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VOYAGER URANUS ENCOUNTER 0.2-lbf T/VA SHORT PULSE TEST REPORT

P67

86-R-1025

Prepared for:

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109

January 17, 1986

ROCKET RESEARCH COMPANY

A DIVISION OF ROCKCOR

Redmond, Washington

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(FINAL)

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JPL Contract No: 957308
RRC Report No.: 86-R-1025
Date: January 17, 1986

Prepared and approved by:

D R Johnson
D. R. Johnson
Project Manager

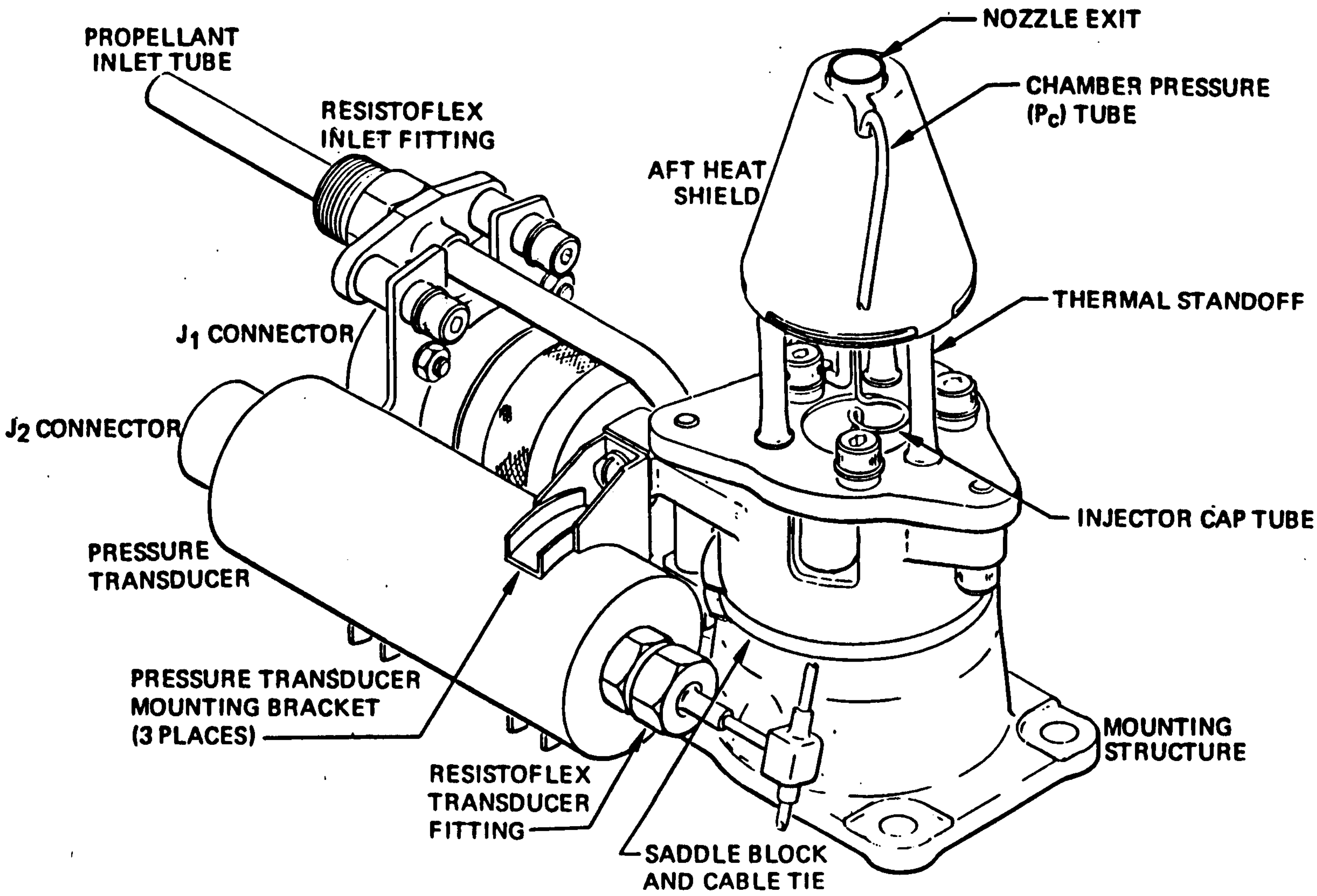
THIS REPORT DOES NOT IDENTIFY "NEW TECHNOLOGY" ITEMS.

