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UNCLASSIFIED   TRW-36244-350-004-01   SD-TR-80-58   NL

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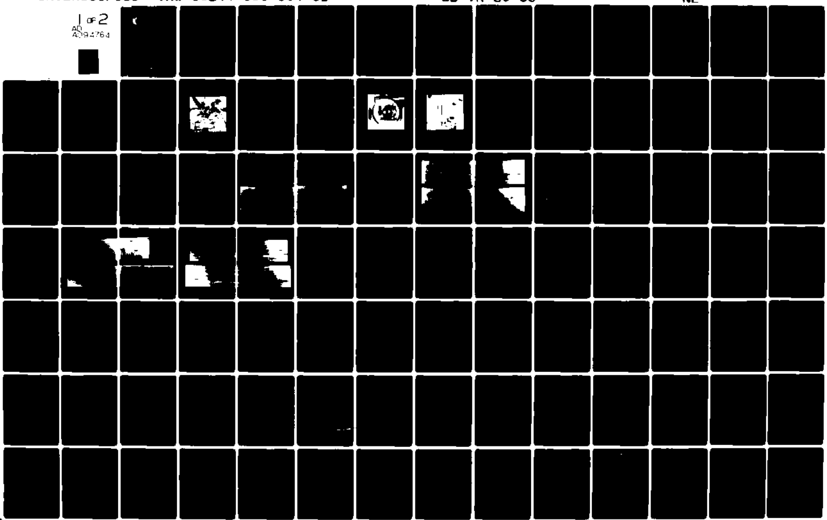

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FLTSATCOM FLIGHT 2
RCS ANOMALY INVESTIGATION
GROUND VERIFICATION TEST
FINAL REPORT

30 JANUARY 1981

APPROVED FOR PUBLIC RELEASE;
UNLIMITED DISTRIBUTION

Prepared for

DEPARTMENT OF THE AIR FORCE
Headquarters Space Division

Contract No. F04701-79-C-0174

TRW
DEFENSE AND SPACE SYSTEMS GROUP

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This report was submitted by TRW Defense and Space Systems Group, Redondo Beach, CA 90278, under Contract F04701-79-C-0174 with the Space Division, Deputy for Space Communications Systems, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for TRW Defense and Space Systems Group by Mr. P. S. Melancon, FLTSATCOM Project Manager. Capt. Arthur F. Havko, SD/YKF, was the project engineer.

This report has been reviewed by the Office of Public Affairs (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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

Thruster Hot-fire Ground Verification Tests have been performed in an attempt to understand the thruster anomalies that were experienced on the FLTSATCOM Flight 2 spacecraft (IRON 6392). While the test objectives of determining the effect of gas bubble ingestion, cold starts with isolation valves closed, effect of seat leakage on first pulses, and susceptibility to "choking" were accomplished, the exact cause for the anomaly was not established. No deleterious effects from cold starts with the isolation valves closed were observed.

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SD-TR-80-58

FLTSATCOM FLIGHT 2
RCS ANOMALY INVESTIGATION
GROUND VERIFICATION TEST
FINAL REPORT

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

1. INTRODUCTION

This Ground Verification Test (GVT) report is a summary of the FSC-F2 thruster anomaly investigation activities performed by TRW Product Engineering to verify certain postulated mechanisms which may be responsible for the apparent malfunction of three 1.0 lb_f thrusters and one 0.10 lb_f thruster. The +PA thruster operating characteristics (loss of impulse of first 1 to 2 pulses during wheel unload) is indicative of and has been attributed to a leaky down-stream seat in the dual seated thruster propellant valve, which was verified via this ground test and discussed herein. The remaining failures are varied and do not indicate a common failure mechanism e.g., total cessation of thrust from one 1.0 lb_f thruster (-Z1A), intermittent loss of impulse from another 1.0 lb_f thruster (-PB), and total cessation thrust from the 0.10 lb_f thruster (-RYB).

Thruster valve driver electronics (VDE) have been analyzed and verified to be operating nominally. The possibility of thruster valve coil "shorts" was also investigated and determined to be a nonviable candidate, thereby eliminating electrical failures from further consideration (Reference 80.4721.2-101 dated 10 April 1980).

It was therefore concluded that the most probable cause of the problems (other than +PA) is associated with either pressurant gas on the liquid side of the tank diaphragms or from localized contamination within the thruster assemblies themselves. The probability of general propulsion system contamination is considered to be quite low because of the extensive nominal operation of the other thrusters. The RCS anomaly Ground Verification Test was established to investigate these remaining potential thruster anomaly mechanisms.

2. BACKGROUND

Four anomalies have occurred recently (November 1979 to March 1980 time frame) involving thrusters on the FLTSATCOM Flight 2 spacecraft. A general summary of these four anomalies is as follows:

- +PA thruster. This is a 1.0 lb_f thruster used primarily for wheel unloading and pitch control. The thruster began operating in an anomalous manner during the wheel unloading operations in late 1979. The type of problem experienced was loss of impulse during the first few pulses in a 5 to 10 pulse train. Telemetry data indicates this behavior is consistent and therefore an anomalous condition which is stable and predictable. Late December 1979 the +PA thruster was "burned out" with a rapid series of ~100 msec pulses (∿50 to 100 pulses). The thruster was then cooled down to ambient and subsequently fired in a wheel unload sequence. The wheel ΔRPM pulse data indicated thruster performance was back to nominal. However, the very next burn (∿3 weeks later) thruster performance was back down again.

- -PB - 1.0 lb_f thruster. During the last 10 to 15 seconds of the 1413 second ΔV burn on -Z1B and +Z2B, satellite rate data indicated that the -PB thruster was underperforming (either missing pulses or putting out low efficiency pulses). After several missed pulses and termination of the ΔV maneuver, the AVCS continued to command -PB to pulse whereupon -PB was able to take control and bring the satellite into the required range. The -PB thruster was later calculated to be operating at nominal efficiency again.

- -Z1A - 1.0 lb_f thruster. After operating nominally for 66 seconds during a ΔV burn, -Z1A failed "off" completely in that while it was still commanded in both the steady state and off-modulation modes, it produced an undetectable amount of force. No further attempts to restart -Z1A have been made to date so the current operating status of -Z1A is yet undetermined.

- -RYB - 0.1 lb_f thruster. The -RYB anomaly occurred on 28 February 1980 where it was noted during a routine pass that the roll/yaw rates were getting excessive, indicating no output from -RYB. Barrier tube temperature data indicated that -RYB was not firing so Roll/Yaw control authority was switched to +RYA thrusters which subsequently eliminated the RY error. Approximately 5 hours later -RYB was again commanded on manually at a rate of three pulses per second for 5 minutes and no temperature rise was observed. It was concluded that -RYB had failed "off." Note that initial firings of the -RYB thruster were performed with the bank "B" isolation valve closed.

Several mechanisms have been postulated as potential or probable causes of the anomalies. The postulated failure modes which were addressed in this ground test procedure are as follows:

- What effects of gas bubbles entrapped in the propellant feed system have on thruster operation as applied directly to the -PB, -Z1A and -RYB thruster failures
- Is thermal "choking" (propellant decomposition upstream of the injector) a possible operating mode for FSC thrusters and could it be a candidate for the observed anomalous behavior
- Determine if a leaky downstream valve seat could cause a loss of impulse as observed from the +PA thruster.

The remaining possible failure mechanism which was not addressed in this test is contamination.

3. TEST OBJECTIVE

The objective of this test program is to improve the understanding of how FSC-type thrusters operate in certain anomalous conditions. This information could aid in determining the cause of the on-orbit anomalies, determining recommendations for flight operations and, possibly, corrective actions for future flights.

The test is segregated into three categories (Tasks I through III) each with individual objectives as outlined below:

- Task I - Gas bubble injection (-Z1A, - PB and -RYB failures)

  These tests were performed to study performance parameters and temperature profiles of both the 0.10 lb_f and 1.0 lb_f thrusters to determine their response during pulse mode firing with gas bubbles in the system.

  Also included in this task was a direct simulation of the -Z1A on orbit failure to investigate the 1.0 lb_f thrusters susceptibility to "choking" given the apparent FSC operating constraints.

- Task II - Closed iso valve (-RYB failure)

  The objective of this task was to measure thruster response (both 1.0 lb_f and 0.10 lb_f thrusters) to "dry firing" (closed isolation valve). Testing the 0.10 lb_f thruster in this configuration attempted to reproduce the -RYB failure. Firing the 1.0 lb_f thruster in this test enabled characterization of the observed response during nominal sun-acquisition checkout maneuvers performed during the ascent operations.

- Task III - Simulation of leaky valve seat (+PA thruster)

  This task reproduced the failure mode of the +PA 1.0 lb_f thruster by firing with a "dry" valve to simulate a downstream seat leak in the thruster propellant valve.

4. SUMMARY/CONCLUSIONS

The following is a consolidated version of Section 10 of this report entitled GVT Test Results/Conclusions.

- System entrapped gas (GN_2) bubbles have been determined to cause random loss of impulse indicative of the -PB failure mode.
- GN_2 gas bubbles can support sustained periods of reduced impulse (<10 percent of nominal) as observed from the RYB thruster.
- The +PA postulated failure mode (leaky downstream valve seat) has been verified.
- Isolation Valve "closed" thruster firings have been determined nondetrimental to thruster health in the near term.
- The 0.10 lb_f thruster was found to be susceptible to choking under certain extreme operating modes not readily obtainable in flight applications.
- The 1.0 lb_f thruster will not "choke" when operated within nominal FSC modes.

5. CORRECTIVE ACTION FORECAST

The following items are recommended to aid in the Flight 2 anomaly investigation and prevent similar failures on future spacecraft.

- Review potential for introducing contamination during RCS handling, testing and servicing operations
- Obtain additional flight data without risk to spacecraft health
- Establish corrective actions for Flight 2 to minimize additional problems, e.g., maintain single tank operation, bleed bubble, etc.
- Actions already taken to prevent contamination introduction include hot f--e acceptance testing with "slave" thruster valves, and ;)pellant loading procedure modifications.

6. TEST HARDWARE

The test item is a FSC similar dual thruster module wherein two thrusters are mounted (1.0 lb_f thruster and 0.10 lb_f thruster). The DTM is otherwise identical to FSC flight units with thermostats, catalyst bed heaters, heat shields, valve heaters, bracket and thermal standoffs inclusive. The DTM is shown in Figures 6-1 and 6-2. The DTM was built to conform with TRW Drawing 412620 except the right side thruster is a 0.10 lb_f thruster with all the associated hardware as per TRW Drawing 412118.

The 1.0 lb_f thruster is a flight spare which was modified to incorporate a chamber pressure tap (P_c) for performance measurement.

The 0.10 lb_f thruster was also a FSC flight spare thruster chamber assembly. The chamber and nozzle were removed to allow installation of a Pc tap in the nozzle. The thruster was then reassembled, catalyst loaded, and reconfigured to a thruster assembly.

The piece-part serial numbers of the major component parts of the DTM is as follows:

• 0.10 lb_f thrust chamber	316
• 1.0 lb_f thrust chamber	319
• Thruster propellant valve (1.0 lb_f)	311A
• Thruster propellant valve (0.10 lb_f).	334A
• 0.10 lb_f thruster	316
• 1.0 lb_f thruster	319
• Dual Thruster Module	X100

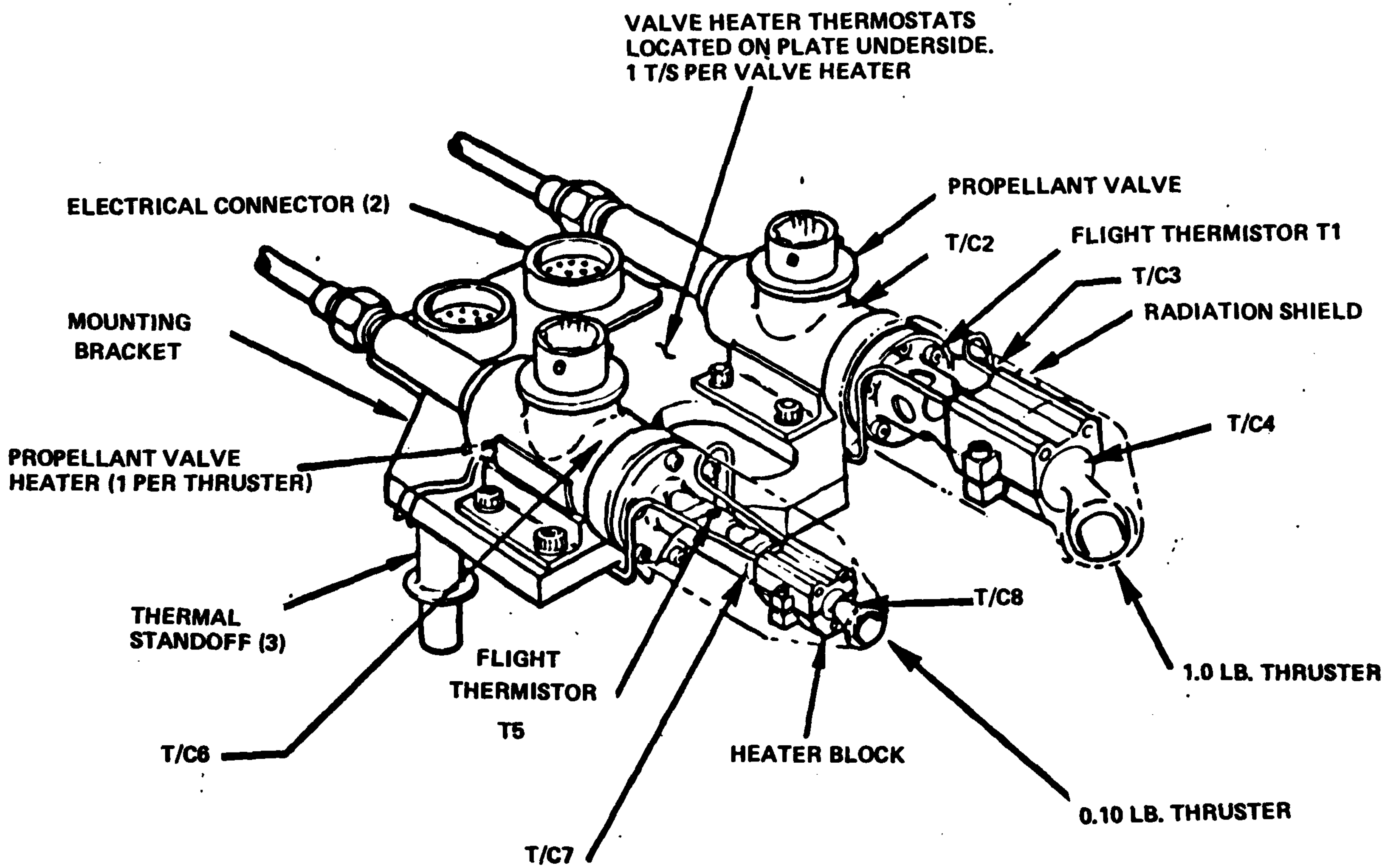


Figure 6-1. GVT Dual Thruster Module

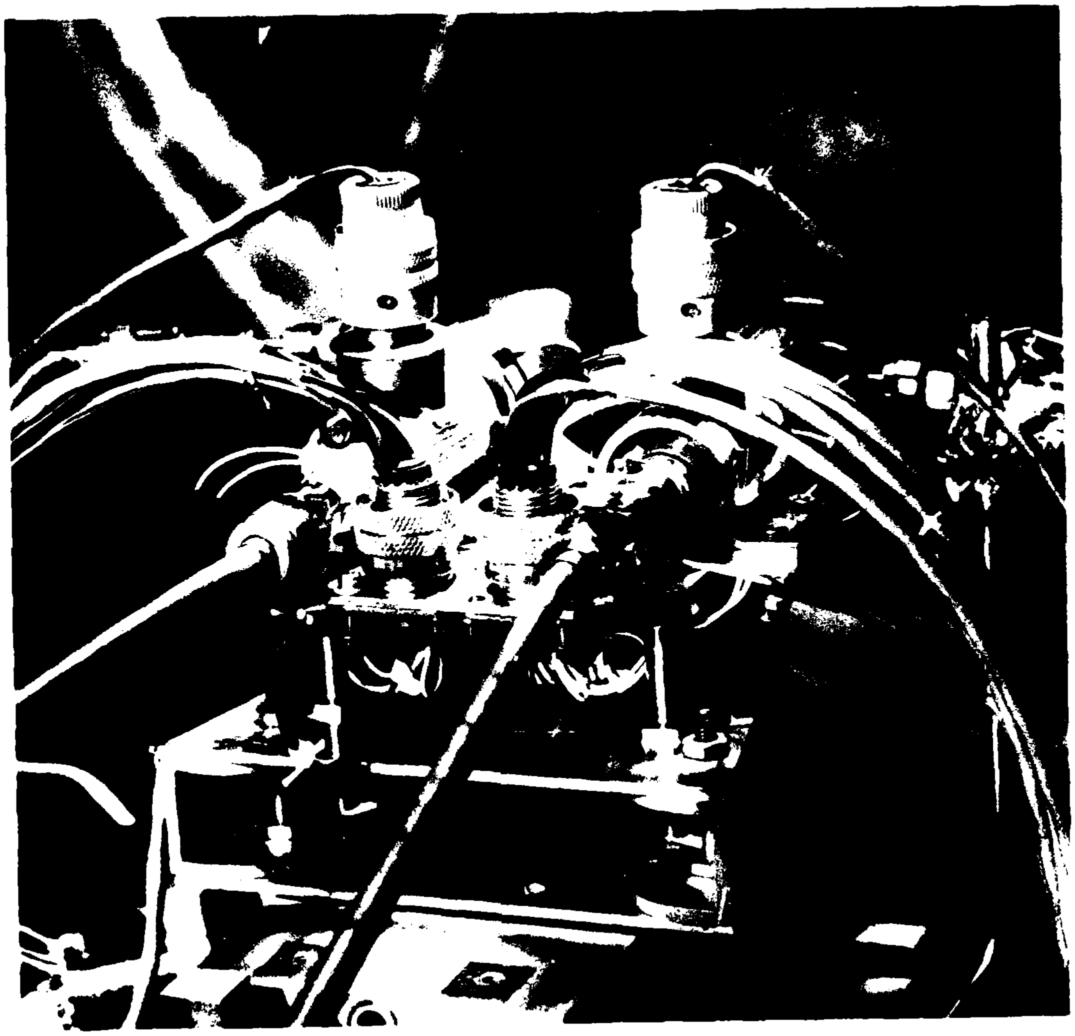


Figure 6-2. Ground Verification Test Dual Thruster Module

7. TEST SET-UP/INSTRUMENTATION

The test was performed in the low thrust test facility in Building 01, Room 1361. The DTM was installed in vacuum chamber No. 2, capable of simulating altitudes of greater than 100,000 feet. The entire propellant supply system with the exception of GN_2 pressurant was installed inside the vacuum chamber. Two propellant supply tanks (1 gallon each) were used to perform the test. The feed system is a reproduction of the FLTSATCOM on-board system which utilized flight-type isolation valves, a facility filter immediately downstream of the tank, and propellant lines of the exact size and length of the spacecraft system (variable to accommodate different thruster locations).

In addition, several in-line components were added to allow testing under special controlled conditions. These and other FLTSATCOM dissimilar components necessary to facilitate testing are outlined below:

- A special GN_2 source with associated lines and fittings necessary to enable GN_2 saturation of the propellant in the tank
- A shutoff valve near the propellant tank outlet and an aspirate valve near the thruster inlet (twenty inches upstream)
- A pressure transducer near the thruster inlet to record system pressure
- A parallel path line system (164 inches in length) to inject GN_2 bubbles into the primary line system during thruster operation.

A schematic of the entire feed system is shown on Figure 7-1. Each task employs a different line length (variable portion) to provide a direct comparison to spacecraft interface. The line system was built with swage-lock fittings with teflon ferrels. To minimize possible gas entrapment areas, the entire system was built within one horizontal plane as much as possible. The test system is pictured on Figures 7-2 and 7-3.

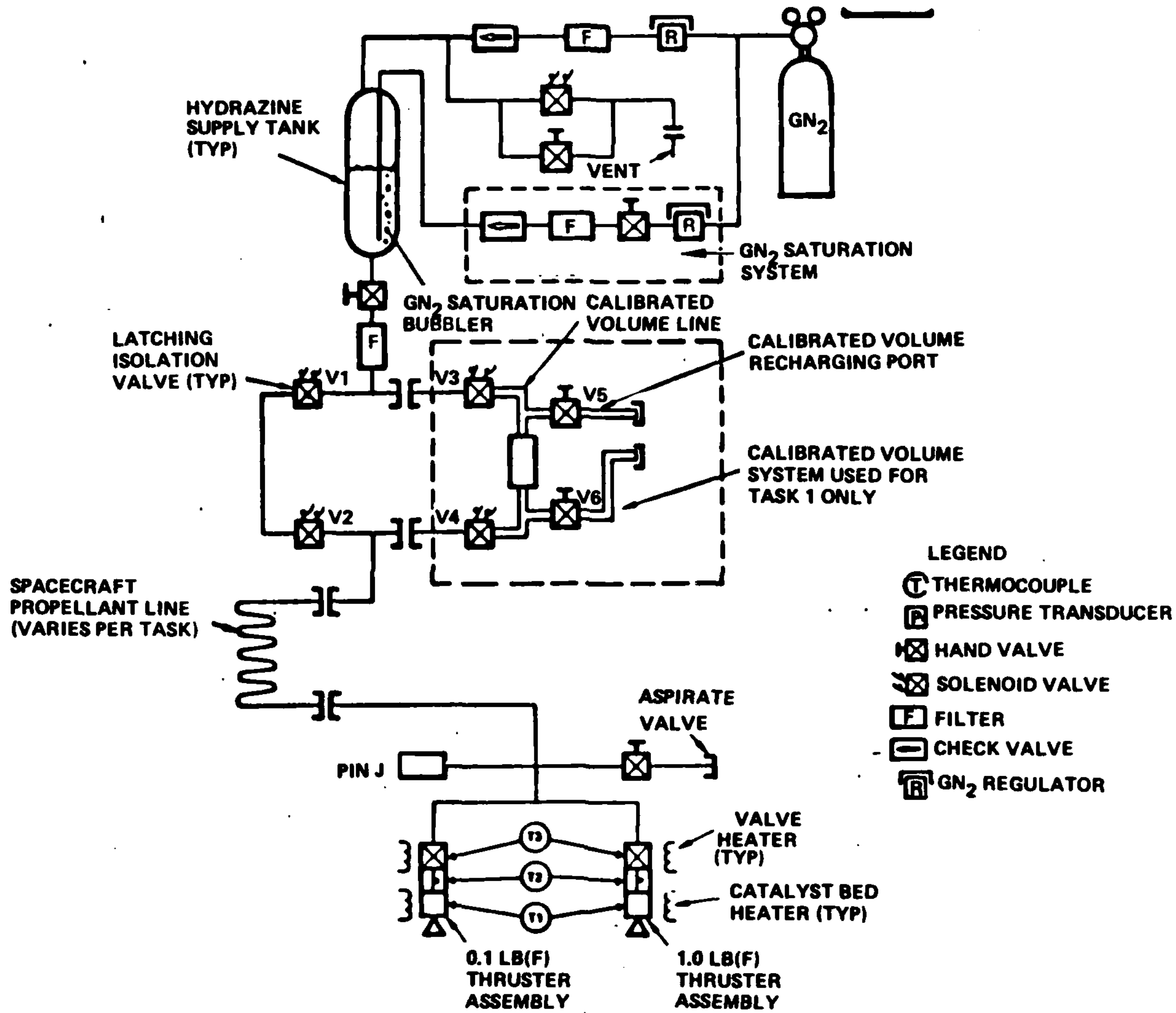


Figure 7-1. Propellant Feed System

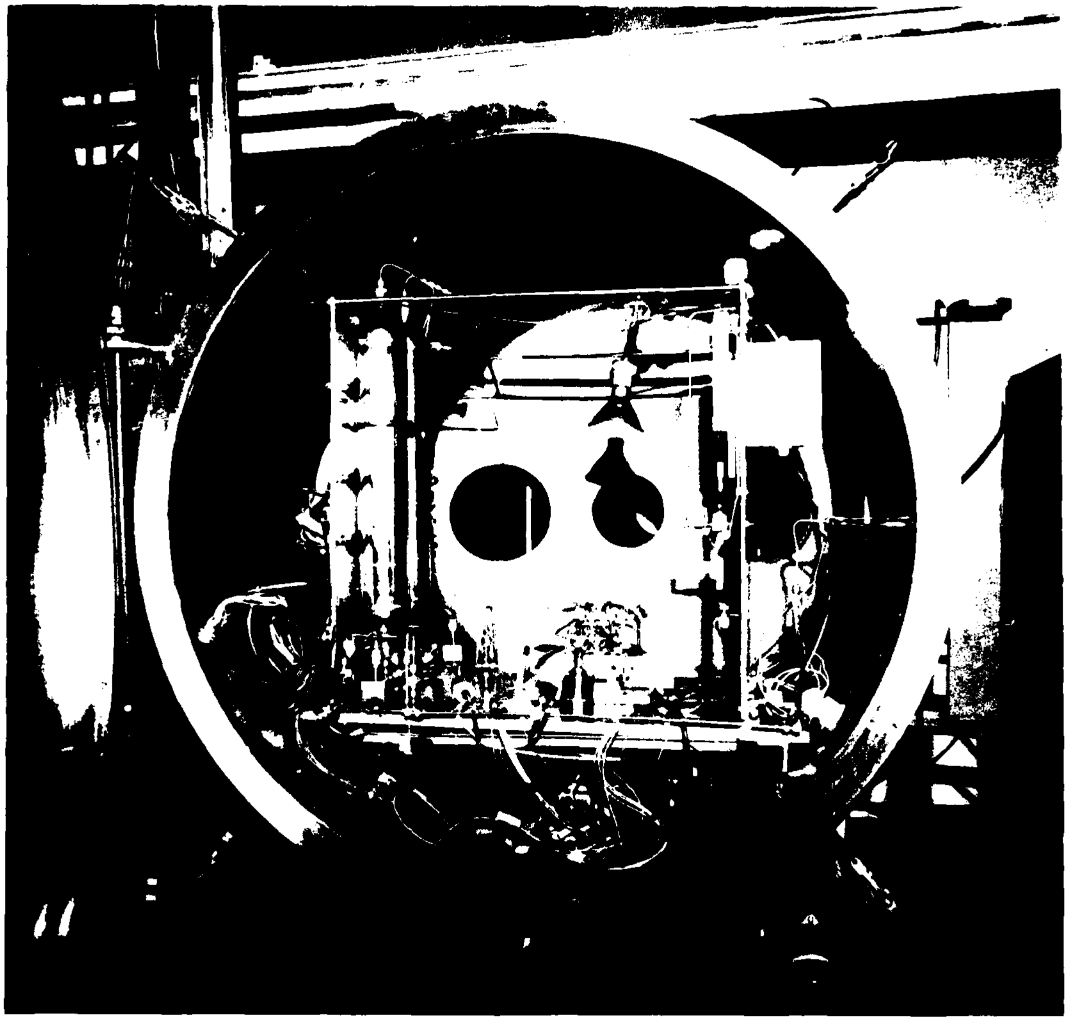


Figure 7-2. Test Vacuum Chamber

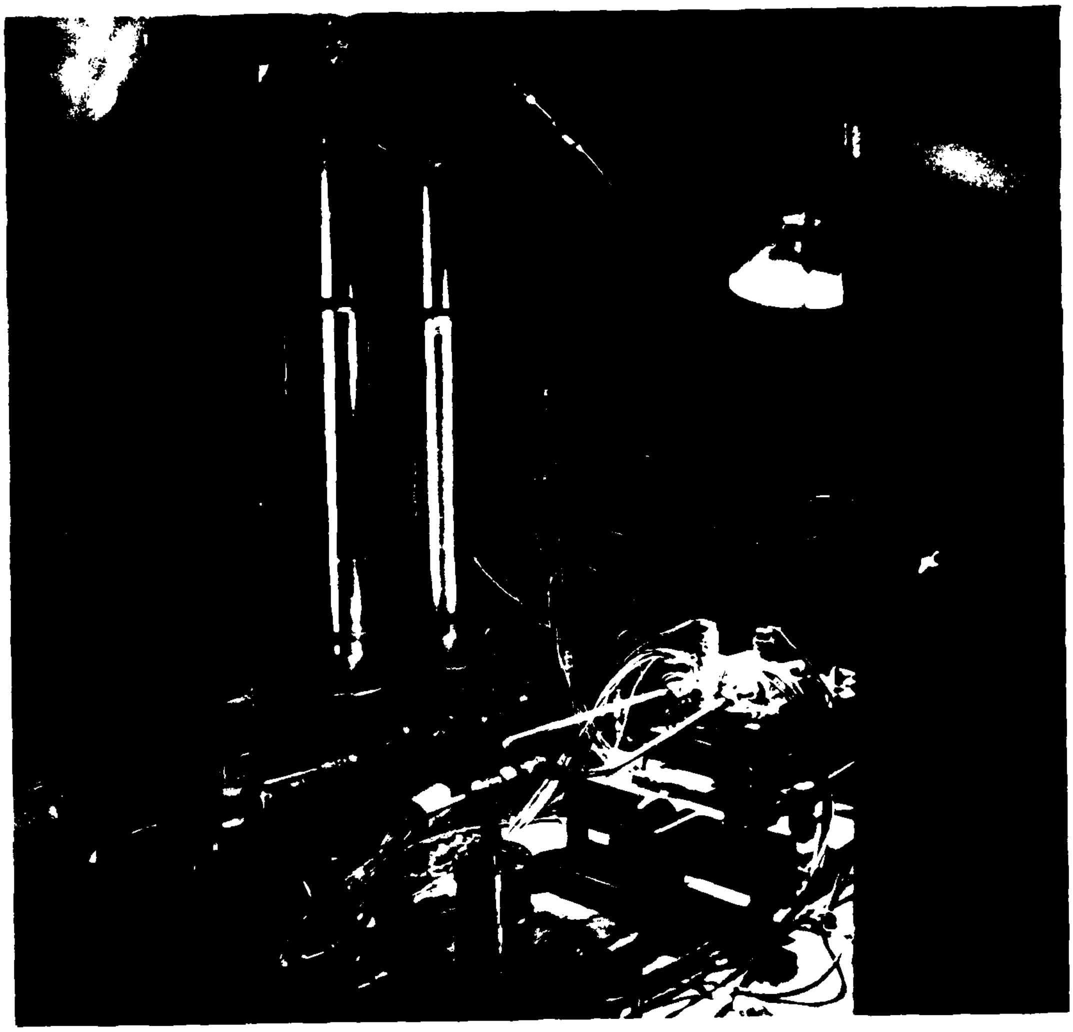


Figure 7-3. Propulsion Feed System

8. TEST MATRIX

A complete summary of all the tests performed along with objectives and results of each test is shown on Table 8-1. The test matrix is separated into three major categories (Tasks I through III) as outlined earlier. An additional category (selected retest) was formed to provide a means of retesting to investigate further or confirm results of the basic test plan. Both thrusters also were exposed to a nominal baseline performance test sequence both with saturated propellant and unsaturated propellant to insure nominal thruster operation. All other tests were run with GN_2 saturated propellant unless otherwise noted.

A description of the various operating modes of each of the four test categories is given in the following paragraphs.

8.1 TASK I TESTING

All tasks performed in Task I have test numbers of the format I - XX (See Table 8-1). Tests were broken down into two major categories (Tests 1 and 2). Test 1 includes operation of both the 1.0 lb_f thruster and 0.10 lb_f thruster in their respective pulsing modes (0.050 sec pulses @ 1 Hz for the 1.0 lb_f thruster and 0.020 sec. on @ 1 Hz for the 0.10 lb_f thruster). Two different size bubbles (10 cc and 100 cc) were ingested by each thruster while pulsing. The feed system was configured in accordance with Figure 7-1 (variable line length equals 37 inches).

The second portion of Task I testing (Test 2) was performed using the 1.0 lb_f thruster in a simulation of the -Z1A failure ΔV. The thruster was fired steady state, then "off-modulated" according to the FSC flight operating modes. Bubbles of two sizes (10 cc and 100 cc) were introduced along with elevated valve temperatures in an attempt to reproduce the -Z1A failure by "choking" the thruster. The variable line length of the feed system was again set at 37 inches as the system was configured to Figure 7-1.

8.2 TASK II ISOLATION VALVE CLOSED

Task II tests were separated into two categories (Test 1 and Test 2) with their respective test designations of II-1XX and II-2XX (see Table 8-1).

The test system was built in accordance with Figure 7-1. Tests were performed on both thrusters with the upstream isolation valve (V2) closed, then again with the valve open in both steady state and in pulse mode. The sequence of testing along with conditions of each test is shown on Table 8-1.

8.3 TASK III - "DRY" VALVE FIRING

Task III was performed with the feed system configured to Figure 7-1 (variable line length of 165 inches). The tests are designated with a prefix "III" (see Table 8-1). Three distinct iterations of the "dry" valve firing were performed with the first being incorporated into the first test of the baseline performance series. Three more tests were run with varying duty cycles as part of the selected retest sequence described in the following paragraph.

8.4 SELECTED RETEST

Additional tests performed were designated with a prefix "SR". These tests were designed to investigate or confirm earlier results obtained during the basic test plan.

The objectives of the individual SR tests and their respective test numbers are listed below:

- <u>Objective 1</u>. Determine critical "choking" trigger temperatures of the 0.10 lb_f thruster. Tests SR-1 through SR-6, SR-13-1 through SR-13-9, SR-14, SR-15, and SR-IX.

- <u>Objective 2</u>. Force choking condition of 1.0 lbf thruster within FSC operational constraints. Tests SR-8X and SR-9.

- <u>Objective 3</u>. Determine steady state GN_2 flow rate of 0.10 lb_f thruster tests SR-11 and SR-14.

- <u>Objective 4</u>. Determine performance decay of both thrusters with decreased duty cycle and the isolation valve closed. Observe startup characteristics of both thrusters with cold starts (60 to 80°F) with isolation valve closed.

Table 8-1. FSC-Ground Verification Test Matrix (as Tested)

Test No.	Thruster Type	P_{inj} (Psia)	Start Temperature (°F) T1	T2	T3	T4	T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
1	1.0	268	-	143	271	192	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
2	1.0	350	-	149	298	208	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
3	1.0	100	-	159	345	243	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
4	1.0	350	-	99	199	146	-	-	-	-	60 sec. steady state	Baseline performance	Nominal performance
5	1.0	240	-	144	265	146	-	-	-	-	60 sec. steady state	Baseline performance	Nominal performance
6	1.0	100	-	168	376	193	-	-	-	-	60 sec. steady state	Baseline performance	Nominal performance
11	0.10	240	-	-	-	-	-	151	544	569	50 pulses .020 sec/1 Hz	Baseline performance plus "dry valve" (14.7 psia)	Nominal performance Missed some pulses on start
10	0.10	350	-	-	-	-	-	157	568	589	50 pulses .020 sec/1 Hz	Baseline performance	Nominal performance
12	0.10	100	-	-	-	-	-	160	579	601	50 pulses .020 sec/1 Hz	Baseline performance	Nominal except missed some pulses due to gas bubbles
7	0.10	350	-	-	-	-	-	161	583	604	60 sec. steady state	Baseline performance	Lost Pc tap
7-1R	0.10	350	-	-	-	-	-	98	430	454	60 sec. steady state	Baseline performance	Nominal performance
8	0.10	240	-	-	-	-	-	119	557	587	60 sec. steady state	Baseline performance	Nominal except for 1150% 'spike'
9	0.10	100	-	-	-	-	-	129	540	573	60 sec. steady state	Baseline performance	Nominal except insipient "spiking"
'S.B.'	1.0	350	-	-	-	-	-	-	-	-	76 sec. steady state	Bleed in saturated propellant	Nominal
4S	1.0	350	-	149	338	413	-	-	-	-	60 sec. steady state	Baseline performance	Nominal performance
2S	1.0	350	-	165	385	410	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
7S	0.10	350	-	-	-	-	-				60 sec. steady state	Baseline performance	Nominal performance
10S	0.10	350	-	-	-	-	-	157	587	613	50 pulses .020 sec/1 Hz	Baseline performance	Nominal performance
III-2A	1.0	268	-	144	261	365	-	-	-	-	20 pulses .050 sec/1 Hz	Dry valve (Task III)	See Table (Task III)
III-3A	1.0	268	-	132	257	359	-	-	-	-	20 pulses .050 sec/1 Hz	Dry valve (Task III)	See Table (Task III)
1S	1.0	240	-	142	293	460	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
5S	1.0	240	-	156	335	541	-	-	-	-	60 sec. steady state	Baseline performance	Nominal performance
11S	0.10	240	-	-	-	-	-	141	467	483	50 pulses .020 sec/1 Hz	Baseline performance	Nominal performance
8S	0.10	240	-	-	-	-	-	144	514	538	60 sec. steady state	Baseline performance	Nominal performance

Table 8-1. FSC-Ground Verification Test Matrix (as Tested) (Continued)

Test No.	Thruster Type	P_{inj} (Psia)	Start Temperature (°F) T1	T2	T3	T4	T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
3 S	1.0	100	-	170	387	449	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
6 S	1.0	100	-	171	411	473	-	-	-	-	60 sec. steady state	Baseline performance	Nominal performance
12 S	0.10	100	-	-	-	-	-	157	483	515	50 pulses .020/1 Hz	Baseline performance	Missed some pulses due to GN_2 bubbles
12S-1R	0.10	100	-	-	-	-	-	157	478	518	50 pulses .020/1 Hz	Baseline performance	Missed pulses 20 and 21
9S	0.10	100	-	-	-	-	-	161	515	546	60 sec. steady state	Baseline performance	Slow start-nominal performance
SR-1	0.10	240	-	-	-	-	-	129	438	475	50 pulses .020/1 Hz	Induce "choking"	No "choke"
SR-2	0.10	240	-	-	-	-	-	136	465	496	50 pulses .020/1 Hz	Induce "choking"	No "choke"
SR-3	0.10	240	-	-	-	-	-	142	488	515	50 pulses .020/1 Hz	Induce "choking"	No "choke"
SR-4	0.10	240	-	-	-	-	-	150	476	520	50 pulses .020/1 Hz	Induce "choking"	No "choke"
SR-5	0.10	240	-	-	-	-	-	158	493	520	50 pulses .020/1 Hz	Induce "choking"	No "choke"
SR-6	0.10	240	-	-	-	-	-	165	491	518	50 pulses .020/1 Hz	Induce "choking"	No "choke"
-	1.0	240	-	-	-	-	-	-	-	-	30 sec. steady state	Bleed-in system	
I-1A	1.0	240	-	-	-	-	-	-	-	-	1855 pulses .050/1 Hz	10 cc bubble ingested	Bubble system malfunction
I-1B	1.0	240	-	-	-	-	-	-	-	-	1144 pulses .050/1 Hz	100 cc bubble ingested	Bubble broke up, I_{bit} variable
-	1.0	240	-	-	-	-	-	-	-	-	30 sec. steady state	Bleed-in system	
I-1B-1R	1.0	240	-	163	324	576	-	-	-	-	1475 pulses .050/1 Hz	100 cc bubble ingested	820 pulses to "pass gas"
I-1D	0.10	240	-	-	-	-	-	147	418	450	5000 pulses .020/1 Hz	100 cc bubble ingested	Thruster reacted nominal to gas bubble then "choked"
I-1A	1.0	240	-	-	-	-	-	-	-	-	518 pulses .050/1 Hz	10 cc bubble ingested	Bubble broke up, I_{bit} variable
-	1.0	240	-	-	-	-	-	-	-	-	30 sec. steady state	System bleed-in	
-	1.0	240	-	-	-	-	-	-	-	-	30 sec. steady state	System bleed-in	
I-3A	1.0	240	-	-	-	-	-	-	-	-	Steady state	Calculate bubble travel time	36 sec travel time
I-2B	1.0	240	-	186	-	-	-	-	-	-	66 sec. S.S. then OFF modulate at .050 sec off/1 Hz	Simulate - Z1A failure mode with "hot" value	No anomalous behavior

Table 8-1. FSC-Ground Verification Test Matrix (as Tested) (Continued)

