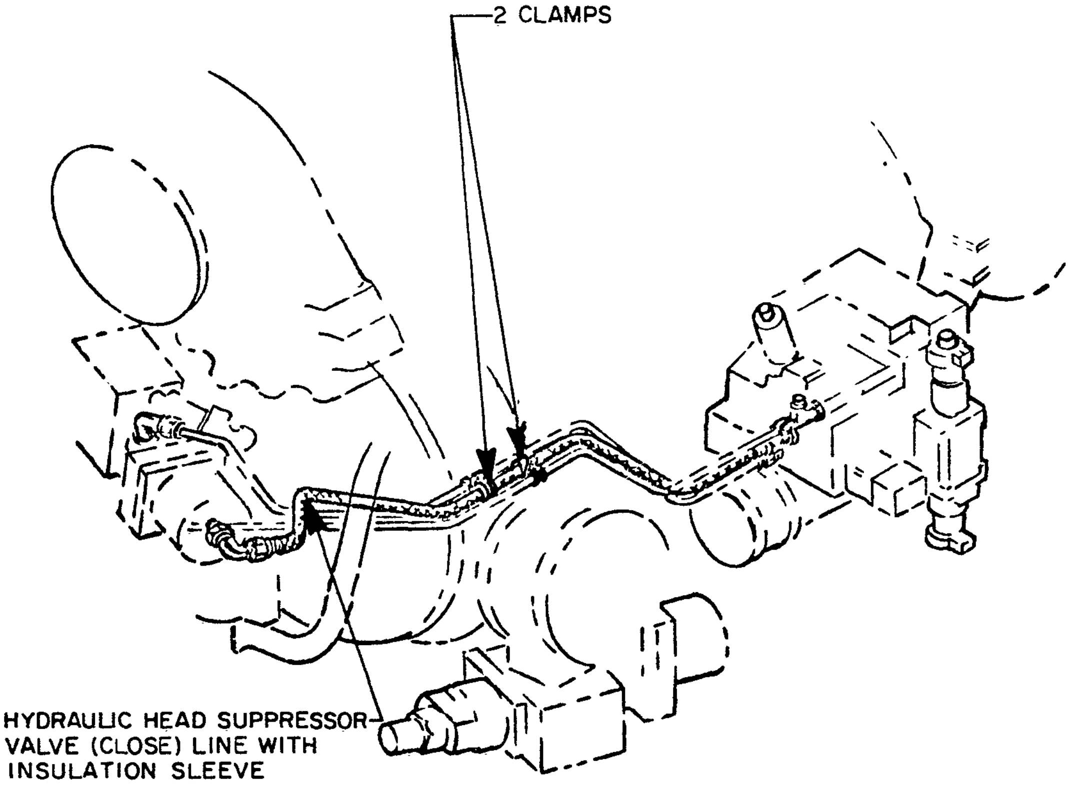


Figure 18. Control Line Insulation and Clamp Installation

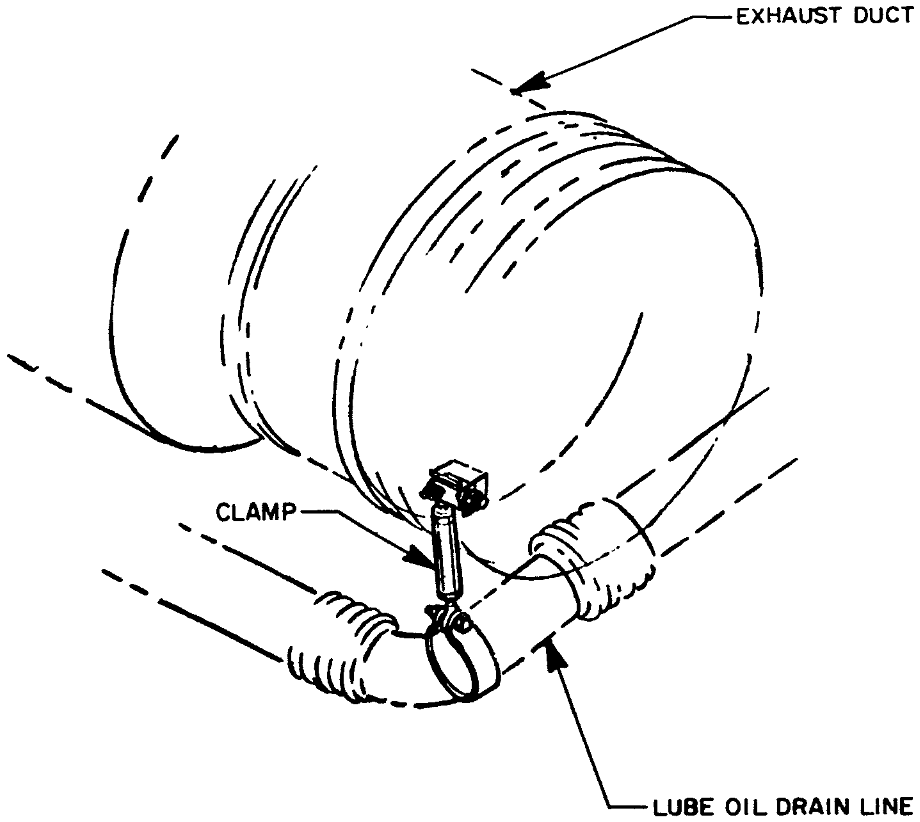


Figure 19. Lube Drain Line Clamp

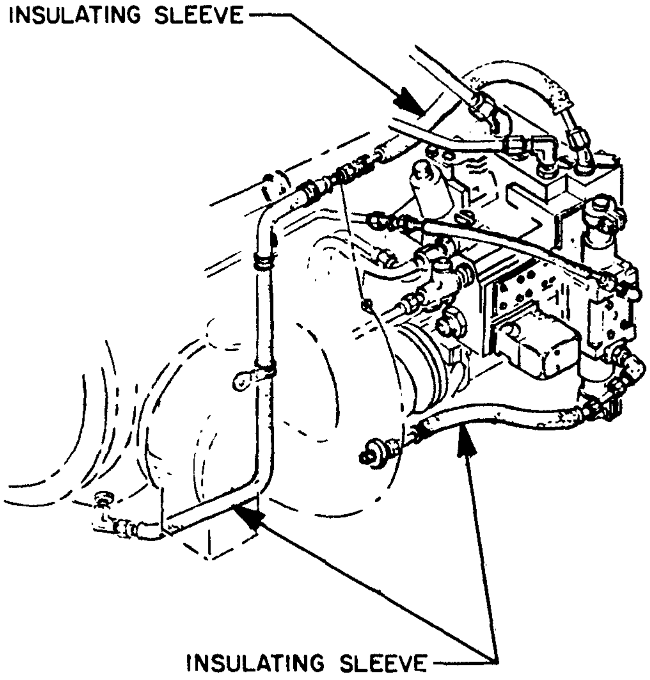


Figure 20. Fuel Control Line Insulation

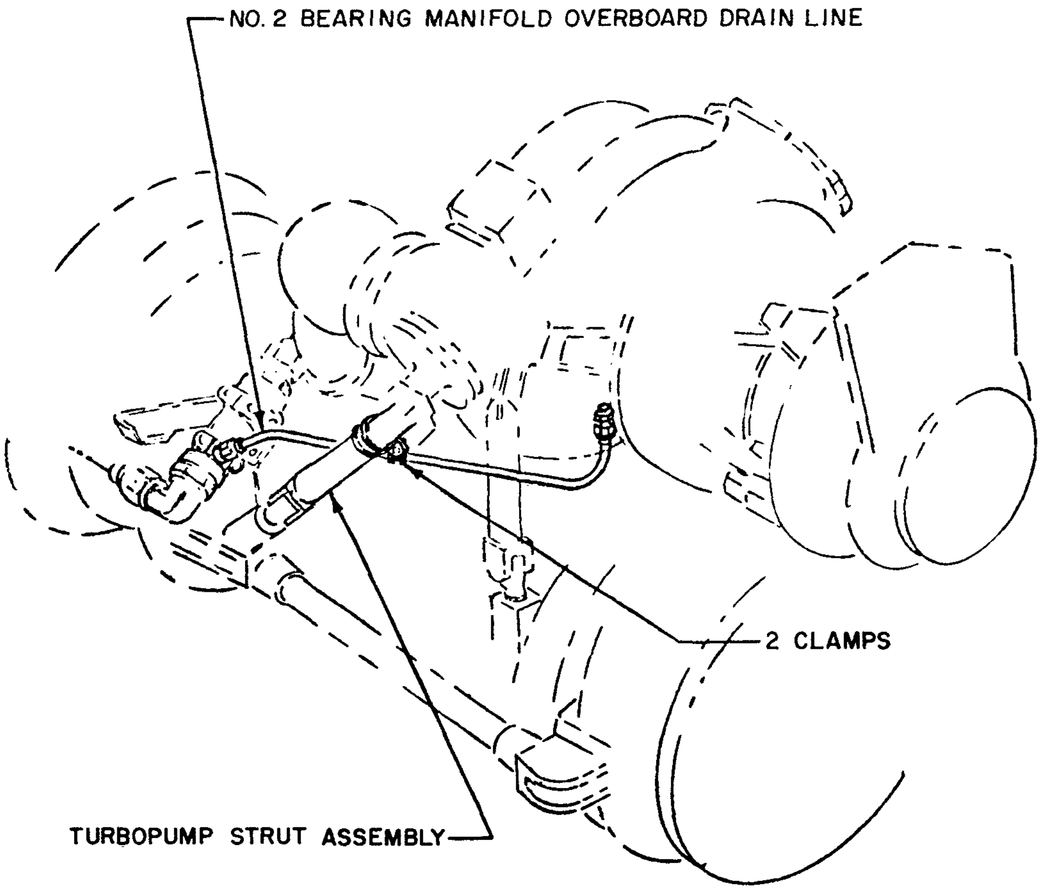


Figure 21. Clamp Between Drain Line and Turbopump Strut

BOOSTER TURBINE EXHAUST FLOWBACK

One of the program objectives was to determine the effects of flowback from the booster turbine exhaust. Other than the normal deposit of soot from the fuel-rich exhaust on the stand structure in the vicinity of the exhaust duct, no harmful effects were noted on the outer surface of the flame shield. Some evidence of exhaust gas was noted inside the flame shield between engine Camloc fasteners of the booster engine boot on both engines but this was very slight and consisted of a light covering of soot. The portion of flowback that approached the booster thrust chambers was sucked down into the flame deflector at the side lip of the deflector.

ACOUSTIC MEASUREMENTS

Two microphones were used to record acoustic measurements during tests 1 through 10. One microphone was fixed in Quadrant II on the A-frame near the sustainer gimbal block but the position of the second microphone was varied from test to test. The locations chosen for the second microphone were (1) near the sustainer hydraulic control manifold, (2) near the sustainer engine LOX pump; (3) near the LOX solo tank, (4) outside the boattail at Quadrant II, and (5) outside the boattail at Quadrant III.