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration.

ABSTRACT

The purpose of this test program was to determine if the attitude control thrusters on the Voyager spacecraft can be operated at electrical pulse widths of less than the current 10-millisecond minimum in order to reduce impulse bit and, therefore, reduce the image smear of the pictures to be taken during the Uranus encounter. Thrusters with the identical configuration of the units on the spacecraft were fired in an altitude chamber to characterize impulse bit and impulse bit variations as a function of electrical pulse widths and to determine if the short pulses decreased thruster life. Pulse widths of 4.0 milliseconds provide approximately 45 percent of the impulse provided by a 10-millisecond pulse, and thruster-to-thruster and pulse-to-pulse variation is approximately plus or minus 10 percent. Pulse widths shorter than 4 ms showed wide variation, and no pulse was obtained at 3 ms. Three thrusters were each subjected to 75,000 short pulses of 4 milliseconds or less without performance degradation. A fourth thruster exhibited partial flow blockage after 13,000 short pulses, but this was attributed to previous test history and not short pulse exposure. The Voyager attitude control thrusters should be considered flight qualified for short pulse operation at electrical pulse widths of 4.0 milliseconds or greater.

LCSSE/MJS 0.2-lbf T/VA



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1.0 SUMMARY

This report documents the short pulse width testing completed on the Voyager 0.2-lbf thruster valve assemblies (T/VA's) under the Jet Propulsion Laboratory contract number 957308. The initial testing was performed under JPL contract 956930 and some of the information is included in this report to preserve continuity. The testing was conducted at Rocket Research Company, Redmond, Washington, in October 1984 through April 1985 and July 1985 through November 1985.

1.1 PURPOSE

1.1.1 Background

The Voyager 2 spacecraft will pass by Uranus on January 24, 1986. During a 6-hour period of close encounter, high resolution phorographs will be taken of the planet and its moons and rings. In order to get quality pictures of these dimly lit objects, the Voyager's cameras will have to track these objects with their shutters open. This technique involves rotation of the entire spacecraft and requires very precise control to prevent "image smear". This control is provided by a computer and the 0.2-lbf thruster valve assemblies (T/VA's) built by RRC. Since Uranus is much farther from the sun than Jupiter or Saturn and therefore there is less light, the camera exposure time is longer, making image smear more of a problem.

In order to help solve this problem, it is desireable to fire the T/VA's using shorter pulses than the standard minimum pulses and therefore reducing the rate of spacecraft movement.

1.1.2 Scope

The purpose of this test program was to determine if the thruster valve assemblies (TVA's) can be successfully and repeatedly fired at pulse widths of less than the standard minimum pulse width of 10 milliseconds. The goal was to demonstrate that the TVA's can be successfully fired using a pulse width that will produce an impulse bit of 10 to 50 percent of the impulse of a 10-millisecond pulse without effecting thruster life.

The objectives of this test program were to determine 1) impulse bit as a function of electrical pulse width, 2) impulse bit variations as a function of electrical pulse width, and 3) determine if the short pulses decrease thruster life. Thruster valve assemblies (T/VA's), identical to the units on the spacecraft, were tested to determine these objectives, and the results of the testing is contained in this report.

1.2 RESULTS

A pulse width of 4.0 millisecond was determined to the minimum acceptable pulse. It provides an impulse bit of approximately 45 percent of the impulse provided by a 10 millisecond pulse and the pulse-to-pulse and unit-to-unit variation is approximately plus or minus 10 percent. A 3.5 millisecond pulse is unsuitable because of the wide pulse-to-pulse variation and at a pulse width of approximately 3.0 milliseconds no impulse is obtained.