Test No.	Thruster Type	P_{inj} (Psia)	Start Temperature (°F) T1	T2	T3	T4	T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
1-2A	1.0	240	164	141	202	252	-	-	-	-	66 sec. S.S. then OFF mod. at .050 sec off/1 Hz	Simulate - Z1A failure mode	No anomalous behavior
1-2B-1R	1.0	240	230	200	224	371	-	-	-	-	66 sec. S.S. then OFF mod. at .050 sec off/1 Hz	Simulate - Z1A failure mode with "hot" valve	No anomalous behavior
1-2F	1.0	240	238	215	234	396	-	-	-	-	30 sec. S.S. then OFF mod at .050 sec off/1 Hz	Ingest 100 cc bubble while off modulating (hot valve)	No anomalous behavior depleted propellant tank
1-2F-1R	1.0	240	233	211	236	395	-	-	-	-	30 sec. S.S. then OFF mod at .050 sec off/1 Hz	Ingest 100 cc bubble while off modulating (hot valve)	No anomalous behavior
1-2G	1.0	240	267	222	444	784	-	-	-	-	36 sec. S.S. then OFF mod at .050 sec off/1 Hz	Off modulate when bubble reaches thruster inlet	No anomalous behavior
1-2H	1.0	240	276	226	442	782	-	-	-	-	42 sec. S.S. then OFF mod at .050 sec off/1 Hz	Off modulate during bubble (hot valve)	No anomalous behavior
1-2C	1.0	240	265	208	427	752	-	-	-	-	30 sec. S.S. then OFF mod at .050 sec off/1 Hz	Off modulate then ingest 10 cc bubble (hot valve)	No anomalous behavior
1-2D	1.0	240	265	208	427	752	-	-	-	-	36 sec. S.S. then OFF mod at .050 sec off/1 Hz	Off modulate when 10 cc bubble reaches thruster inlet (hot valve)	No anomalous behavior
1-2E	1.0	240	264	206	407	722	-	-	-	-	36 sec. S.S. then OFF mod at .050 sec off/1 Hz	Off modulate while 10 cc bubble is in thruster (hot valve)	No anomalous behavior
1-2E-1R	1.0	240	-	-	-	-	-	-	-	-	36 sec. S.S. then OFF mod at .050 sec off/1 Hz	Off modulate while 10 cc bubble is in thruster (hot valve)	No anomalous behavior

Table 8-1. FSC-Ground Verification Test Matrix (as Tested) (Continued)

Test No.	Thruster Type	Pin_J (Psia)	Start Temperature (°F) T1	T2	T3	T4	T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
I-2F-1X	1.0	240	224	212	205	170	-	-	-	-	22 sec S.S., reheat valve off-mod at .050 sec off/1 Hz while ingesting 100 cc bubble	Induce choking with hot valve condition	No "choke"
II-1C	1.0	240	156	177	-	-	-	-	-	-	354 pulses .050 sec/ 1 Hz	Isolation valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 3.2 psia inlet pressure.
II-1C-X	1.0	240	-	-	-	-	-	-	-	-	100 sec. steady state	Clear line of possible bubbles formed during previous test	No bubbles found.
II-2A	0.10	240	-	-	-	-	150	140	274	-	637 pulses .020/1 Hz	Iso valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 28 psia inlet pressure.
II-1B	1.0	240	162	142	-	-	-	-	-	-	20 pulses .050/1 Hz	Determine performance recovery	Nominal performance
II-2B	0.10	240	-	-	-	-	153	140	-	-	20 pulses .020/1 Hz	Determine performance recovery	Nominal performance
II-1AX	1.0	240	178	140	213	-	-	-	-	-	200 pulses .050/1 Hz	Iso valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 10.6 psia inlet pressure
II-1XA	1.0	240	-	-	-	-	-	-	-	-	100 sec. steady state	Clear line of possible bubbles formed during previous test	Nominal performance no bubbles
II-1A	1.0	240	-	-	-	-	-	-	-	-	247 pulses .050/1 Hz	Iso valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 9 psia inlet pressure
SR-13-1	0.10	240	-	-	-	-	229	159	467	497	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-2	0.10	240	-	-	-	-	247	171	586	604	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"

Table 8-1. FSC-Ground Verification Test Matrix (as Tested) (Continued)

Test No.	Thruster Type	P_{inj} (Psia)	Start Temperature (°F) T1	T2	T3	T4	T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
SR-13-3	0.10	240	-	-	-	-	254	181	645	652	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-4	0.10	240	-	-	-	-	257	191	690	691	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-5	0.10	240	-	-	-	-	259	201	746	730	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-6	0.10	240	-	-	-	-	259	212	718	716	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-7	0.10	240	-	-	-	-	261	219	757	744	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-8	0.10	240	-	-	-	-	251	230	522	546	50 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-9	0.10	240	-	-	-	-	256	242	585	599	10 pulses .020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-14	0.10	240	-	-	-	-	241	191	490	516	888 pulses .020/1 Hz	Force "choking" condition with hot valve and 100 cc bubble.	No "choke" and bubble had not reached thruster yet.
			-	-	-	-	-	-	-	-	50 sec. steady state	Propagate bubble	
			-	-	-	-	262	201	782	784	908 pulses .020/1 Hz	Force "choke" with bubble and hot valve	Thruster "choked" at pulse No. 233. Bubble had not reached thruster yet.
			-	-	-	-	263	222	877	752	442 sec. steady state	Confirm "choked" condition and calibrate GN_2 flow since bubble was still in line (100 cc)	Delay start characteristic of "choked" condition, flowed 100 cc bubble through.
SR-11	0.10	240	-	-	-	-	-	-	-	-	11 min. steady state	Calibrate GN_2 flow rate for 10 cc bubble	Bubble flowed through nominally.
SR-1X	0.10	240	-	-	-	-	263	208	1052	883	50 pulses .020/1 Hz	Force "choke" with hot valve, and catbed chamber. Allow >15 min. for propellant in valve to reach equilibrium valve temp.	"No choke"

Table 8-1. FSC-Ground Verification Test Matrix (as Tested) (Continued)

Test No.	Thruster Type	P_{inj} (Psia)	Start Temperature (°F) T1	T2	T3	T4	T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
SR-12	0.10	240	-	-	-	-	-	72	81	84	50 pulses .020- 1 pulse/min.	Determine performance degradation with Iso closed and cold start	All pulses nominal based on inlet pressure.
			-	-	-	-	-	-	-	-	49 pulses .020- 1 pulse/min. after 15 hour hold	Determine performance degradation with Iso closed and cold start	All pulses nominal based on inlet pressure.
			-	-	-	-	-	-	-	-	Steady state	Blow down to <1 psia.	No adverse effects observed during this operation mode.
SR-8	1.0	240	259	212	312	647	-	-	-	-	.050 sec. "OFF-MOD" pulses at 2 pulses per second	Force "choke" with increased duty cycle, hot valve, 100 cc bubble	No "choke"
SR-8X	1.0	240	255	214	290	590	-	-	-	-	.050 sec. "OFF-MOD" pulses at 10 cps	Force "choke" with increased duty cycle, hot valve, *100 cc bubble*	*No "choke"*
SR-9	1.0	100	-	-	-	-	-	-	-	-	65 sec. steady state	Move bubble from ingestion chamber to thruster inlet	
	1.0	100	270	212	498	942	-	-	-	-	.050 sec "OFF-MOD" pulses at 10 cps (1226 pulses)	Force "choke" with increased duty cycle, hot valve, 100 cc bubble	No "choke"
	1.0	100	-	210	-	-	-	-	-	-	.050 sec. "OFF-MOD" pulses at 10 cps	Force "choke" with increased duty cycle, hot valve, and initiate off mod pulsing during bubble	No "choke"
SR-15	0.10	100	-	-	-	-	240	195	470	493	300 pulses .020/1 Hz	Force "choking" at E.O.L. conditions	Choked at pulse No. 230
SR-7	1.0	240	65	77	63	96	-	-	-	-	20 pulses .050- 1 pulse/min	Determine effects of cold start with Iso closed	Nominal performance
SR-16	1.0	270	-	103	146	199	-	-	-	-	5 Pulses .050/300 sec.	"Dry" valve firing	Missed first pulse
SR-17	1.0	270	-	98	158	219	-	-	-	-	5 Pulses .050/50 sec.	"Dry" valve firing	Missed first pulse
SR-18	1.0	270	-	108	156	220	-	-	-	-	5 Pulses .050/100 sec.	"Dry" valve firing	Missed first pulse

9. TEST RESULTS

Test results are discussed in the following sections according to test objectives. A "quick-look" summary of test results is included in both the summary/conclusions section and on the test matrix table (Table 8-1).

9.1 PULSE MODE BUBBLE INGESTION (TASK I)

9.1.1 1.0 lb_f Thruster

Bubble ingestion tests with the 1.0 lb_f thruster are part of the Task I test series (Table 9-1). The purpose of these tests was to determine the effects gas bubbles on thruster performance. All tests in this sequence were performed with GN_2 saturated propellant to insure proper correlation with the specific anomalies.

Figure 9-1 is a typical oscillograph trace of bubble flow during pulse mode operation of the 1.0 lb_f thruster. Bubble breakup was observed in each of the tests in the above matrix. I_{bit} levels were variable during bubble flow indicating the random nature of the apparent two-phase flow. Quantization of impulse during a bubble was regarded as secondary to a complete qualitative observation and proved difficult due to the I_{bit} variability.

Impulse per pulse dropped to approximately 5 to 15 percent of a nominal pulse during bubble ingestion. It is concluded however, based on qualitative observations of bubble flow, that the results obtained herein support and in fact, duplicate the failure mode observed during the -PB thruster anomaly period.

In addition, it is concluded that these results do not conform to the failure modes of the remaining 1.0 lb_f thrusters (+PA, -ZIA).

Table 9-1. Task I - Gas Bubble Ingestion Tests, 1.0 lb_f Thruster

Test No.	PIN_J (PSIA)	Start Temperature (°F)				Duty Cycle	Test Objective	Test Results
		T1	T2	T3	T4			
-	240	-	-	-	-	30 sec Steady State	Bleed-in System	Nominal Performance
I-1A	240	-	-	-	-	1855 Pulses 0.050/1 Hz	10 cc Bubble Ingested	Bubble System Malfunction
I-1B	240	-	-	-	-	1144 Pulses 0.050/1 Hz	100 cc Bubble Ingested	Bubble Broke up I_{bit} Variable
-	240	-	-	-	-	30 Sec Steady State	Bleed-in System	Nominal Performance
I-1B-1R	240	-	163	324	576	1475 Pulses 0.050/1Hz	100 cc Bubble Ingested	I_{bit} Variable 820 Pulses to "Pass Gas"
I-1A-1R	240	-	-	-	-	518 Pulses 0.050/1 Hz	10 cc Bubble Ingested	Bubble Broke up, I_{bit} Variable

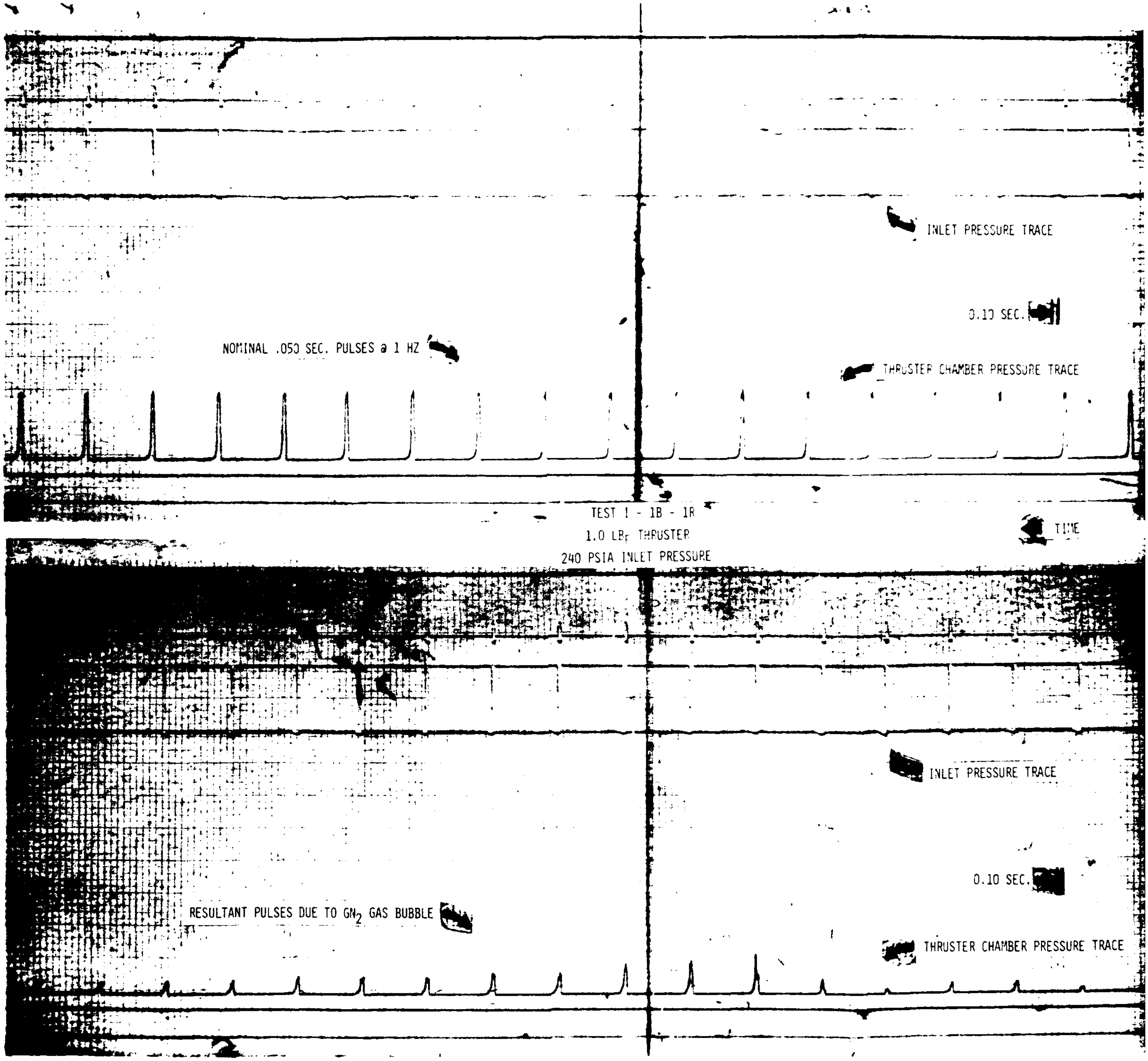


Figure 9-1. 1.0 lb_f T
Oscillogr
During GN

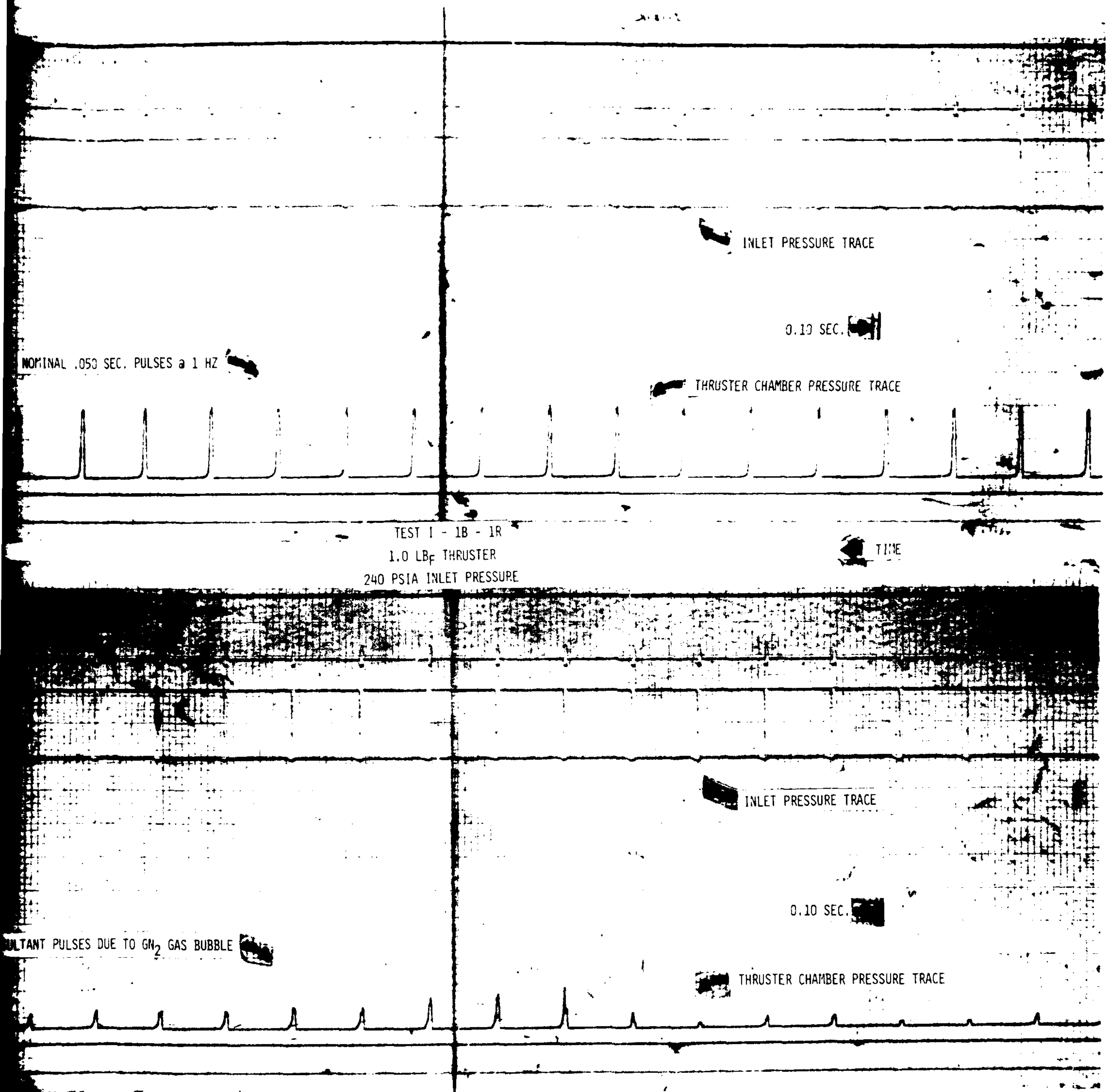


Figure 9-1. 1.0 lb_f Thruster Oscillograph Trace During GN_2 Bubble Flow

2

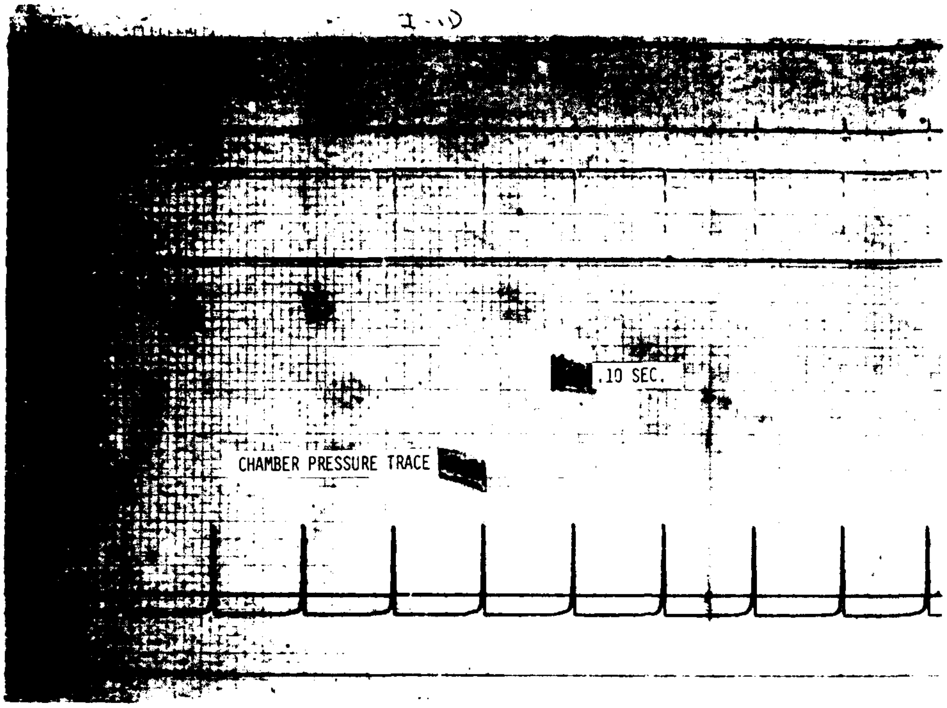
9.1.2 0.10 lb_f Thruster

One test was performed with the 0.10 lb_f thruster to observe the effects of bubble ingestion on thruster performance during pulse mode operation. Only the 100 cc bubble was ingested as the 10 cc bubble ingestion test was determined unnecessary due to the observations made during 1.0 lb_f thruster testing. The appropriate test number is I-ID and was run at an inlet pressure of 240 psia with a duty cycle of 0.020 second duration pulses at a rate of one pulse per second. A total of 5000 pulses were fired with the first sign of bubble flow at pulse number 3760. The bubble again "broke up" with I_{bit} variable between 5 and 100 percent of nominal during the bubble duration. After the bubble had completely passed, the thruster "choked" reducing the I_{bit} level to approximately 25 percent of nominal.

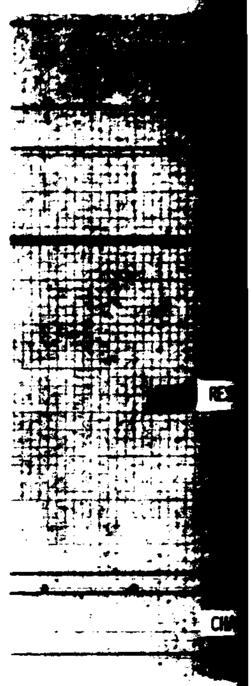
Immediately after termination of the test, the thruster was again restarted in the steady state mode for 30 seconds to confirm the "choked" condition and verify thruster recovery capability. The oscillograph trace of the steady state startup is shown on Figure 9-2 and confirms the "choked" condition as shown by the characteristic "delay start." The trace also confirms the thruster's ability to recover from the "choked" flow condition. The specific test condition for test I-ID is shown on Table 8-1 and a temperature time curve for the entire test duration is shown on Figure 9-3.

It is concluded from the test that bubble flow and/or "choking" are sufficient to initiate the type of failure as experienced on the -RYB thruster during the F-2 anomaly period. It is also recognized, however, that "choking" is the less viable candidate due to the apparent thermal conditions as realized by -RYB. During ground tests, the 0.10 lb_f thruster "choked" while operating in the high temperature mode while there is insufficient flight data to support this theory during the anomaly period.

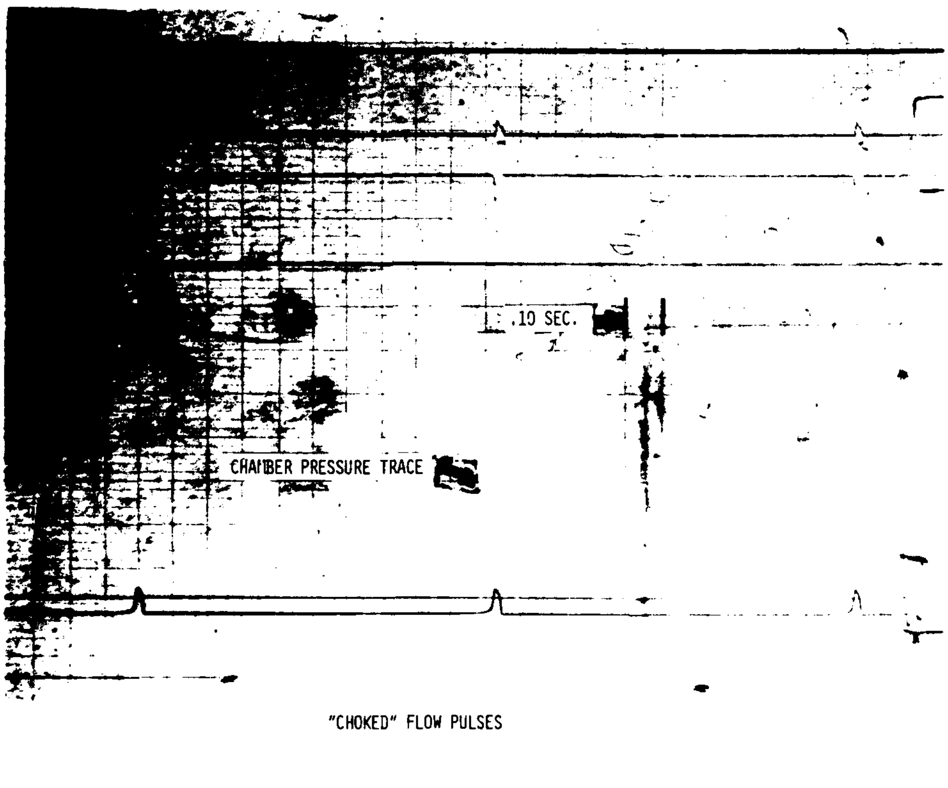
TEST I-1D
0.10 LB_F THRUSTER
240 PSIA INLET PRESSURE



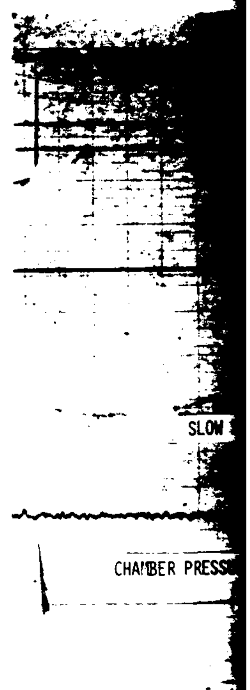
NOMINAL .020 SEC PULSES @ 1 HZ



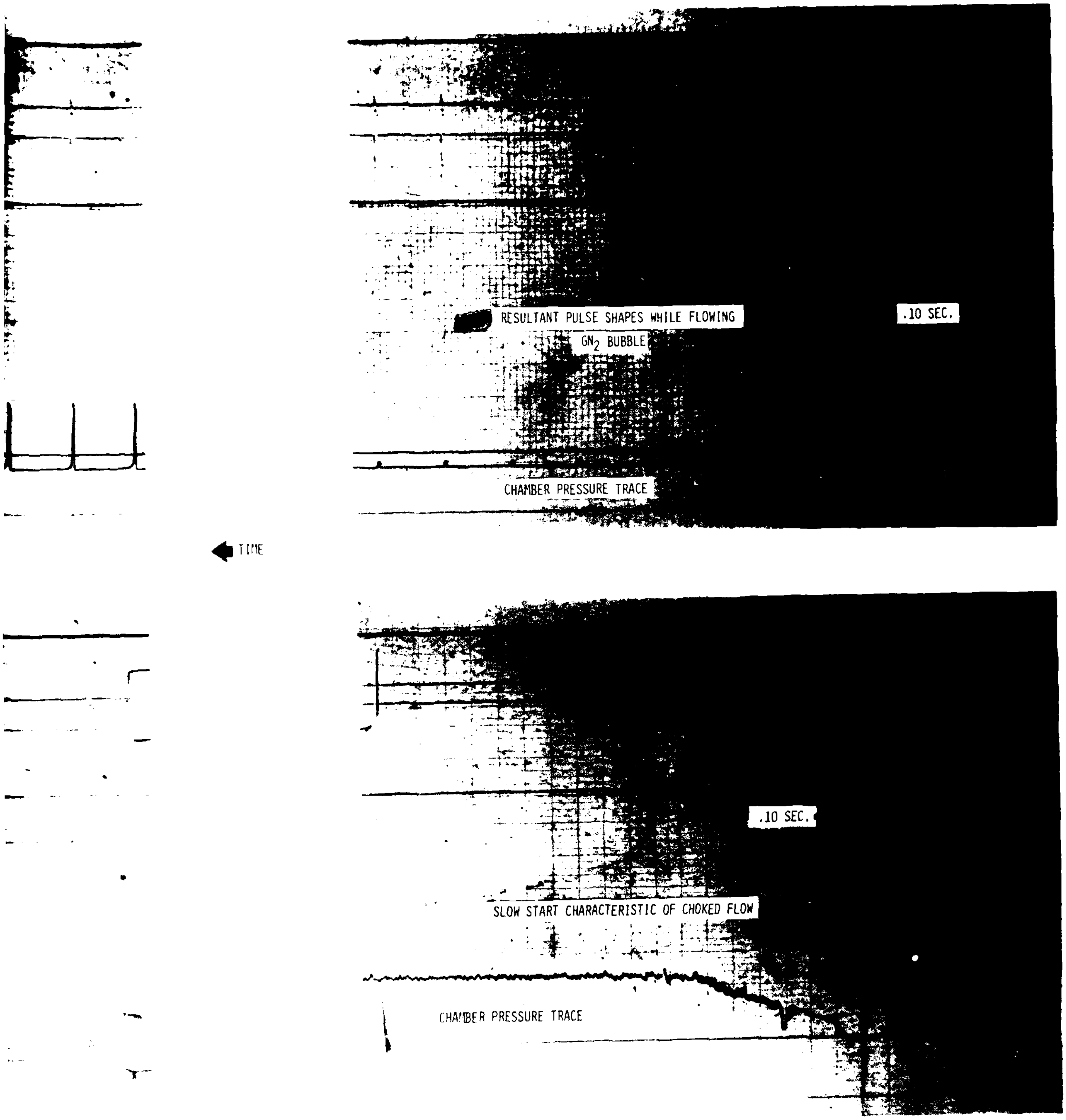
TIME



"CHOKED" FLOW PULSES

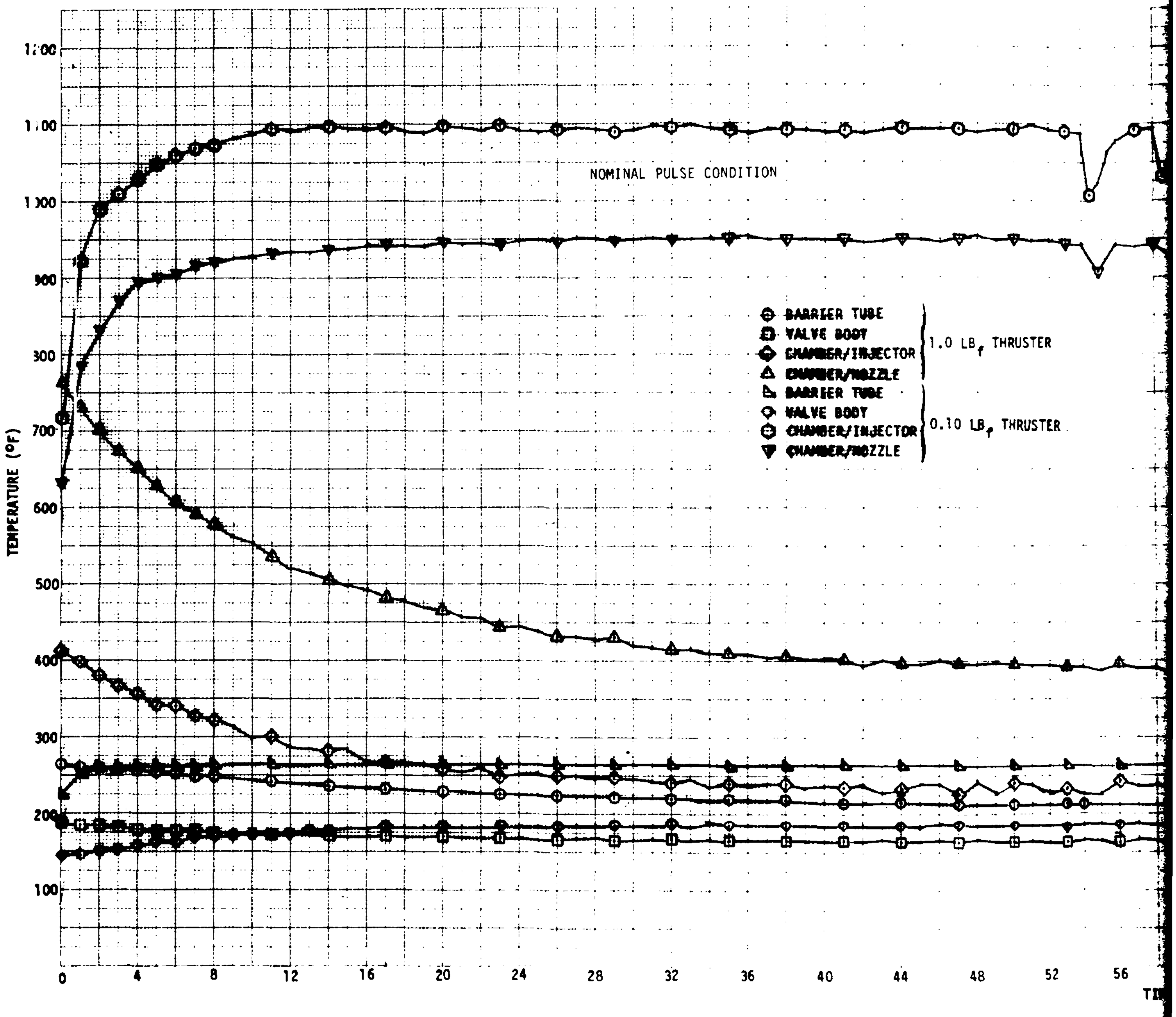


R5-168-80



STEADY STATE START AFTER CHOKED CONDITION.

Figure 9-2. Test I-1D 0.10 lb_f Thruster 240 Psia Inlet Pressure



NOMINAL PULSE CONDITION
BARRIER TUBE
VALVE BODY
CHAMBER/INJECTOR
CHAMBER/NOZZLE
1.0 LB$_f$ THRUSTER
BARRIER TUBE
VALVE BODY
CHAMBER/INJECTOR
CHAMBER/NOZZLE
0.10 LB$_f$ THRUSTER
TEMPERATURE (°F)
1100
900
700
600
500
400
300
200
100
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56

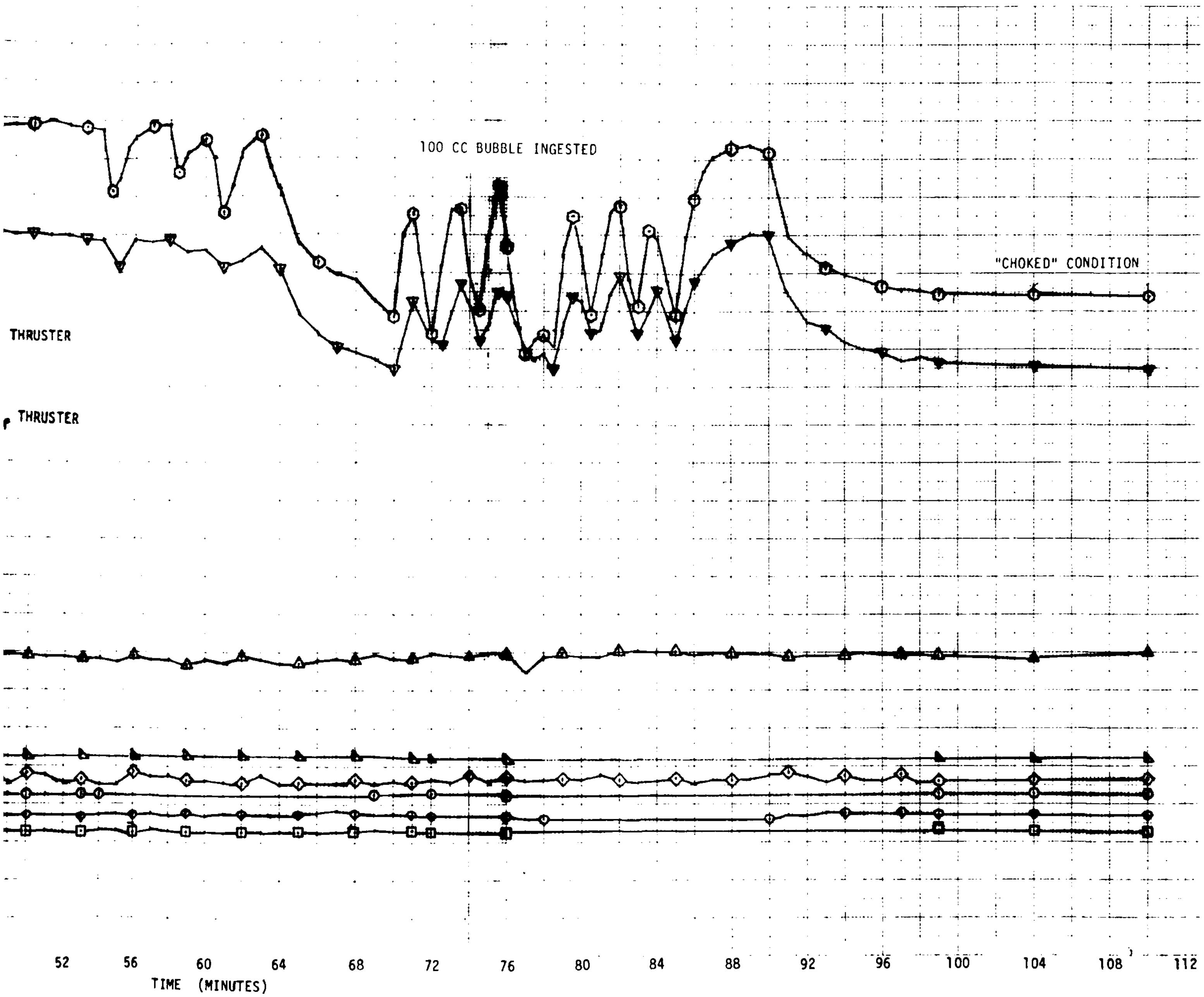


Figure 9-3. Temperature Versus Time (Test I-1D)

9.2 1.0 lb_f THRUSTER "OFF-MODULATION" AND FORCE "CHOKE" TEST RESULTS (TASK I)

A total of 15 tests were run in an effort to reproduce the -ZIA failure. The thruster was run in the exact sequence as reported during the anomalous ΔV maneuver in both the nominal operating configuration and also with the addition of elevated valve temperatures (Test I-2A and I-2B). Additional tests were run where both 10 cc and 100 cc bubbles were ingested 5 seconds before, coincident with, and 5 seconds after the initiation of off-modulation pulsing following a 30 to 66 second steady state (ΔV) burn. Test I-2F-1X was run in an attempt to force a "choking" condition by reheating the valve to 210°F before initiation of "off-modulation" pulsing. Tests SR-8, SR-8X, and SR-9 are attempts to force a "choking" condition by increasing the "off-modulation" rate, increasing valve body temperature (>210°F), introducing a 100 cc bubble, and lowering inlet pressure to 100 psia (end-of-life conditions). The aforementioned tests are outlined in Table 9-2.

Results of the aforementioned tests are shown in the following oscillograph traces and temperature-time plots (Figures 9-4 through 9-7). It is noted therein that the thruster showed absolutely no tendency to "choke" during any of the runs as the valve body temperatures consistently decreased as a result of thruster firing. It should be noted, however, that the test setup does not include a thermal enclosure (doghouse) which would tend to keep the valve body warmer due to the resultant back radiation.

Temperature curves are shown on Figures 9-8 and 9-9 along with flight data (barrier tube) to exhibit the apparent temperature difference due to the thermal environment. Catalyst bed temperatures can be assumed to be consistent with flight thrusters but barrier tube and valve temperature data exhibit significant differences. GVT test barrier tube data is consistently 15-20°F lower than flight data when compared during similar case steady state tests. Pulse mode temperature data was difficult to compare due to the random nature (automatic mode) of thruster firings of the in-flight thrusters.

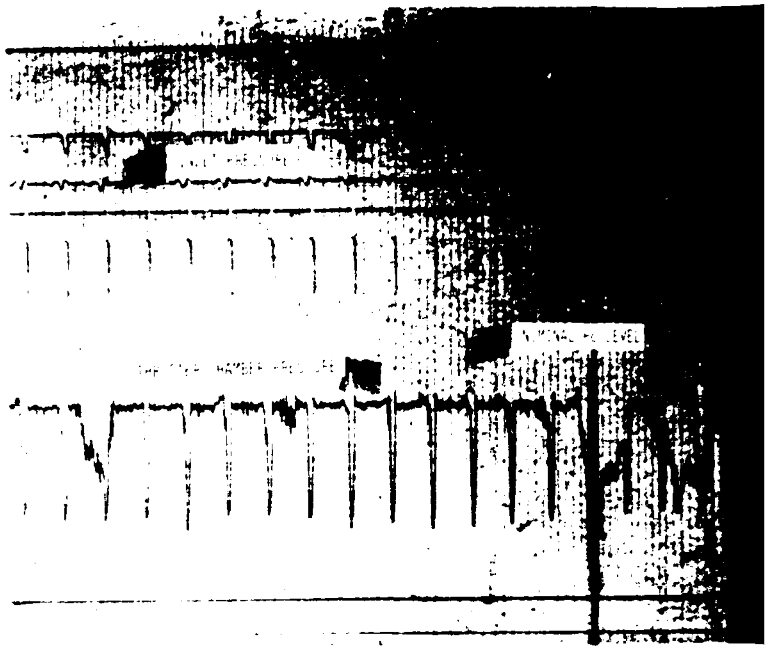
The thruster reacted nominally to the introduction of gas bubbles during all modes of operation. It is concluded that within the operational constraints of FSC (0.050 sec max "off-modulation" pulse width). The 1.0 lb_f thruster will not "choke" in the "as-tested" thermal environment and therefore indicates choking as not a viable candidate for the -ZIA failure.