The acoustic recordings were made on a portable tape recorder supplied and operated by GD/A personnel. The results were to be analyzed and presented by GD/A.

FLAME DEFLECTOR TEMPERATURE STUDY

Temperature of the flame deflector was measured at four locations to define the temperature profile during the start sequence. The lowest temperature recorded was -210 F. Figures 22 through 27 present temperature measurements recorded during six tests.

GRATING TEMPERATURE STUDY

The environment of the launcher grating (work platform) was studied during the program and the first 13 tests were conducted with a steel grating installed on the launcher During the last four tests an aluminum grating similar to that used at the OSTF-2 facility was installed on the flame side of the platform. Two thermocouples were installed on the grating, and the typical temperature recorded was 100 F at 1500 milliseconds after start (Fig. 28 and 29).

The roadside steel work platform was found warped (Fig. 30) after the twelfth test and two bolt heads had pulled through the diamond-tread plate on Quadrant IV. After the last test with the aluminum grating a crack was found in one center slot at the extreme end of the platform in Quadrant II. No conclusion can be formed concerning the capabilities of the aluminum grating to withstand actual launch conditions, because the liftoff process introduces variations in the pattern and duration of flame impingement. The damage of Alfa-1 is attributed to repetitive thermal and pressure loads imposed by numerous engine tests