Table 9-2. 1.0 lb_F Thruster "Off-modulation" and Force "Choke" Test Matrix

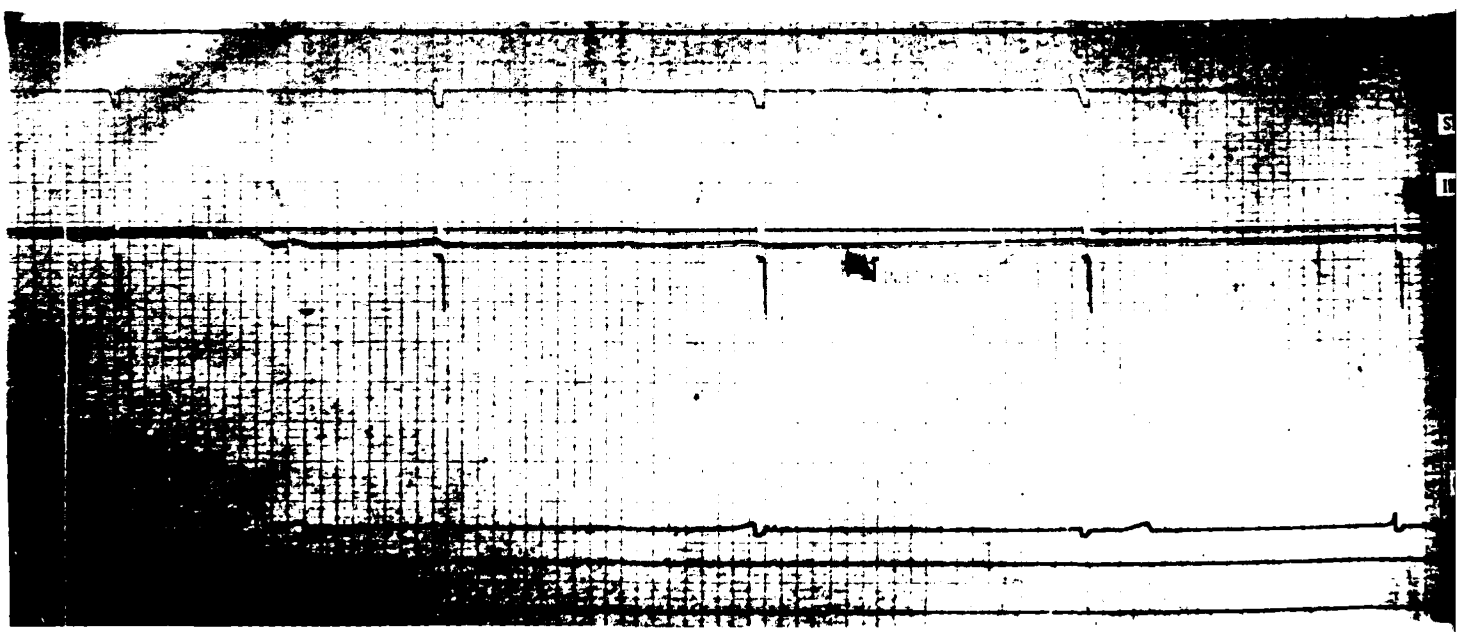
Test No.	P_{IN_J} (PSIA)	Start Temperature (°F)				Duty Cycle	Test Objective	Test Results
		T1	T2	T3	T4			
I-2B	240	-	186	-	-	66 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Simulate - Z1A failure mode with "hot" valve	No anomalous behavior
I-2A	240	164	141	202	252	66 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Simulate - Z1A failure mode	No anomalous behavior
I-2B-1R	240	230	200	224	371	66 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Simulate - Z1A failure mode with "hot" valve	No anomalous behavior
I-2F	240	238	215	234	396	30 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Ingest 100 cc bubble while off modulating (hot valve)	No anomalous behavior depleted propellant tank
I-2F01R	240	233	211	236	395	30 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Ingest 100 cc bubble while off modulating (hot valve)	No anomalous behavior
I-2G	240	267	222	444	784	36 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Off modulate when bubble reaches thruster inlet	No anomalous behavior
I-2H	240	276	226	442	782	42 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Off modulate during bubble (hot valve)	No anomalous behavior
I-2C	240	265	208	427	752	30 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Off modulate then ingest 10 cc bubble (hot valve)	No anomalous behavior
I-2D	240	265	208	427	752	36 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Off modulate when 10 cc bubble reaches thruster inlet (hot valve)	No anomalous behavior

Table 9-2. 1.0 lb_F Thruster "Off-modulation" and Force "Choke" Test Matrix (Continued)

Test No.	PIN_J (PSIA)	Start Temperature (°F) T1	T2	T3	T4	Duty Cycle	Test Objective	Test Results
I-2E	240	264	206	407	722	36 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Off modulate while 10 cc bubble is in thruster (hot valve)	No anomalous behavior
I-2E-1R	240	-	-	-	-	36 sec S.S. then OFF modulate at 0.050 sec off/1 Hz	Off modulate while 10 cc bubble is in thruster (hot valve)	No anomalous behavior
I-2F-1X	240	224	212	205	170	22 sec S.S., reheat valve off-modulate at 0.050 sec off/1 Hz while ingesting 100 cc bubble	Induce choking with hot valve condition	No "choke"
SR-8	240	259	212	312	647	0.050 sec "OFF-MOD" pulses at 2 pulses per second	Force "choke" with increased duty cycle, hot valve, 100 cc bubble	No "choke"
SR-8X	240	255	214	290	590	0.050 sec "OFF-MOD" pulses at 10 cps	Force "choke" with increased duty cycle, hot valve, 100 cc bubble	No "choke"
SR-9	100	-	-	-	-	65 sec steady state	Move bubble from ingestion chamber to thruster inlet	No "choke"
	100	270	212	498	942	0.050 sec "OFF-MOD" pulses at 10 cps (1226 pulses)	Force "choke" with increased duty cycle, hot valve, 100 cc bubble	No "choke"
	100	-	210	-	-	0.050 sec "OFF-MOD" pulses at 10 cps	Force "choke" with increased duty cycle, hot valve, and initiate off mod pulsing during bubble	No "choke"



PSIA
PULS
PER 2



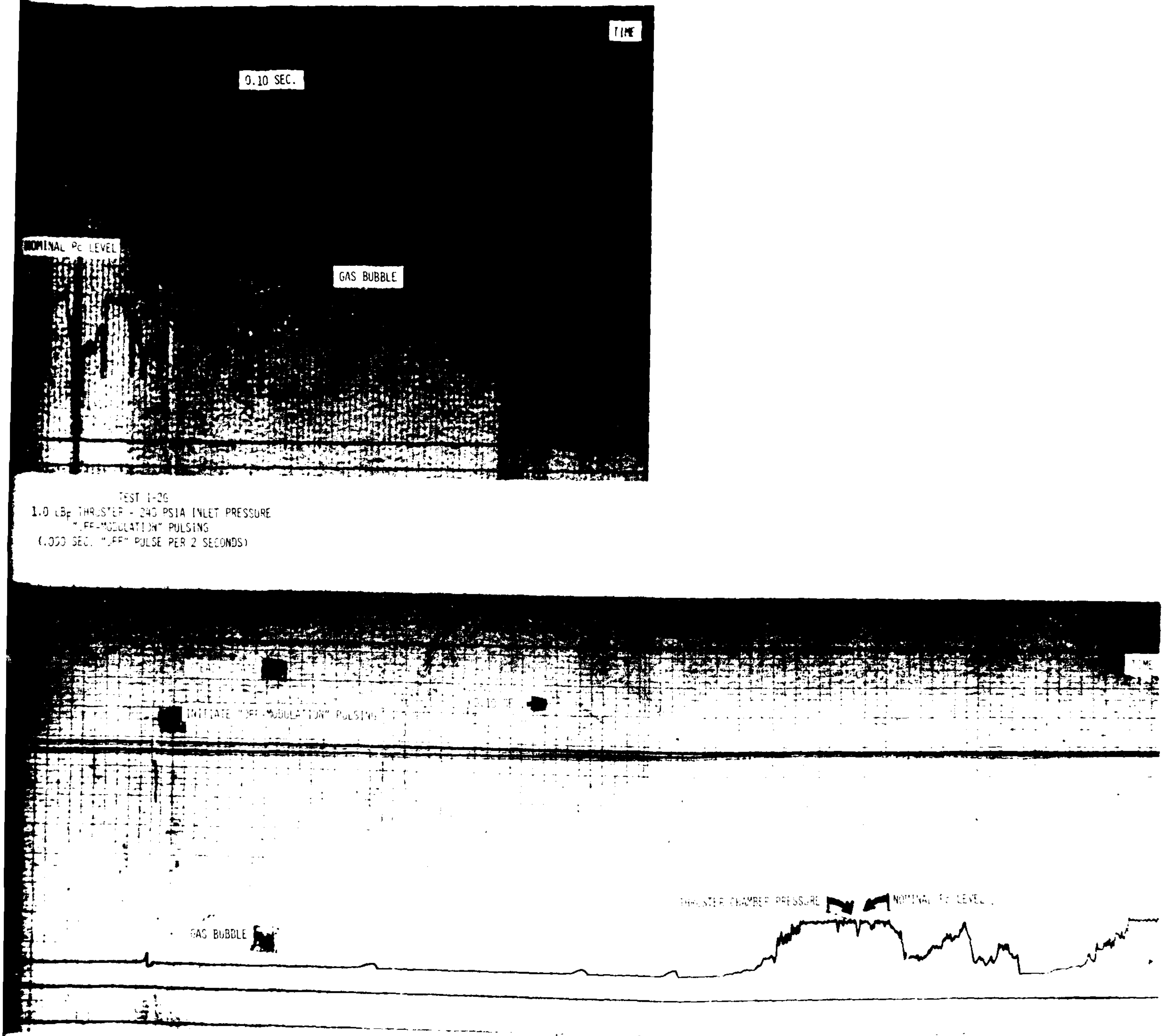
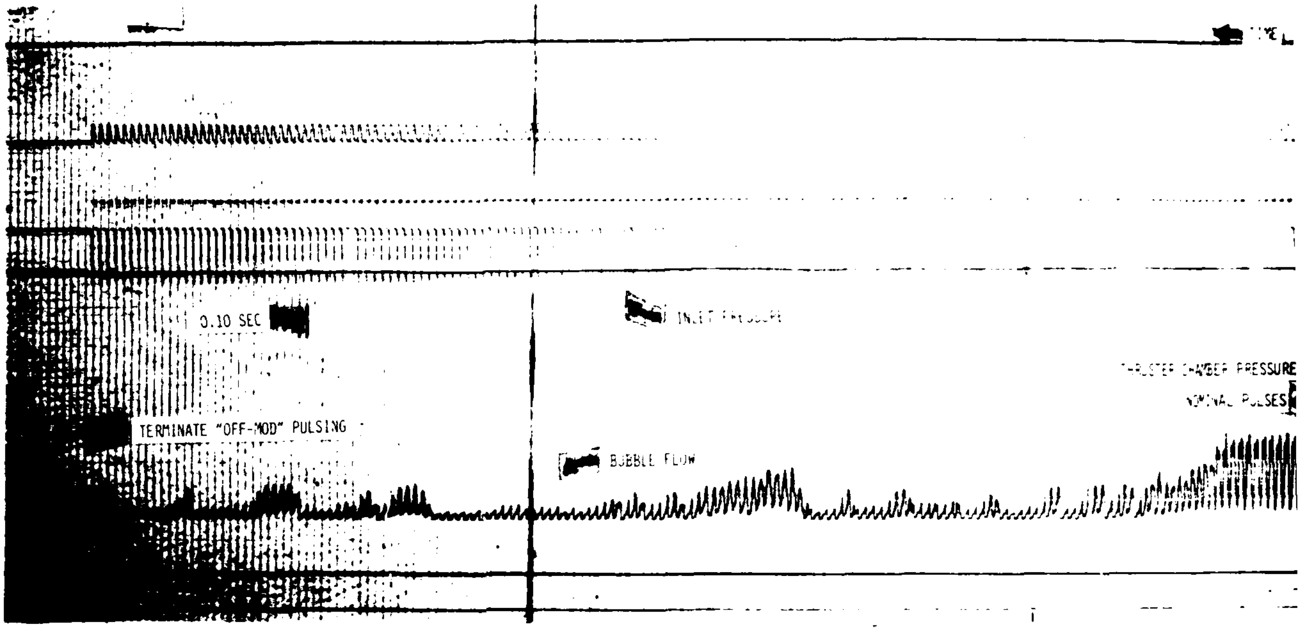
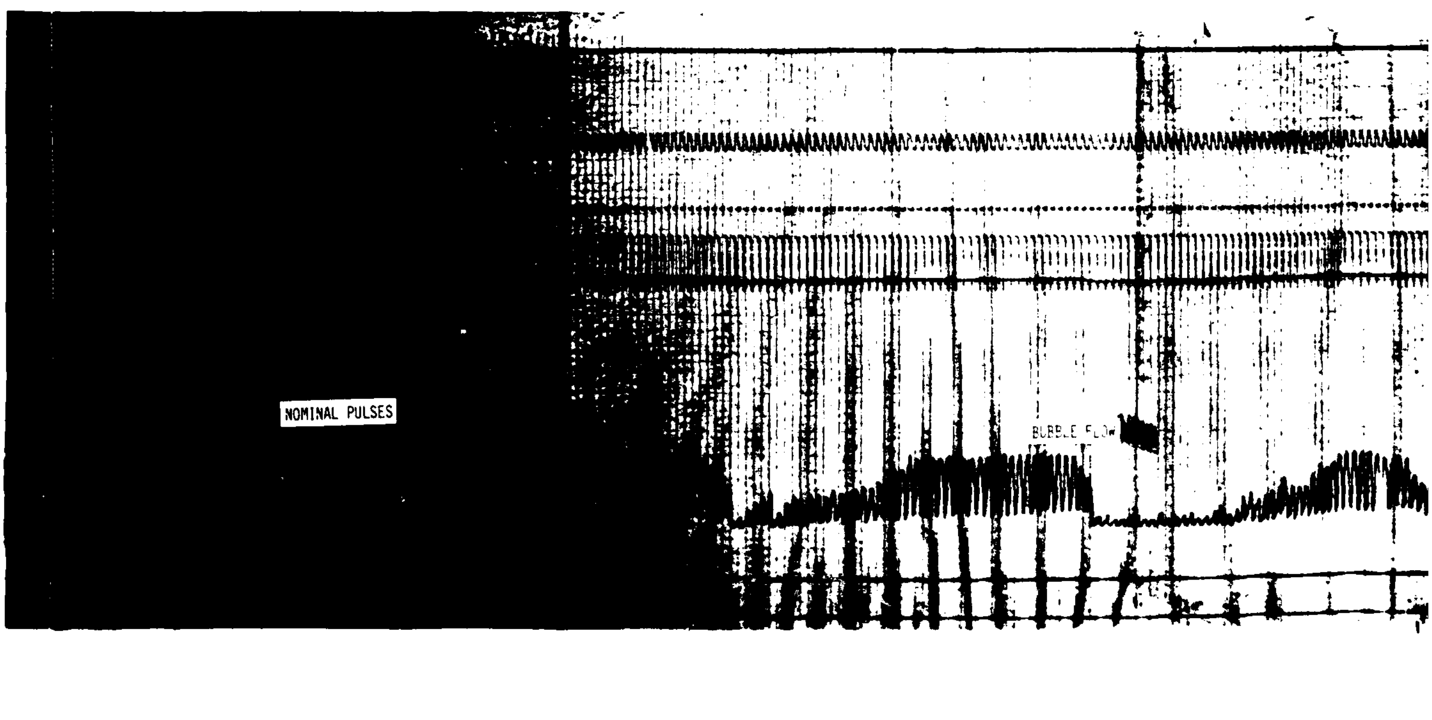


Figure 9-4. Oscillograph Trace - 1.0 lb_f Thruster Test I-2G

TEST


0.10 SEC
TERMINATE "OFF-MOD" PULSING
BUBBLE FLOW


NOMINAL PULSES

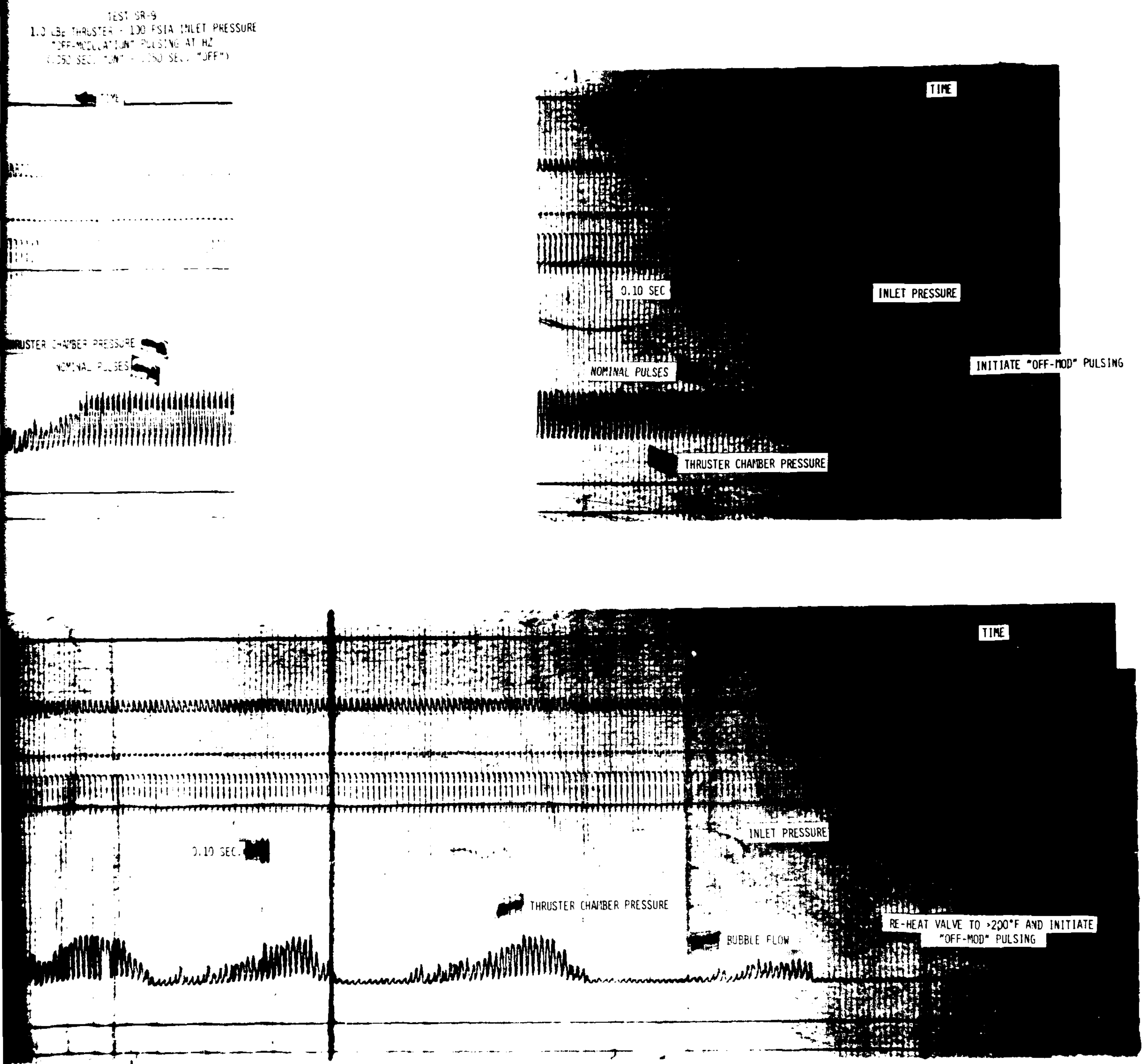


Figure 9-4A. Test SR-9 1.0 lb_f Thruster - 100 Psia Inlet Pressure "Off-Modulation" Pulsing at Hz (0.050 sec "ON" - 0.050 sec "OFF")

Test No. I-2A

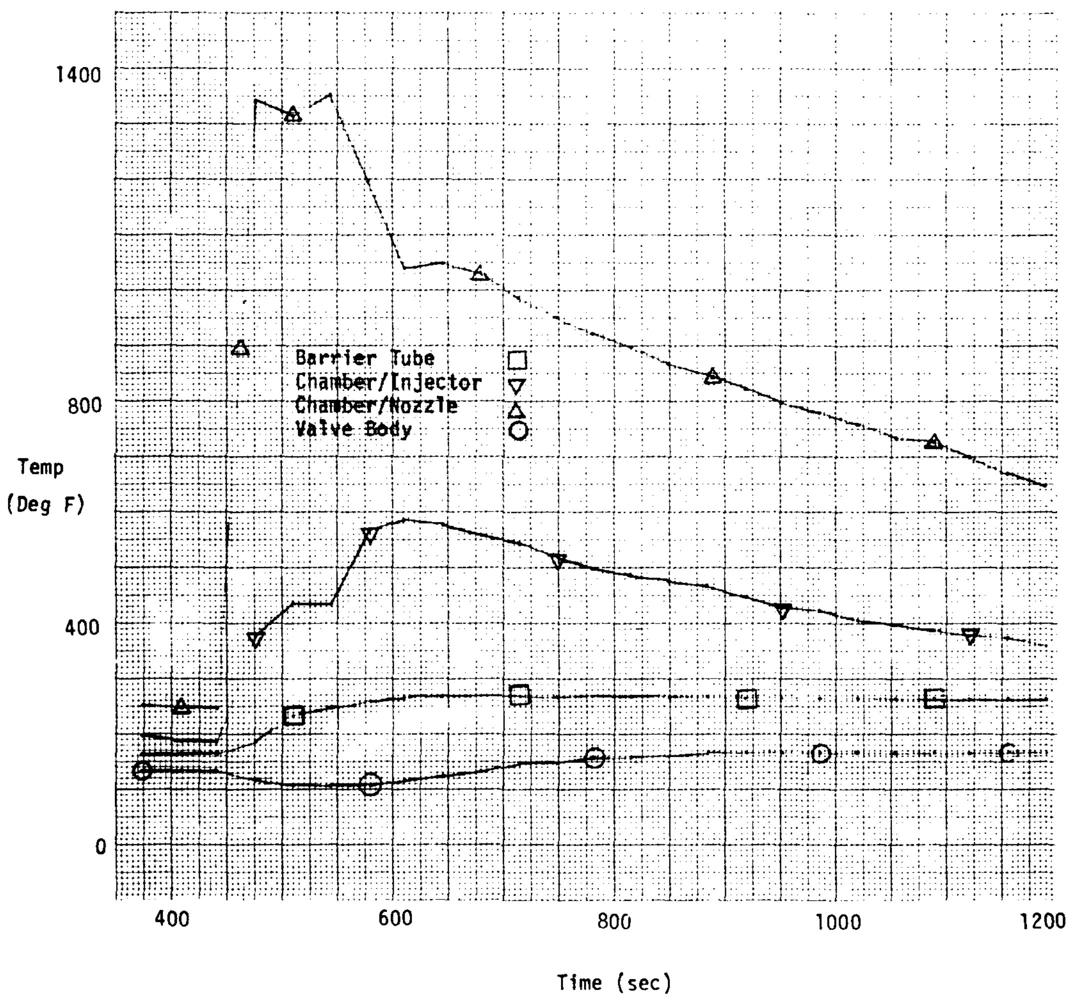


Figure 9-5. Test No. I-2A 1.0 lb_f Thruster 66 Sec. Steady State and "Off Modulation" Pulsing - Temperature vs. Time

Test No. I-2C

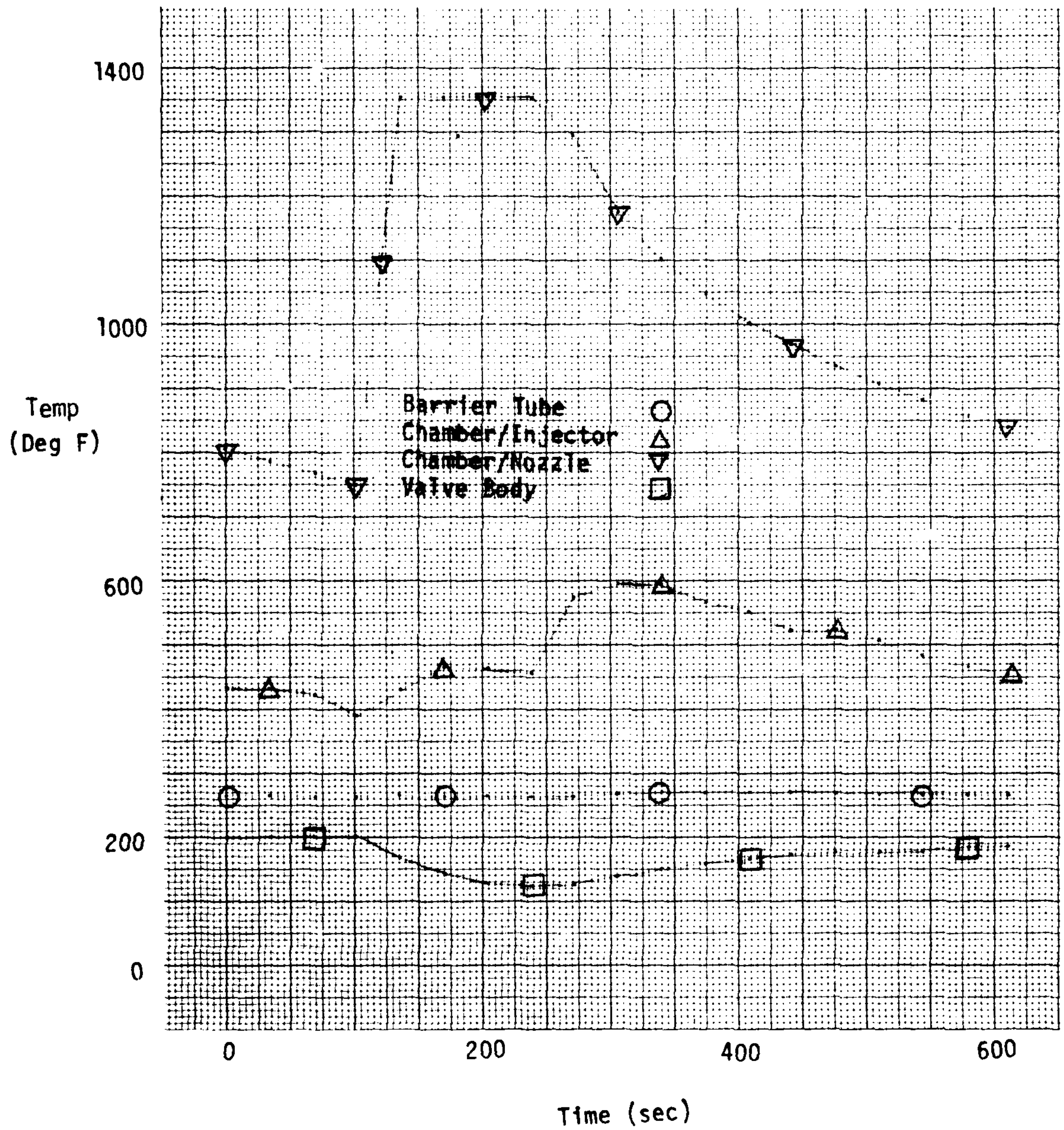


Figure 9-6. Test No. I-2C 1.0 lb_f
Thruster Temp. vs. Time

Test No. I-2H

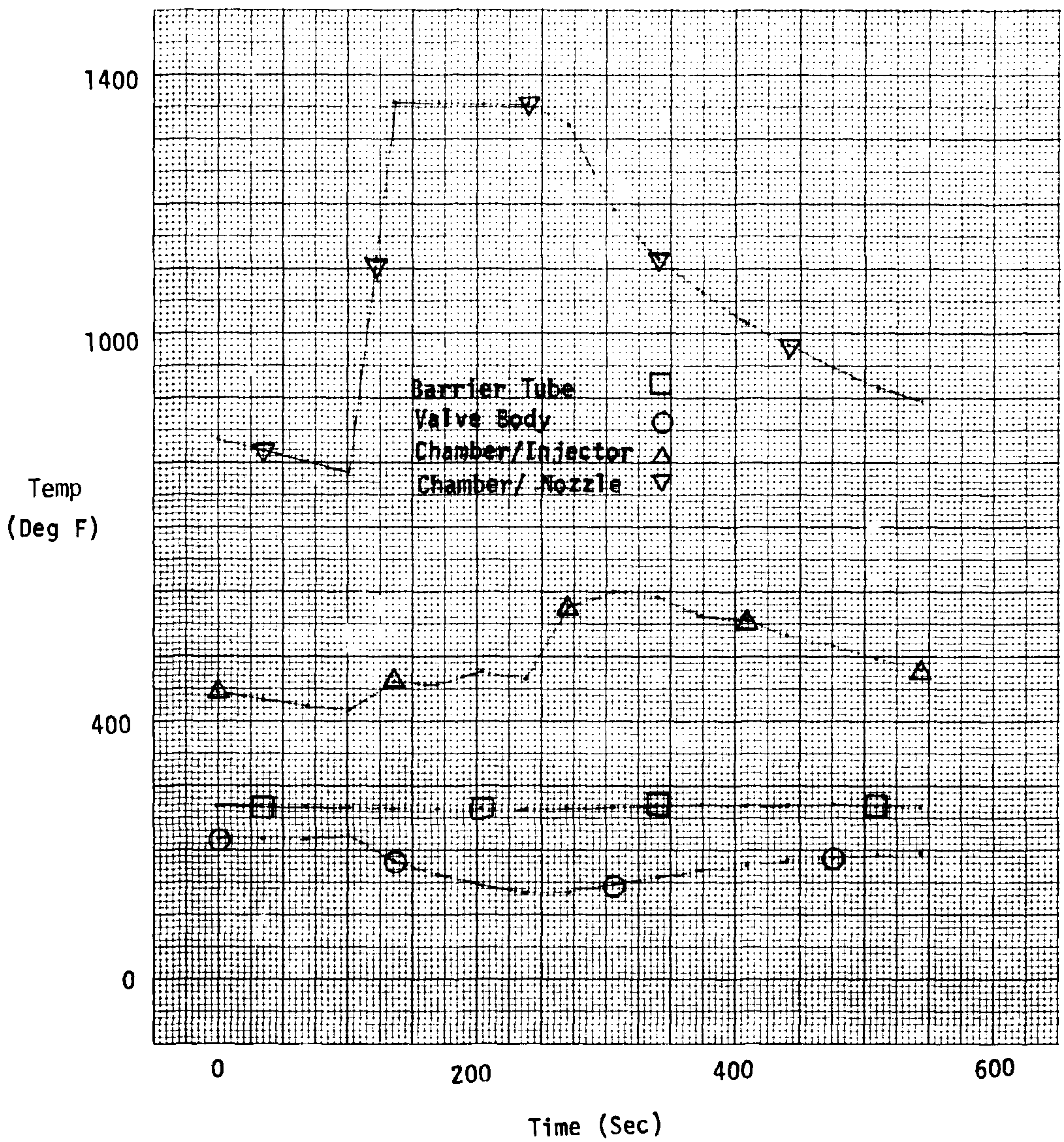


Figure 9-7. Test No. I-2H 1.0 lb_f Thruster Temperature vs. Time

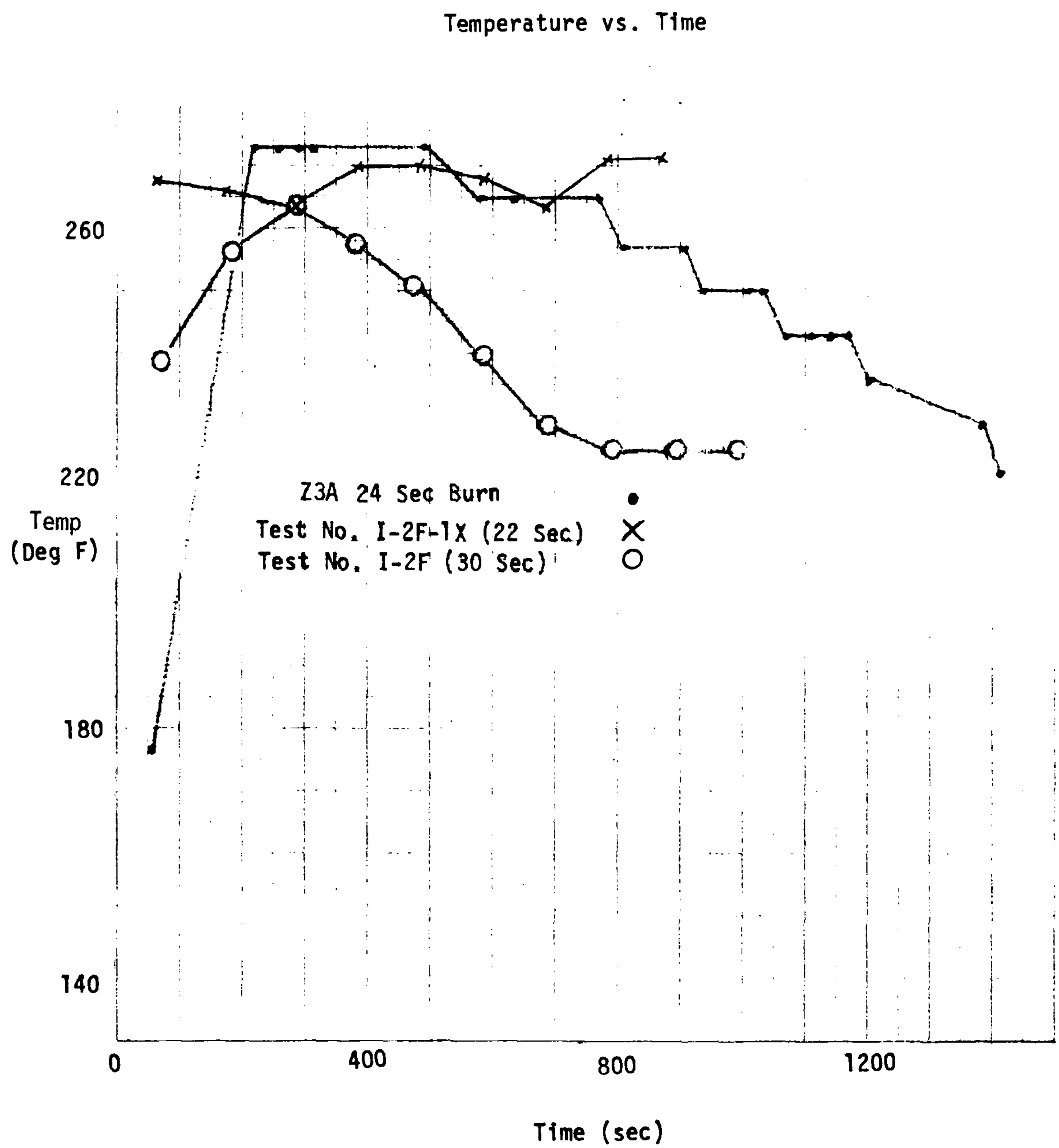


Figure 9-8. Barrier Tube Temperature Flight Data vs. Test Data

Temperature vs. Time

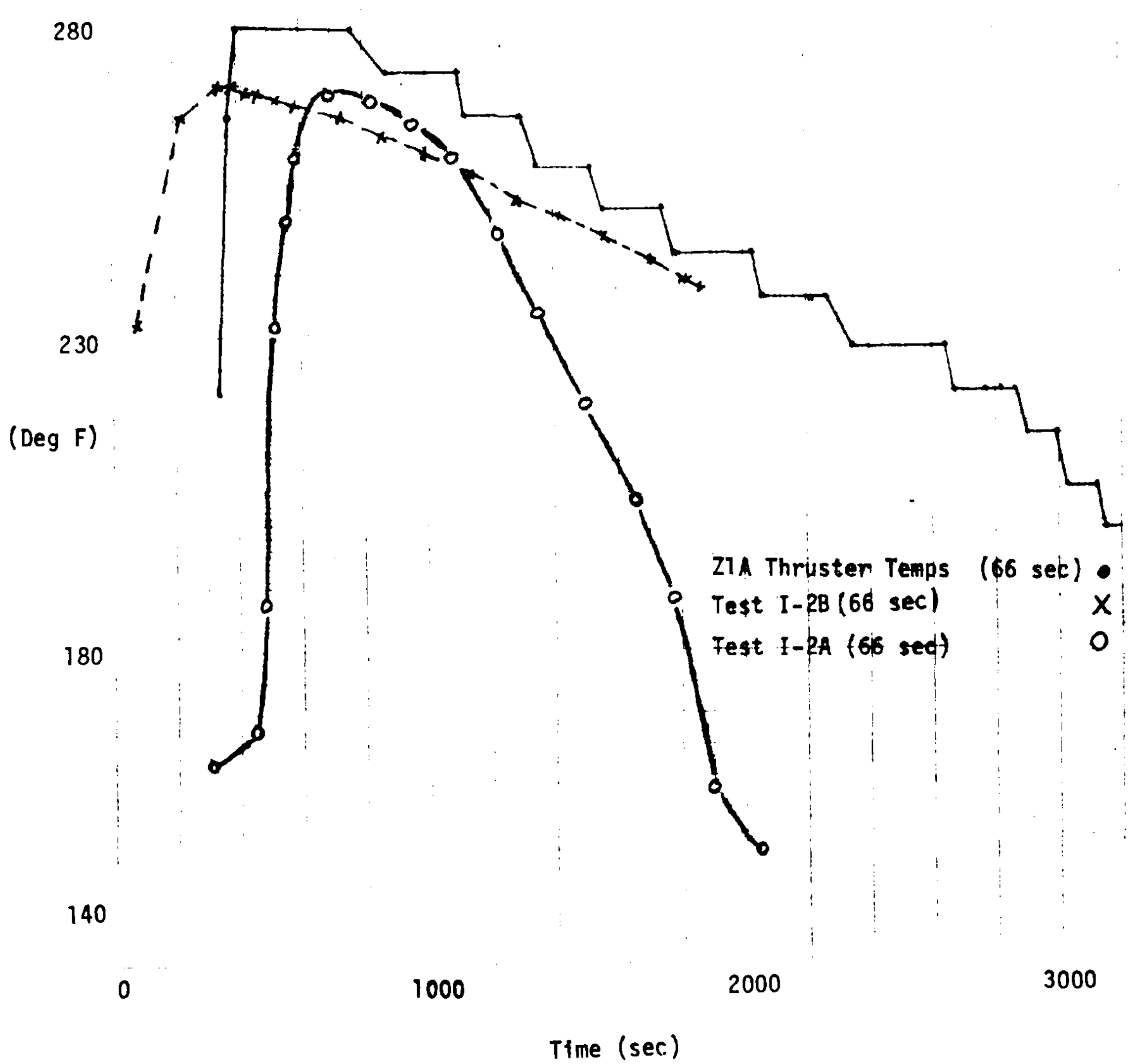


Figure 9-9. Barrier Tube Temperature Flight Data vs. Test Data

9.3 0.10 lb_f THRUSTER "CHOKE" CONDITION "TRIGGER" TEMPERATURE MAPPING TEST RESULTS

During pulse mode testing of the 0.10 lb_f thruster (baseline performance test 12S) with saturated propellant, reduced impulse pulse shapes were identified and attributed to thruster "choking" or thermal induced decomposition of the propellant in the feed tube upstream of the catalyst chamber. In order to verify this "choked" condition, six tests were devised (tests SR-1 through SR-6) to reproduce and if possible characterize the thermal conditions necessary to "choke." The tests are identified in the test matrix included in this section (Table 9-3). In each test, 50 to 60, 20 msec pulses were fired at a rate of one pulse per second with incrementally increased valve temperatures to induce choking.

No thruster choking was observed during this test sequence as the thruster performed nominally in each case. While performing Task I testing, (Test I-1D), the thruster was found to "choke" after approximately 4600 pulses and a 100 cc bubble. The choke condition was confirmed by qualitative observation of a subsequent steady-state startup which was characteristic of "choked" flow. Chamber pressure and temperature curves of test I-1D are shown in Section 9.1.2 along with an oscillograph trace of the subject steady-state startup. As a result of test I-1D, critical "choke" trigger temperature mapping tests were devised as part of the selected retest sequence. The specific test parameters of all applicable tests run including the aforementioned six are outlined in Table 9-3.