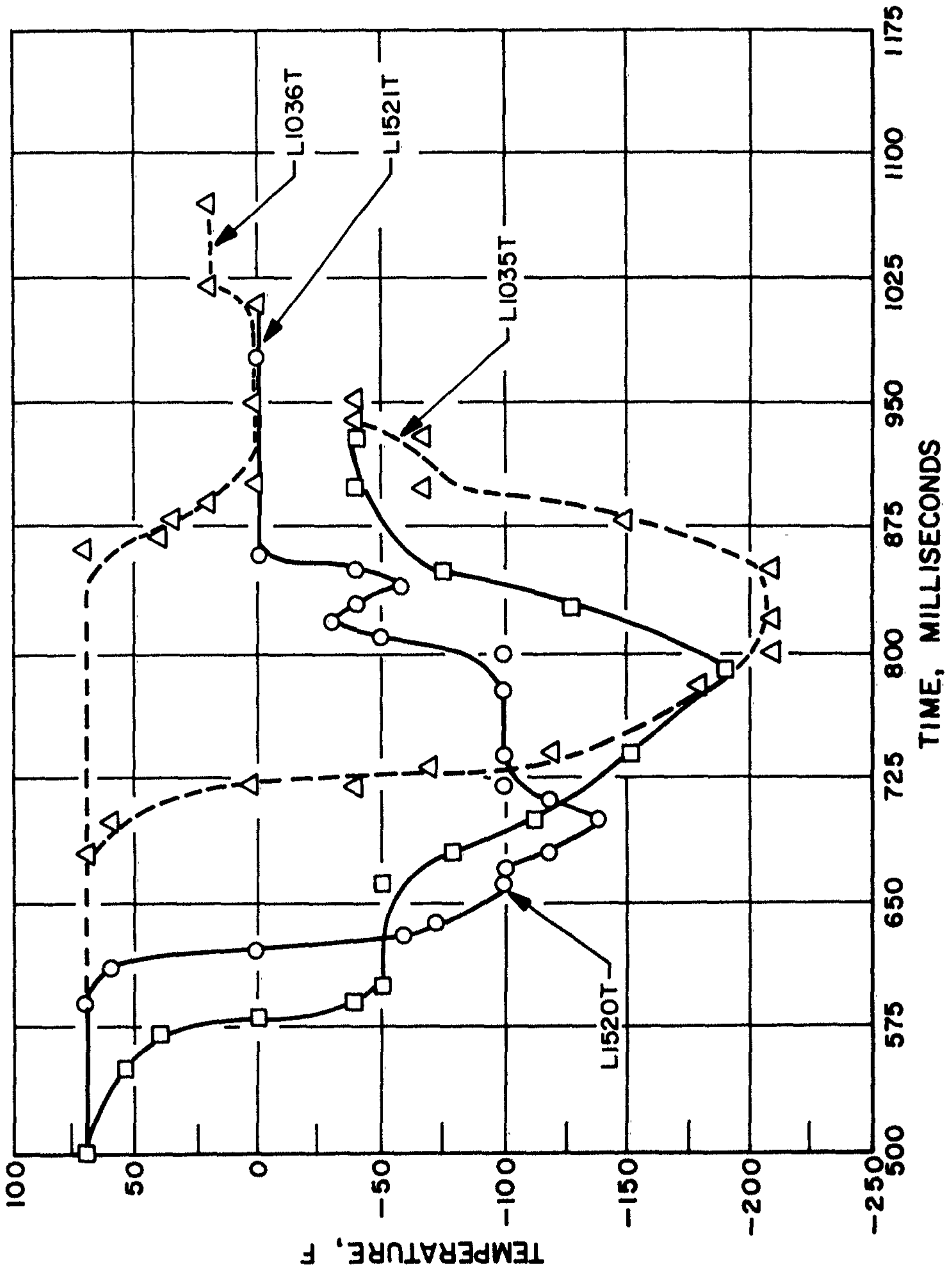


Figure 22 . Deflector Temperature vs Time, Test 2

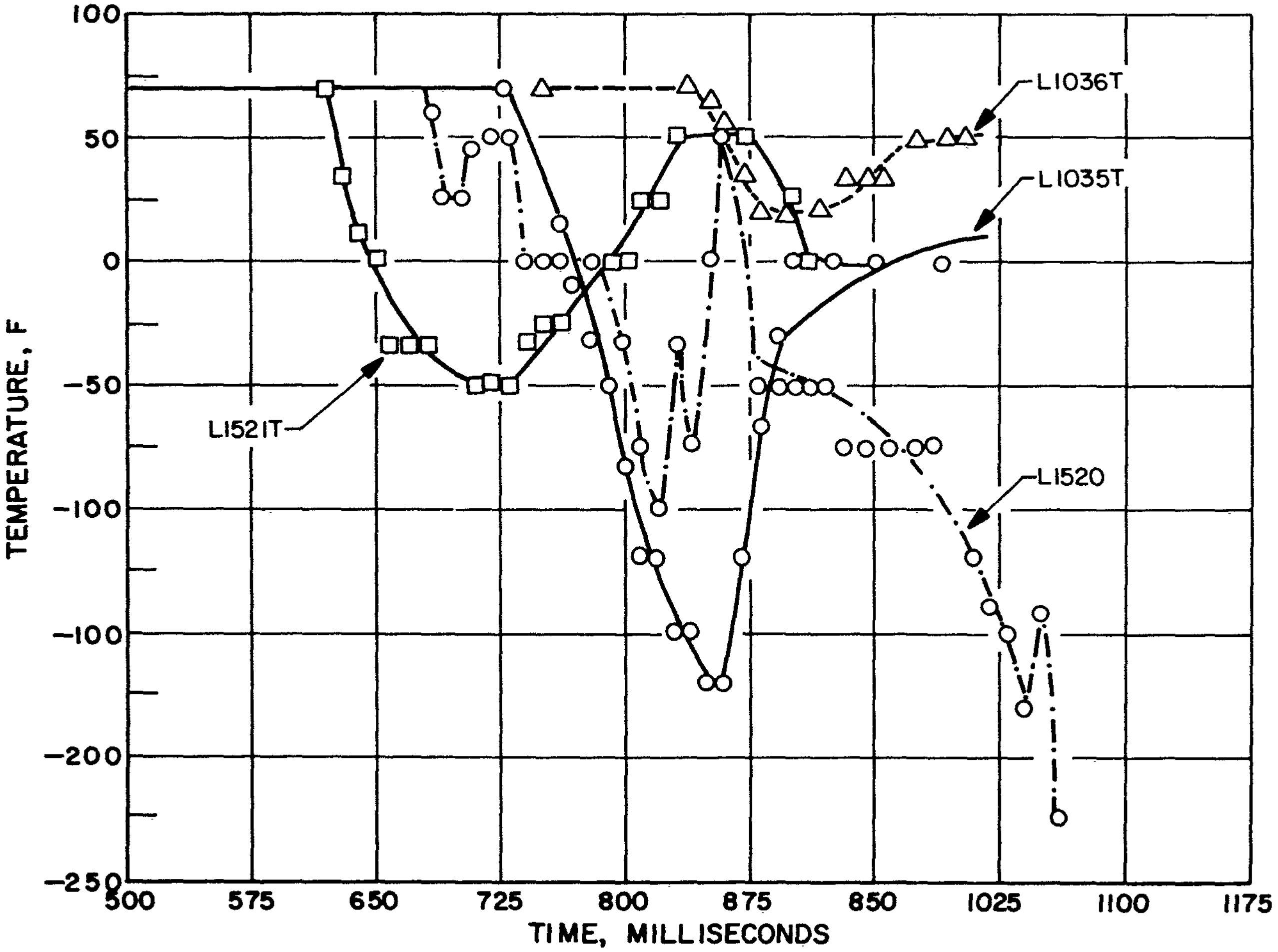


Figure 23. Deflector Temperature vs Time, Test 3

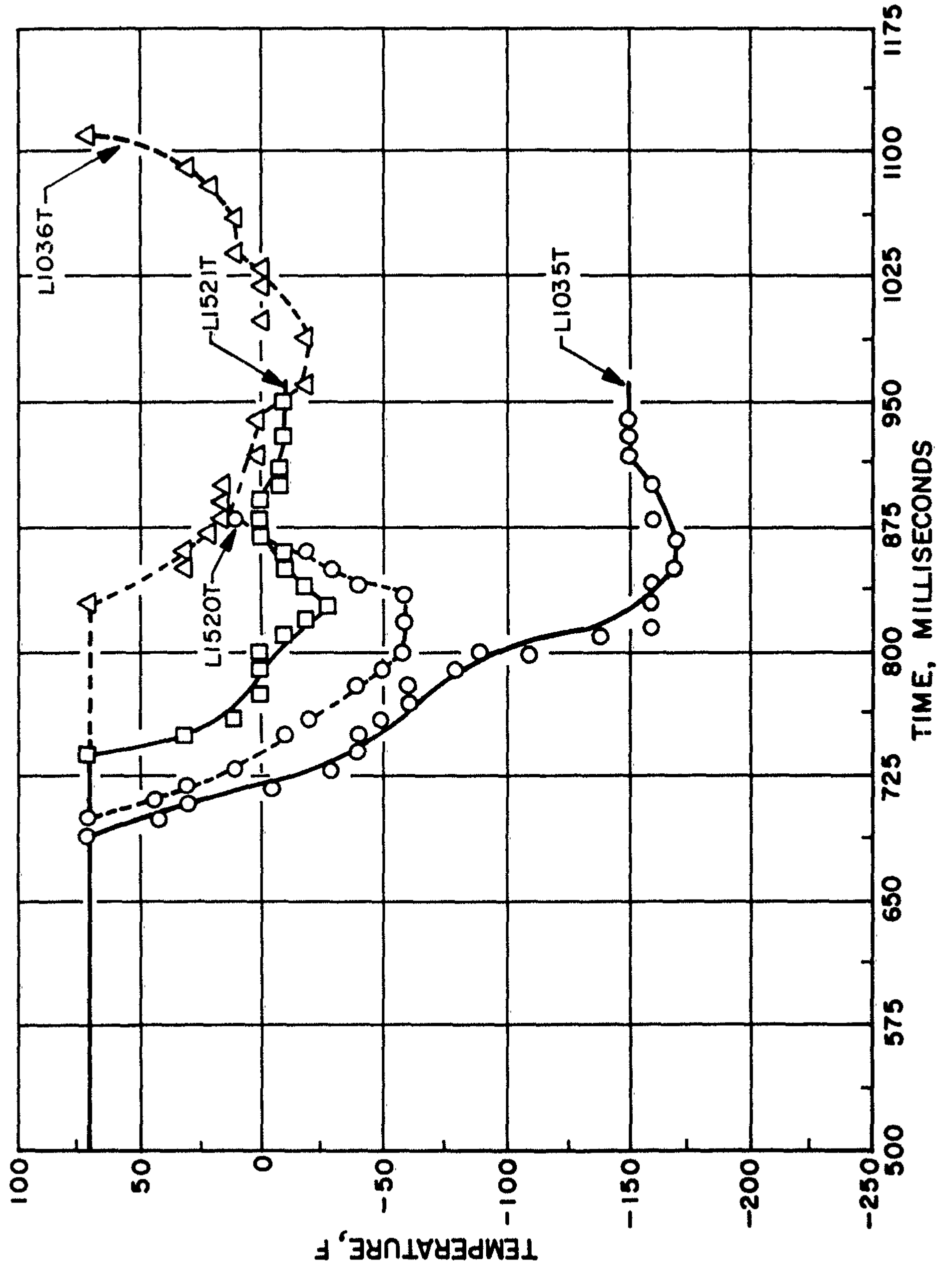


Figure 24. Deflector Temperature vs Time, Test 4