The critical temperature mapping tests are designated tests SR-13-1 through SR-13-9 wherein 50 0.20 msec pulses were fired at 1 Hz incrementally increasing the initial valve temperature 10^{o}F each test. The thruster was fired with elevated valve temperatures as high as 242^{o}F without any indication of "choking". Test SR-14 was then run to force "choked" flow by firing with a hot valve (>200^{o}F) and with the introduction of a 100 cc bubble. Initially 888 pulses were fired with no trace of choked flow when the thruster was fired for 50 seconds steady state to propagate the bubble to the thruster inlet. The thruster was then fired in the pulse mode after reheating the valve above 200^{o}F wherein the thruster choked at pulse No. 233. A total of 908 pulses were fired in an attempt to flow the bubble through while in the "choked" firing mode without success. A

442-second steady-state firing was then initiated in order to verify the choked condition and to use the existing bubble to calibrated GN_2 flowrate per test SR-10. Oscillograph traces of chamber pressure (P_c) and temperature-time curves of test SR-14 are shown in the following Figures 9-4A and 9-11 through 9-13. Test SR-1X was run with a 15-minute minimum temperature soak time with the valve body temperature held at >200°F to insure an elevated bulk temperature of the propellant in the valve inner-seat cavity. Fifty pulses were then fired with no choking observed. The last test in this sequence was run to determine thruster's susceptibility to "choking" at "end of life" (EOL) conditions (100 psia inlet pressure). There were no bubbles introduced during the test and the thruster again "choked" at approximately pulse number 230. Again, the "choked" flow I_{bit} level was approximately 20 to 30 percent of a nominal pulse. The results of the thermal mapping the the "choke" trigger temperature are outlined below:

Barrier Tube	≥265°F
Valve Body	≥200°F
Chamber/Injector	≥1050°F
Chamber/Nozzle	≥875°F

Table 9-3. 0.10 lb_f Thruster "Choke" Characterization

Test No.	P_{INJ} (PSIA)	Start Temperature (°F)				Duty Cycle	Test Objective	Test Results
		T5	T6	T7	T8			
SR-1	240	-	129	438	475	50 pulses 0.020/1 Hz	Induce "choking"	No "choke"
SR-2	240	-	136	465	496	50 pulses 0.020/1 Hz	Induce "choking"	No "choke"
SR-3	240	-	142	488	515	50 pulses 0.020/1 Hz	Induce "choking"	No "choke"
SR-4	240	-	150	476	520	50 pulses 0.020/1 Hz	Induce "choking"	No "choke"
SR-5	240	-	158	593	520	50 pulses 0.020/1 Hz	Induce "choking"	No "choke"
SR-6	240	-	165	491	518	50 pulses 0.020/1 Hz	Induce "choking"	No "choke"
SR-13-1	240	229	159	467	497	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-2	240	247	171	586	604	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-3	240	254	181	645	652	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-4	240	257	191	690	691	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-5	240	259	201	746	730	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-6	240	259	212	718	716	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-7	240	261	219	757	744	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-13-8	240	251	230	522	546	50 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"

Table 9-3. 0.10 lb_f Thruster "Choke" Characterization (Continued)

Test No.	P_{INJ} (PSIA)	Start Temperature (°F) T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
SR-13-9	240	256	242	585	599	10 pulses 0.020/1 Hz	Critical temperature mapping (choke condition)	No "choke"
SR-14	240	241	191	490	516	888 pulses 0.020/1 Hz	Force "choking" condition with hot valve and 100 cc bubble.	No "choke" and bubble had not reached thruster yet.
		-	-	-	-	50 sec. steady state	Propagate bubble	
		262	201	782	784	908 pulses 0.020/1 Hz	Force "choke" with bubble and hot valve	Thruster "choked" at pulse No. 223. Bubble had not reached thruster yet.
SR-14	240	263	222	877	752	442 sec. steady state	Confirm "choked" condition and calibrate GN2 flow since bubble was still in line (100 cc)	Delay start characteristics of "choked" condition, flowed 100 cc bubble through.
SR-1X	240	263	208	1052	883	50 pulses 0.020/1 Hz	Force "choke" with hot valve, and catbed chamber. Allow 15 min. for propellant in valve to reach equilibrium valve temp.	"No choke"
SR-15	100	240	195	470	493	300 pulses 0.020/1 Hz	Force "choking" at E.O.L. conditions	Choked at pulse No. 230

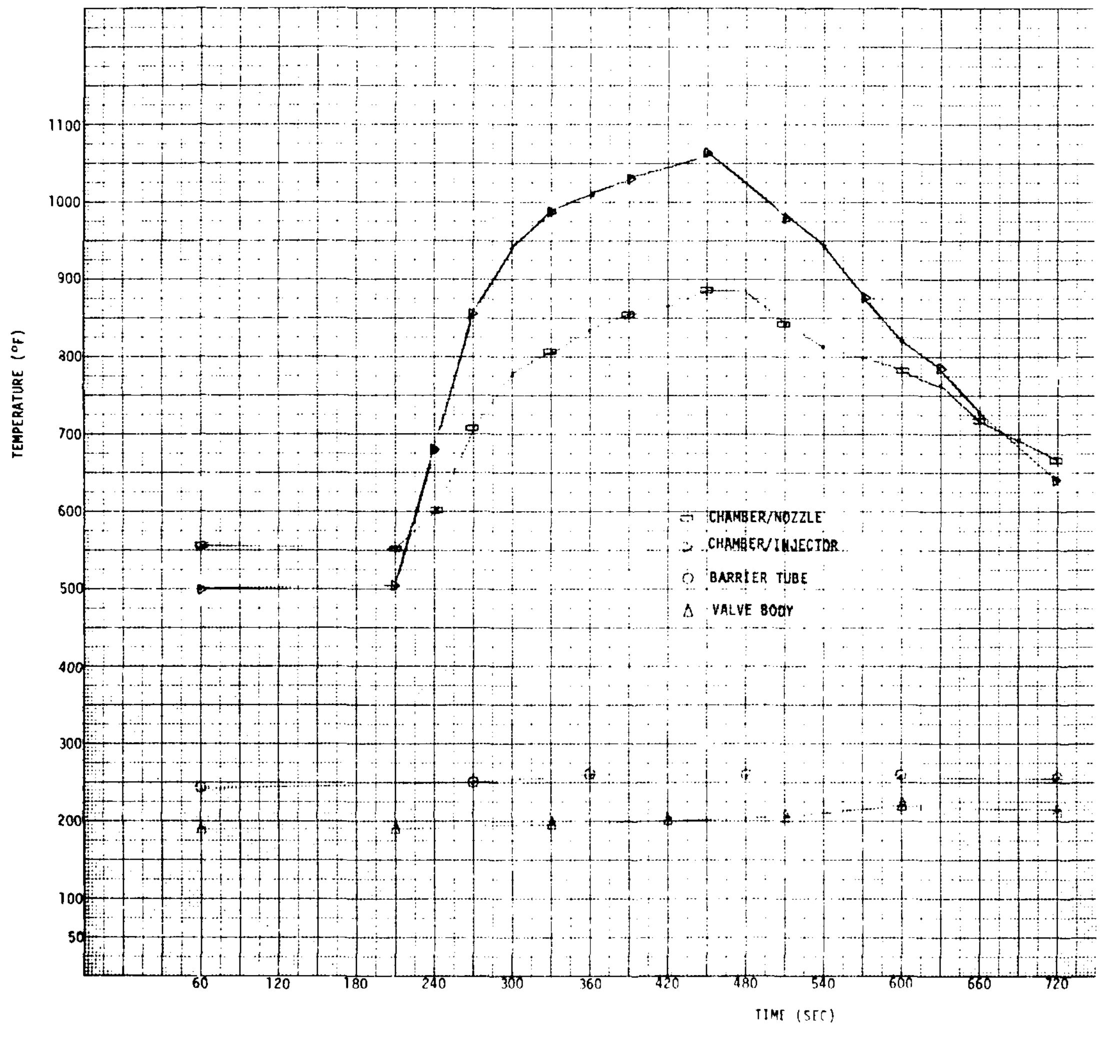


Figure 9-11. Test SR-14 0.10 lb_f Thruster Temperature vs. Time

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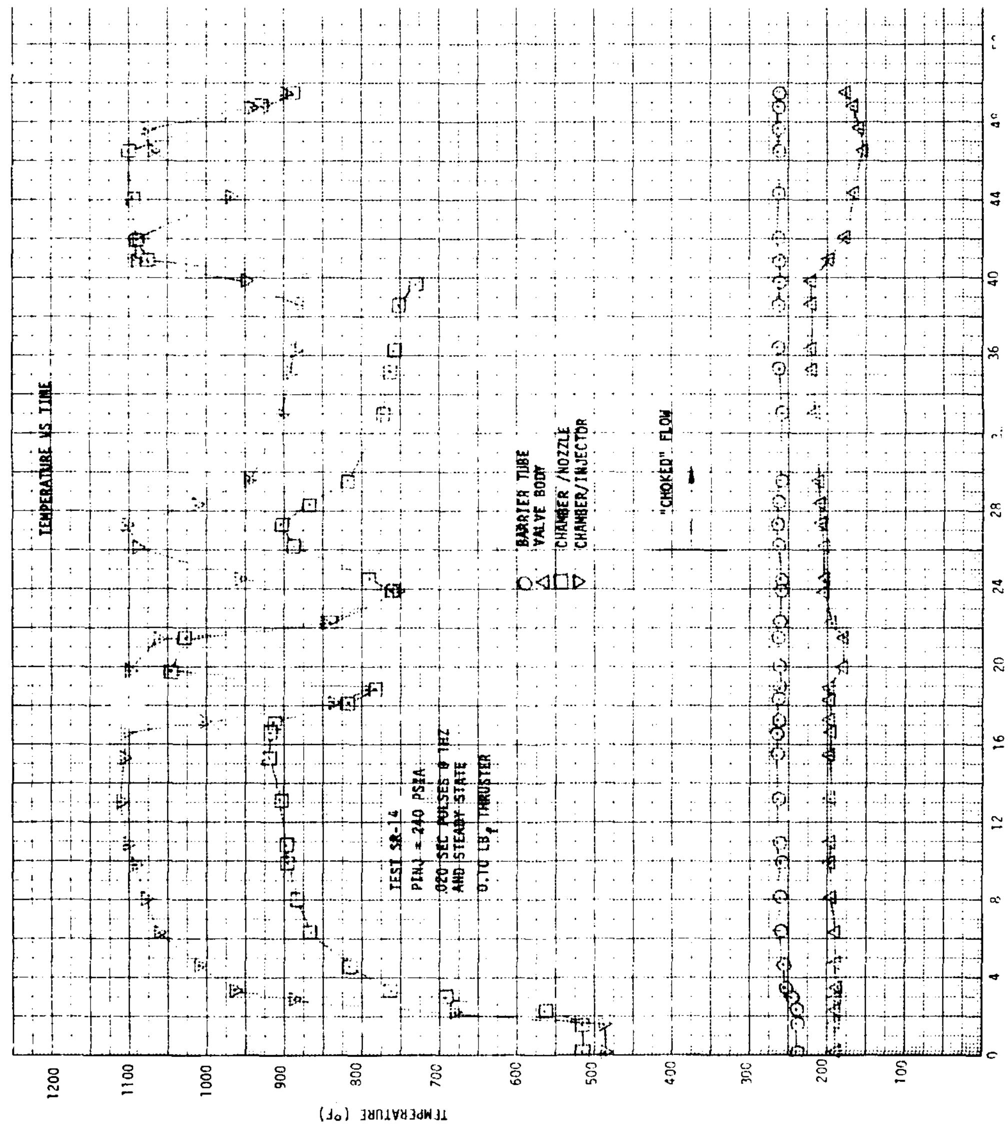

Figure 9-12. Test SR-14 Temperature vs. Time

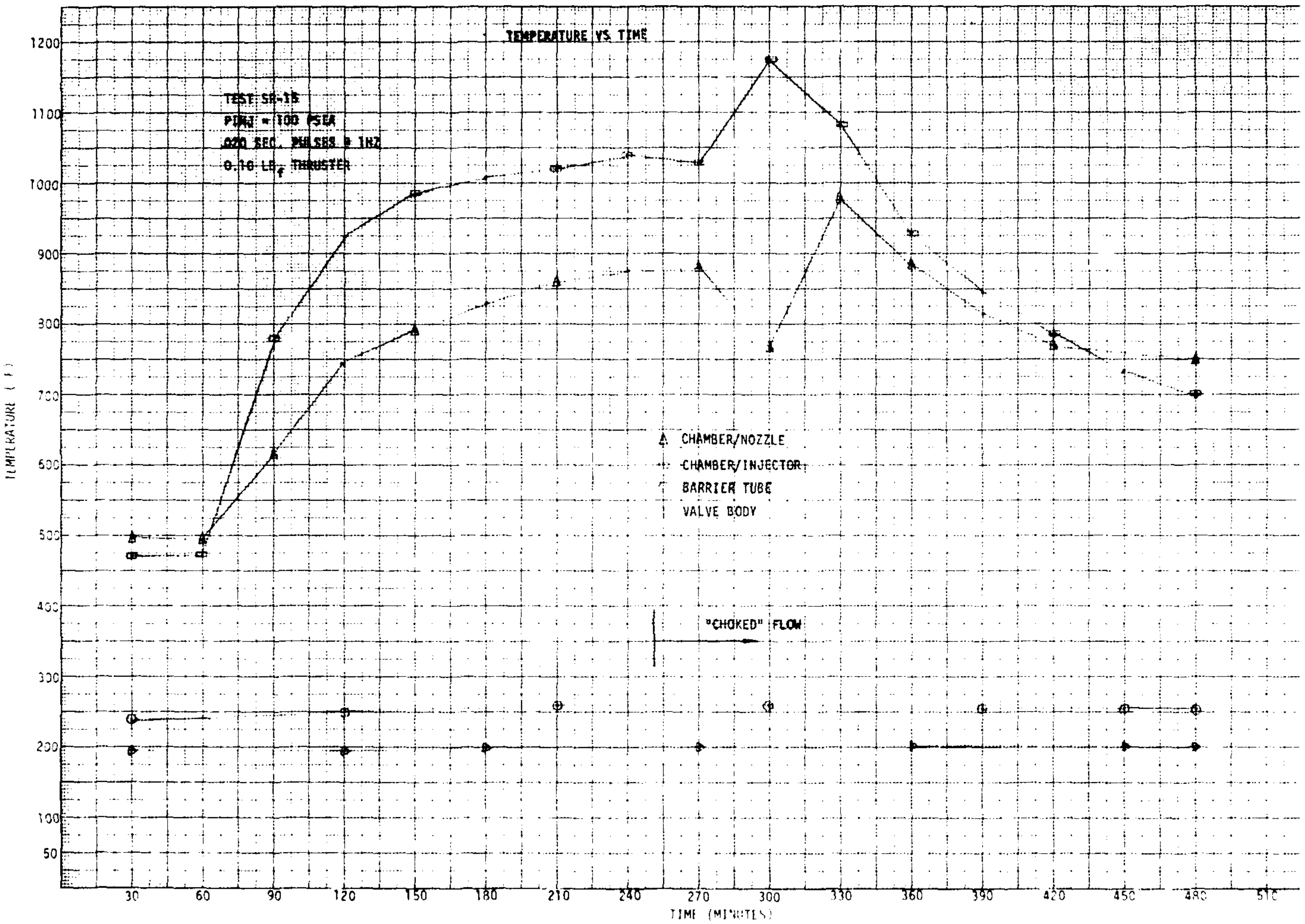

Figure 9-13. Test SR-15 Temperature vs. Time

9.4 ISOLATION VALVE CLOSED TESTS RESULTS 1.0 LB_f THRUSTER

9.4.1 1.0 lb_f Thruster

The 1.0 lb_f thruster was run with the bank isolation valve closed to determine performance decay, temperature response, and investigate possible resulting thruster degradation. A total of seven tests were run with the last test a part of the selected retest sequence which addressed the resultant performance decay after a cold start with the isolation valve closed.

Table 9-4 is a summary of the tests run with their respective test conditions.

Tests II-1C, II-1AX, II-1A were run with 0.50 sec pulses at a rate of 1 pulse per second down to inlet pressures of ~10 psia. Approximately 200 pulses are required to vent the upstream line systems from 240 psia to 10 psia. In addition, 854 pulses were fired during test II-1C with a resultant inlet pressure of 8.2 psia. The resultant pressure blow-down curves are presented on Figures 9-14 through 9-16. Typical temperature response curves for firings while in the isolation valve closed configuration are shown on Figures 9-17 and 9-18. The temperature response curves support on-orbit data obtained while firing thrusters during the sun-acquisition checkout exercise performed during FSC ascent operations at Sunnyvale.

The last test in this series (test SR-7) was performed to determine thruster performance resulting from firing with the isolation valve closed in the "cold" (~70°F) catalyst bed configuration with 0.050 sec pulses at a rate of 1 pulse per minute. A total of 20 pulses were fired during this sequence with the first and last 5 pulses of the 20 pulse train shown on Figure 9-19.

Note that in Figure 9-19 the impulse delivered during the first pulses in the pulse train of test SR-7 is slightly lower than normal which is attributed to the cold start condition (~70°F). Subsequent to isolation valve closed firings, the thruster was operated in both the steady state and pulse modes to determine if there were GN_2 bubbles generated as a result of the apparent pressure decay or if such operation causes thruster degradation. As predicted, it was concluded that isolation valve closed firings do not affect thruster performance or reliability in the near-term nor are bubbles (large enough to be detected) generated.

Table 9-4. Test Matrix

Test No.	Thruster Type	P_{inj} (Psia)	Start Temperature (°F)				Duty Cycle	Test Objective	Test Results
			T1	T2	T3	T4			
II-1C	1.0	240	156	177	-	-	854 pulses .050 sec/1 Hz	Isolation valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 8.2 psia inlet pressure.
II-1C-X	1.0	240	-	-	-	-	100 sec steady state	Clear line of possible bubbles formed during previous test	No bubbles found.
II-1B	1.0	240	162	142	-	-	20 pulses .050/1 Hz	Determine performance recovery	Nominal performance.
II-1AX	1.0	240	178	140	213	-	200 pulses .050/1 Hz	Isolation valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 10.6 psia inlet pressure
II-1XA	1.0	240	-	-	-	-	100 sec steady state	Clear line of possible bubbles formed during previous test	Nominal performance no bubbles
II-1A	1.0	240	-	-	-	-	247 pulses .050/1 Hz	Isolation valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 9 psia inlet pressure
SR-7	1.0	240	65	77	63	96	20 pulses .050/1 pulse/min	Determine effects of cold start with isolation closed	Nominal performance

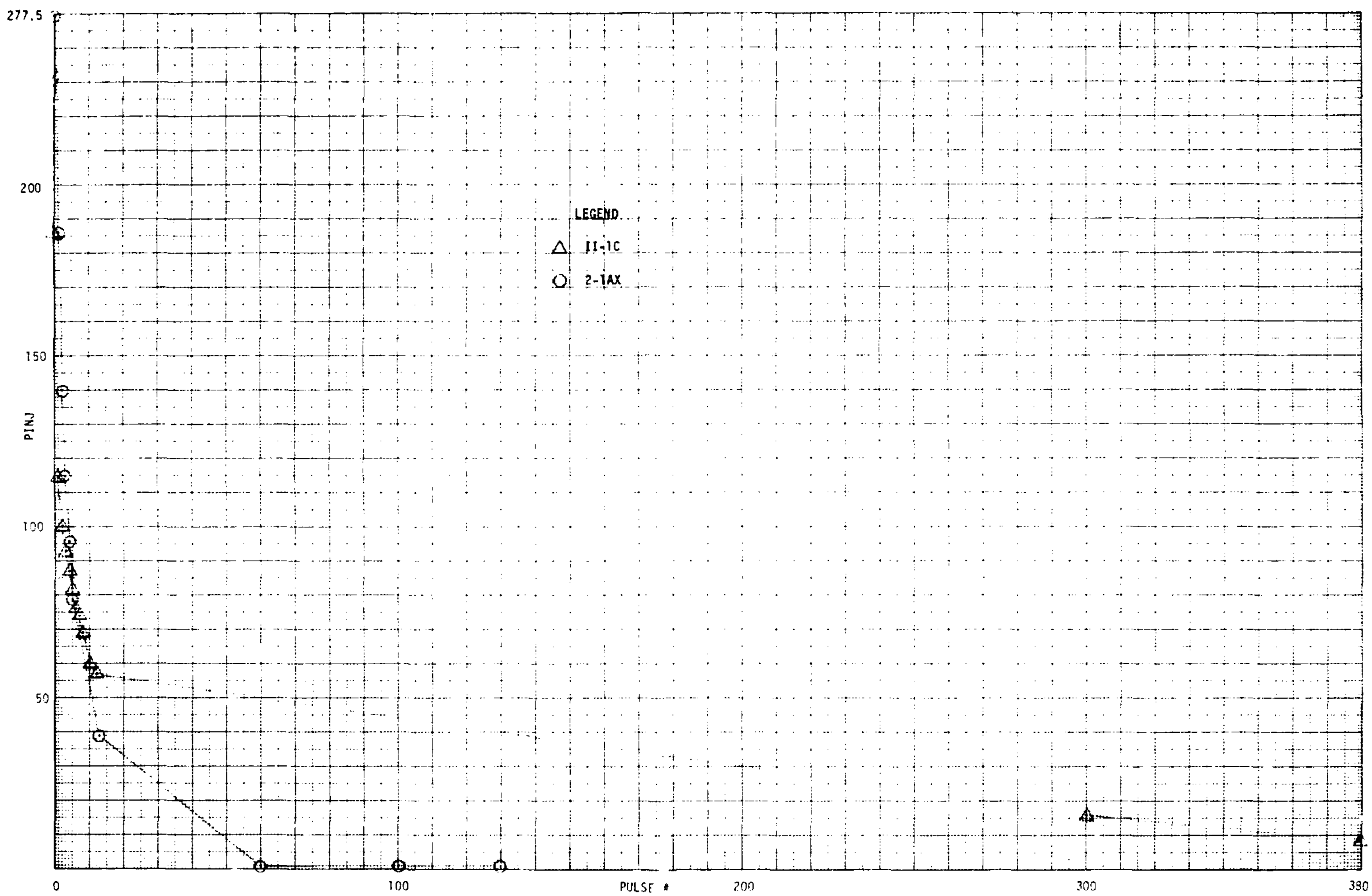

Figure 9-14. Inlet Pressure (PIN_J) vs. Pulse Number, Isolation Valve Closed

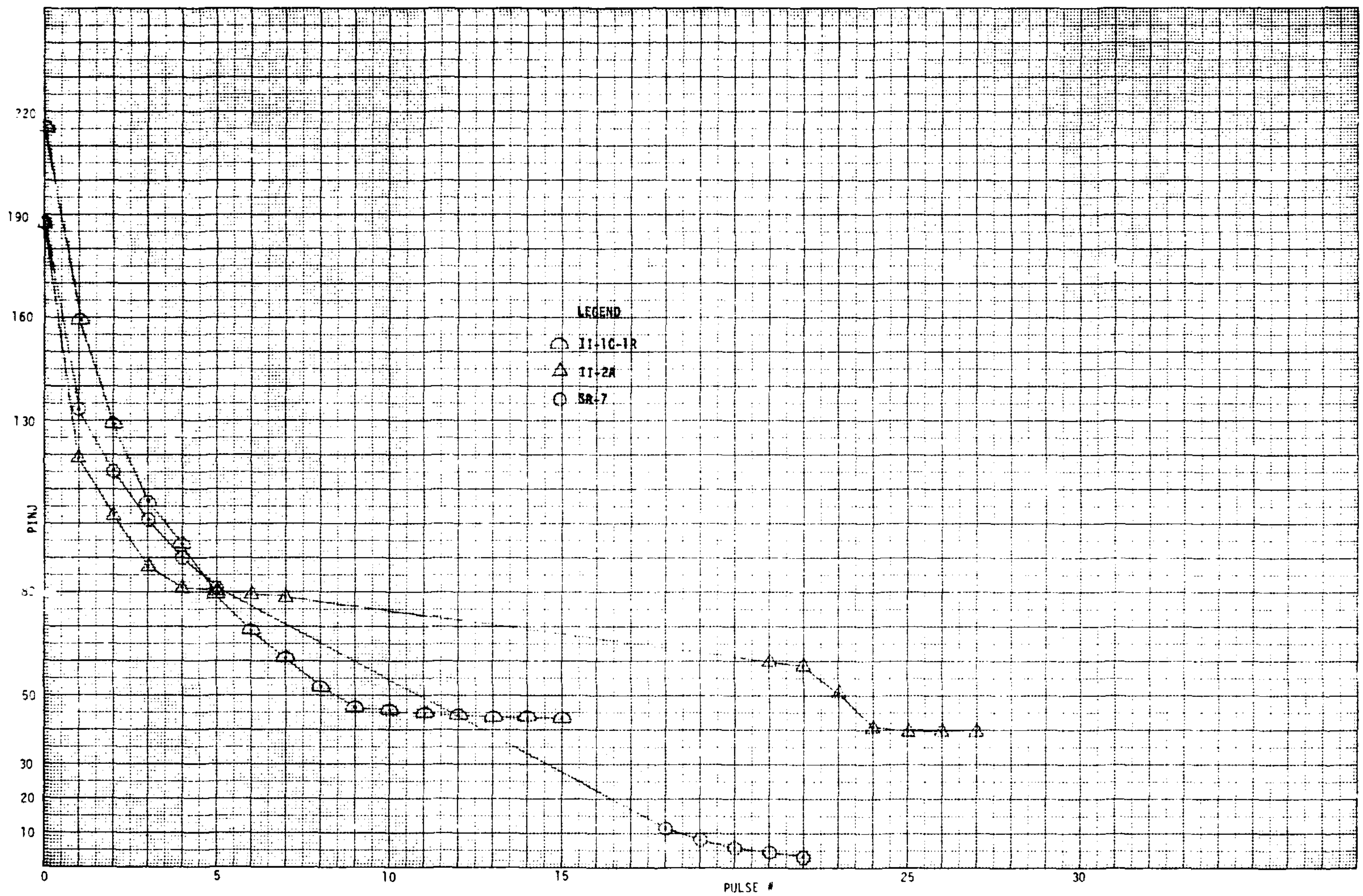

Figure 9-15. Inlet Pressure (PIN_J) vs. Pulse Number, Isolation Valve Closed

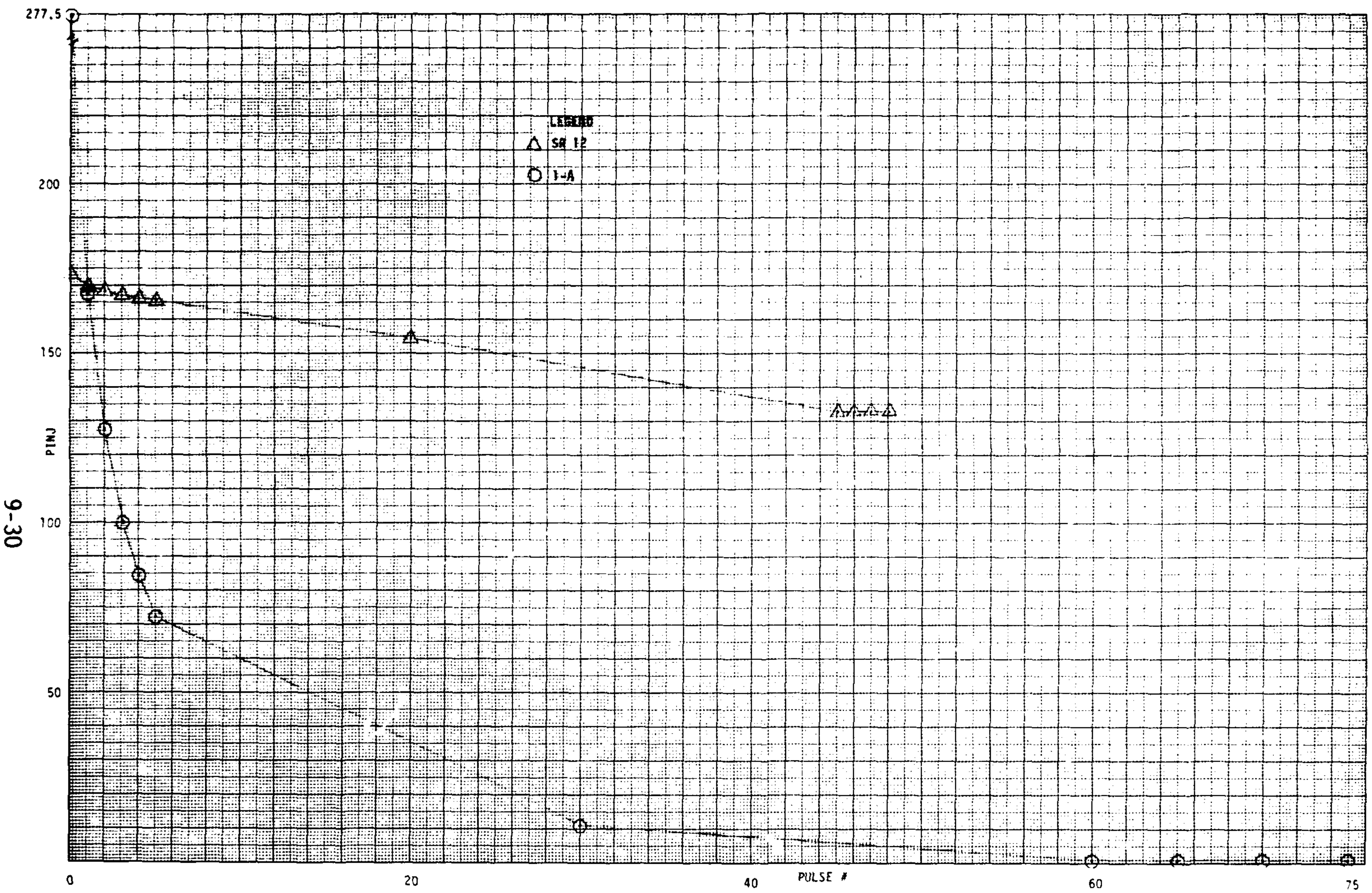

Figure 9-16. Inlet Pressure (PIN_J) vs. Pulse Number, Isolation Valve Closed

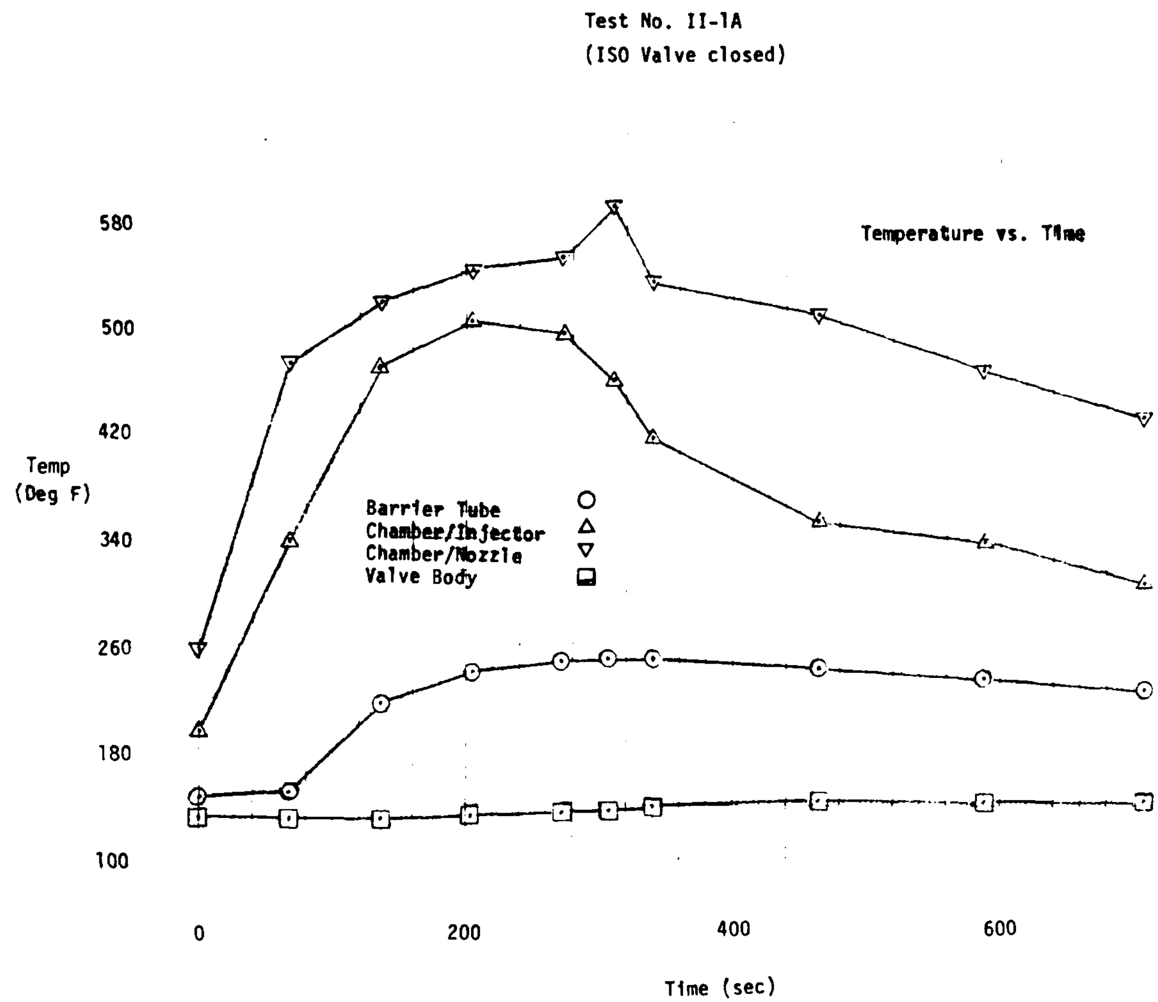

Figure 9-17. Test No. II-1A, Isolation Valve Closed

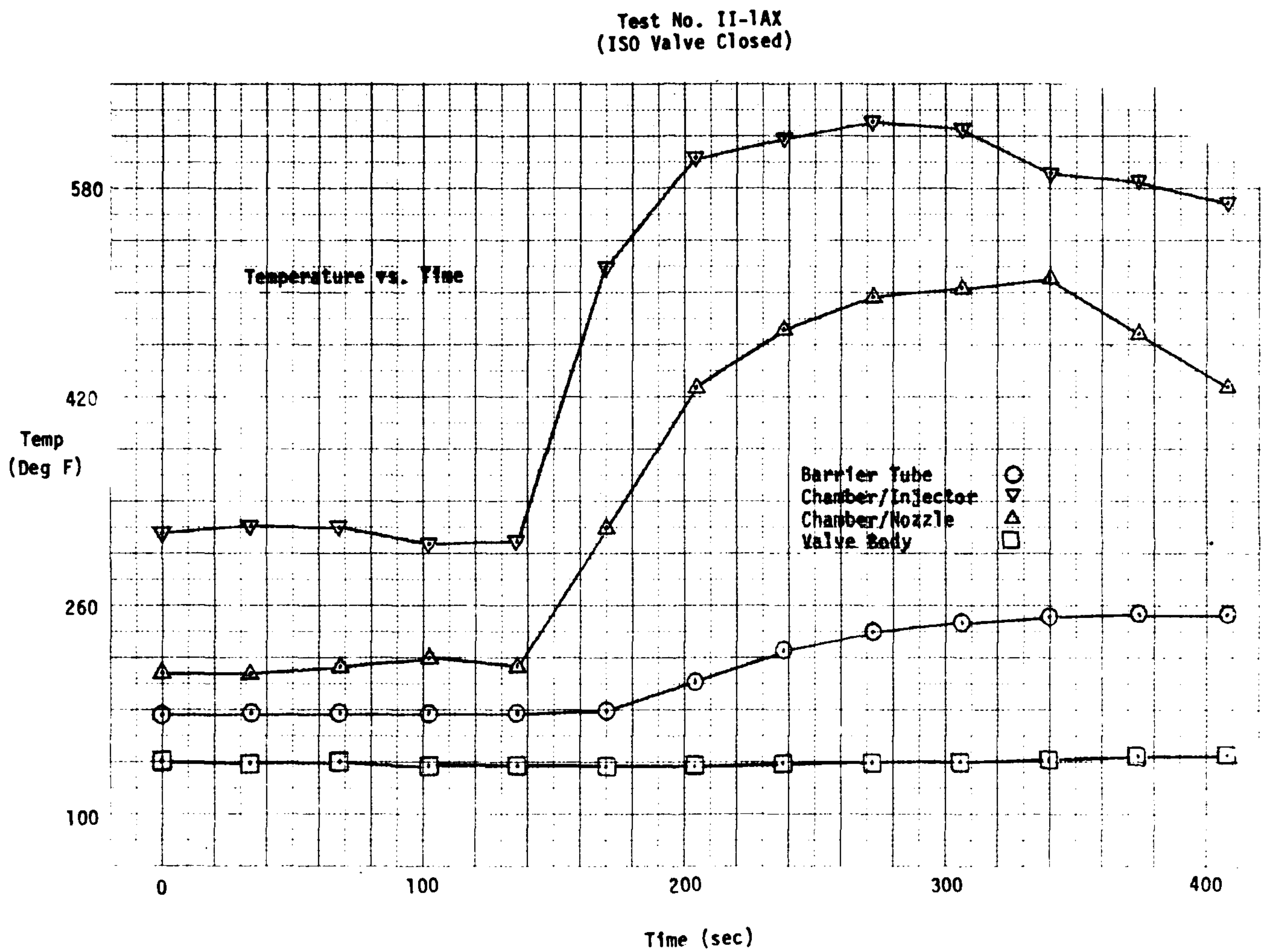

Figure 9-18. Test No. II-1AX, Isolation Valve Closed

TEST SR 7
1.0 LBF THRUSTER - 240 PSI INLET PRESSURE
PULSING MODE ISOLATION VALVE CLOSED, COLD START
.059 SEC PULSES 1 PULSE/MIN

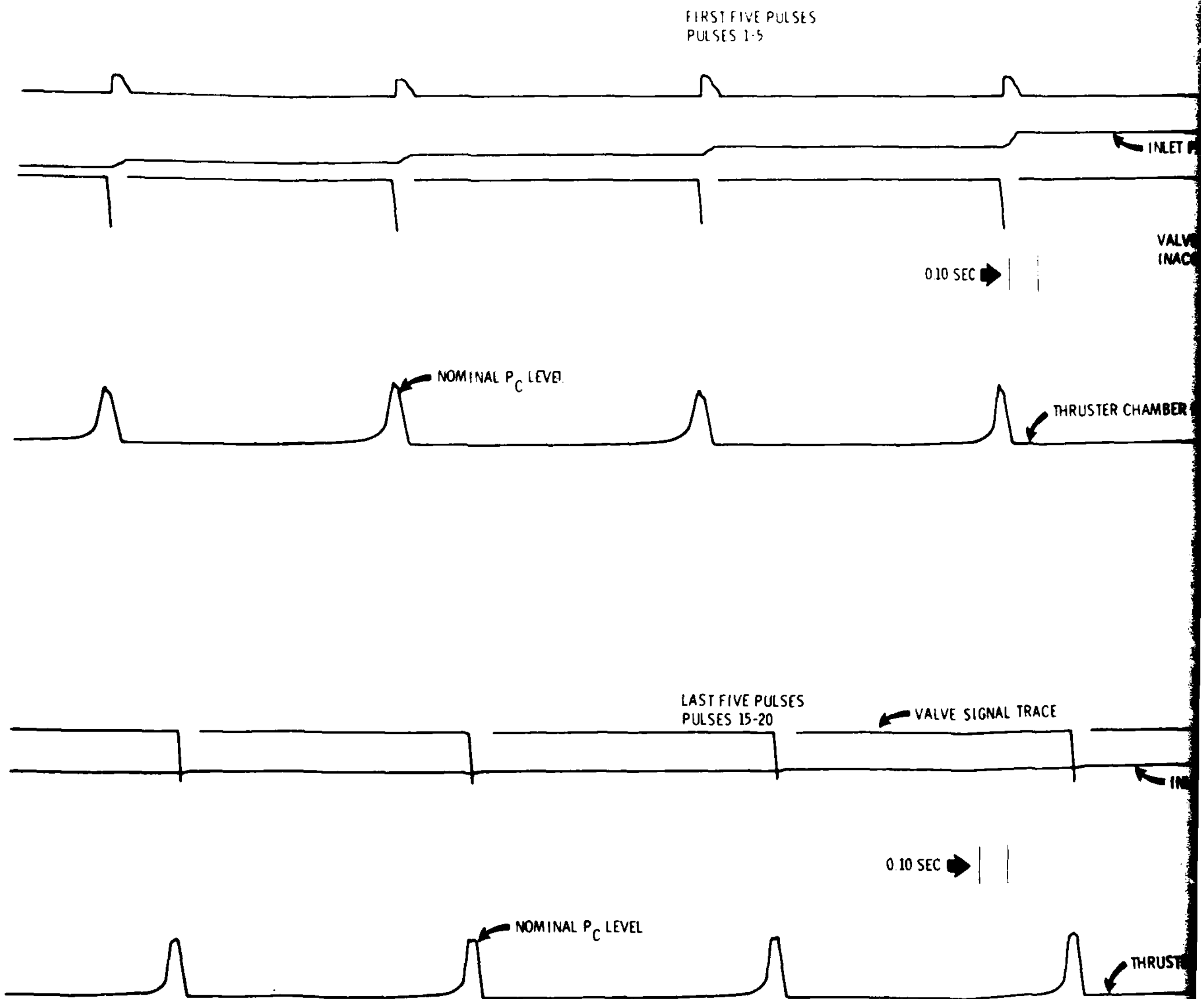

Figure 9-1

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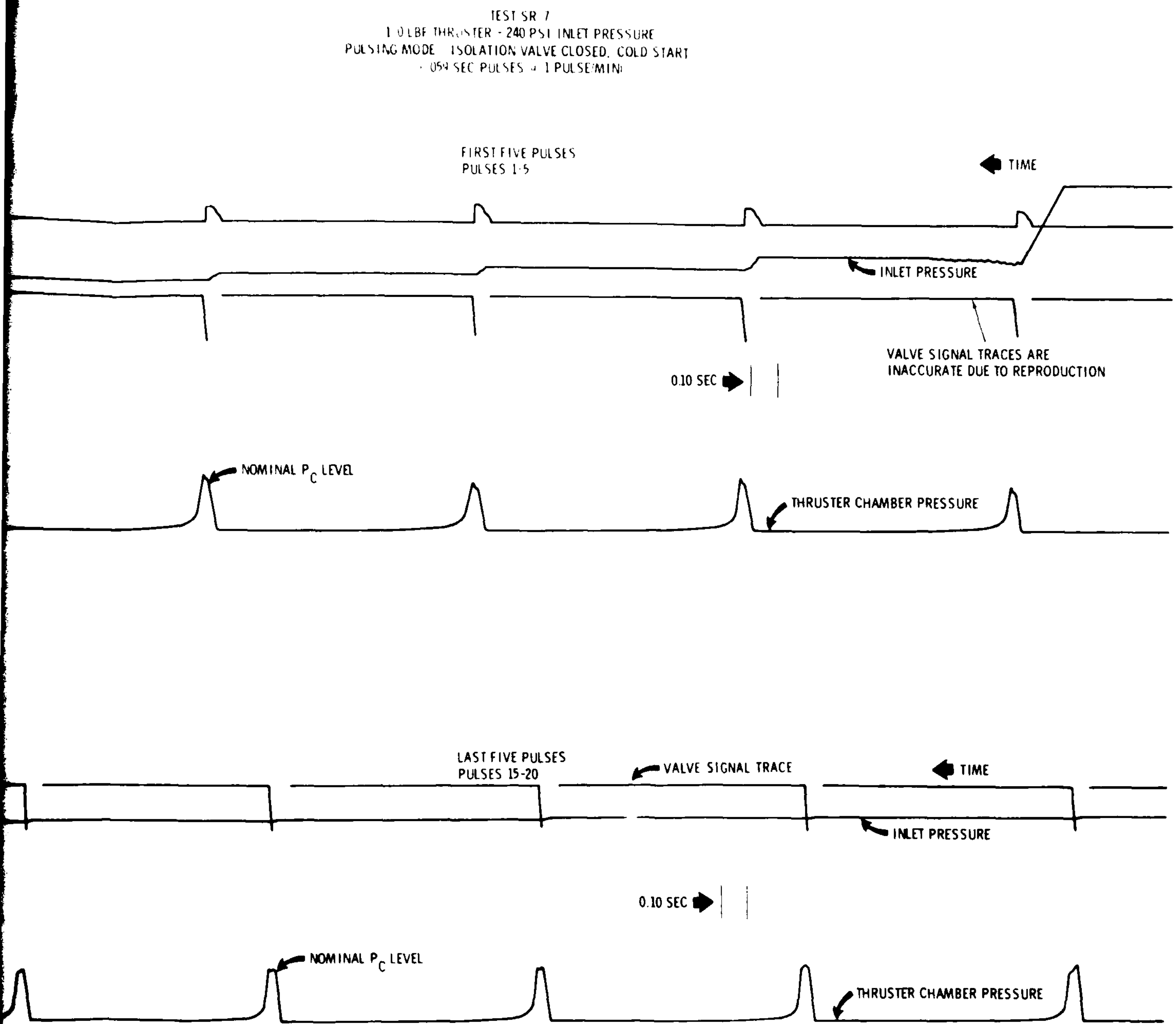


Figure 9-19. Test SR-7. 1.0 lb_f Thruster, 240 PSI Inlet Pressure, Iso Valve Closed

9.4.2 0.10 lb_f Thruster

The 0.10 lb_f thruster was operated in the pulse mode (0.50 sec 'on' at 1 Hz) with the isolation valve closed to determine performance decay as of a function of pulse number to verify results obtained from in-flight data during the -RYB anomaly period.