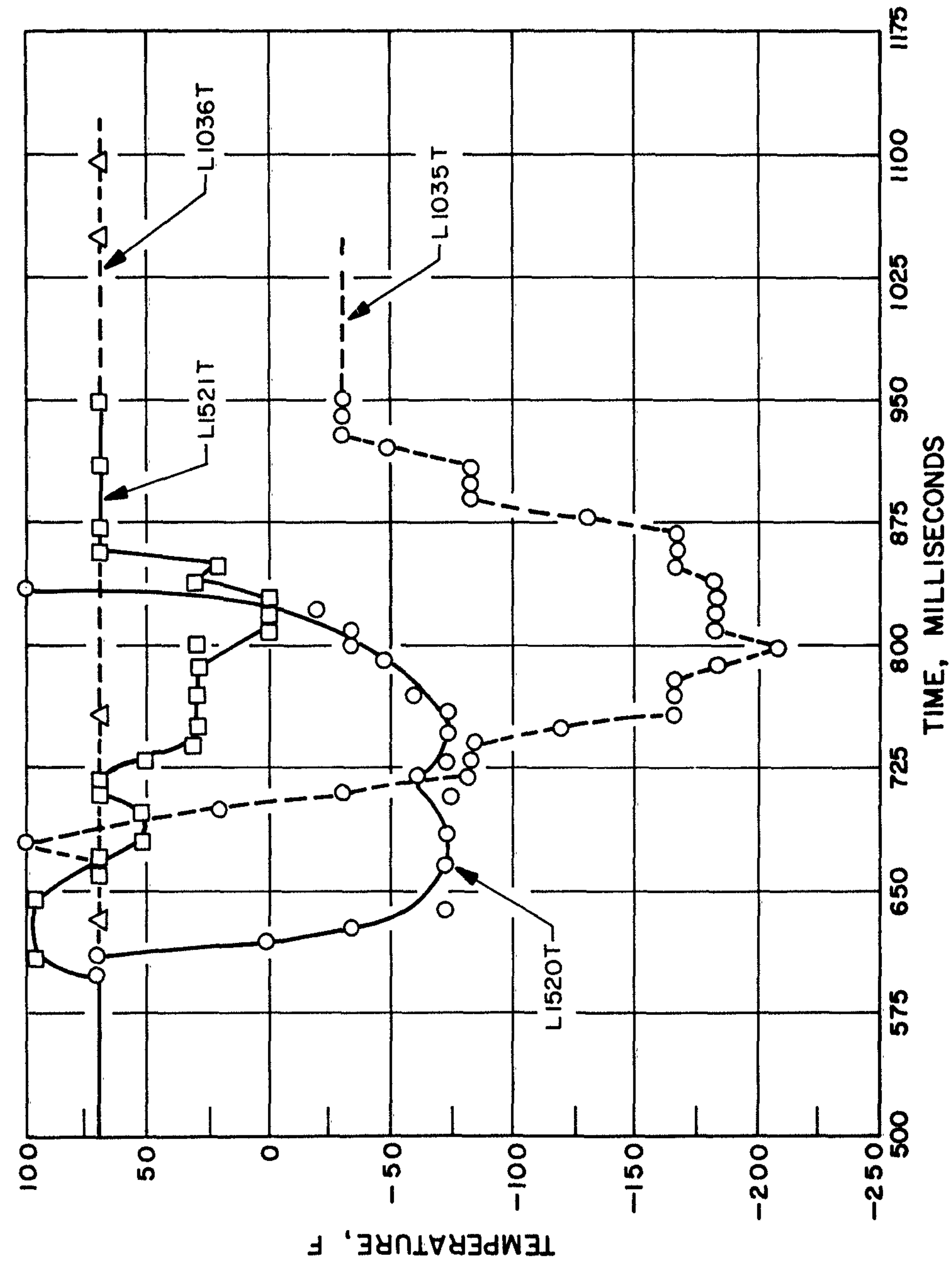


Figure 25. Deflector Temperature vs Time, Test 5

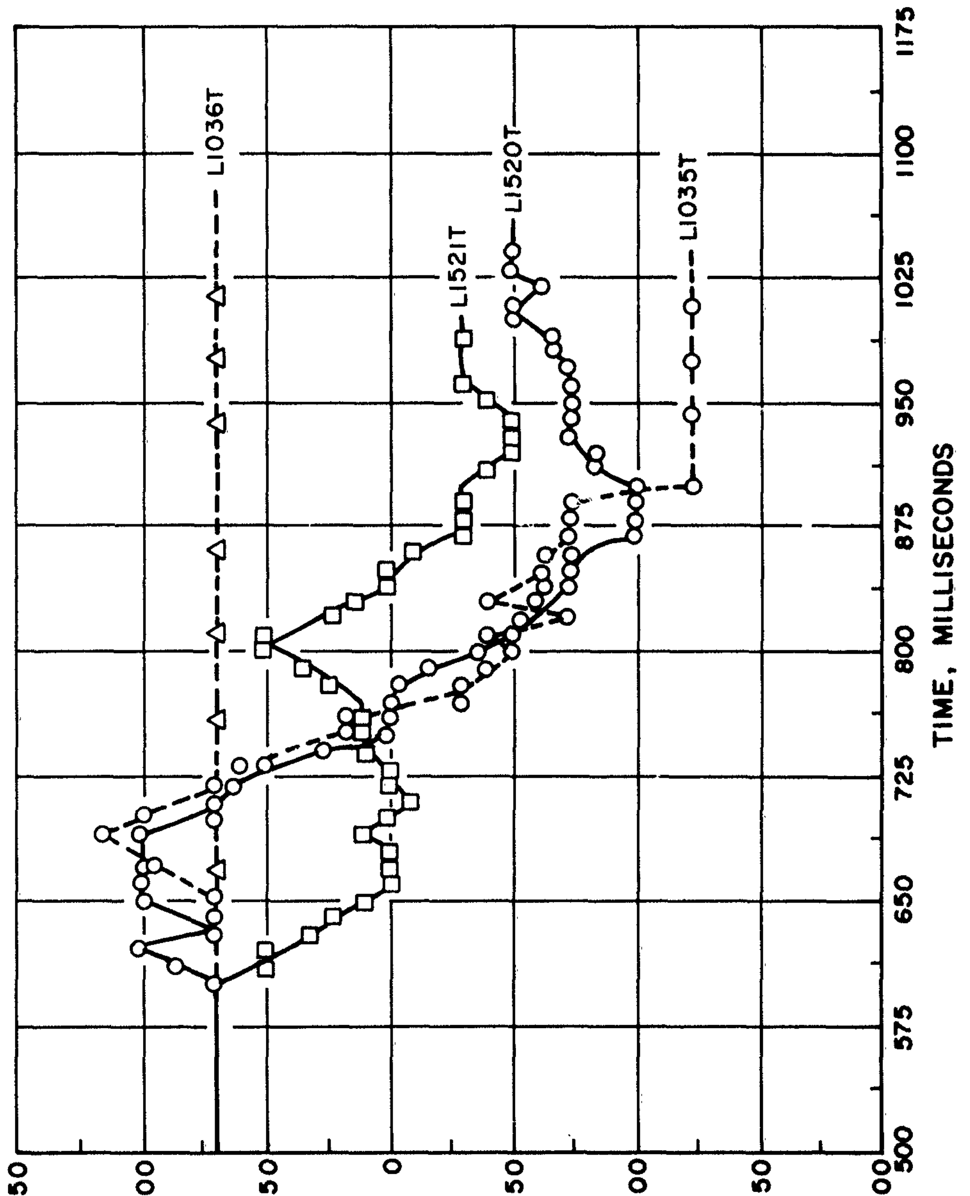


Figure 26, Deflector Temperature vs Time, Test 6

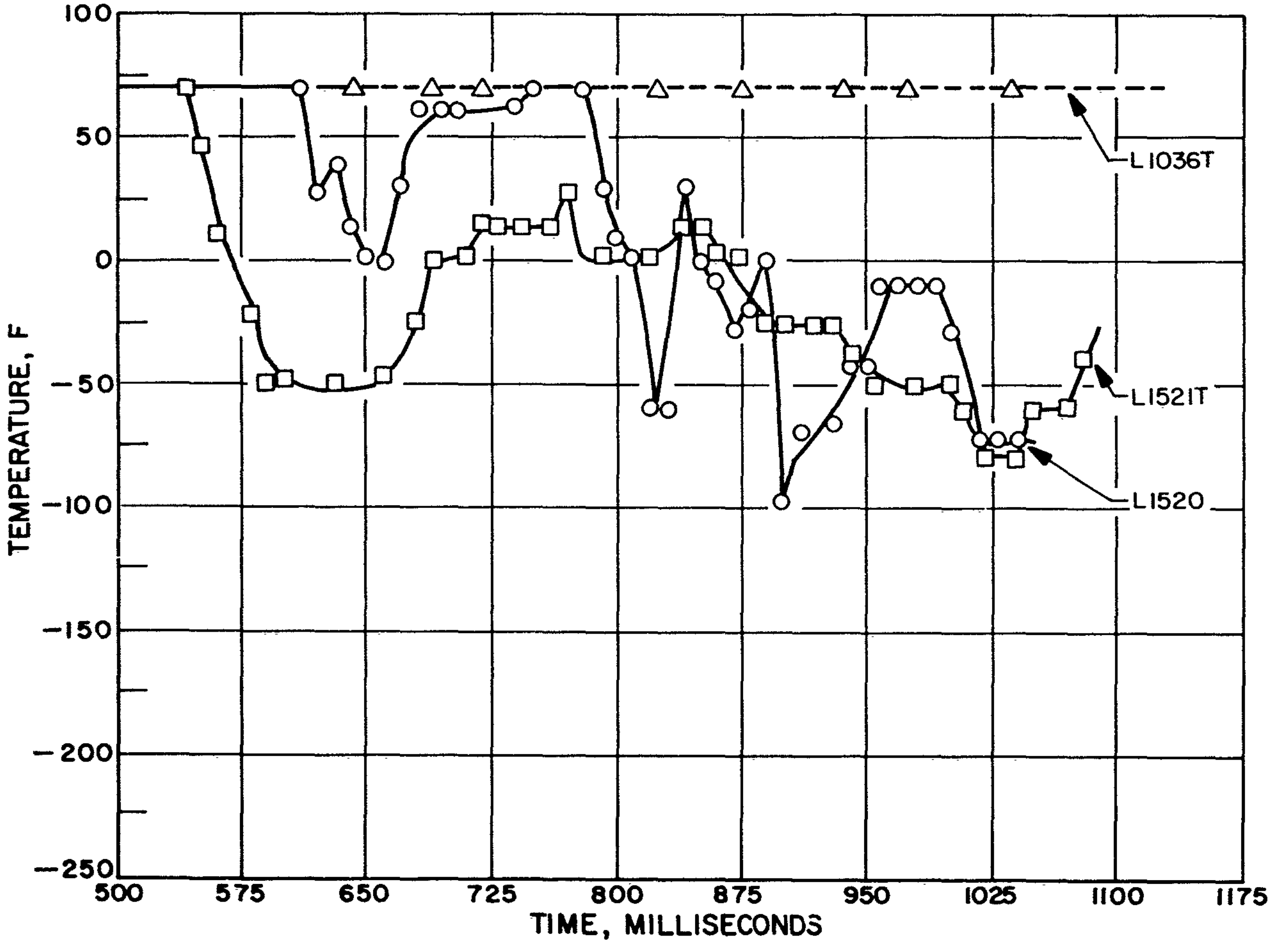


Figure 27. Deflector Temperature vs Time, Test 7

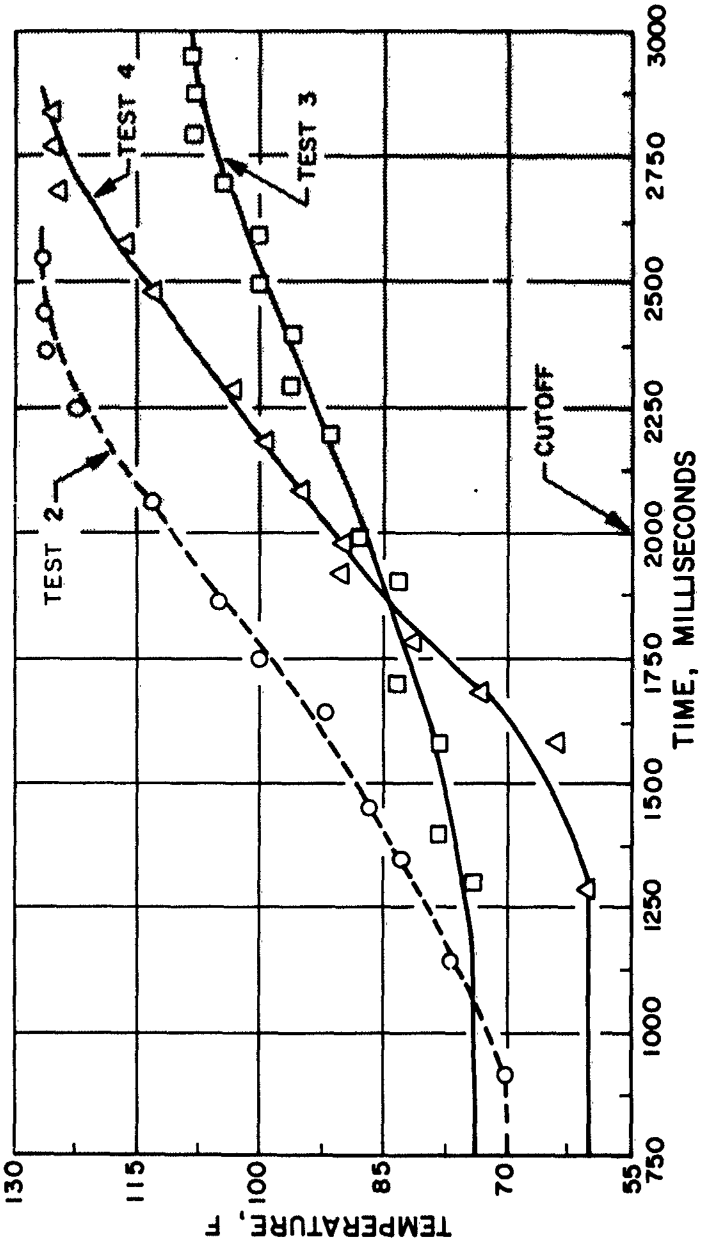