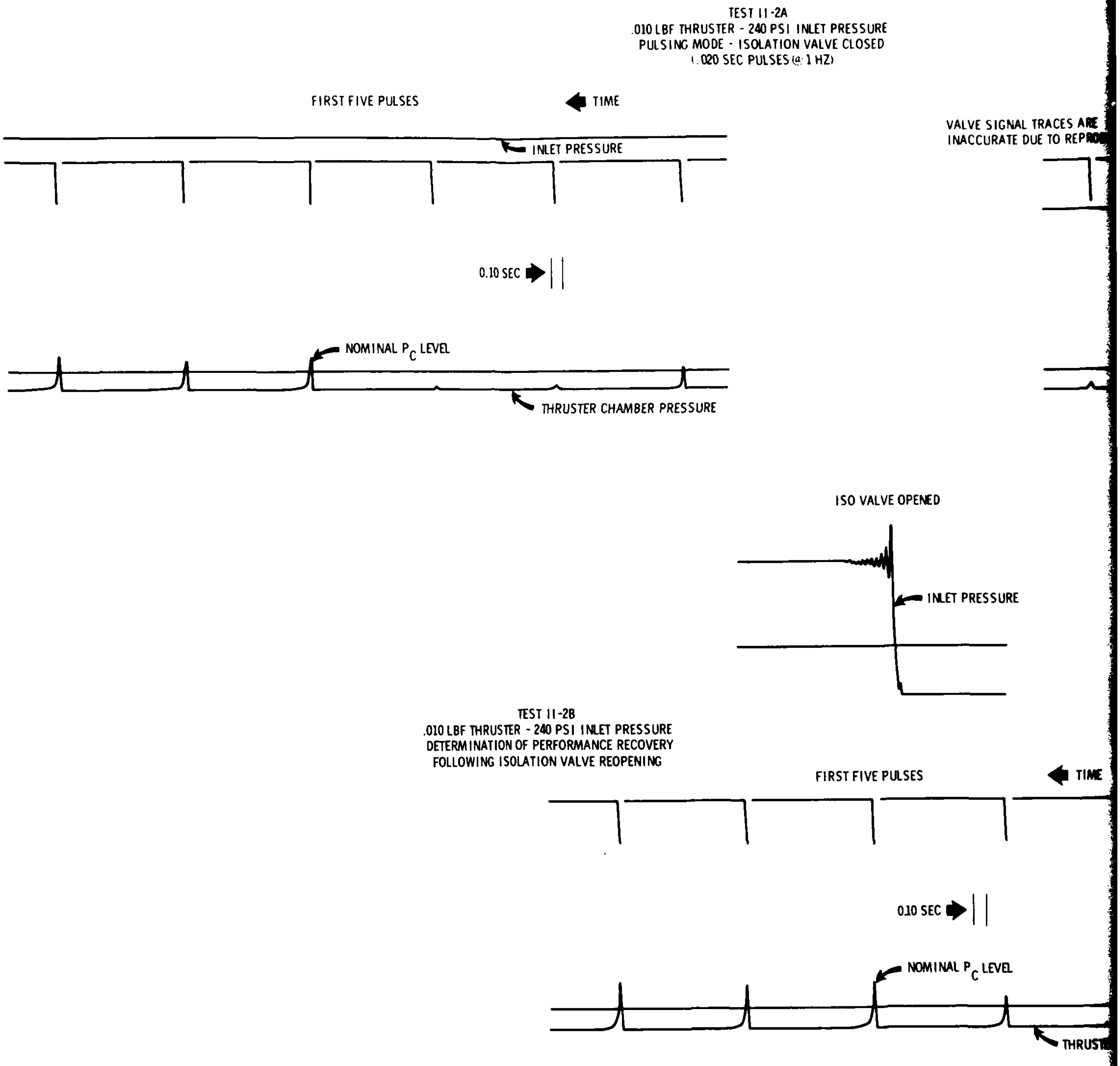
Test II-2A was run with the appropriate conditions as outlined in Table 9-5.

Chamber pressure traces for test II-2A are shown on Figure 9-20. The corresponding inlet pressure versus pulse number curve is shown on Figure 9-15. The isolation valve was subsequently reopened, repressurizing the thruster inlet prior to the start of test II-2B. The repressurization transient is shown in Figure 9-20 (oscillograph trace). Test II-2B was then performed according to Table 9-5 with no anomalous thruster behavior observed. The initial pulses of test II-2B are shown on Figure 9-20. The temperature response curve for test II-2A is shown on Figure 9-21 and support observed in flight data during the anomaly period.

In conclusion the thruster performed nominally throughout the isolation valve closed test sequence with no deleterious operation observed. Therefore, it is noted that thruster operation with upstream isolation valves closed is not detrimental to thruster health in the near term.

Table 9-5. Test Matrix

Test No.	Thruster Type	Pin_J (Psia)	Start Temperature (°F) T1	T2	T3	T4	Duty Cycle	Test Objective	Test Results
II-2A	0.10	240	150	140	274	-	637 pulses .020/1 Hz	Isolation valve closed, determine performance decay	Significant impulse delivered with corresponding temp rise down to 8.2 psia inlet pressure.
II-2B	0.10	240	153	140	-	-	20 pulses .020/1 Hz	Determine performance decay	Nominal performance
SR-12	0.10	240	-	72	81	84	50 pulses .020-1 pulse/min	Determine performance degradataion with Iso closed and cold start	All pulses nominal based on inlet pressure
			-	-	-	-	49 pulses .020-1 pulse/min after 15 hour hold	Determine performance degradation with Iso closed and cold start	All pulses nominal based on inlet pressure
			-	-	-	-	Steady state	Blow down to <1 psia	No adverse effects observed during this operation mode


TEST 11-2A
.010 LBF THRUSTER - 240 PSI INLET PRESSURE
PULSING MODE - ISOLATION VALVE CLOSED
(.020 SEC PULSES @ 1 HZ)
FIRST FIVE PULSES
TIME
INLET PRESSURE
0.10 SEC
NOMINAL P_C LEVEL
THRUSTER CHAMBER PRESSURE
ISO VALVE OPENED
INLET PRESSURE
TEST 11-2B
.010 LBF THRUSTER - 240 PSI INLET PRESSURE
DETERMINATION OF PERFORMANCE RECOVERY
FOLLOWING ISOLATION VALVE REOPENING
FIRST FIVE PULSES
TIME
0.10 SEC
NOMINAL P_C LEVEL

R5-168-80

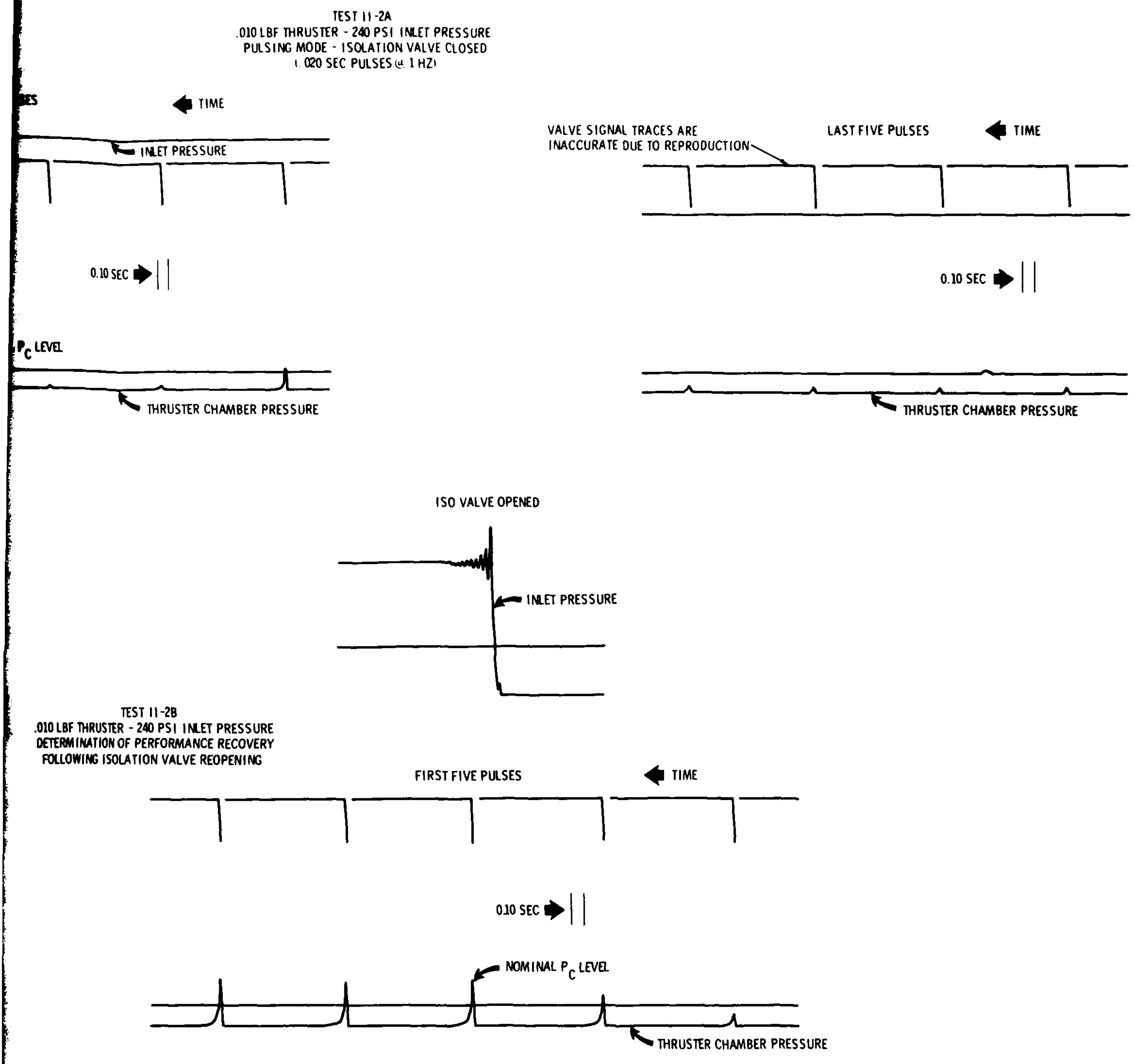


Figure 9-20. Tests II-A and II-B: .010 lb_f Thruster, 240 PSI Inlet Pressure, Iso. Valve Closed/Open

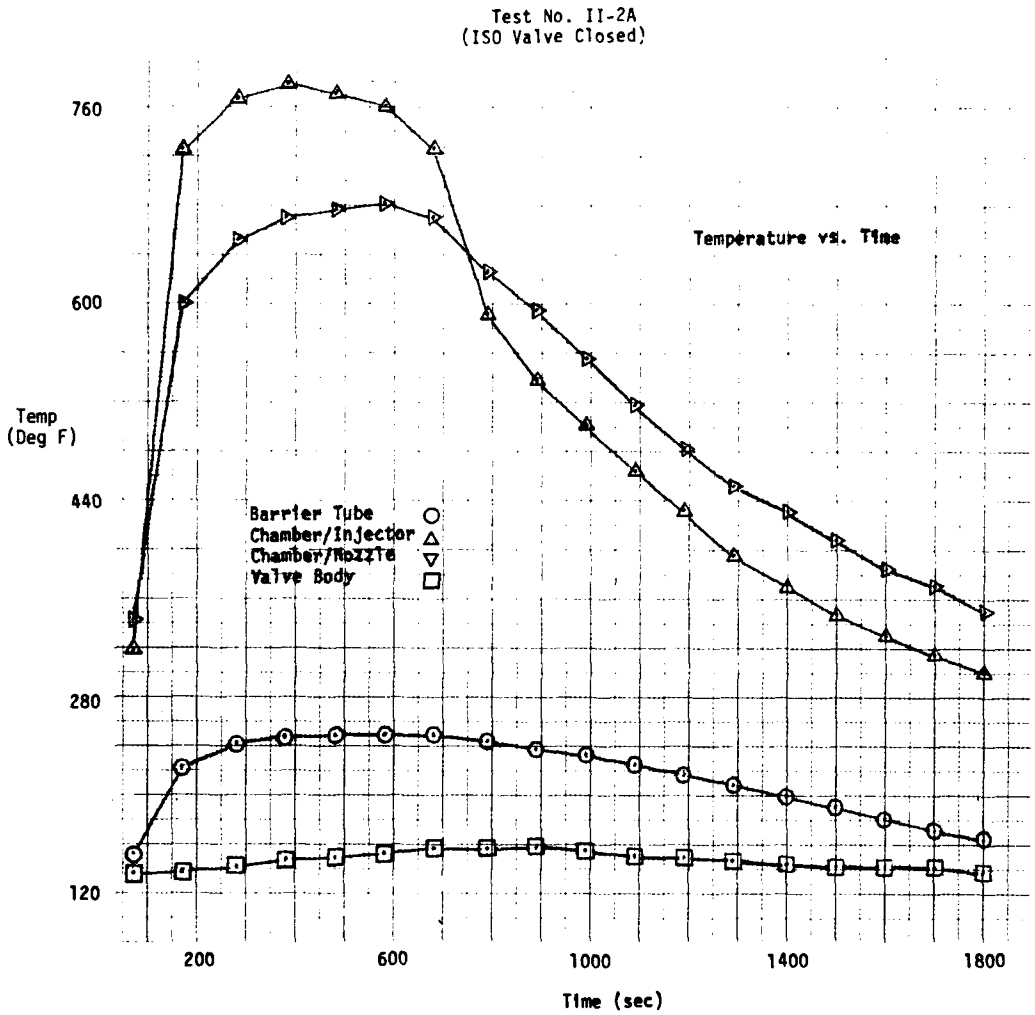
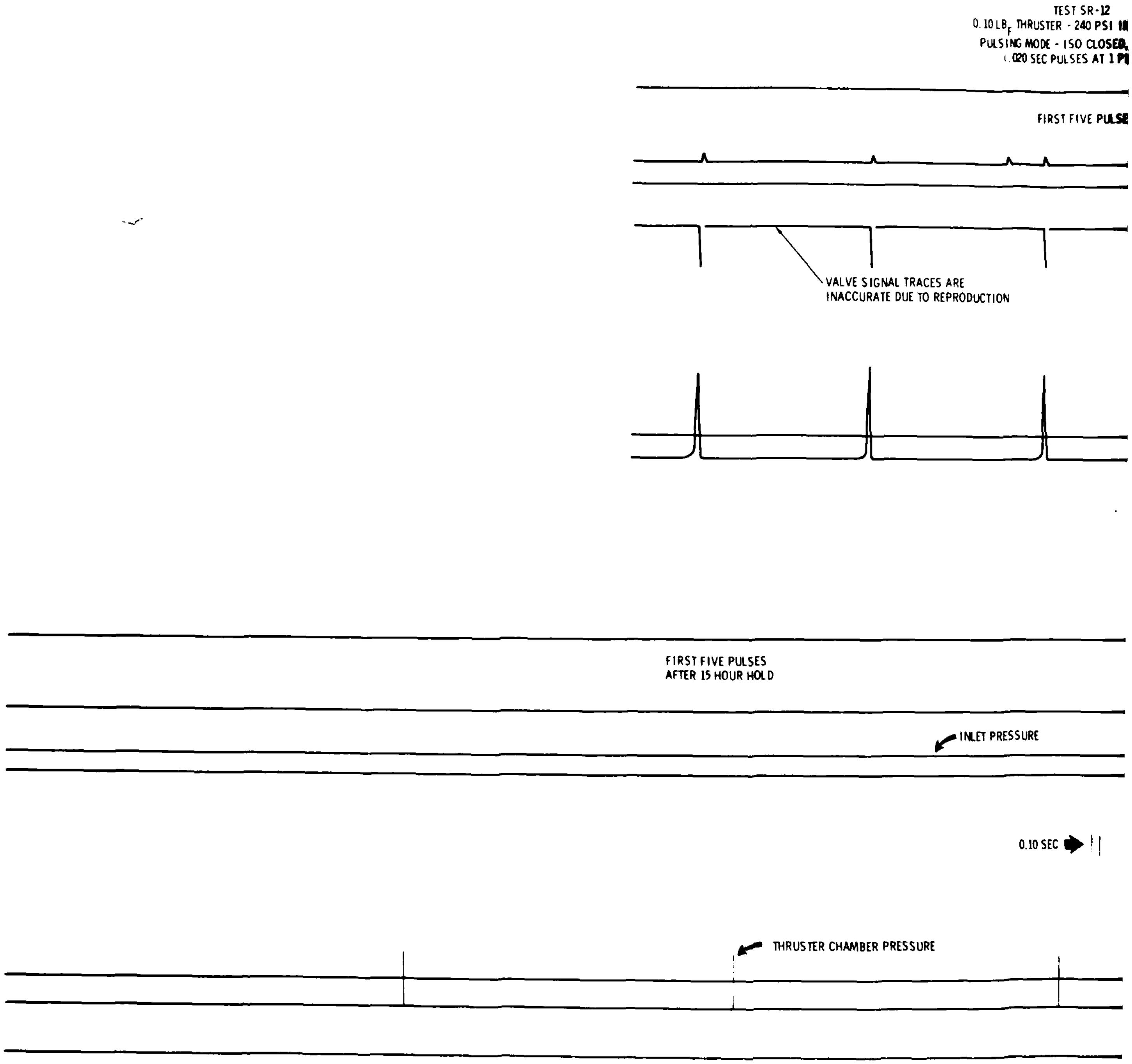


Figure 9-21. Test No. II-2A, Isolation Valve Closed



TEST SR-12
0.10 LB_F THRUSTER - 240 PSI
PULSING MODE - ISO CLOSED,
.020 SEC PULSES AT 1
FIRST FIVE PULSE
VALVE SIGNAL TRACES ARE INACCURATE DUE TO REPRODUCTION
FIRST FIVE PULSES AFTER 15 HOUR HOLD
INLET PRESSURE
0.10 SEC
THRUSTER CHAMBER PRESSURE

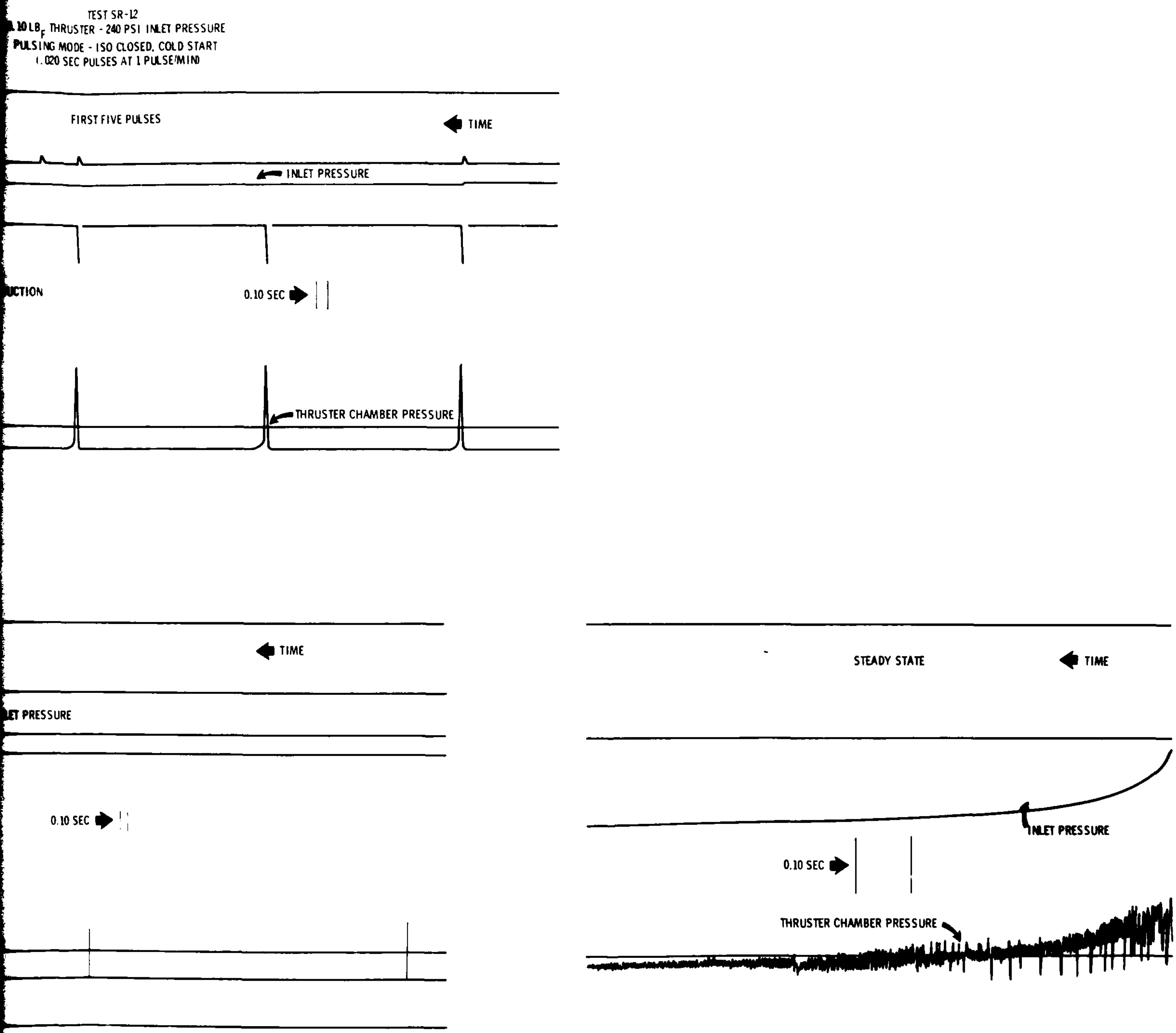


Figure 9-22. Test SR-12. 0.10 lb$_f$ Thruster, 240 PSI Inlet Pressure, Iso. Valve Closed

9.5 "DRY VALVE" TESTS (TASK III)

The +PA thruster failure mode (first 2-1/2 pulses missed in 5-10 pulse train) was simulated by firing the 1.0 lb_f thruster with the valve inner-seat cavity evacuated. The propellant feed system was configured as per Figure 7-1. The propellant was aspirated out of the line system between the downstream isolation valve and the thruster inlet. With the isolation valve closed, the chamber was evacuated and the thruster valve opened until any residual N_2H_4 had passed through the thruster ($\sim$10 minutes). The thruster valve was then closed and the system was bled. All tests in the task were run in an identical fashion except for Test 1 (III-1A) which was run during the baseline performance series as the initial test.

The second set of tests (SR-16, SR-17, SR-18) were run as a part of the selected retest sequence where the pulse duty cycle was varied to determine performance decay as a function of duty cycle. The corresponding test conditions along with the test results for all applicable tests are shown on Table 9-6. Tests SR-16, SR-17, SR-18, were run with longer propellant feed system line lengths which inhibited system bleed capabilities. Therefore, it is noted that first and second pulse impulse for these tests is higher than corresponding pulses of the first series. This trend can be extrapolated to the near perfect bleed capabilities of the spacecraft environment where a leaky downstream seat could allow a total evacuation of the valve inner-seat cavity and therefore cause an increased loss of impulse during the first 2 or 3 pulses. It is therefore concluded that the test data obtained supports the postulated +PA failure mode and that impulse loss during the first few pulses is a function of valve inner-seat cavity bleed and not duty cycle. Oscillograph traces for the Task III test series are shown on Figure 9-22. Note that test SR-12 was interrupted according to procedure with a 15 hour hold between pulse numbers 50 and 51 to investigate possible repressurization phenomena and that the respective data indicates no tendancy for system repressurization or impulse recovery as a result of this 'hold' period. The following data table summarized the Task III results.

Table 9-6. "Dry Valve" Test Results 1.0 lb_f Thruster

Test No.	Inlet Pressure (psia)	Duty Cycle on/off (sec)	Impulse (% of Nominal)				
			1st Pulse	2nd Pulse	3rd Pulse	4th Pulse	5th Pulse
*1 (III-1A)	240	.050/.950	0	73	93	98	100
III-2A	240	.050/.950	0	61	93	97	100
III-3A	240	.050/.950	0	63	95	100	100
**SR-17	240	.050/50	18	91	100	100	100
**SR-18	240	.050/100	34	91	97	100	100
**SR-16	240	.050/300	17	100	97	100	100

*Unsaturated propellant, all other tests run with saturated N_2H_4.

**Tests run with longer line lengths as previous 3 tests. Data consistent with system bleed.

9.6 NITROGEN GAS FLOWRATE CALIBRATION

Tests were performed with both the 1.0 lb_f thruster to establish expected thruster "off times" as a result of GN_2 flow. As outlined in Section 9.1, thruster "off times" due to bubble flow while operating in the pulse mode were inconclusive due to the random nature of the apparent bubble break-up during firing. It was therefore concluded that gas flowrates can be obtained for each thruster while firing steady state to preclude bubble break-up and then extrapolate the results to provide pulse mode data. Flowrate data was generated from both 10 cc and 100 cc bubble ingestion tests: I-3A, SR-14, SR-11, I-2F-1X.

Resultant thruster off times (periods of negligible impulse delivered due to bubble) is outlined below.

1.0 lb_f Thruster

Bubble Size	"OFF" Time	Flowrate
100 cc bubble	13 seconds	0.469 $in^3/sec)$ GN_2
10 cc bubble	2 seconds	0.305 $in^3/sec)$ GN_2

0.10 lb_f Thruster

Bubble Size	"OFF" Time	Flowrate
100 cc bubble	47 seconds	0.129 $in^3/sec)$ GN_2
10 cc bubble	10 seconds	0.061 $in^3/sec)$ GN_2

Then, gas flowrate data were obtained analytically for pulse mode operation as follows: 0.52 inches of FSC type propellant line used per 0.050 second pulse (1.0 lb_f thruster); 0.05 inches of FSC type propellant line used per 0.020 second pulse (0.10 lb_f thruster).

9.7 BASELINE PERFORMANCE TEST SERIES

A total of twenty-six tests were performed to calibrate nominal performance levels for both the 1.0 lb_f and 0.10 lb_f thrusters and to ensure thruster operation was typical of previous FSC flight units. In addition, identical tests were run with unsaturated and again with saturated propellant to identify any performance variance.

The entire Baseline Performance test sequence is shown in Table 9-7. Tests designated with a suffix 'S' were run with propellant saturated with

GN_2 at the respective inlet pressure conditions. Incorporated into the Baseline Performance test series was the first test of Task III (dry valve firing) as the initial thruster firing of the 1.0 lb_f thruster was with a dry or evacuated valve inter-seat cavity. Results of this test are discussed in Section 9.5.

The chamber pressure (Pc) tap fell off the 0.10 lb_f thruster while performing test seven due to and inadequate braze joint. The Pc tap was subsequently welded back onto the thruster nozzle and the test rerun (7-1R). Inlet pressures of 240 psia were chosen for this test sequence to provide a direct comparison to data obtained during subsequent GVT testing to eliminate the need of a post test performance baseline test series in the event of time constraints.

The results of this test series have been tabulated and plotted and are shown on Table 9-8 and Figures 9-23 through 9-30.

In conclusion, data shows a negligible performance change due to saturated propellant and both thrusters exhibit nominal performance characteristics and are considered typical of FSC flight units.

Table 9-7. Test Matrix

Test No.	Thruster Type	P_{inj} (Psia)	Start Temperature (°F) T1	T2	T3	T4	T5	T6	T7	T8	Duty Cycle	Test Objective	Test Results
1	1.0	268	-	143	271	192	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
2	1.0	350	-	149	298	208	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
3	1.0	100	-	159	345	243	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
4	1.0	350	-	99	199	146	-	-	-	-	60 sec steady state	Baseline performance	Nominal performance
5	1.0	240	-	144	265	146	-	-	-	-	60 sec steady state	Baseline performance	Nominal performance
6	1.0	100	0	168	376	193	-	-	-	-	60 sec steady state	Baseline performance	Nominal performance
11	0.10	240	-	-	-	-	-	151	544	469	50 pulses .020 sec/1 Hz	Baseline performance plus "dry valve" (14.7 psia)	Nominal performance Missed some pulses on start
10	0.10	350	-	-	-	-	-	157	568	589	50 pulses .020 sec/1 Hz	Baseline performance	Nominal performance
12	0.10	100	-	-	-	-	-	160	579	601	50 pulses .020 sec/1 Hz	Baseline performance	Nominal except missed some pulses due to gas bubbles
7	0.10	350	-	-	-	-	-	161	583	604	60 sec steady state	Baseline performance	Lost Pc tap
7-1R	0.10	350	-	-	-	-	-	98	430	454	60 sec steady state	Baseline performance	Nominal performance
8	0.10	240	-	-	-	-	-	119	557	587	60 sec steady state	Baseline performance	Nominal except for 1150Հ 'spike'
9	0.10	100	-	-	-	-	-	129	540	573	60 sec steady state	Baseline performance	Nominal except insipient "spiking"
'S.B.'	1.0	350	-	-	-	-	-	-	-	-	76 sec steay state	bleed in saturated propellant	Nominal
4S	1.0	350	-	149	338	413	-	-	-	-	60 sec steady state	Baseline performance	Nominal performance
2S	1.0	350	-	165	385	410	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
7S	0.10	350	-	-	-	-	-				60 sec steady	Baseline performance	Nominal performance
10S	0.10	350	-	-	-	-	-	157	587	613	50 pulses .020 sec/1 Hz	Baseline performance	Nominal performance
1S	1.0	240	-	142	293	460	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
5S	1.0	240	-	156	335	541	-	-	-	-	60 sec steady	Baseline performance	Nominal performance
11S	0.10	240	-	-	-	-	-	141	467	483	50 pulses .020 sec/1 Hz	Baseline performance	Nominal performance
8S	0.10	240	-	-	-	-	-	144	514	538	60 sec steady	Baseline performance	Nominal performance
3S	1.0	100	-	170	387	449	-	-	-	-	50 pulses .050 sec/1 Hz	Baseline performance	Nominal performance
6S	1.0	100	-	171	411	473	-	-	-	-	60 sec steady	Baseline performance	Nominal performance
12S	0.10	100	-	-	-	-	-	157	483	515	50 pulses .020 sec/1 Hz	Baseline performance	Missed some pulses due to GN_2 bubbles
12S-1R	0.10	100	-	-	-	-	-	157	478	518	50 pulses .020 sec/1 Hz	Baseline performance	Missed pulses 20 and 21
9S	0.10	100	-	-	-	-	-	161	515	546	60 sec steady	Baseline performance	Slow start-nominal performance

Table 9-8. FSC-GVT 0.10 lb_f Thruster Baseline Performance

Test No.	Pin (psia)	Duty Cycle	Starting Temps °F				P_c (psia)	$P_c dt$ (psia-sec)	Comments - Performance
			1	2	3	4			
1	277.9	50 pulses .0505/1 Hz	-	143	271	192	-	6.83	Nominal
2	355.4	50 pulses .0505/1 Hz	-	149	298	208	-	7.76	Nominal
3	103.4	50 pulses .0505/1 Hz	-	159	345	243	-	3.57	Nominal
4	353.6	60 sec steady state	-	99	199	146	185.27	-	Nominal
5	220.5	60 sec steady state	-	144	265	146	136.66	-	Nominal
6	85.2	60 sec steady state	-	168	376	193	65.70	-	Nominal
15	245.6	50 pulses .0505/1 Hz	-	142	293	460	-	6.55	Nominal
25	348.9	50 pulses .0505/1 Hz	-	165	385	410	-	8.19	Nominal
35	116.3	50 pulses .0505/1 Hz	-	170	387	449	-	3.57	Nominal
45	355.2	60 sec steady state	-	149	338	413	186.57	-	Nominal
55	235.3	60 sec steady state	-	156	335	541	136.18	-	Nominal
65	68.1	60 sec steady state	-	171	411	473	68.09	-	Nominal

Table 9-8. FSC-GVT 0.10 lb_f Thruster Baseline Performance (Continued)

Test No.	Pin (psia)	Duty Cycle	Starting Temps °F				P_c (psia)	$P_c dt$ (psia-sec)	Comments - Performance
			5	6	7	8			
7-1R	363.0	60 sec steady state	-	98	430	454	178.8	-	Nominal
8	253.9	60 sec steady state	-	119	557	587	135.5	-	Nominal except for ±150 percent spike
9	93.5	60 sec steady state	-	129	540	573	42.8	-	Nominal except for insipient spiking
10	362.0	50 pulses .0205/1 Hz	-	157	568	589	-	3.81 (±.54)	Nominal
11	247.0	50 pulses .0205/1 Hz	-	151	544	569	-	3.26 (±.54)	Nominal except for missed pulses at start
12	105.0	50 pulses .0205/1 Hz	-	160	579	601	-	1.91 (±.54)	Nominal except missed pulses due to gas bubbles
75	360.8	60 sec steady state	-	-	-	-	178.1	-	Nominal
85	237.5	60 sec steady state	-	144	514	538	129.6	-	Nominal
95	98.8	60 sec steady state	-	161	515	546	47.7	-	Slow start - nominal
105	356.0	50 pulses .0205/1 Hz	-	157	587	613	-	3.08	Nominal
115	239.0	50 pulses .0205/1 Hz	-	141	467	483	-	2.81	Nominal
125	109.0	50 pulses .0205/1 Hz	-	157	483	515	-	1.54	Missed some pulses due to GN_2 bubbles

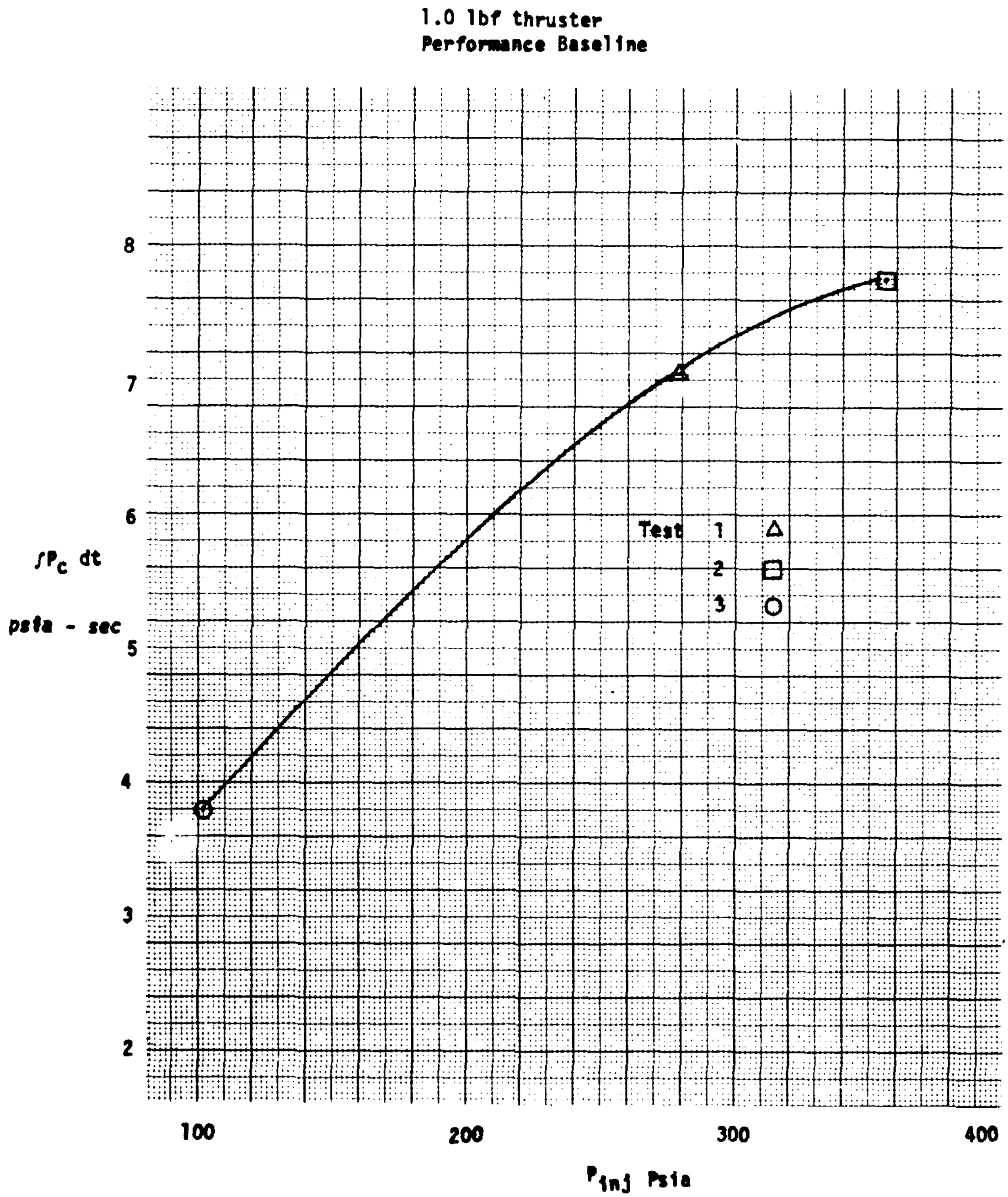


Figure 9-23. 1.0 lb_f Thruster Performance Baseline, $\int P_c dt$ vs. PIN_J (Pulse Mode)