Figure 28 . Grating Temperature vs Time, Booster No. 1

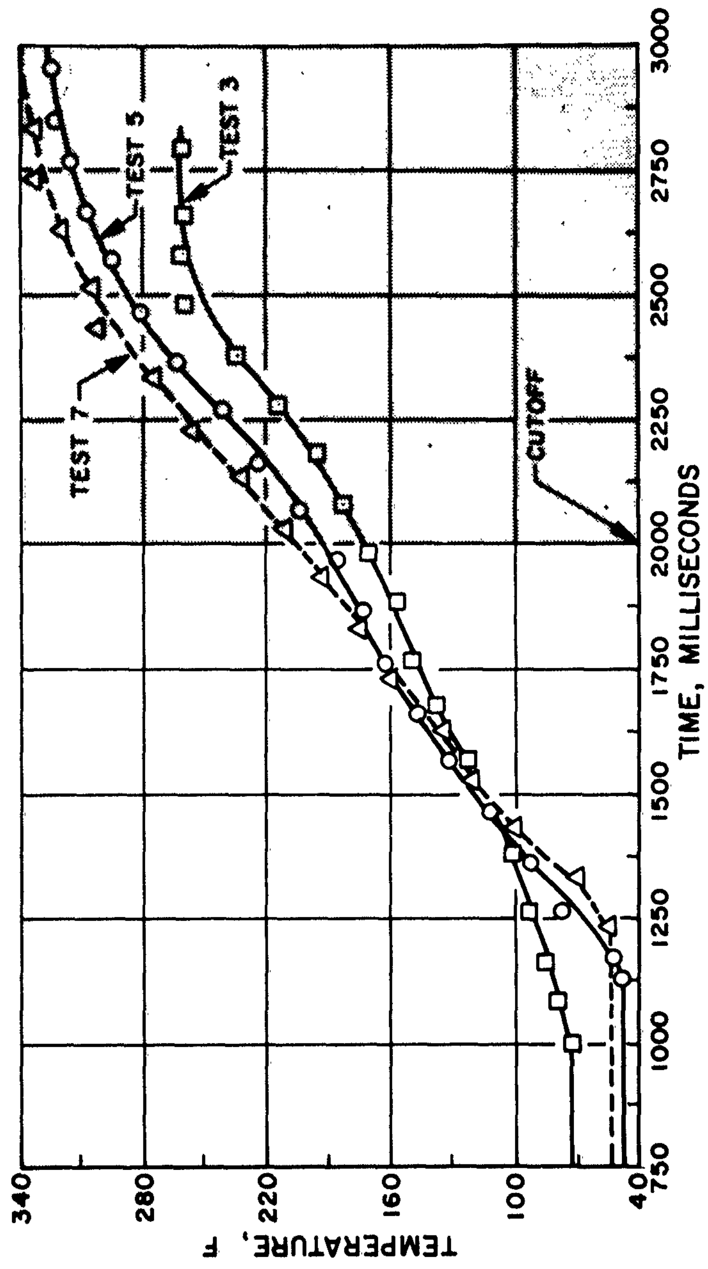


Figure 29 . Grating Temperature vs Time, Booster No. 2

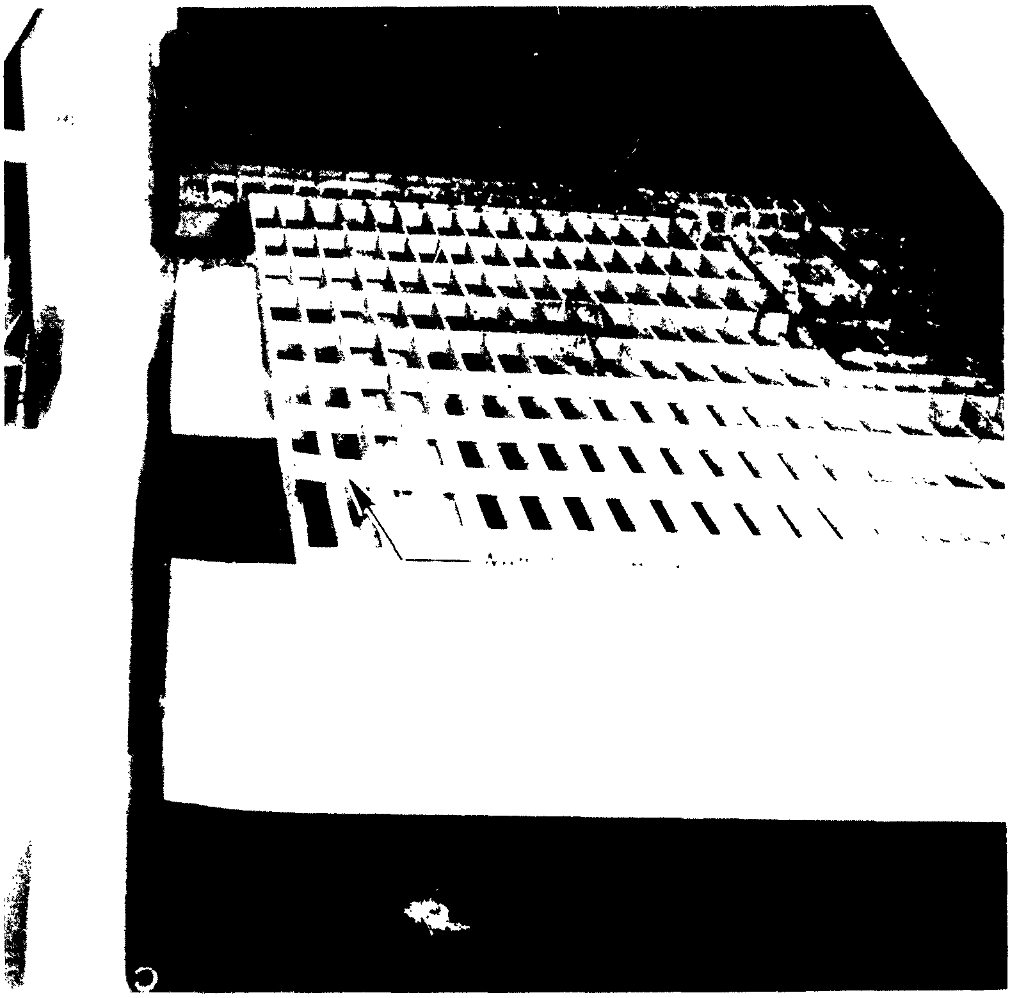


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Figure [illegible]. Damage to Work Platform

HEAT SHIELD TEMPERATURE STUDY

Temperature of the surface of the heat shield aluminum batting was measured inside the boattail, and the data (Fig. 31 and 32) showed that booster No. 1 temperature rose to a maximum of 130 F at 2500 milliseconds after start (cutoff occurred at 2000 milliseconds). All recordings were similar at both locations. In no instance did the temperature stabilize at engine cutoff, so no decisive conclusions can be formed concerning the magnitude of temperature following an actual launch. The temperatures prior to normal liftoff time were not excessive.