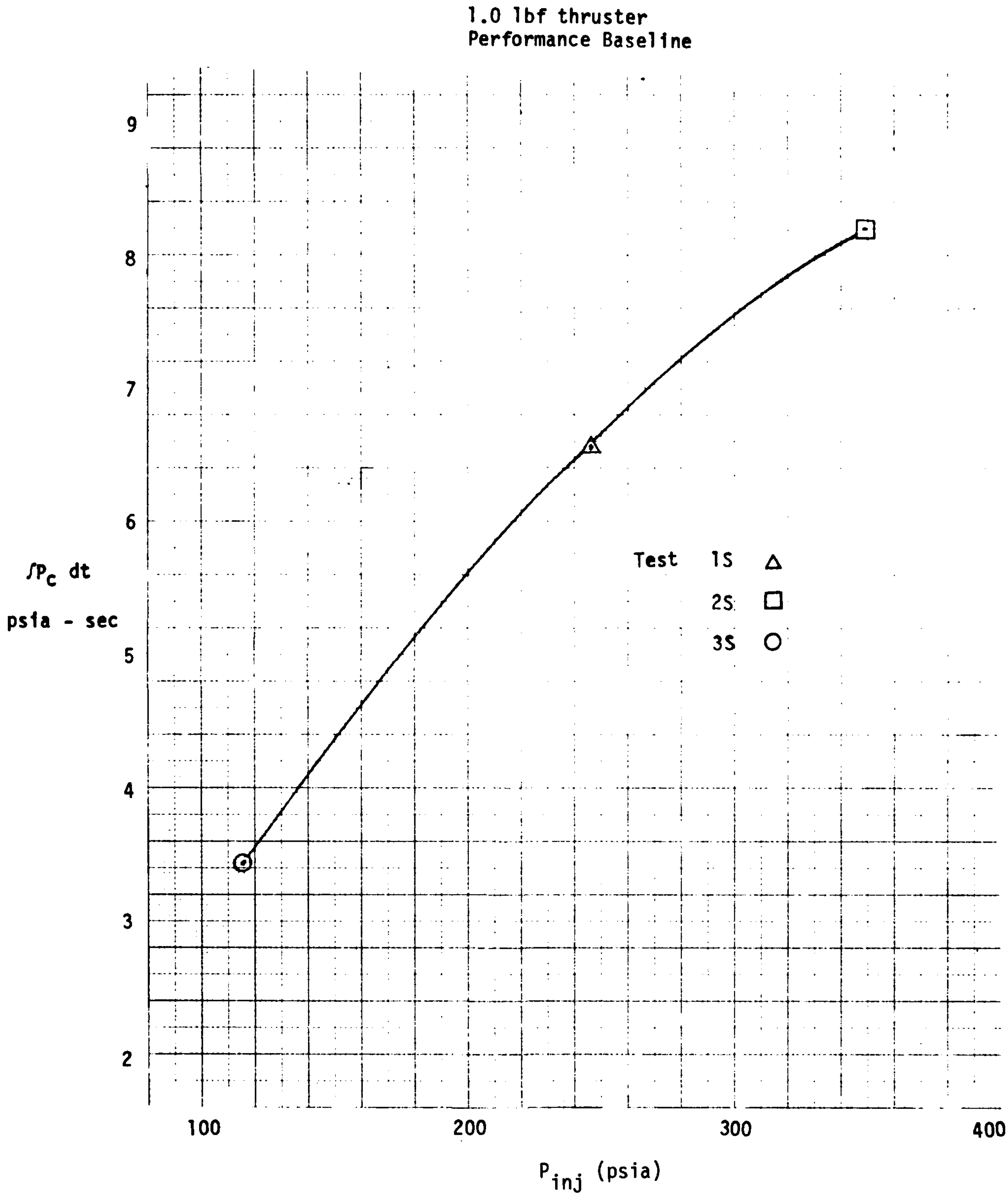


Figure 9-24. 1.0 lb_f Thruster Performance Baseline $\int P_c dt$ vs PIN_J (Pulse Mode)

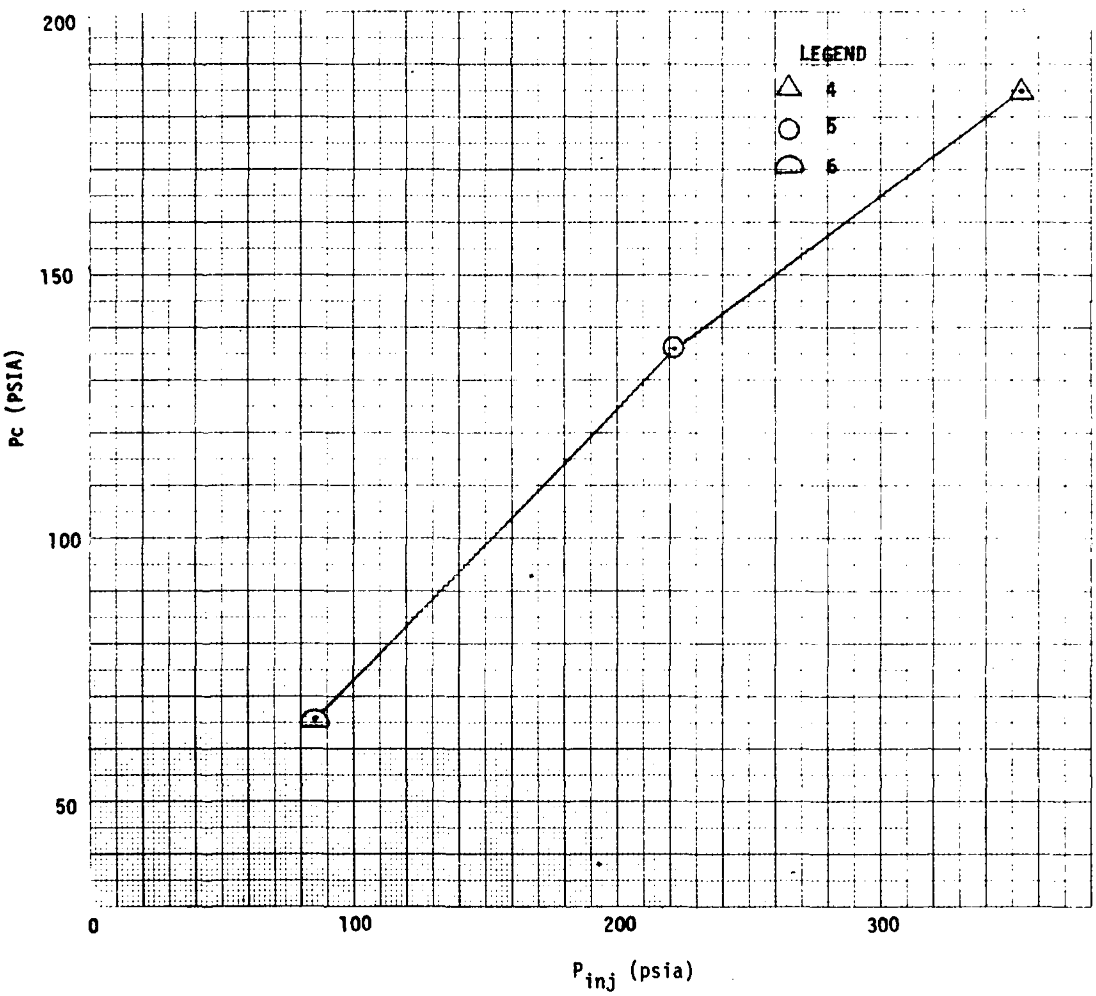


Figure 9-25. Steady-state PC vs. PIN_J, 1.0 lb_f Thruster

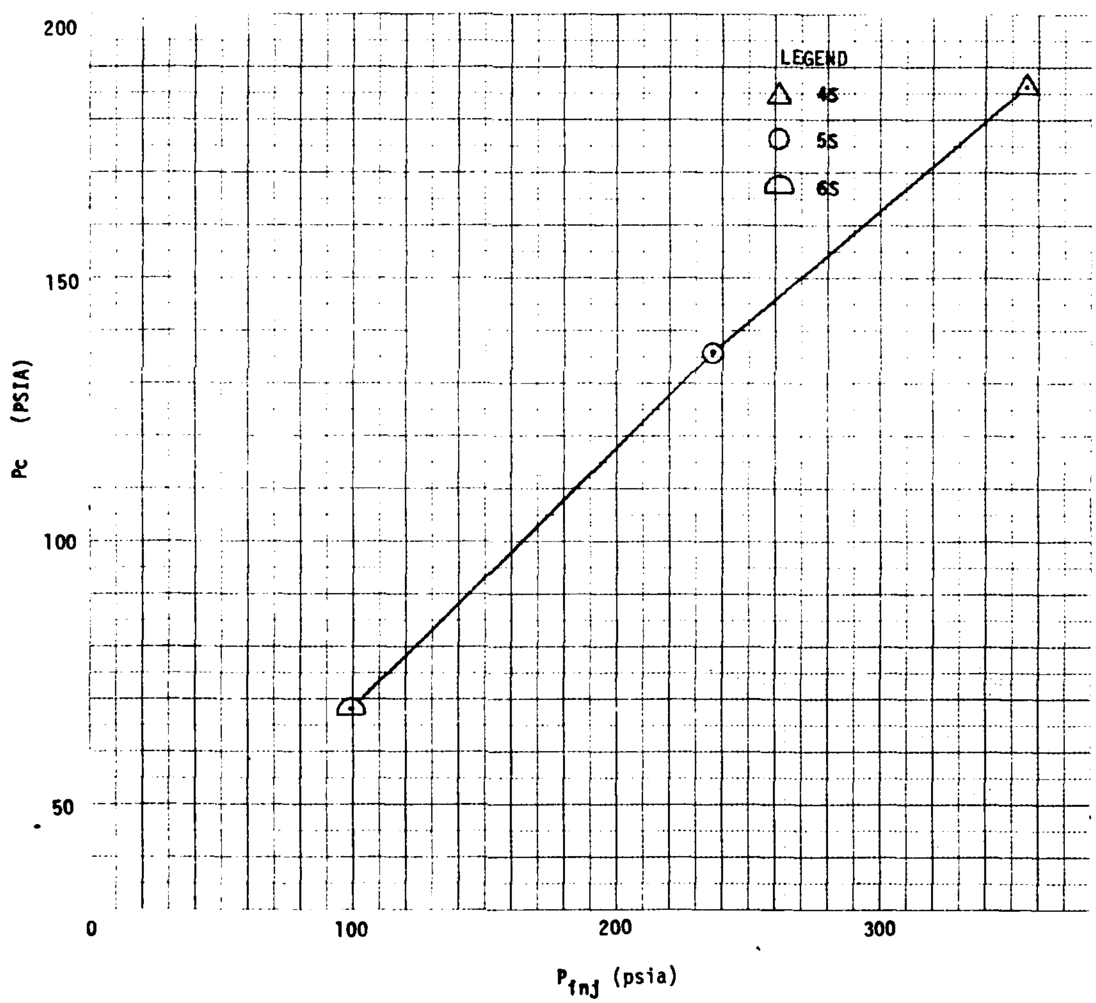


Figure 9-26. Steady-state PC vs. PIN_J, 1.0 lb_f Thruster (Saturated Propellant)

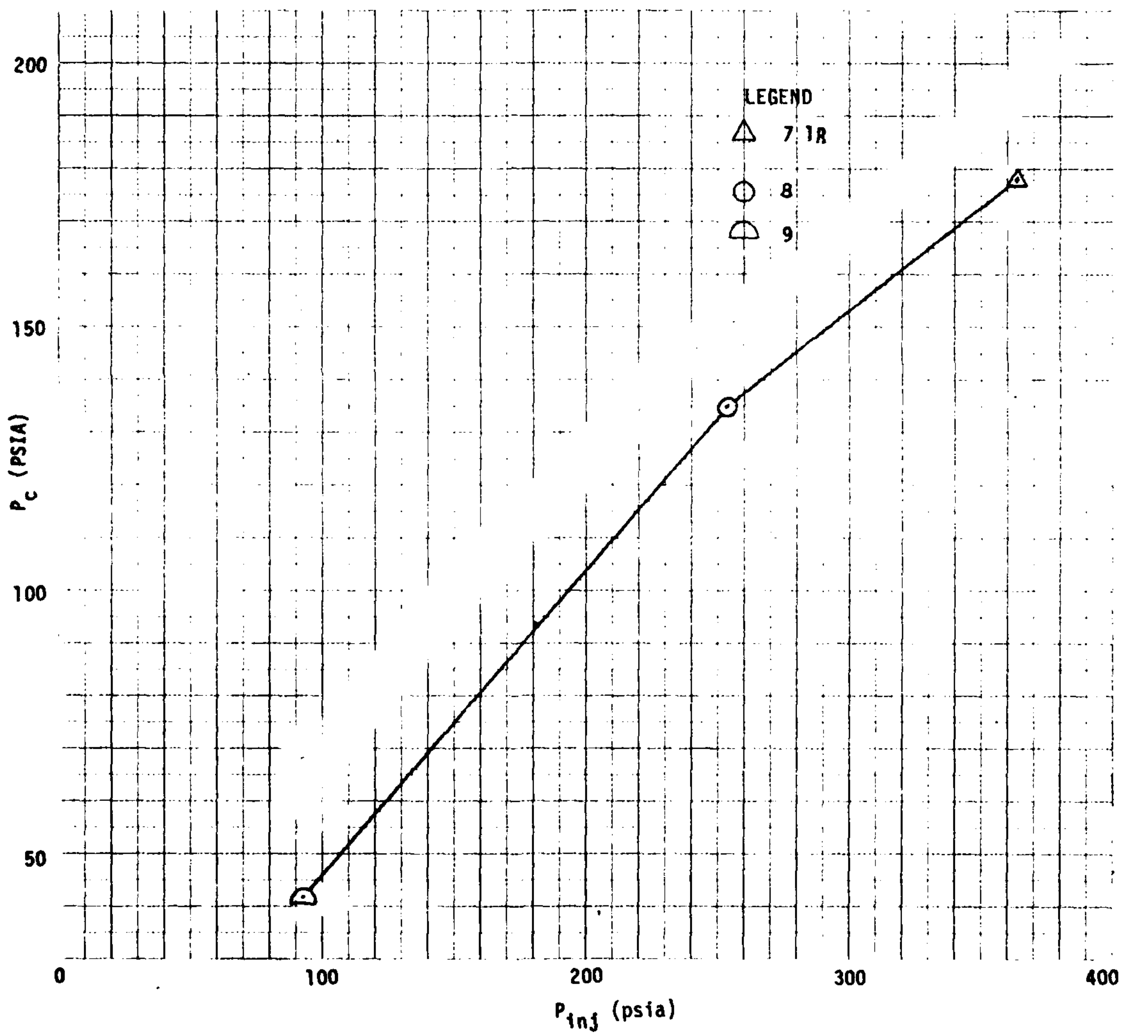


Figure 9-27. Steady-state PC vs. PIN_J, 0.10 lb_f Thruster

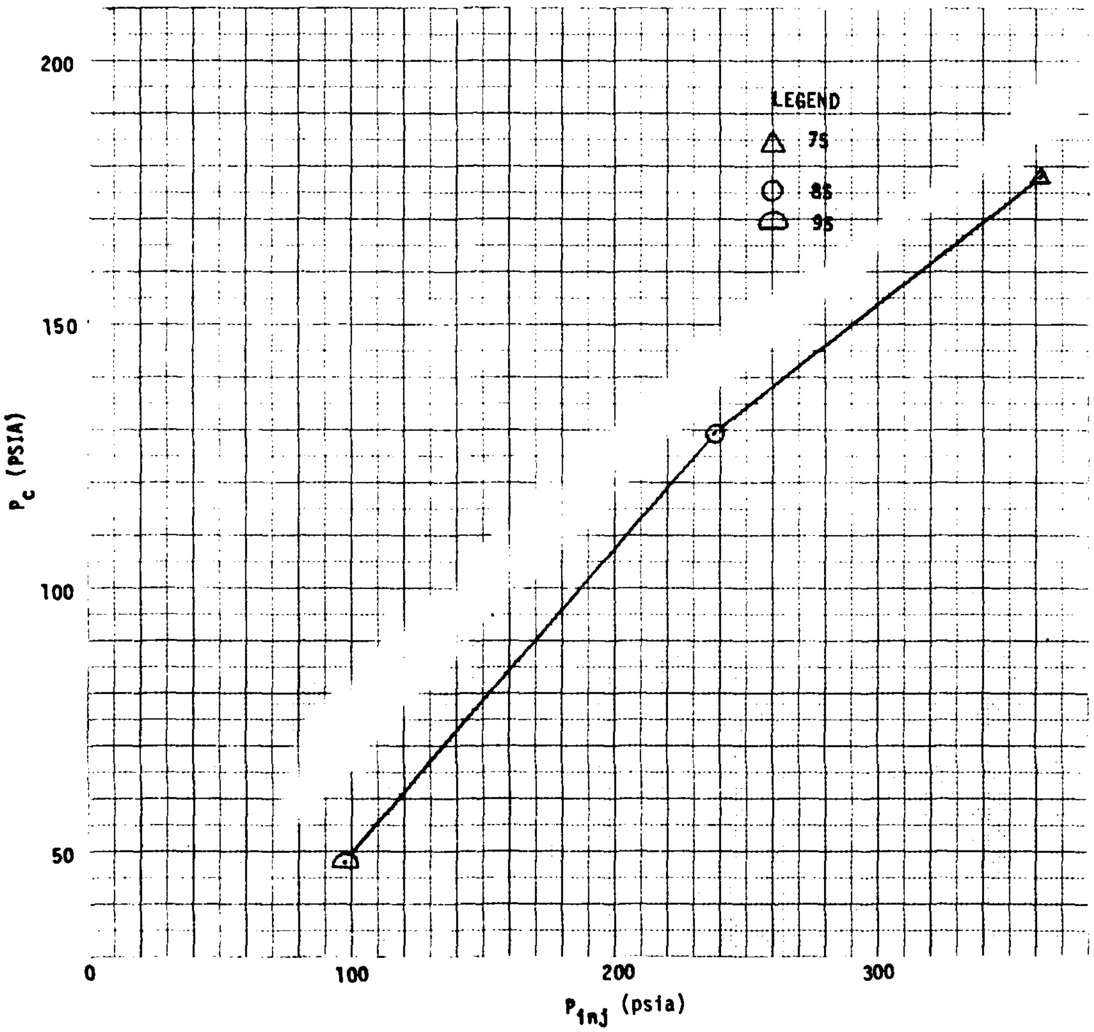


Figure 9-28. Steady-state PC vs. PIN_J, 0.10 lb_f Thruster (Saturated Propellant)

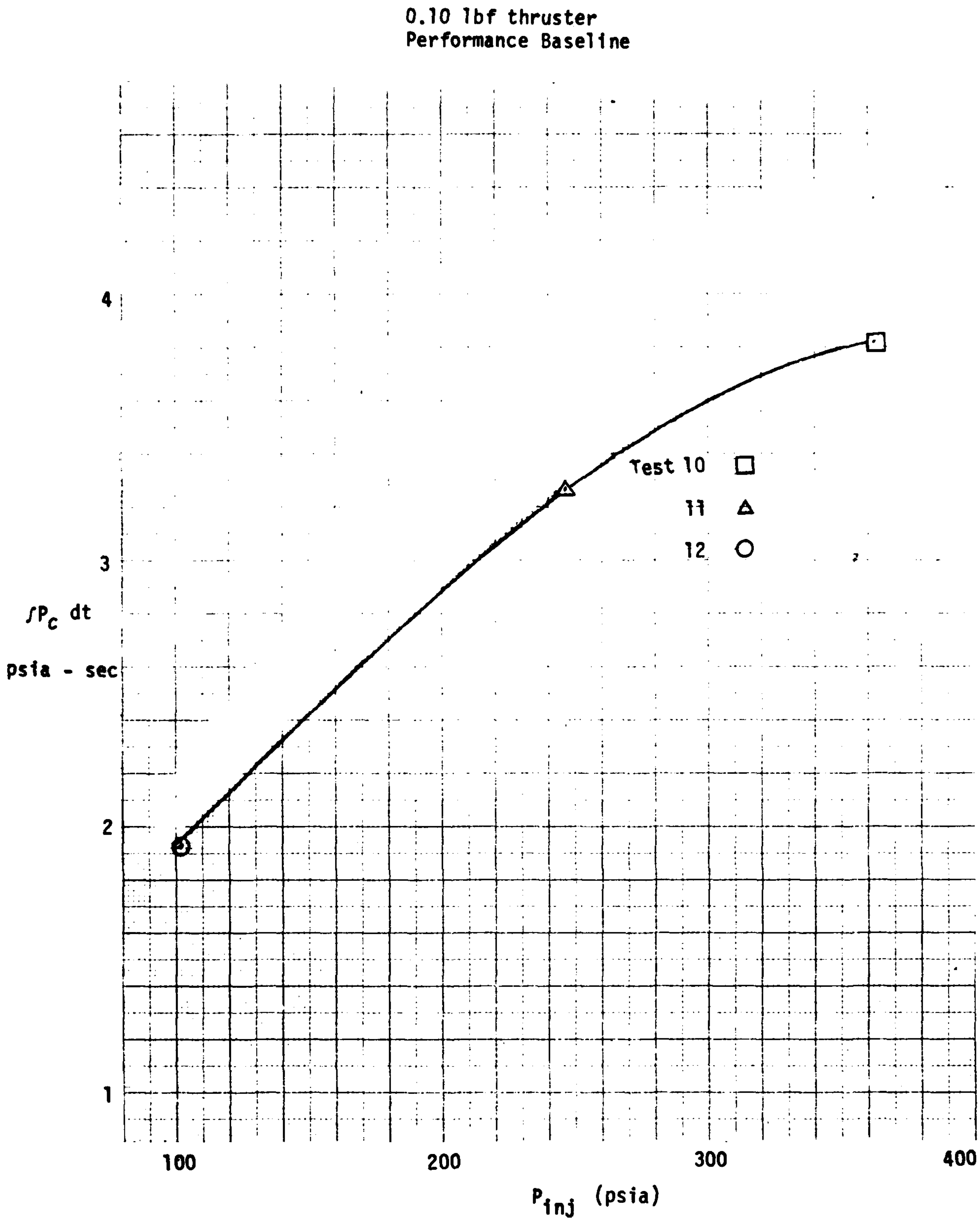


Figure 9-29. 0.10 lb_f Thruster Performance Baseline $\int P_c dt$ vs. PIN_J

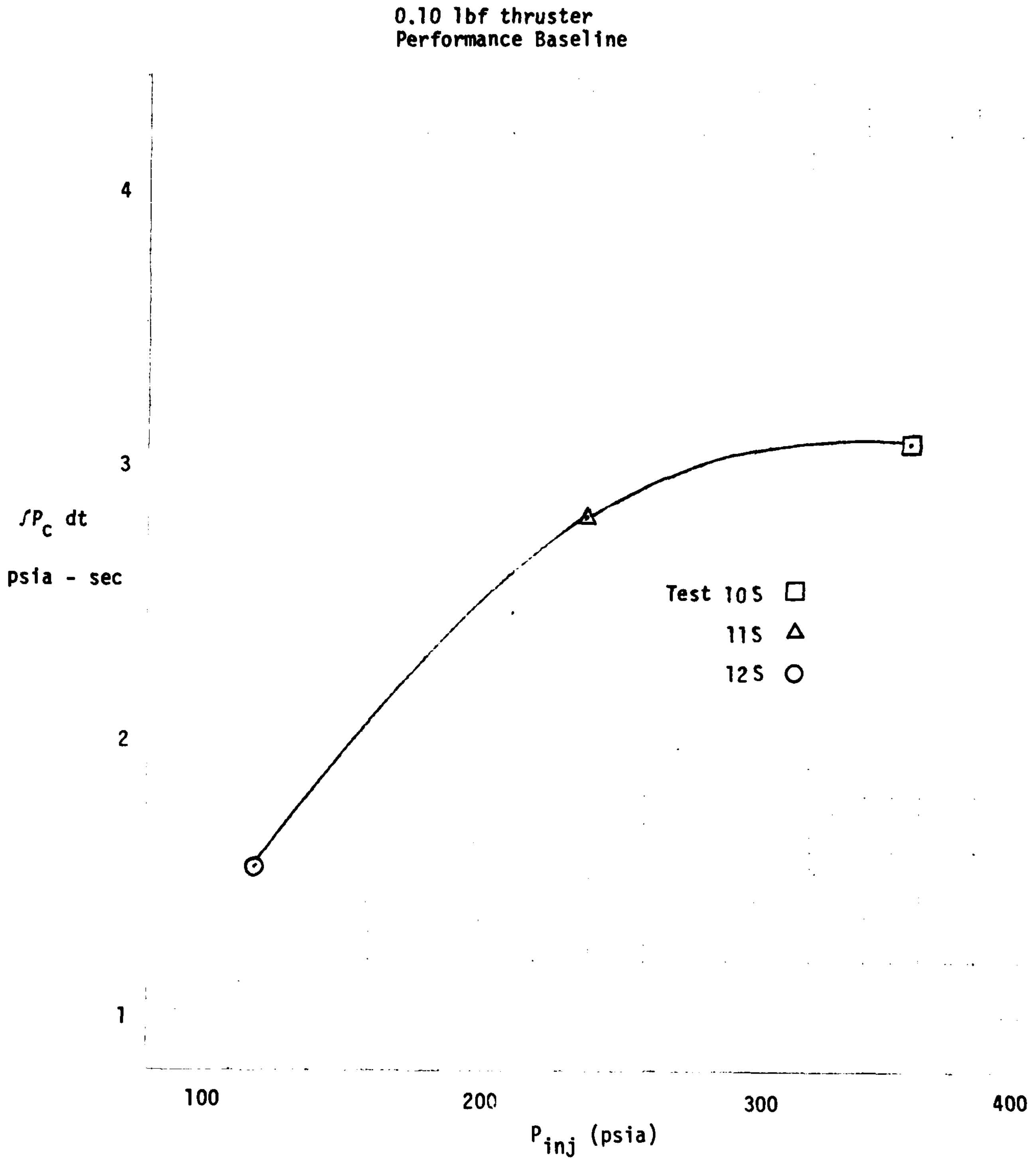


Figure 9-30. 0.10 lb_f Thruster Performance Baseline, $\int P_c\,dt$ vs. PIN_J (Saturated Propellant)

10. GVT TEST RESULTS/CONCLUSIONS

The following conclusions were derived from the Ground Verification Test and are applied to both the 1.0 lb_f and 0.10 lb_f thrusters unless otherwise specified.

- System entrapped gas (GN_2) bubbles:
  - Determined nondetermental to thruster health
  - Propagate with propellant flow and will eventually be exhausted (in the 1 g test environment)
  - Reduce impulse to negligible levels (5% of nominal) during the GN_2 flow period
  - Break up to form smaller bubbles causing random loss of impulse during pusle mode operation
- 1.0 lb_f thruster firing with evacuated inner seat cavity of thruster valve:
  - Produces loss of impulse during first 1/2 to 1-1/2 pulses
  - Number of pulses missed is dependent on cavity bleed and not duty cycle
  - Is shown to provide verification of postulated +PA failure mechanism (down-stream seat leak)
  - Nondetrimental to thruster integrity (near-term)
- Thruster firing with upstream isolation valve closed:
  - Is determined not harmful to thruster performance characteristics in the near term
  - Provides sustained inlet pressures resulting in significant impulse delivered in first 10 pulses
  - Does not form GN_2 bubbles large enough to be detected via thruster performance measurements
  - Total thruster performance recovery upon reopening of isolation valve
  - Performance characteristics remain unchanged as a result of cold firing (60-80°F) with the isolation valve closed

- 0.10 lb_f thruster "choke" investigation tests show:
  - Thruster will "choke" when operated within certain extreme duty cycles not readily obtainable in flight
  - Total performance recovery realized after "choking" as a result of a steady state restart or adequate cooling period
  - Thruster bulk temperature must be elevated (catalyst bed above 1000°F, valve above 200°F) in order to "trigger" premature decomposition
  - Impulse drops to 25-35% of nominal during "choked" flow operation
  - Thruster choked at inlet pressures of 240 psia and 100 psia as long as "trigger" temperatures are reached
- 1.0 lb_f thruster will not "choke" when operated within nominal FSC operational constraints as tested in worst case conditions

As a result of the Ground Verification Test the following possible anomaly explanations are proposed:

Thruster Anomaly	Probable Cause
+PA	1. Leaky down-stream valve seat 2. Self generated gas in valve inner seat cavity
-PB	1. Gas bubbles 2. Intermittent flow blockage cause by particle obstruction which was subsequently dislodged
-RYB	1. Large gas bubble 2. Physical obstruction causing total flow blockage 3. Thruster valve stuck closed due to contamination
-Z1A	1. Contamination causing flow blockage 2. Thruster valve stuck closed due to contamination

APPENDIX A

TEST PLAN

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

FSC-F2-PROP-007
80-4721.4-018

INTEROFFICE CORRESPONDENCE

TO: R. L. Sackheim

CC: R. A. Carlson
C. R. Hunter
M. Cirilo
D. R. Snoke
D. Saliba

DATE: 9 April 1980

SUBJECT: FSC - Ground Verification Test Plan

FROM: G. W. Joseph
BLDG: 01 MAIL STA.: 2261 EXT.: 53553

Introduction

Four anomalies have recently occurred involving thrusters on the FSC - F2 spacecraft as summarized below:

- +PA - loss of impulse during first few pulses in pulse train.
- -PB - loss of impulse during latter pulses in pulse train.
- -ZIA - complete loss of thrust 66 sec into steady state burn.
- -RYB - no impulse observed during pulse mode operation.

Several mechanisms have been postulated as potential or probable causes of the anomalies. The subject test program is designed to improve the understanding of how the thrusters operate in certain anomalous conditions. This will aid in determining the cause of the on-orbit anomalies, determining recommendations for flight operations, and, possibly, future corrective actions.

Objective

The objective of this test is to enhance the understanding of the theorized failure mechanisms responsible for the F-2 anomalies.

The test plan is segregated into three categories (Tasks I-III), each with individual objectives as outlined below:

SYSTEMS 0100 REV. 3-76

- Task I - Gas Bubble Ingestion (-Z1A & -PB Failures)

  Task I will investigate the effects of gas bubbles on system performance.

  Test 1 will measure performance parameters of both the 0.10 lb_f and 1.0 lb_f thrusters to determine the response during pulse mode firing with gas bubbles in the system.

  Test 2 will simulate the -Z1A failure directly in that a 1.0 lb_f thruster will be fired steady state for 66 sec using saturated propellant and subsequently off-modulated. This test will be done for both the nominal temperature case and the hot-valve case. The hot-valve case will attempt to force a "choking" condition in the thruster feed-tube.

- Task II - Closed ISO Valve Simulation (-RYB failure).

  The objective of this task is to measure thruster response (both 1.0 and 0.10 lb_f thrusters) to "dry firing" with ISO valves closed. The simulation with the 0.10 lb_f thruster will attempt to reproduce the -RYB failure. Firing the 1.0 lb_f thruster in this test will enable characterization of the responses observed during nominal sun-acq. check-out and the -PB failure.

- Task III - Simulation of Leaky Valve Seat (+PA failure).

  This task will reproduce the failure mode of the +PA 1.0 lb_f thruster by firing with a "dry" valve to simulate a downstream seat leak in the propellant valve.

Test Item and Configuration

The engines to be used during this test are a 1.0 lb_f FSC Flight Thruster and a 0.10 lb_f FSC Flight Thruster. The 1.0 lb_f thruster was taken from stores as a complete flight thrust chamber. A Pc port was then installed in the nozzle for performance measurement and the thruster will then be installed on an Allen (Consolidated Controls) valve.

The 0.10 lb_f thruster was similarly removed from stores as FSC spare (also flight designated) and modified via installation of a Pc tap by cutting the head end apart from the chamber, installing a Pc tap in a new nozzle, and building up the test unit with a new chamber, Allen valve, and reloading catalyst.

Both thrusters will be mounted on a bracket to form a DTM (see Figure 1). All hardware on the DTM will be identical to flight hardware. The DTM will then be installed on a vacuum chamber in the low thrust test facility in 01 where the tests will be performed.

The propellant supply system (Figure 2 through 5) will be a reproduction of the FSC on-board system. It will incorporate flight type isolation valves, filters (facility filter similar ΔP to flight) and propellant lines of the exact size and length of the S/C system (variable to accommodate different thruster locations). The additional components to the test system which made it dissimilar to the S/C system are outlined as follows:

- A GN_2 source with the necessary lines and fittings to enable saturation of propellant in the tank.
- A parallel path line system to inject GN_2 bubbles into the line during thruster firing.
- A pressure transducer near the thruster to record system pressure.
- A valve near the propellant tank outlet.

The thruster will be instrumented with thermocouples and thermistors as shown on Figure 1. Test data requirements are given on Table 2.

Schedule

The current schedule is shown on Figure 6. Testing is scheduled to begin on 28 April 1980. Total duration of testing including set-up is scheduled for 6 1/2 weeks, with a completion date of 24 may 1980. Final test report is due on 16 June 1980.

Test Sequence

Hot-fire testing will commence wit'. Task I and proceed through Task III.

TASK I - TEST 1

1.0 LB_F THRUSTER

The test system shall be configured with the bubble injection chamber and variable line length as shown in Figure 2. All Task I tests shall be performed with GN_2 saturated propellant at 240 psia.

The thruster shall be fired in the pulsing mode (.050 sec on, at 1HZ) while a 10 C.C. bubble is formed and introduced into the flow stream. As soon as the bubble has passed through the thruster and the appropriate data has been recorded, thruster firing shall be terminated. In addition, the time required for the bubble to flow from the bubble chamber to the thruster shall be recorded as T_B. The thruster shall then be tested again as outlined above except the bubble size will be increased to 100 C.C.

0.10 LB_F THRUSTER

The bubble injestion tests shall be performed on the 0.10 lb_f thruster in an identical manner as outlined for the 1.0 lb_f thruster above.

TASK I - TEST 2

1.0 LB_F THRUSTER

The test system shall be remain configured as above and figure 2.

The thruster will then be fired steady state for 66 seconds, then off-modulated (0.50 sec. off, 2 sec. on) for an additional 300 seconds. This test is to be performed under nominal thermal conditions.

Subsequently, the thruster valve temperature will be increased to 200°F (hot valve case). A bubble (10 C.C.) will then be formed in the bubble injection chamber and later introduced into the flow-stream.

After thruster firing has been initiated (steady state) the bubble shall be introduced and the thruster will be off-modulated T_B - TBD seconds later. Off-modulation pulsing shall continue for 300 seconds or until "choking" is observed. Two subsequent tests will be performed with the 10 C.C. bubble as outlined above except the steady state firing time shall be T_B seconds and T_B + TBD seconds. Off modulation thus starts before, during, and after initiation of gas ingestion.

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FLTSATCOM FLIGHT 2 RCS ANOMALY INVESTIGATION GROUND VERIFICATIO--ETC(U)
JAN 81 G W JOSEPH F04701-79-C-0174
UNCLASSIFIED TRW-36244-350-004-01 SD-TR-80-58 NL

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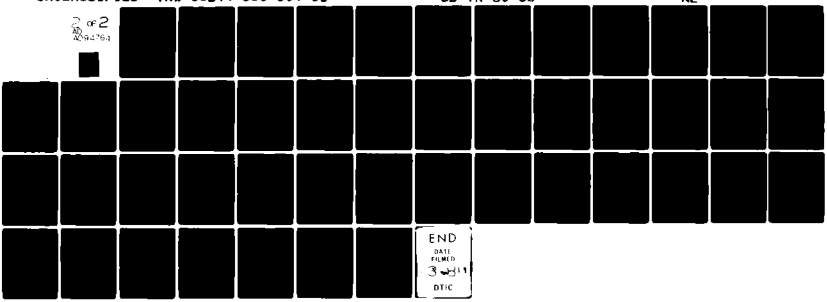


The entire test sequence shall be repeated with a new bubble size of 100 C.C.

TASK II - TEST 1

1.0 LB_F THRUSTER

The test system shall be configured as shown in Figure 3. Propellant shall be saturated with GN_2 and pressurized to TBD psia. The Iso valve shall then be closed and the thruster fired in the pulse mode (.050 sec. on, at 1 HZ) for TBD pulses. The supply tank pressure shall then be vented to 240 psia. After the Iso valve is opened, the thruster will be fired (.050 sec. on, at 1 HZ) for TBD pulses until all the propellant between the Iso valve and the thruster has been consumed.

TASK II - TEST 2

0.10 LB_F THRUSTER

The test system shall be reconfigured per Figure 4. Propellant shall be GN_2 saturated and pressurized at 240 psia. The thruster will be fired for 10 seconds steady state to assure proper bleed-in. The Iso valve will then be closed and the thruster will be pulsed (.020 sec. on at 1 HZ) until all the propellant in the line has been depleted. The Iso valve will then be re-opened and thruster will be fired for TBD pulses.

TASK III

The test system shall be configured per Figure 5. This test is to be performed with saturated propellant and 265 psia.

The test system downstream of the Iso valve shall be opened and evacuated. The thruster valve will then be opened. (Iso valve is still closed) to insure a proper vacuum between the valve seats. The thruster valve will then be closed and the system bled in up to the front seat of the propellant valve. The thruster will then be pulsed (.050 sec. on at 1 HZ) for 20 pulses or until the chamber pressure has stabilized. This sequence shall be repeated a minimum of 2 times with the option of performing one iteration during the initial thruster firing of the thruster baseline performance tests.

Thruster Baseline Performance Tests

The following performance characterization test shall be performed prior to any other hot-fire testing of the thrusters. Test system set-up for the test shall be as shown in figure 5.

$1.0\ lb_f$ thruster.

Nominal thruster performance characteristics will be obtained by pulsing the thruster (.050 on sec. on at 1 Hz) for 50 pulses at 350 psia, 240 psia and 100 psia. Steady state runs of 60 sec. duration will also be performed at the aforementioned pressures. Note that the first test can be run at 240 psia (pulse mode) and perform test III-1C concurrently as the propellant valve will be "Dry" at this time.

$0.10\ lb_f$ thruster

The $0.10\ lb_f$ thruster will be fired in the same manner as the $1.0\ lb_f$ thruster as described above except the pulse width shall be .020 sec. on at 1 Hz.

TABLE 1. GVT TEST MATRIX

Test No.	Pint (PSIA)	Pulse Width (Sec)	Duty Cycle	No. of Pulses	Thruster	T1/T5 Start (°F)	Comments
I-1A	240±5	.050	1 HZ	TBD	1.0 lbf	150	10 cc bubble ingested
I-1B	240±5	.050	1 HZ	TBD	1.0 lbf	150	100 cc bubble ingested
I-1C	240±5	.020	1 HZ	TBD	0.10 lbf	150	10 cc bubble ingested
I-1D	240±5	.020	1 HZ	TBD	0.10 lbf	150	100 cc bubble ingested
I-2A	240±5	66 S.S.*	Off-Mod	TBD	1.0 lbf	150	Nominal ΔV firing with off-modulation
I-2B	240±5	66 S.S.*	Off-Mod	TBD	1.0 lbf	T/C 2=200	Off-mod with hot propellant valve
I-2C	240±5	TB-TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	10 cc bubble ingested w/off-mod (hot valve)
I-2D	240±5	TB	Off-Mod	TBD	1.0 lbf	T/C 2=200	10 cc bubble ingested w/off-mod (hot valve)
I-2E	240±5	TB-TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	10 cc bubble ingested w/off-mod (hot valve)
I-2F	240±5	TB-TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	100 cc bubble ingested w/off-mod (hot valve)
I-2G	240±5	TB	Off-Mod	TBD	1.0 lbf	T/C 2=200	100 cc bubble ingested w/off-mod (hot valve)
I-2H	240±5	TB+TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	100 cc bubble ingested w/off-mod (hot valve)
II-1A	300±5	.050	1 HZ	TBD	1.0 lbf	150	Thruster firing with ISO closed
II-1B	240±5	.050	1 HZ	TBD	1.0 lbf	150	Thruster firing (ISO open)
II-1C	240±5	.050	1 HZ	TBD	1.0 lbf	150	Thruster firing (ISO closed)
II-2A	240±5	.020	1 HZ	TBD	0.10 lbf	150	Thruster firing (ISO closed)
II-2B	240±5	.020	1 HZ	TBD	0.10 lbf	150	Thruster firing (ISO open)
III-1A	268±5	.050	1 HZ	TBD	1.0 lbf	150	"Dry valve"
III-1A	268±5	.050	1 HZ	TBD	1.0 lbf	150	"Dry valve"
III-1C	268±5	.050	1 HZ	TBD	1.0 lbf	150	"Dry valve" Note: This test may be performed during thruster baseline performance

*66 seconds steady state followed by off-modulation at .05 sec off/1.95 sec on.

TABLE 2. TEST INSTRUMENTATION AND DATA REQUIREMENTS

Parameter	Symbol	Strip-Chart	O-Graph	Digital Computer
Chamber Pressure (1.0 lb_f Thruster)	P_{C1}	X	X	X
Chamber Pressure (0.10 lb_f Thruster)	P_{C2}	X	X	X
Injection Pressure	P_{INJ}	X	X	X
Vacuum Pressure	P_{VAC}			X
Valve Voltage (1.0 lb_f Thruster)	V_{E1}		X	
Valve Voltage (0.10 lb_f Thruster)	V_{E2}		X	
Valve Current (1.0 lb_f Thruster)	V_{I1}		X	
Valve Current (0.10 lb_f Thruster)	V_{I2}		X	
Thermistor (Barrier Tube) (1.0 lb_f Thruster)	T_1	X		X
Thermocouple (Valve) (1.0 lb_f Thruster)	TC_2	X		X
Thermocouple (Chamber) (1.0 lb_f Thruster)	TC_3	X		X
Thermocouple (Nozzle) (1.0 lb_f Thruster)	TC_4	X		X
Thermistor (Barrier Tube) (0.10 lb_f Thruster)	T_5	X		X
Thermocouple (Valve) (0.10 lb_f Thruster)	TC_6	X		X
Thermocouple (Chamber) (0.10 lb_f Thruster)	TC_7	X		X
Thermocouple (Nozzle) (0.10 lb_f Thruster)	TC_8	X		X

BASELINE PERFORMANCE TESTS

Test NO.	Pinj (PSIA)	Pulse Width (sec)	Off time (sec.)	No. of Pulses	Thruster	Comments
1	240 ± 5	.050	1 Hz	50	1.0 lb_f	Also use data from Test III - 1C
2	350	.050	1 Hz	50	1.0 lb_f	
3	100	.050	1 Hz	50	1.0 lb_f	All baseline performance tests shall be done with T1/T5 start temps. of 150°F, and saturated propellant.
4	350	60	-	1	1.0 lb_f	
5	240	60	-	1	1.0 lb_f	
6	100	60	-	1	1.0 lb_f	
7	350	60	-	1	0.10 lb_f	
8	240	60	-	1	0.10 lb_f	
9	100	60	-	1	0.10 lb_f	
10	350	.020	1 Hz	50	0.10 lb_f	
11	240	.020	1 Hz	50	0.10 lb_f	
12	100	.020	1 Hz	50	0.10 lb_f	

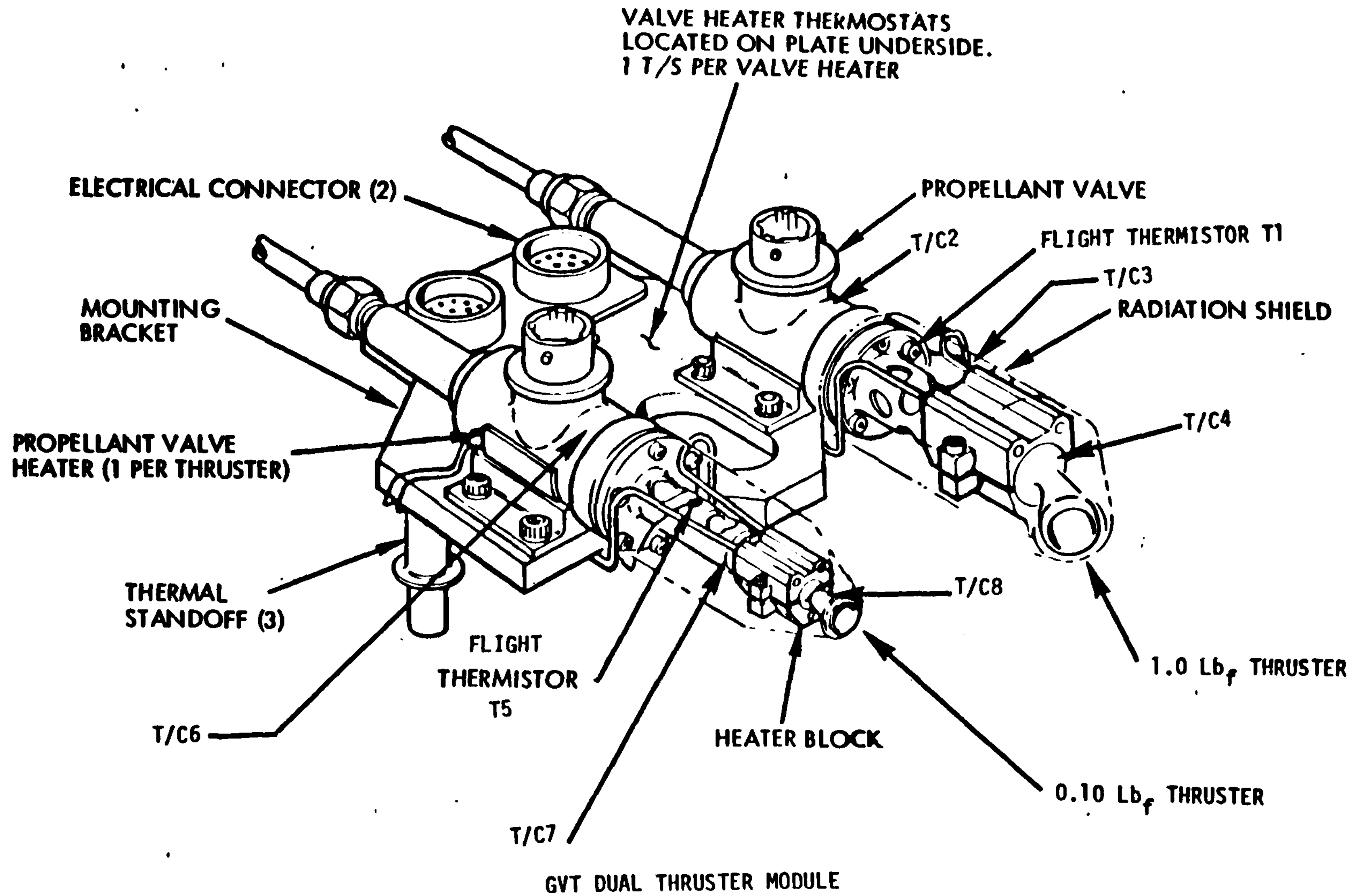


Figure 1. GVT Dual Thruster Module

Figure 1.

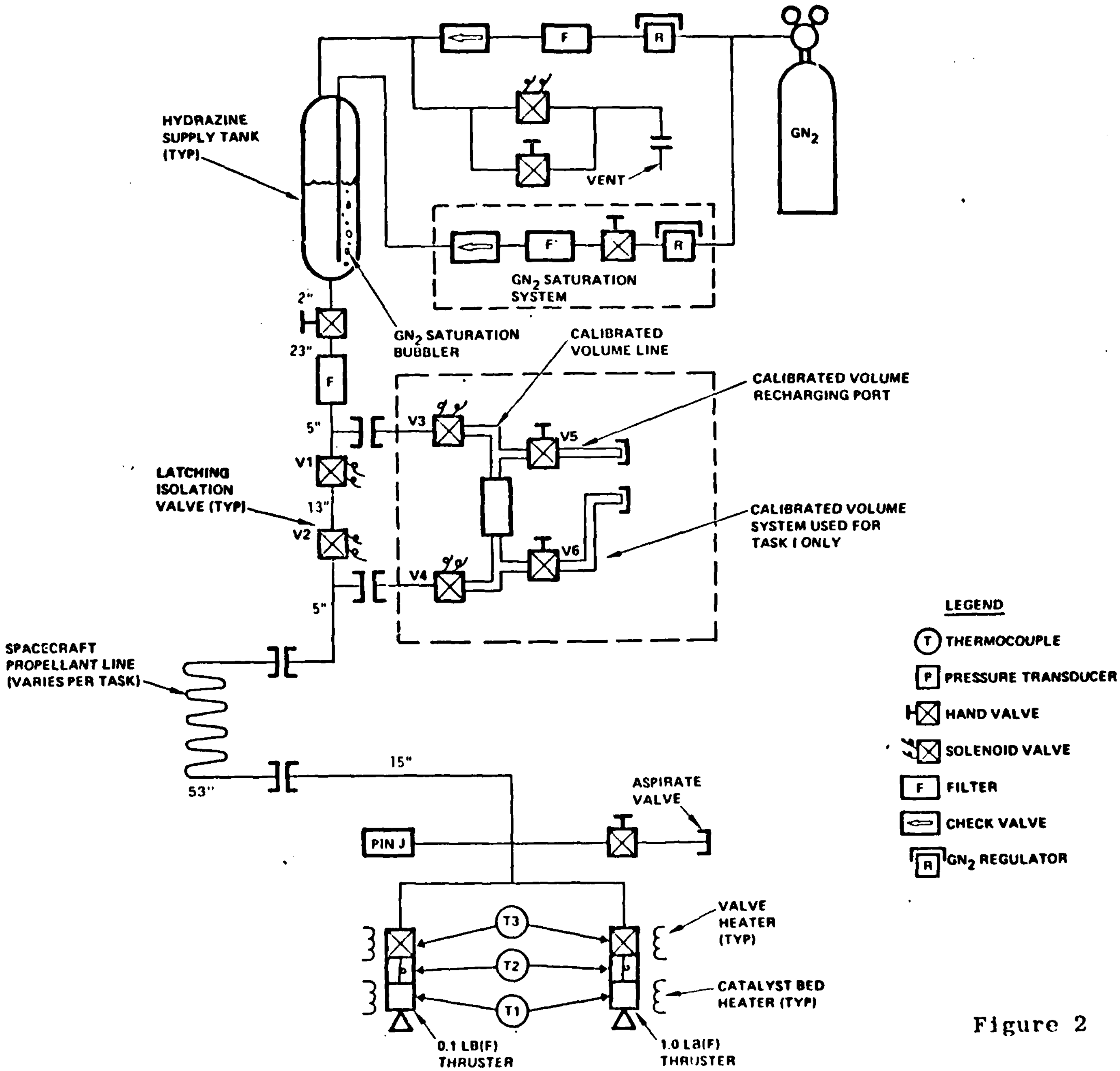

HYDRAZINE SUPPLY TANK (TYP)
VENT
GN2
GN2 SATURATION SYSTEM
GN2 SATURATION BUBBLER
CALIBRATED VOLUME LINE
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
LATCHING ISOLATION VALVE (TYP)
V1
V2
V3
V4
V5
V6
2"
23"
5"
13"
5"
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
53"
15"
ASPIRATE VALVE
PIN J
T3
T2
T1
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
0.1 LB(F) THRUSTER
1.0 LB(F) THRUSTER
LEGEND
THERMOCOUPLE
PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
FILTER
CHECK VALVE
GN2 REGULATOR

Figure 2

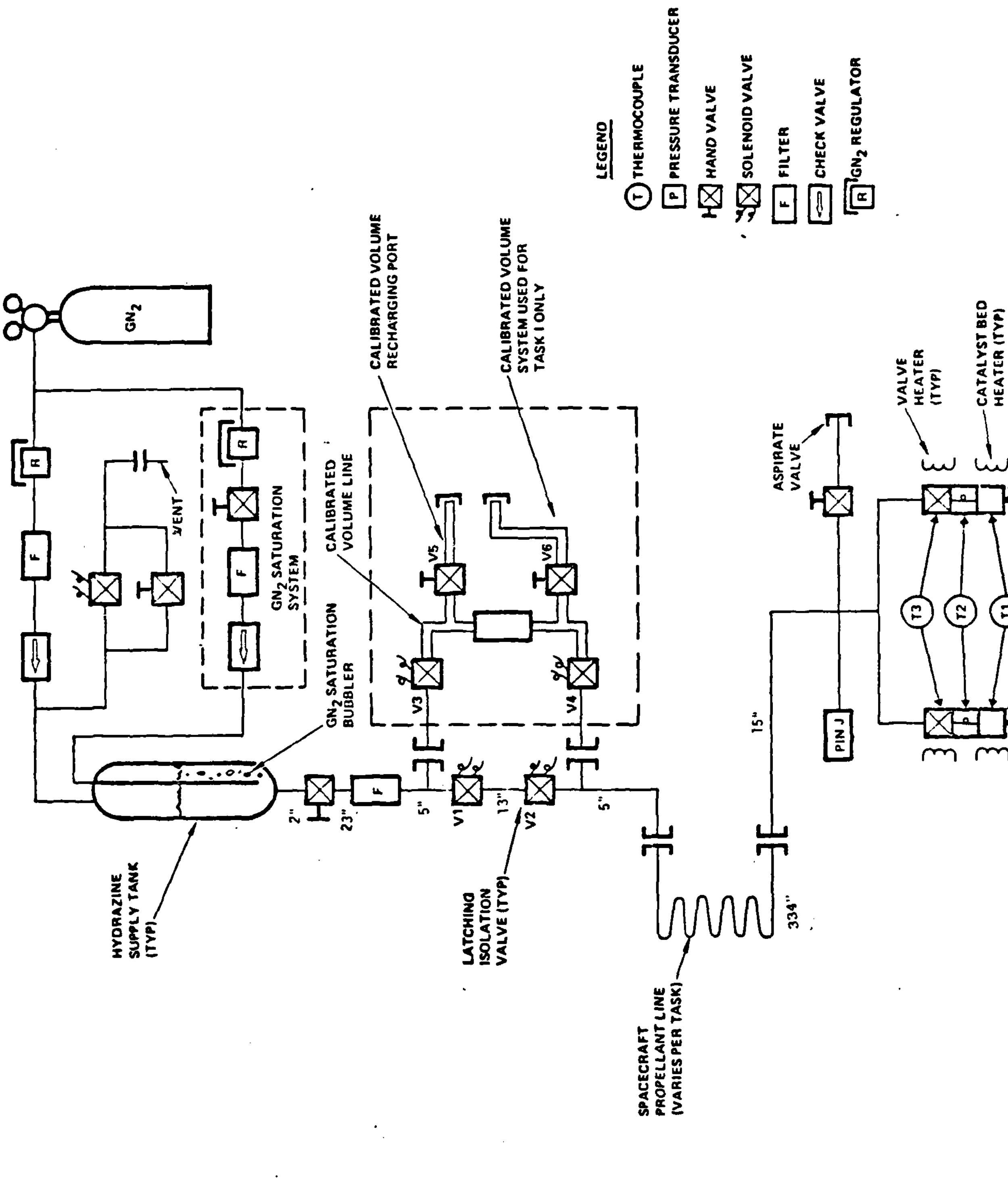
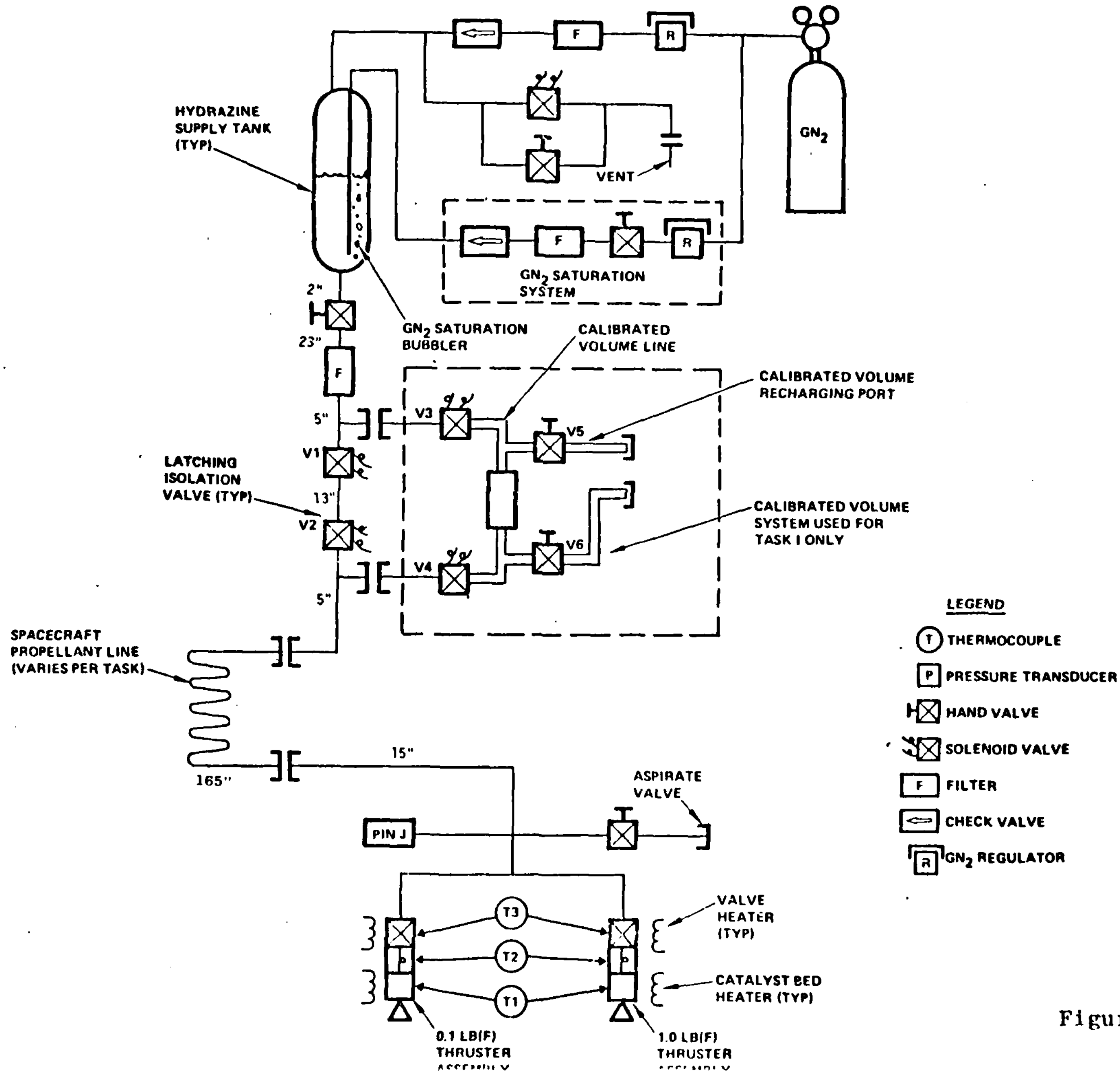
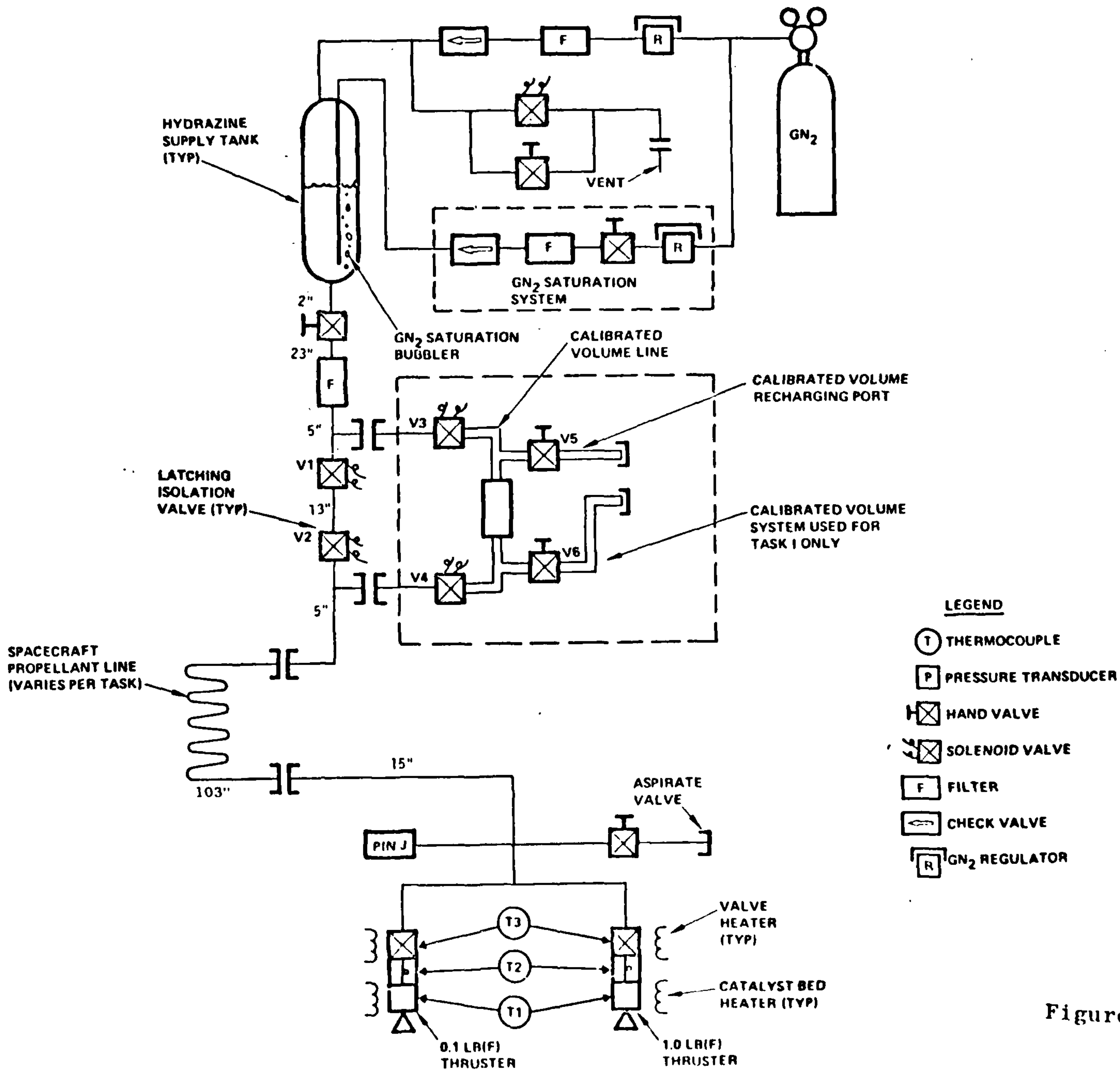

LEGEND
T THERMOCOUPLE
P PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
F FILTER
CHECK VALVE
R GN2 REGULATOR
GN2
R
F
VENT
GN2 SATURATION SYSTEM
GN2 SATURATION BUBBLER
HYDRAZINE SUPPLY TANK (TYP)
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
CALIBRATED VOLUME LINE
V1
V2
V3
V4
V5
V6
2"
23"
5"
13"
5"
LATCHING ISOLATION VALVE (TYP)
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
334"
15"
ASPIRATE VALVE
PINJ
T1
T2
T3
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
1.0 LB(F) THRUSTER
0.1 LB(F) THRUSTER

Figure 3



HYDRAZINE SUPPLY TANK (TYP)
GN_2
VENT
GN_2 SATURATION SYSTEM
GN_2 SATURATION BUBBLER
CALIBRATED VOLUME LINE
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
2"
23"
5"
13"
5"
V1
V2
V3
V4
V5
V6
LATCHING ISOLATION VALVE (TYP)
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
165"
15"
PIN J
ASPIRATE VALVE
T3
T2
T1
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
0.1 LB(F) THRUSTER
1.0 LB(F) THRUSTER
LEGEND
THERMOCOUPLE
PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
FILTER
CHECK VALVE
GN_2 REGULATOR

Figure 4



HYDRAZINE SUPPLY TANK (TYP)
VENT
GN_2
GN_2 SATURATION SYSTEM
GN_2 SATURATION BUBBLER
CALIBRATED VOLUME LINE
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
LATCHING ISOLATION VALVE (TYP)
V1
V2
V3
V4
V5
V6
2"
23"
5"
13"
5"
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
103"
15"
PIN J
ASPIRATE VALVE
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
T1
T2
T3
0.1 LB(F) THRUSTER
1.0 LB(F) THRUSTER
LEGEND
THERMOCOUPLE
PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
FILTER
CHECK VALVE
GN_2 REGULATOR

Figure 5

SCHEDULE AND ACTIVITY/EVENT REPORT

		Plan	Changed	New	Complete
ACTIVITY PERIOD		▭	▨	▭ (DATE)	■
DELIVERED OR COMPLETED ITEMS		△	△ (changed)	△ (DATE)	▲

CHECK ONE: NUMBER DESCRIPTION / TITLE

[ ] WORK UNIT ______ ______ FOR PERIOD ENDING ______

[ ] WORK PACKAGE ______ ______ RESPONSIBLE MGR ______

[ ] PROJECT ______ ______ BLDG./ROOM/EXT ______

PAGE 1 OF 1

FSC - GROUND VERIFICATION TEST (GVT)

LINE NO	WORK DESCRIPTION	SUB ELEMENT NUMBER	1980 3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/6	6/13	6/20
1	DESIGN TEST SYSTEM			▽											
2	WRITE TEST PLAN (DRAFT)				▽										
3	WRITE TEST PROCEDURE (DRAFT)				▽										
4	TEST PLAN/PROCEDURE REVIEW				▽										
5	RELEASE TEST PLAN (FINAL)					▽									
6	RELEASE TEST PROCEDURE (FINAL)						▽								
7	OBTAIN SYSTEM HARDWARE		△		▽										
8	THRUSTER BUILD (DTM)		△		▽										
9	BUILD TEST SYSTEM				△		▽								
10	CHECKOUT TEST SYSTEM						△	▽							
11	TEST TASK I							△	▽						
	TEST TASK II							△	▽						
	TEST TASK III								△	▽					
14	SELECTED RETESTING									△	▽				
15															
16	ANALYZE TEST DATA										△	▽			
17	TEST REPORT (DRAFT)											△	▽		
18	TEST REPORT (APPROVAL)													▽	
19	TEST REPORT (FINAL)													△	▽
20															
21															
22															
23															
24															
25															
26															
27															
28															

G. Joseph	R. A. Carlson	
PROJECT, WORK PACKAGE, WORK UNIT MGR. DATE	FUNCTIONAL MGR DATE	REVIEWING PROJECT AUTHORITY DATE

SYSTEMS 3000 REV. 9-66

Figure 6. FSC — Ground Verification Test (GVT)

APPENDIX B

TEST PROCEDURE

TRW

DEFENSE AND SPACE SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

FSCM NO. 11982

TITLE

FLTSATCOM - GROUND
VERIFICATION TEST
(HOT - FIRE)

DATE 18 APRIL 1980 NO. FSC-F2-PROP-010

SUPERSEDING: ____________

PREPARED BY: G. W. Joseph

APPROVAL SIGNATURES:

R. A. Carlson	DATE 4/24/80		DATE 4/28/80
R. L. Sackheim	DATE 4/28/80		DATE
R. S. Eastman	DATE 4/29/80		DATE

SYSTEMS 1391 REV. 9-77

CONTENTS

SAFETY ALERT

Listed below are the paragraphs covering special safety precautions and brief descriptions of the general safety alerts/cautions required per this procedure

Paragraph 2.2.1	Personnel Safety
Paragraph 2.2.2	Hardware Safety

* * CAUTION * *

Personnel shall pay particular attention to the following potential safety hazards:

- Caution shall be exercised when hydrazine is in the work area.
- Caution shall be exercised during and after tests so as not to contact hot surfaces.
- Caution shall be exercised operating the test equipment as potentially harmful voltages are present.
- Caution shall be exercised when working around a pressurized system.
- Extreme caution shall be exercised when heating hydrazine in confined volumes (i.e., operating the valve heaters in non-firing mode); in <u>no</u> case shall stagnant hydrazine be heated above 240^{o}F.

1. SCOPE

1.1 Scope. This test procedure describes the requirements and methods for performing the hot-fire ground verification test of a FSC 1.0 lb_f thruster and a 0.10 lb_f thruster mounted on a common DTM with a spacecraft similar propellant feed system.

1.2 Purpose of Test

1.2.1 Test Objective. The objective of this test is to enhance the understanding of the theorized failure mechanisms responsible for the F-2 anomalies.

The test plan is segregated into three categories (Tasks I-III), each with individual objectives as outlined below:

- Task I — Gas Bubble Ingestion (-Z1A and -PB Failures)

  Task I will investigate the effects of gas bubbles on system performance.

  Test 1 will measure performance parameters of both the 0.10 lb_f and 1.0 lb_f thrusters to determine the response during pulse mode firing with gas bubbles in the system.

  Test 2 will simulate the -Z1A failure directly in that a 1.0 lb_f thruster will be fired steady state for 66 sec using saturated propellant and subsequently off-modulated. This test will be done for both the nominal temperature case and the hot-valve case. The hot-valve case will attempt to force a "choking" condition in the thruster feed-tube.

- Task II — Closed ISO Valve Simulation (-RYB failure)

  The objective of this task is to measure thruster response (both 1.0 and 0.10 lb_f thrusters) to "dry firing" with ISO valves closed. The simulation with the 0.10 lb_f thruster will attempt to reproduce the -RYB failure. Firing the 1.0 lb_f thruster in this test will enable characterization of the responses observed during nominal sun-acq. check-out and the -PB failure.

- Task III — Simulation of Leaky Valve Seat (+PA failure).

  This task will reproduce the failure mode of the +PA 1.0 lb_f thruster by firing with a "dry" valve to simulate a downstream seat leak in the propellant valve.

1.2.2 Test Description. The dual thruster module is installed in a vacuum chamber capable of maintaining simulated altitudes of 100,000 feet or greater. Adequate instrumentation for performance and temperature determination is installed and calibrated. The thrusters are subjected to several different modes of operation. Performance and temperature response is recorded and evaluated. Thruster testing (hot-fire) is conducted in three distinct test configurations with objectives as outlined above. A description of the test sequence and configuration is as follows:

TASK I — TEST 1

1.0 LB_F THRUSTER

The test system shall be configured with the bubble injection chamber and variable line length as shown in Figure 2. All Task I tests shall be performed with GN_2 saturated propellant at 240 psia.

The thruster shall be fired in the pulsing mode (0.050 sec on, at 1 Hz) while a 10 C.C. bubble is formed and introduced into the flow stream. As soon as the bubble has passed through the thruster and the appropriate data has been recorded, thruster firing shall be terminated. In addition, the time required for the bubble to flow from the bubble chamber to the thruster shall be recorded as T_B. The thruster shall then be tested again as outlined above except the bubble size will be increased to 100 C.C.

0.10 LB_F THRUSTER

The bubble injestion tests shall be performed on the 0.10 lb_f thruster in an identical manner as outlined for the 1.0 lb_f thruster above.

TASK I — TEST 2

1.0 LB_F THRUSTER

The test system shall be remain configured as above and Figure 2.

The thruster will then be fired steady state for 66 seconds, then off-modulated (0.50 sec. off, 2 sec. on) for an additional 300 seconds. This test is to be performed under nominal thermal conditions.

Subsequently, the thruster valve temperature will be increased to 200°F (hot valve case). A bubble (10 C.C.) will then be formed in the bubble injection chamber and later introduced into the flow-stream.

After thruster firing has been initiated (steady state) the bubble shall be introduced and the thruster will be off-modulated T_B — TBD seconds later. Off-modulation pulsing shall continue for 300 seconds or until "choking" is observed. Two subsequent tests will be performed with the 10 C.C. bubble as outlined above except the steady state firing time shall be T_B seconds and T_B + TBD seconds. Off-modulation thus starts *before*, *during*, and after initiation of gas ingestion. Aforementioned TBD times will be calculated from observed gas flowrates.

The entire test sequence shall be repeated with a new bubble size of 100 C.C.

TASK II — TEST 1

1.0 LB_F THRUSTER

The test system shall be configured as shown in Figure 3. Propellant shall be saturated with GN_2 and pressurized to 278 psia. The Iso valve shall then be closed and the thruster fired in the pulse mode (0.050 sec. on, at 1 Hz) for TBD pulses. The supply tank pressure shall then be vented to 240 psia. After the Iso valve is opened, the thruster will be fired (0.050 sec. on, at 1 Hz) for TBD pulses until all the propellant between the Iso valve and the thruster has been consumed.

TASK II — TEST 2

0.10 LB_F THRUSTER

The test system shall be reconfigured per Figure 4. Propellant shall be GN_2 saturated and pressurized at 240 psia. The thruster will be fired for 10 seconds steady state to assure proper bleed-in. The Iso valve will then be closed and the thruster will be pulsed (0.020 sec. on at 1 Hz) until all the propellant in the line has been depleted. The Iso valve will then be re-opened and thruster will be fired for TBD pulses.

TASK III

The test system shall be configured per Figure 5. This test is to be performed with saturated propellant and 265 psia.

The test system downstream of the Iso valve shall be opened and evacuated. The thruster valve will then be opened. (Iso valve is still closed) to insure a proper vacuum between the valve seats. The thruster valve will then be closed and the system bled in up to the front seat of the propellant valve. The thruster will then be pulsed (0.050 sec. on at 1 Hz) for 20 pulses or until the chamber pressure has stabilized. This sequence shall be repeated a minimum of 2 times with the option of performing one iteration during the initial thruster firing of the thruster baseline performance tests.

2. CONDITIONS

2.1 Personnel. The following personnel are required to perform this test.

a) Test Engineer or Conductor (1)

b) Instrumentation technician (1)

c) Mechanical technician (1)

2.2 Safety Precautions.

2.2.1 Personnel Safety

* CAUTION *

All persons engaged in this test shall be thoroughly familiar with this procedure, the facilities used in the performance of this test, and the hardware to be tested. Further, all personnel must be familiar with the test area, the appropriate operating procedures, and the methods established for the handling of mono-propellant hydrazine.

2.2.2 Hardware Safety

* CAUTION *

Personnel shall exercise caution to prevent damage to the test hardware.

2.3 Preparations

2.3.1 Documentation

a) Required on hand:

- This procedure with attached data sheets
- Ground Verification Test Plan I.O.C. - FSC-F2-PROP-007

b) Reference:

- TRW Drawing 410618 1.0 lb_f Thruster Assembly
- TRW Drawing 412118 0.10 lb_f Thruster Assembly
- TRW Drawing 412156 Propulsion Feed System Assembly
- TRW 77.4751.2-119, Procedure for Propellant Tank Filling with Hydrazine
- TRW 77.4751.2-120, Procedure for Operating Electrothermal and Catalytic Hydrazine Engines

2.3.2 <u>Test Setup</u>. Hot fire testing using monopropellant hydrazine shall be performed in TRW's Low Thrust Test Facility in Building 01 and according to approved operating and test procedures. The test activity shall be in accordance with facility operating procedures 77.4751.2-119 and 77.4751.2-120. The test setup shall consist of the following facility hardware, test media, and instrumentation.

a) Facility Hardware:

- Propellant Supply System (see Figures 2 through 5)
- DTM mounting bracket
- Vacuum chamber, 0.1 psia max at 0.005 lbs/sec N_2H_4
- Latching Isolation vavles (4) TRW Drawing No. C410613
- In-line Filter 10 μ (1) TRW Drawing No. C410612 or equivalent

b) Test Media:

- Propellant, Hydrazine, MIL P 26536C Amendment 1, monopropellant grade with the following exceptions:

  Water = 0.5 to 1.0 percent by weight

  Aniline = 0.005 percent maximum by weight

  CO_2 = 0.005 percent maximum by weight

  Ammonia = 0.4 percent maximum by weight

- Pressurant, Nitrogen, MIL-P-27401B

c) Instrumentation

- Digital Data Acquisition System, 01 Low Thrust Test Facility
- Transducer, Pressure (Taber Model 226 or equivalent)
- Transducer, Pressure (Bell and Howell Model 4-353-0001 or equivalent)
- Thermocouple, chromel-alumel, 6 required (Thermocouples may be added or deleted at the direction of the Test Conductor or Thruster Engineer).
- Timing Equipment for Steady State firings
- Data Recording Equipment (Oscillograph and Stripcharts)
- Power Supplies: 0-35 Vdc
- Flight equivalent valve driver circuit (SK107-2)
- Pulse generator and timing equipment for duty cycle firings
- Thermocouple data recorder (Esterline Angus Series E)

2.3.3 Test Items. The test item is a FSC similar dual thruster module wherein two thrusters are mounted (1.0 lb_f and a 0.10 lb_f). The DTM shall be identical to FSC flight units, i.e., thermostats, catalyst bed heaters, heat shields, valve heaters, bracket and thermal standoffs.

The 1.0 lb_f thruster is a flight spare which has been acquired from stores and modified to incorporate a chamber pressure (P_c) tap for performance measurement. The thruster chamber shall be mounted to a Allen or Consolidated Controls manufactured valve.

The 0.10 lb_f thruster is also a FSC spare thruster assembly. The chamber has been removed to allow installation of a P_c tap in the nozzle. The thruster is then re-assembled, catalyst loaded, and installed on an Allen or Consolidated Controls propellant valve. The DTM with both thrusters is shown in Figure 1.

2.3.4 Propellant Sampling. Propellant sample shall be taken and analyzed from the drum when a new drum of propellant is used. A line sample shall be taken from the propellant supply system within four weeks immediately preceding the test. Re-sampling shall be performed whenever the tank is reloaded.

2.3.5 Photographs. Pre and post test photographs shall be taken of the DTM in each test setup configuration. Sufficient photos shall be taken to document each test configuration.

3. PROCEDURES

3.1 Propellant Feed System Installation (Fixed Length Portion)

3.1.1 Install the propellant tank and GN_2 pressurizing system in accordance with each test requirement. The part of the propellant system that comes in contact with the propellant shall be comprised only of stainless steel components with Teflon or EPR seals. Liquid lines shall be fabricated of 0.25 x .016w tubing only. Tube fittings in the liquid flow stream shall be bored out to 0.218 inch I.D. The hand valve directly below the propellant tank shall be of 3/8 inch capacity.

3.1.2 Prior to final leak testing the system shall be removed and cleaned to PR 2-2 level S and reinstalled.

3.1.3 The propellant tank shall be filled in accordance with Procedure No. 77.4751.2-001, procedure for filling propellant tank from drums.

3.1.4 Propellant saturation shall be accomplished by bubbling GN_2 at a controlled TBD rate through the propellant at a pressure 50 psi higher than the test pressure. The propellant shall be saturated in this manner for a minimum of TBD hours. After saturation has been accomplished the propellant shall be vented to the proper test pressure and allowed to stand for an additional TBD minutes prior to initiation of testing.

3.2 Dual Thruster Module (DTM) Installation

3.2.1 Install the DTM on the facility mounting bracket and secure.

3.2.2 Connect propellant lines and leak test at 300 psig with Snoop. Verify no leaks.

3.2.3 Bleed in propellant in accordance with 77.4751.2-120 para. 3.2.11.

3.3 Pre-test Procedure

NOTE: The following may be completed simultaneously with DTM Installation, Paragraph 3.2.

3.3.1 Verify that all applicable test equipment has current calibration stickers. Complete instrumentation list in Data Sheet.

3.3.2 Install thermocouples as required by instrumentation configuration sheet. Connect thermocouples to patch board inside vacuum tank.

3.3.3 Connect catalyst bed and valve heater leads.

3.3.4 Check out heater and thermocouple circuits. Check TA's valve coils for continuity.

3.3.5 Check flight type valve driver circuits as follows:

3.3.5.1 Turn 110 VAC switch to "ON."

3.3.5.2 Turn 28 VDC switch to "ARM," test switch to "TEST."

3.3.5.3 Measure voltage across test points 8 and 11. The measured valve shall be 29 ±0.5 VDC.

3.3.5.4 Turn manual fire switch to ON."

3.3.5.5 Measure voltage across test points 8 and 11. The measured value shall be less than 0.5 VDC.

3.3.5.6 Turn the manual fire switch to "OFF."

3.3.6 Complete instrumentation and recording requirements as required by Instrumentation Configuration Sheet.

3.3.7 Verify magnetic tape, oscillograph and strip chart operation.

3.3.8 Verify proper operation of "off-modulation" circuit by performing "dry-firing" with simulated valve resistance.

3.3.9 Verify proper operation of all latching (ISO) and remote valves in propellant feed system.

3.4 Pre-fire Procedure

3.4.1 Verify that all hydrazine aspirate valves are closed and capped.

3.4.2 Verify all instrumentation is secured and patched in.

3.4.3 Close vacuum chamber door and pump down to 0.01 psia maximum.

3.4.4 Activate catalyst bed heaters and stabilize thruster barrier tube temperature at 150 ±20°F. Do not exceed 15 VDC on catalyst bed heater voltage. Valve heaters may be used as required if the barrier tube does not attain 150°F.

3.5 Thruster Operation (Performance Baseline)

NOTE: Reference Table 3.

3.5.1 Conduct pulse mode tests as follows:

Note that para. 3.5 shall be performed twice for each thruster under the following conditions:

- o Perform 3.5 with unsaturated propellant.
- o Perform 3.5 with saturated propellant.

3.5.1.1 Configure feed system per Figure 5 and perform Paragraphs 3.1, 3.3 and 3.4.

3.5.1.2 Conduct high and low signal calibration on each computer channel as applicable.

3.5.1.3 Set pulse width to the requirement of Test 1 Table 3 (0.050 sec.)

3.5.1.4 Check pulse width with simulated valve resistance. Adjust as necessary.

3.5.1.5 Select TA valve coil AB.

3.5.1.6 Adjust TA inlet pressure to 240 ± 5 psia.

3.5.1.7 Verify that TA barrier tube temperature is 150 ±20°F.

3.5.1.8 Activate computer and start recorders.

3.5.1.9 Start oscillograph and fire ten (10) pulses. (Test III-1C, Task III).

3.5.1.10 Stop oscillograph. Verify thruster pulse and chamber temperature rise.

3.5.1.11 Monitor chamber temperature on digital readout. Fire next pulse when barrier tube temperature returns to 150 ±20°F. Continue firing per Test 1 until required number of pulses has been fired.