SUSTAINER LOX PUMP SHAFT DEFLECTION

A Kel-F liner was installed in the inducer tunnel of the turbopump for the sustainer engine used during this test series. One objective of the test program was to determine the effects that changes in the start sequence would have on shaft deflection of the sustainer LOX pump. The liner was inspected before and after test No. 9, which was the first test incorporating the sustainer-lead start sequence. Initial inspection revealed a slight marking on the surface of the liner. The origin of the mark is not known, but is assumed to be a tool mark that occurred during fabrication or installation of the liner. Posttest inspection revealed no change in the condition of the liner. No inspection was made after the second sustainer-lead test because of the urgency of completing the test program.

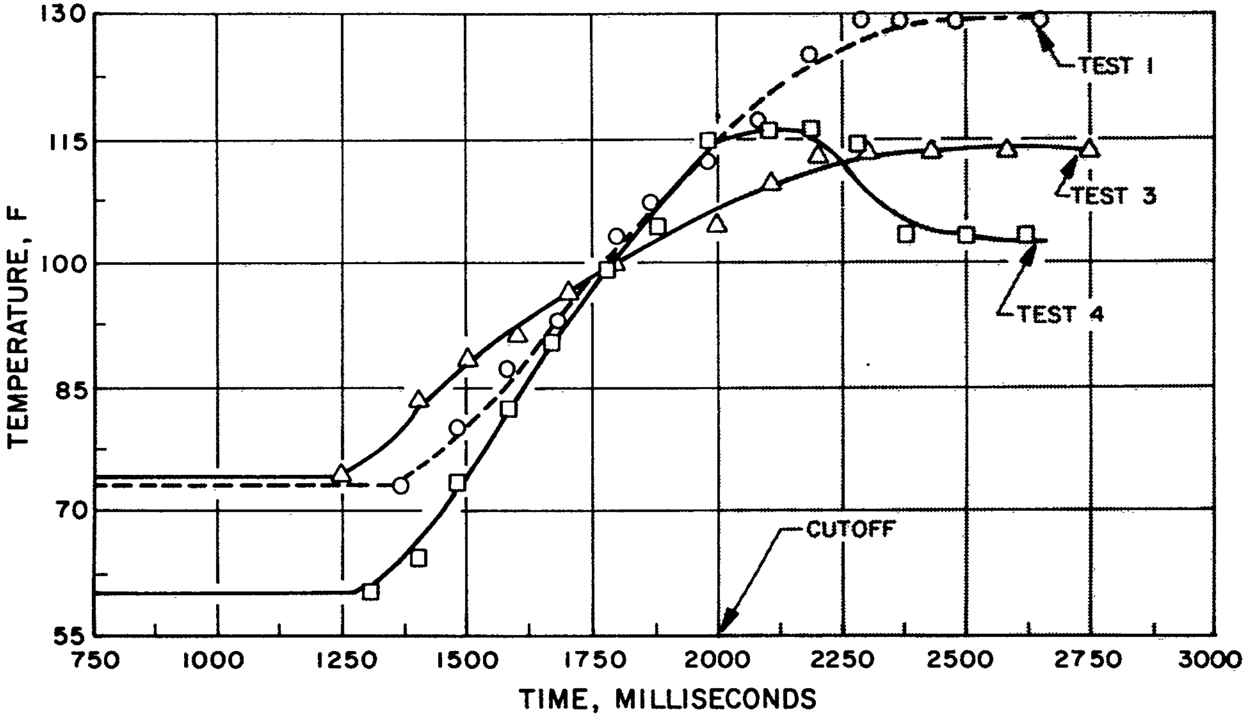

Figure 31. Heat Shield Temperature vs Time, Booster No. 1

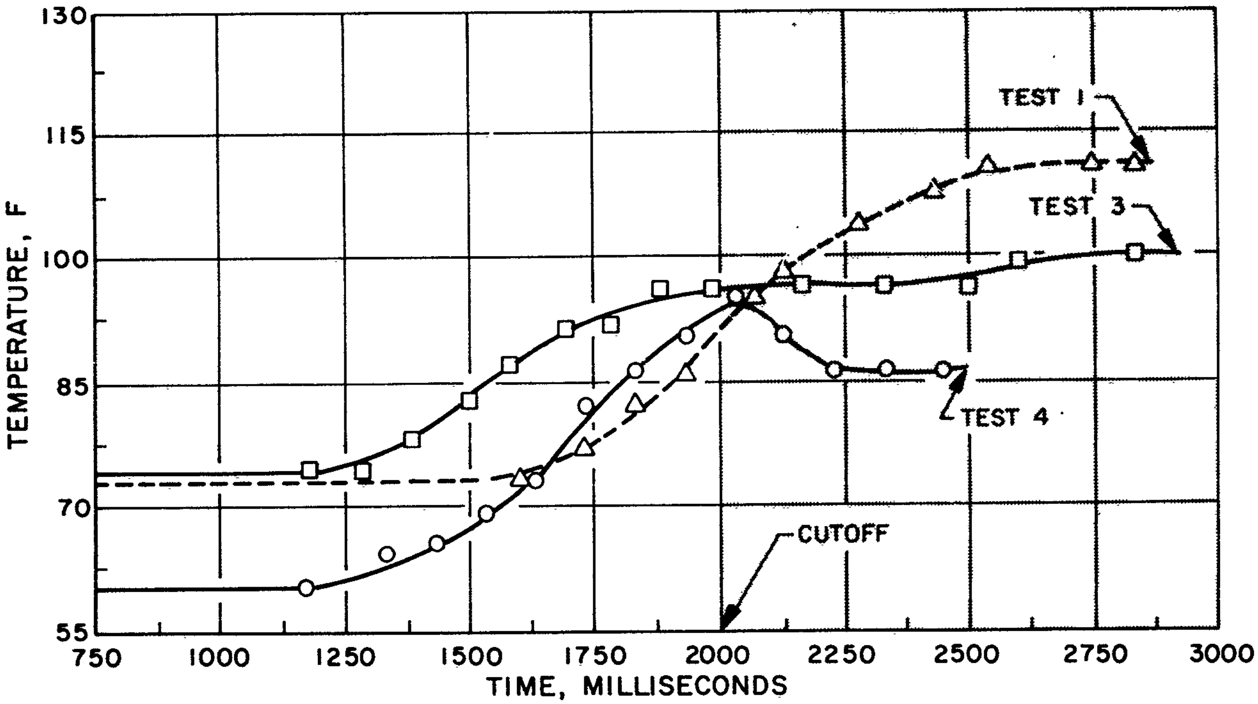

Figure 32. Heat Shield Temperature vs Time, Booster No. 2