3.5.1.12 Adjust TA inlet pressure to the requirement of Test 2 Table 3 (350 ± 5 psia).

3.5.1.13 Repeat steps 3.5.1.7, 3.5.1.8 and 3.5.1.11.

3.5.1.14 Adjust TA inlet pressure to the requirement of Test 3 Table 3 (100 ± 5 psia).

3.5.1.15 Repeat steps 3.5.1.7, 3.5.1.8 and 3.5.1.11.

3.5.1.16 Conduct post test calibrations as required.

3.5.2. Conduct steady state firing as follows:

3.5.2.1 Conduct high and low signal calibration on each computer channel.

3.5.2.2 Increase TA inlet pressure to 350 ± 5 psia (Test 4 Table 3).

3.5.2.3 Select valve coil AB.

3.5.2.4 Verify that TA barrier tube temperature is 150 ±15°F.

3.5.2.5 Start recorders.

3.5.2.6 Activate computer.

3.5.2.7 On the valve driver panel, turn 28 VDC switch to "ARM" and test switch to "RUN."

3.5.2.8 Start oscillograph in accordance with Table 1.

3.5.2.9 Turn Manual fire switch to "ON" position. Visual monitor chamber pressure. Fire thruster for 60 ±1 seconds. Turn manual fire switch to "OFF" position. Stop Oscillograph.

3.5.2.10 Conduct post test calibrations as required. Stop recorders.

3.5.2.11 Repeat steps 3.5.2.2 - 3.5.2.10 for inlet prssures of 240 ± 5 psia and 100 ± 5 psia.

3.5.3 Repeat Paragraph 3.5 for 0.10 lb_f thruster firing, except note that pulse width is now 0.020 seconds on, and delete steps 3.5.1.9 and 3.5.1.10. Change test numbers in accordance with Table 3.

3.6 Thruster Operation (Task III)

3.6.1 Configure propellant feed system per Figure 5 and Paragraph 3.1.

3.6.2 Aspirate propellant line between downstream ISO valve and thruster assembly.

3.6.3 GN_2 purge above line length for 5 minutes minimum.

3.6.4 Perform Paragraph 3.3 of this procedure.

3.6.5 Close vacuum chamber door and evacuate to 0.01 psia maximum with aspirate valve open. Note: Be sure ISO valve (V2) is closed.

3.6.6 Open TA valve for 5 minutes minimum. Note: Reduce voltage applied to valve coils and monitor valve temperature during this holding period. Valve temperature shall not exceed 220°F.

3.6.7 After closing TA valve, open vacuum chamber door and bleed in propellant up to TA. Close aspirate valve and perform Paragraph 3.4 of this procedure.

3.6.8 Conduct high and low signal calibration on each computer channel as applicable.

3.6.9 Set pulse width to requirement of Test III-1A Table 1 (0.050 sec.).

3.6.10 Check pulse width with simulated valve resistance. Adjust as necessary.

3.6.11 Select TA valve coil AB.

3.6.12 Adjust TA inlet pressure to 240 ± 5 psia.

3.6.13 Verify TA barrier tube temperature is 150 ±20°F.

3.6.14 Activate computer and start recorders.

3.6.15 Start oscillograph and fire twenty (20) pulses. Stop oscillograph. Verify thruster pulse and chamber temperature rise.

3.6.16 Conduct post test calibrations as required.

3.6.17 Repeat steps 3.8.1 through 3.8.15.

3.7 Thruster Operation (Task I)

Note: Perform informal "walk-through" of gas ingestion chamber operating procedures before beginning this portion of the test sequence.

3.7.1 Perform pulse mode testing of the 1.0 lb_f and 0.10 lb_f thrusters with bubble ingestion as follows:

3.7.1.1 Configure propellant feed system per Figure 2 and Paragraphs 3.1, 3.3 and 3.4.

3.7.1.2 Aspirate (if necessary) the Bubble ingestion chamber with valves V3 and V4 closed, valve V5 open.

3.7.1.3 GN_2 purge the bubble ingestion system for 5 minutes minimum with valves V3 and V4 closed, V5 and V6 open.

3.7.1.4 Close V6. Pressurize bubble ingestion system through V5 to TBD psia. Close V5. Open V3.

3.7.1.5 Conduct high and low signal calibration on each computer channel as applicable.

3.7.1.6 Set pulse width to requirement of Test I-1A Table 1.

3.7.1.7 Check pulse width with simulated valve resistance. Adjust as necessary.

3.7.1.8 Select TA valve coil AB.

3.7.1.9 Adjust TA inlet pressure to 240 ± 5 psia. Close V2, open V6. Verify PINJ is 240 ± 5 psia.

3.7.1.10 Verify TA barrier tube temperature is 150 ±20^{o}F.

3.7.1.11 Activate computer and start recorders.

3.7.1.12 Start Oscillograph and initiate pulse mode firing for TBD pulses. Start timer simultaneously.

3.7.1.13 Monitor chamber pressure and temperature to verify proper thruster operation.

3.7.1.14 Stop timer as soon as bubble has reached thruster (indicated by loss of chamber pressure). Record time (T_B) on data sheet.

3.7.1.15 Continue firing until bubble has completely passed through the thruster (indicated by nominal chamber pressure level). Continue firing for 15 ±5 pulses, then terminate.

3.7.1.16 Repeat steps 3.7.1.2 through 3.7.1.15 with bubble ingestion pressure (GN_2) of TBD.

3.7.1.17 Repeat step 3.7.1.2 through 3.7.1.6 firing the 0.10 lb_f thruster.

3.7.2 Perform ΔV simulation tests as follows:

3.7.2.1 Configure propellant feed system as shown in Figure 3 per Paragraph 3.1 of this procedure.

3.7.2.2 Perform Paragraphs 3.3 and 3.4 of this procedure.

3.7.2.3 Insure the following valve status: V3, V4, V5, V6 closed, V1 V2 open.

3.7.2.4 Conduct high and low signal calibration on each computer channel as required.

3.7.2.5 Set off-modulation pulse width to requirement of Test I-2A Table 1.

3.7.2.6 Check off modulation pulse width with simulated valve resistance. Adjust if necessary.

3.7.2.7 Select TA valve coil AB.

3.7.2.8 Adjust TA inlet pressure to 240 ± 5 psia.

3.7.2.9 Verify TA barrier tube temperature is 150 $\pm 20^{o}$F.

3.7.2.10 Activate computer and start recorders.

3.7.2.11 Start Oscillograph and initiate thruster steady state firing for 66 ±5 sec., then off modulate per Table 1 (0.050 sec. off, 2 sec. on) for TBD pulses, or unt l "choking" is observed (loss of chamber pressure).

3.7.2.12 Repeat steps 3.7.2.3 through 3.7.2.11 except insure that valve temperature is 200^{o}F minimum prior to initiation of steady state firing. (Test I-2B)

3.7.3 Perform thruster "thermal choking" investigation tests as follows:

3.7.3.1 Configure propellant feed system per figure 3 and paragraph 3.1, 3.3 and 3.4.

3.7.3.2 Aspirate (if necessary) the bubble ingestion chamber with valves V3 and V4 closed, valve V5 open.

3.7.1.3 GN_2 purge the bubble ingestion system for 5 minutes minimum with valves V3 and V4 closed, V5, V6 open.

3.7.1.4 Close V6. Pressurize bubble ingestion system through V5 to TBD psia. Close V5. Open V3.

3.7.1.5 Conduct high and low signal calibration on each computer channel as applicable.

3.7.1.6 Set off-modulation pulse width to requirement of test I-2C table 1.

3.7.1.7 Check off-modulation pulse operation with simutated valve resistance. Adjust if necessary.

3.7.1.8 Select TA valve coil AB.

3.7.1.9 Adjust TA inlet pressure to 240 ± 5 psia. Close V2, open V6. Verify Pinj is 240 ± 5 psia.

3.7.1.10 Verify TA barrier tube temperature is 200°F minimum.

3.7.1.11 Activate computer and start recorders.

3.7.1.12 Start oscillograph and initiate thruster steady state firing for T_B-TBD seconds, off-modulate for TBD pulses or until "choking" is observed.

3.7.1.13 Repeat steps 3.7.3.2 through 3.7.1.12 an additional five times in accordance with tests I-2D through I-24 of table 1.

3.8 Thruster Operation (Task II)

3.8.1.1 Configure propellant feed system in accordance with figure 3 and paragraph 3.1.

3.8.1.2 Perform paragraph 3.3 and 3.4.

3.8.1.3 Conduct high and low signal calibration on each computer channel as applicable.

3.8.1.4 Set pulse width to the requirement of test II-1A table 1. (.050 sec.)

3.8.1.5 Check pulse width with simulated valve resistance. Adjust as necessary.

3.8.1.6 Select TA valve coil AB.

3.8.1.7 Verify ISO valve status: V3, V4, V5, V6 closed, V1, V2 open.

3.8.1.8 Adjust TA inlet pressure to 278± 5 psia.

3.8.1.9 Close V1.

3.8.1.10 Verify TA barrier tube temperature is 150 ±20°F.

3.8.1.11 Activate computer and start recorders.

3.8.1.12 Start oscillograph and fire TBD pulses. Monitor strip charts to verify pulse and chamber temperature rise.

3.8.1.13 Vent tank to 240 ± 5 psia and wait for TBD minutes.

3.8.1.14 Open V1.

3.8.1.15 Activate computer, start recorders, start oscillograph and fire TBD pulses.

3.8.1.16 Close V1.

3.8.1.17 Activate computer, start recorders, start oscillograph and fire thruster until all propellant in line has been used (indicated by loss of chamber pressure and inlet pressure.)

3.8.2 Perform tests on 0.10 lb_f thruster as follows:

3.8.2.1 Configure propellant feed system in accordance with Figure 4 and Paragraph 3.1.

3.8.2.2 Perform Paragraphs 3.3 and 3.4.

3.8.2.3 Conduct high and low signal calibration of each computer channel as applicable.

3.8.2.4 Set pulse width to the requirement of test II-2A, Table 1. (0.020 second).

3.8.2.5 Check pulse width with simulated valve resistance. Adjust as necessary.

3.8.2.6 Select TA valve coil AB.

3.8.2.7 Verify ISO valve status: V3, V4, V5, V6 closed, V1, V2 open.

3.8.2.8 Adjust TA inlet pressure to 240 ± 5 psia.

3.8.2.9 Close V1.

3.8.2.10 Verify TA barrier tube temperature is 150 ±20°F.

3.8.2.11 Activate computer and start recorders.

3.8.2.12 Start oscillograph and fire TBD pulses to completely remove propellant in line. Monitor pulse and chamber temperature use for thruster firing verification.

3.8.2.13 Allow thruster barrier tube temperature to cool to 150 ±20°F.

3.8.2.14 Open V1.

3.8.2.15 Activate computer and start recorders.

3.8.2.16 Start oscillograph and fire TBD pulses to completely remove propellant in line. Monitor pulse and chamber temperature use to verify proper thruster operation.

3.9 Thruster Operation (Performance Re-Baseline)

NOTE: Reference Table 3.

3.9.1 Conduct pulse mode tests by performing Paragraph 3.5.1, except delete steps 3.5.1.9 and 3.5.1.10.

3.9.2 Conduct steady state tests by performing Paragraph 3.5.2.

3.10 System Shutdown

3.10.1 Reduce inlet pressure to 50 ± 20 psia.

3.10.2 Wait until thruster cools to 300 °F.

3.10.3 Stop vacuum pump and return chamber pressure to atmospheric using nitrogen gas. Open door of vacuum tank.

3.10.4 Remove instrumentation leads from thruster. Remove heaters and mount.

3.10.5 Close manual TA isolation valve.

3.10.6 Remove thruster. Immediately cap TA inlet and propellant supply line.

4. DATA REQUIREMENTS

4.1 Acquisition

4.1.1 All tests shall be conducted in accordance with Tables 1, 2 and 3.

4.1.2 If data from a particular test run is invalid due to instrumentation or procedural errors, that test may be repeated. The retest is contingent upon approval of the thruster engineer and documentation of the error necessitating retest.

4.1.3 Data acquisition shall be by digital computer with storage of reduced data on magnetic tape. Additional data will be recorded on oscillograph and strip charts directly and be hand recorded on data sheets from DVM's.

4.1.4 Test instrumentation shall be in accordance with Table 2 and Figure 1.

4.2. Reduction

4.2.1 Digital data shall be processed to produce the following measurements:

- Inlet pressure
- Nozzle temperature (for each thruster)
- Chamber temperature (for each thruster)
- Barrier tube temperature (for each thruster)
- Valve temperature (for each thruster)
- Chamber pressure (for each thruster)

4.3 Data Retention and Reporting

4.3.1 All data shall be submitted to the thruster engineer for review.

TABLE 1. GVT TEST MATRIX

Test No.	Pint (PSIA)	Pulse Width (Sec)	Duty Cycle	No. of Pulses	Thruster	T1/T5 Start (°F)	Comments
I-1A	240±5	.050	1 HZ	TBD	1.0 lbf	150	10 cc bubble ingested
I-1B	240±5	.050	1 HZ	TBD	1.0 lbf	150	100 cc bubble ingested
I-1C	240±5	.020	1 HZ	TBD	0.10 lbf	150	10 cc bubble ingested
I-1D	240±5	.020	1 HZ	TBD	0.10 lbf	150	100 cc bubble ingested
I-2A	240±5	66 S.S.*	Off-Mod	TBD	1.0 lbf	150	Nominal ΔV firing with off-modulation
I-2B	240±5	66 S.S.*	Off-Mod	TBD	1.0 lbf	T/C 2=200	Off-mod with hot propellant valve
I-2C	240±5	TB-TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	10 cc bubble ingested w/off-mod (hot valve)
I-2D	240±5	TB	Off-Mod	TBD	1.0 lbf	T/C 2=200	10 cc bubble ingested w/off-mod (hot valve)
I-2E	240±5	TB-TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	10 cc bubble ingested w/off-mod (hot valve)
I-2F	240±5	TB-TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	100 cc bubble ingested w/off-mod (hot valve)
I-2G	240±5	TB	Off-Mod	TBD	1.0 lbf	T/C 2=200	100 cc bubble ingested w/off-mod (hot valve)
I-2H	240±5	TB+TBD	Off-Mod	TBD	1.0 lbf	T/C 2=200	100 cc bubble ingested w/off-mod (hot valve)
II-1A	278±5	.050	1 HZ	TBD	1.0 lbf	150	Thruster firing with ISO closed
II-1B	240±5	.050	1 HZ	TBD	1.0 lbf	150	Thruster firing (ISO open)
II-1C	240±5	.050	1 HZ	TBD	1.0 lbf	150	Thruster firing (ISO closed)
II-2A	240±5	.020	1 HZ	TBD	0.10 lbf	150	Thruster firing (ISO closed)
II-2B	240±5	.020	1 HZ	TBD	0.10 lbf	150	Thruster firing (ISO open)
III-1A	268±5	.050	1 HZ	TBD	1.0 lbf	150	"Dry valve"
III-1A	268±5	.050	1 HZ	TBD	1.0 lbf	150	"Dry valve"
III-1C	268±5	.050	1 HZ	TBD	1.0 lbf	150	"Dry valve" Note: This test may be performed during thruster baseline performance

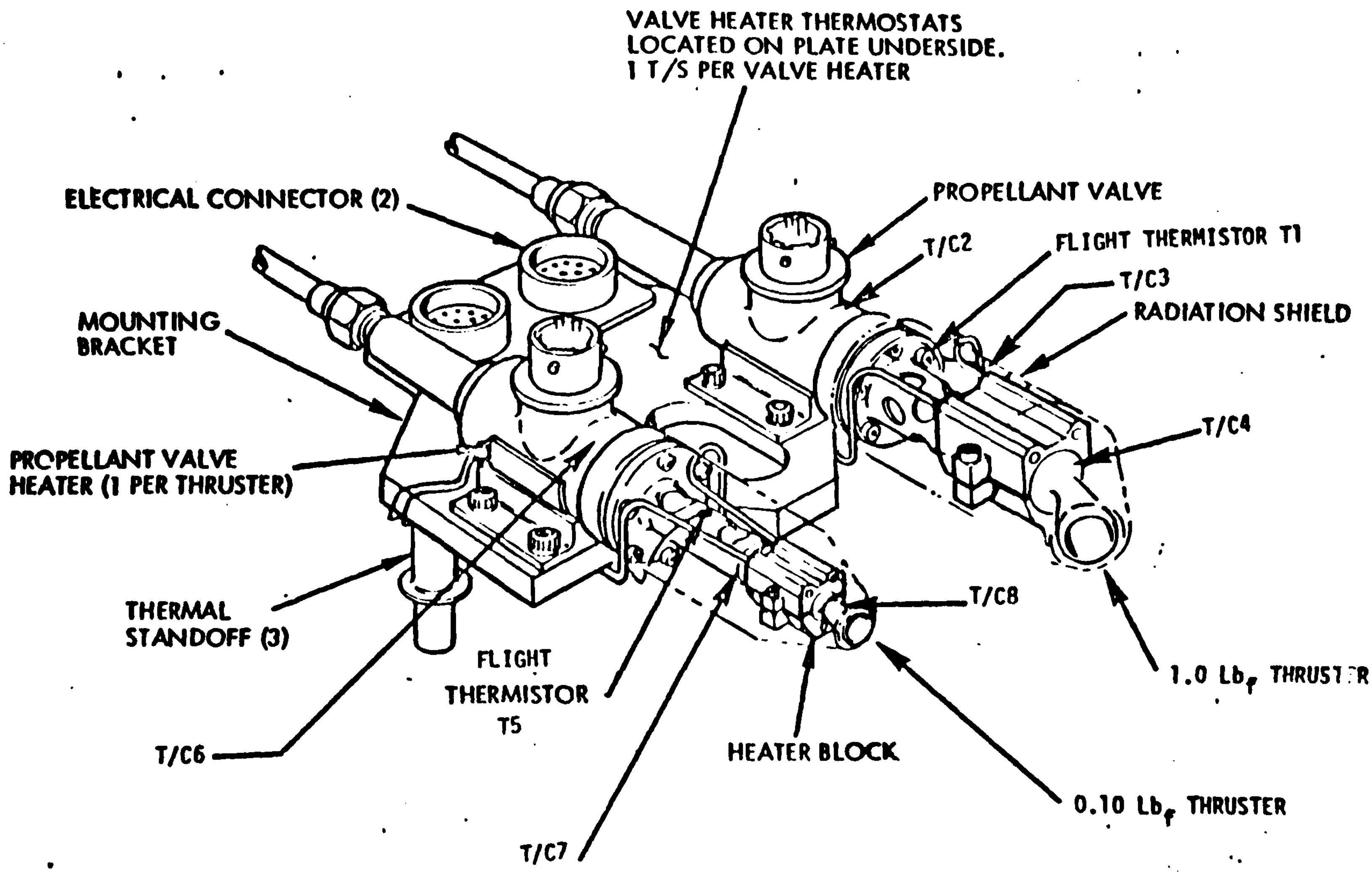
*66 seconds steady state followed by off-modulation at .05 sec off/1.95 sec on.

TABLE 2. TEST INSTRUMENTATION AND DATA REQUIREMENTS

Parameter	Symbol	Strip-Chart	O-Graph	Digital Computer
Chamber Pressure (1.0 lb_f Thruster)	P_{C1}	X	X	X
Chamber Pressure (0.10 lb_f Thruster)	P_{C2}	X	X	X
Injection Pressure	P_{INJ}	X	X	X
Vacuum Pressure	P_{VAC}			X
Valve Voltage (1.0 lb_f Thruster)	V_{E1}		X	
Valve Voltage (0.10 lb_f Thruster)	V_{E2}		X	
Valve Current (1.0 lb_f Thruster)	V_{I1}		X	
Valve Current (0.10 lb_f Thruster)	V_{I2}		X	
Thermistor (Barrier Tube) (1.0 lb_f Thruster)	T_1	X		X
Thermocouple (Valve) (1.0 lb_f Thruster)	TC_2	X		X
Thermocouple (Chamber) (1.0 lb_f Thruster)	TC_3	X		X
Thermocouple (Nozzle) (1.0 lb_f Thruster)	TC_4	X		X
Thermistor (Barrier Tube) (0.10 lb_f Thruster)	T_5	X		X
Thermocouple (Valve) (0.10 lb_f Thruster)	TC_6	X		X
Thermocouple (Chamber) (0.10 lb_f Thruster)	TC_7	X		X
Thermocouple (Nozzle) (0.10 lb_f Thruster)	TC_8	X		X

TABLE 3. BASELINE PERFORMANCE TESTS

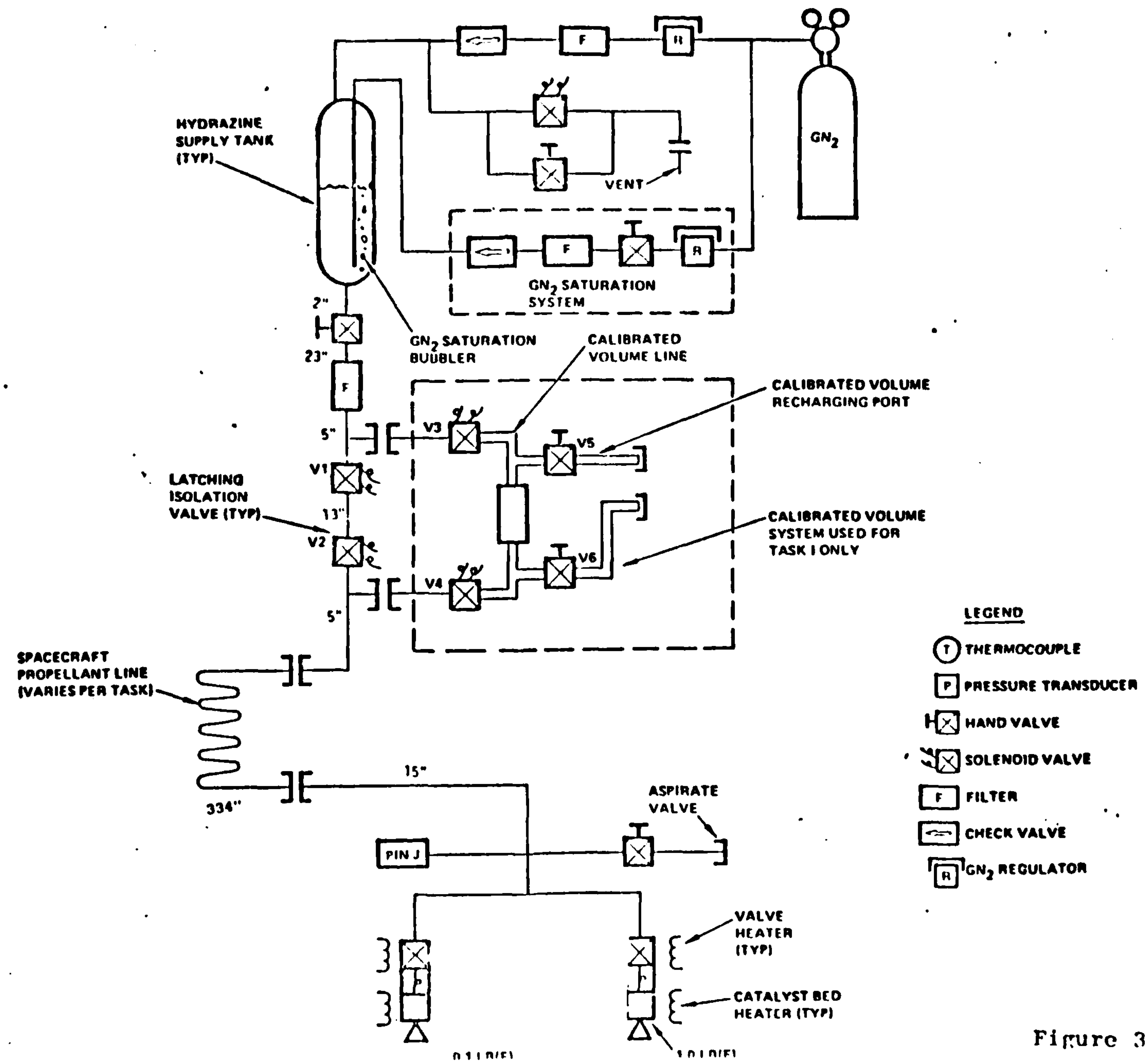
Test NO.	Pinj (PSIA)	Pulse Width (sec)	Off time (sec.)	No. of Pulses	Thruster	Comments
1	240 ± 5	.050	1 Hz	50	1.0 lb_f	Also use data for Test III - 1C
2	350	.050	1 Hz	50	1.0 lb_f	
3	100	.050	1 Hz	50	1.0 lb_f	All baseline performance tests shall be done with T1/T5 start temps. of 150°F.
4	350	60	-	1	1.0 lb_f	
5	240	60	-	1	1.0 lb_f	
6	100	60	-	1	1.0 lb_f	
7	350	60	-	1	0.10 lb_f	
8	240	60	-	1	0.10 lb_f	
9	100	60	-	1	0.10 lb_f	
10	350	.020	1 Hz	50	0.10 lb_f	
11	240	.020	1 Hz	50	0.10 lb_f	
12	100	.020	1 Hz	50	0.10 lb_f	



GVT DUAL THRUSTER MODULE

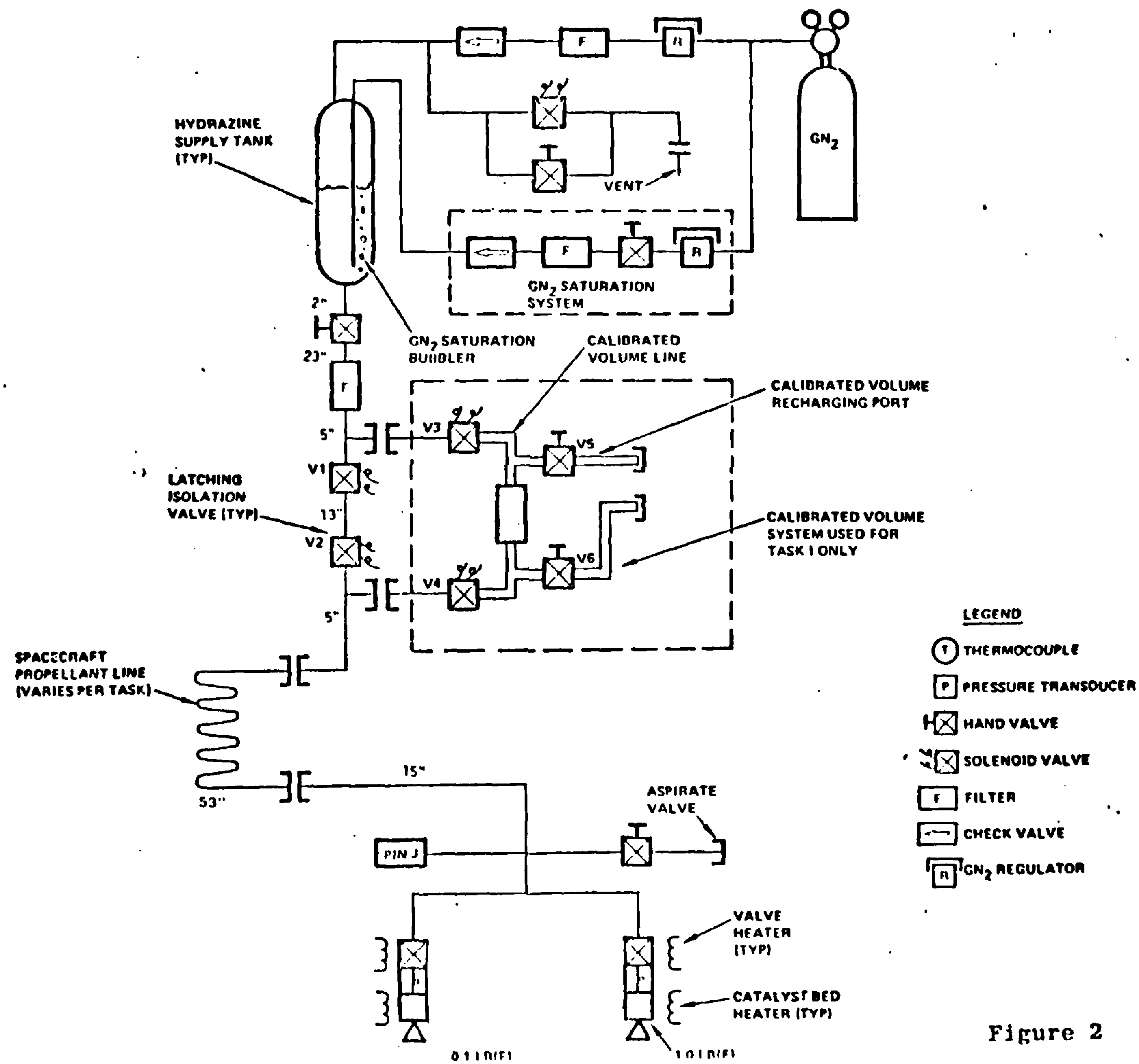
Figure 1. GVT Dual Thruster Module

Figure 1.



HYDRAZINE SUPPLY TANK (TYP)
GN2
VENT
GN2 SATURATION SYSTEM
GN2 SATURATION BUBBLER
2"
23"
5"
13"
5"
V1
V2
V3
V4
V5
V6
CALIBRATED VOLUME LINE
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
LATCHING ISOLATION VALVE (TYP)
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
334"
15"
PIN J
ASPIRATE VALVE
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
LEGEND
THERMOCOUPLE
PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
FILTER
CHECK VALVE
GN2 REGULATOR

Figure 3



HYDRAZINE SUPPLY TANK (TYP)
GN_2
VENT
GN_2 SATURATION SYSTEM
GN_2 SATURATION BUBBLER
CALIBRATED VOLUME LINE
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
V1
V2
V3
V4
V5
V6
2"
23"
5"
13"
5"
LATCHING ISOLATION VALVE (TYP)
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
53"
15"
ASPIRATE VALVE
PIN J
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
LEGEND
THERMOCOUPLE
PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
FILTER
CHECK VALVE
GN_2 REGULATOR

Figure 2

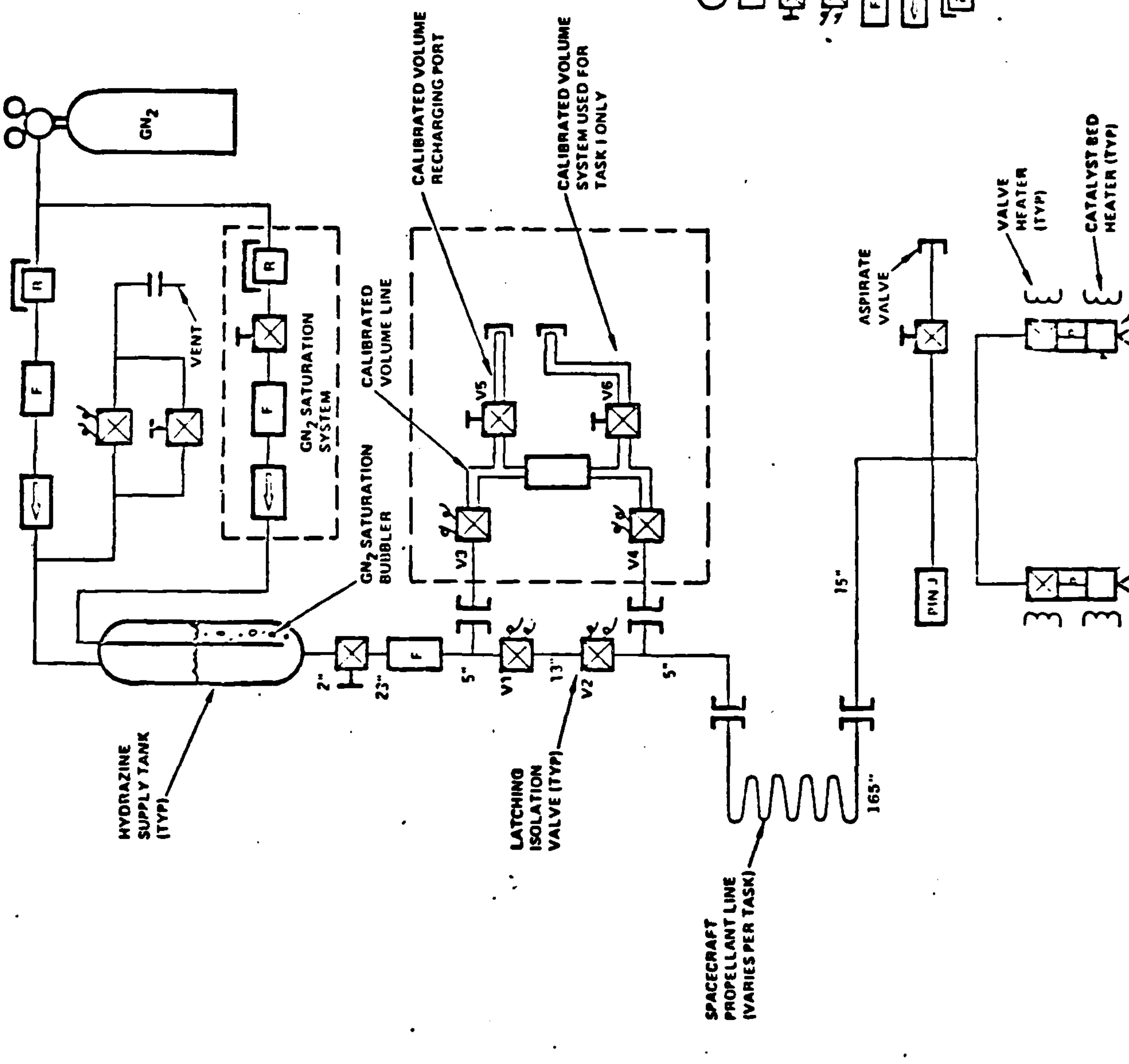

GN2
HYDRAZINE SUPPLY TANK (TYP)
GN2 SATURATION BUBBLER
GN2 SATURATION SYSTEM
VENT
LATCHING ISOLATION VALVE (TYP)
CALIBRATED VOLUME LINE
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
V1
V2
V3
V4
V5
V6
2"
23"
5"
13"
5"
15"
165"
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
ASPIRATE VALVE
PINJ
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
1.0 LB(F)
0.1 LB(F)
LEGEND
THERMOCOUPLE
PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
FILTER
CHECK VALVE
GN2 REGULATOR

Figure 4

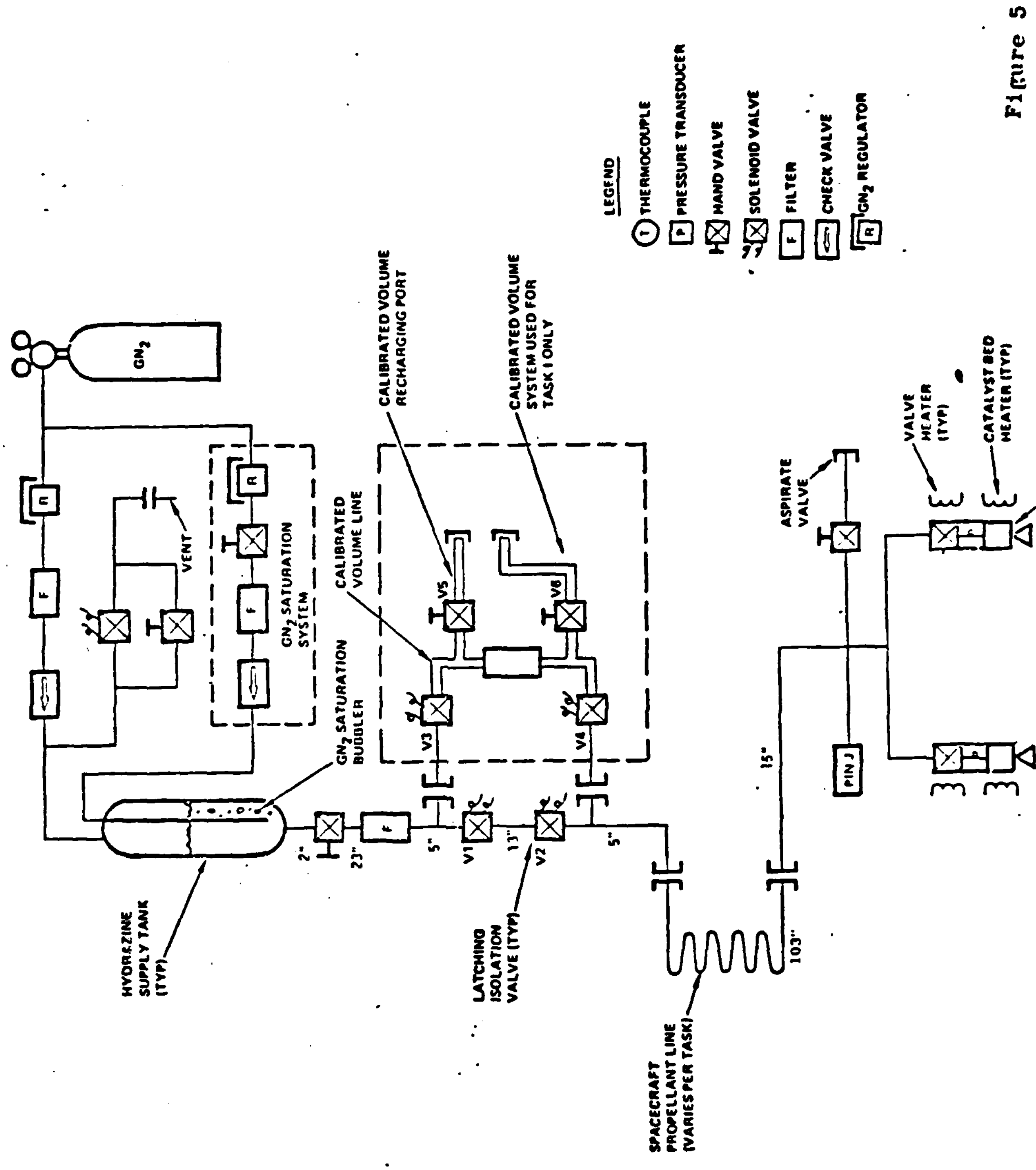

GN2
HYDRAZINE SUPPLY TANK (TYP)
GN2 SATURATION BUBBLER
GN2 SATURATION SYSTEM
VENT
R
F
2"
23"
5"
V1
13"
V2
5"
V3
V4
V5
V6
LATCHING ISOLATION VALVE (TYP)
CALIBRATED VOLUME LINE
CALIBRATED VOLUME RECHARGING PORT
CALIBRATED VOLUME SYSTEM USED FOR TASK I ONLY
SPACECRAFT PROPELLANT LINE (VARIES PER TASK)
103"
15"
P IN J
ASPIRATE VALVE
VALVE HEATER (TYP)
CATALYST BED HEATER (TYP)
1.0 LB(F)
0.1 LB(F)
LEGEND
THERMOCOUPLE
PRESSURE TRANSDUCER
HAND VALVE
SOLENOID VALVE
FILTER
CHECK VALVE
GN2 REGULATOR

Figure 5

DATA SHEET

TA (1.0 Lb_f) S/N ____________ Date ____________

Valve S/N ____________ Test Start Date ____________

TA (0.10 Lb_f) S/N ____________ Test End Date ____________

Valve S/N ____________

Propellant Analysis:

Date of Analysis ____________

Density at 77^{9}F, g/mi ____________

Water, % ____________

Hydrazine, % ____________

Particulate, mg/L ____________

Instrumentation:

Verify curron validation stickers ____________

List Primary Data Transducers

Inlet Pressure Model ____________ S/N ____________

Inlet Pressure Model ____________ S/N ____________

Chamber Pressure Model ____________ S/N ____________

TEST DATA SUMMARY 1.0 LB_F THRUSTER S/N

Test No.	Pinj (Psia)	Pc (Psia)	Start Temperature (^oF)				Observations/Comments
			T_1	T/C_2	T/C_3	T/C_4	

TEST DATA SUMMARY 0.10 LB_F THRUSTER S/N

Test No.	Pinj (Psia)	Pc (Psia)	Start Temperature (^oF)				Observations/Comments
			T_5	T/C_6	T/C_7	T/C_8	

APPENDIX C
PROPELLANT ANALYSIS

TRW

DEFENSE AND SPACE SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

INTEROFFICE CORRESPONDENCE

4344.3.80-020

TO: G. Joseph

CC: D. M. Wever

DATE: 12 May 1980

SUBJECT: Analysis of Monopropellant Hydrazine

FROM: J. R. Denson

BLDG: 44AT | MAIL STA.: CTS | EXT.: 482

Reference: MIL-P-26536C, Amendment 1, dated 25 Jul 1974, "Military Specification, Propellant, Hydrazine, Monopropellant Grade"

A sample of monopropellant grade hydrazine, without a sample number, was submitted about 1 May 1980 for analysis. Your request was that only the constituents to be determined are those listed below. The analyses were performed according to the methods described in the Reference.

Analysis of Hydrazine

Tests	Spec Limits	Results
Density at 77°F, g/cc	NR*	1.004
Hydrazine, % (W/W)	98.5 min	99.64
Ammonia, % (W/W)	NR*	0.08
Water, % (W/W)	1.0 max	0.28
Other Volatile Carbonaceous Material, % (W/W)	0.2 max	<0.01
Chloride, % (W/W)	0.0005 max	0.000003
Non-Volatile Residue, % (W/W)	0.02 max	0.006
Carbon Dioxide, % (W/W)	0.02 max	0.001

*NR = Not Required