Seventy-five thousand (75,000) short pulses of 4 milliseconds and shorter cause no performance degradation. Three units showed no effect. One unit exhibited partial flow reduction after 13,000 pulses but this is attributed to the previous testing history.

1.3 CONCLUSIONS

There is no significant risk associated with short pulse operation. This is supported by: 1) a successful demonstration test program was completed, 2) 410,000 pulses were accumulated on one T/VA during the Voyager qualification test, and 3) 75,000 short pulses represents less than 1 percent of the qualified hydrazine throughout capability.

The Voyager T/VA's should be considered flight qualified for short pulse operation at pulse widths of 4 milliseconds or greater.

2.0 TEST PLAN

2.1 TEST UNIT SELECTION

Five thruster valve assemblies (TVA's), four prime, and one backup were selected from the Voyager (MJS) program residual hardware. These units are identical in configuration to the units on the Voyager spacecraft. The previous firing histories of the test TVA's bracketed the firing histories of the flight units. The test TVA's and their firing histories are listed below:

S/N	Pulses	On-time (sec)	Remarks
016	9,555	1,211	Prime
019	2,965	426	Prime
020	2,530	86,300	Prime
022	120,189	58,082	Prime
021	37,057	1,269	Backup

All of the TVA's successfully completed the initial functional testing.

The four prime TVA's (S/N 016, 019, 020, and 022) were subjected to the initial characterization test. The characterization test duty cycle is equivalent to the original acceptance test duty cycle. The four TVA's successfully completed this test, meeting all of the original acceptance test criteria. If one of the four units had not met the original acceptance test requirements it would have been replaced with the backup unit, S/N 021.

2.2 PROPELLANT USED FOR TESTING

The propellant used throughout this test program was of high purity grade hydrazine from drum number H-8300 furnished by the Jet Propulsion Laboratory. This hydrazine is of the same quality as used on the Voyager spacecraft and also meets the specification requirements for Viking, MMC, and high purity grade MIL-P-26536, Amendments 1 and 2.

The hydrazine in drum number H-8300 was analyzed at JPL prior to shipment to RRC and found to meet the Voyager requirements. The hydrazine in the drum was analyzed at RRC and found to meet the requirements of high purity grade and Voyager hydrazine. The propellant system of test cell number 4, the test cell in which the short pulse testing was performed, was filled from hydrazine drum number H-8300. The hydrazine in the propellant system was analyzed and found to meet all of the requirements. An analysis of the hydrazine in the system was performed several times during and at the completion of the test program; and in all cases, the requirements were met. The detailed hydrazine analyses are contained in Appendix A.

2.3 TEST FLOW PLAN

The test flow plans of Figures 2-1, 2-2, 2-3 and 2-4 delineates the testing and test sequencing of the entire test program.

The overall test flow plan is described in Figure 2-1. This plan shows the sequencing of the characterization and short pulse tests performed over the 75,000 short pulse life testing. The test flow plans of Figures 2-2, 2-3, and 2-4 describe the testing in more detail and show the test sequencing for the first, second, and third 25,000 life test pulses respectively.

Specific details of the tests presented in these flow plans are described in the following sections.

2.4 FUNCTIONAL TESTS

The thruster valve assemblies (TVA's) were subjected to the following functional tests:

- Thrust control valve opening response
- TVA gas (GN_2) flow
- Internal and external leakage
- Thruster heater resistance
- Proof pressure (before and after first 25,000 pulses only)

The purpose of these tests was to 1) determine the TVA acceptability for the test program, 2) establish a functional baseline, and 3) verify functional performance after 25,000 and 75,000 pulses.

2.5 CHARACTERIZATION TESTS

The characterization test duty cycle is described in Table 2-1 and is representative of the original acceptance test.

VOYAGER 0.2-lbf T/VA SHORT PULSE TEST FLOW PLAN
75,000 PULSE LIFE TEST

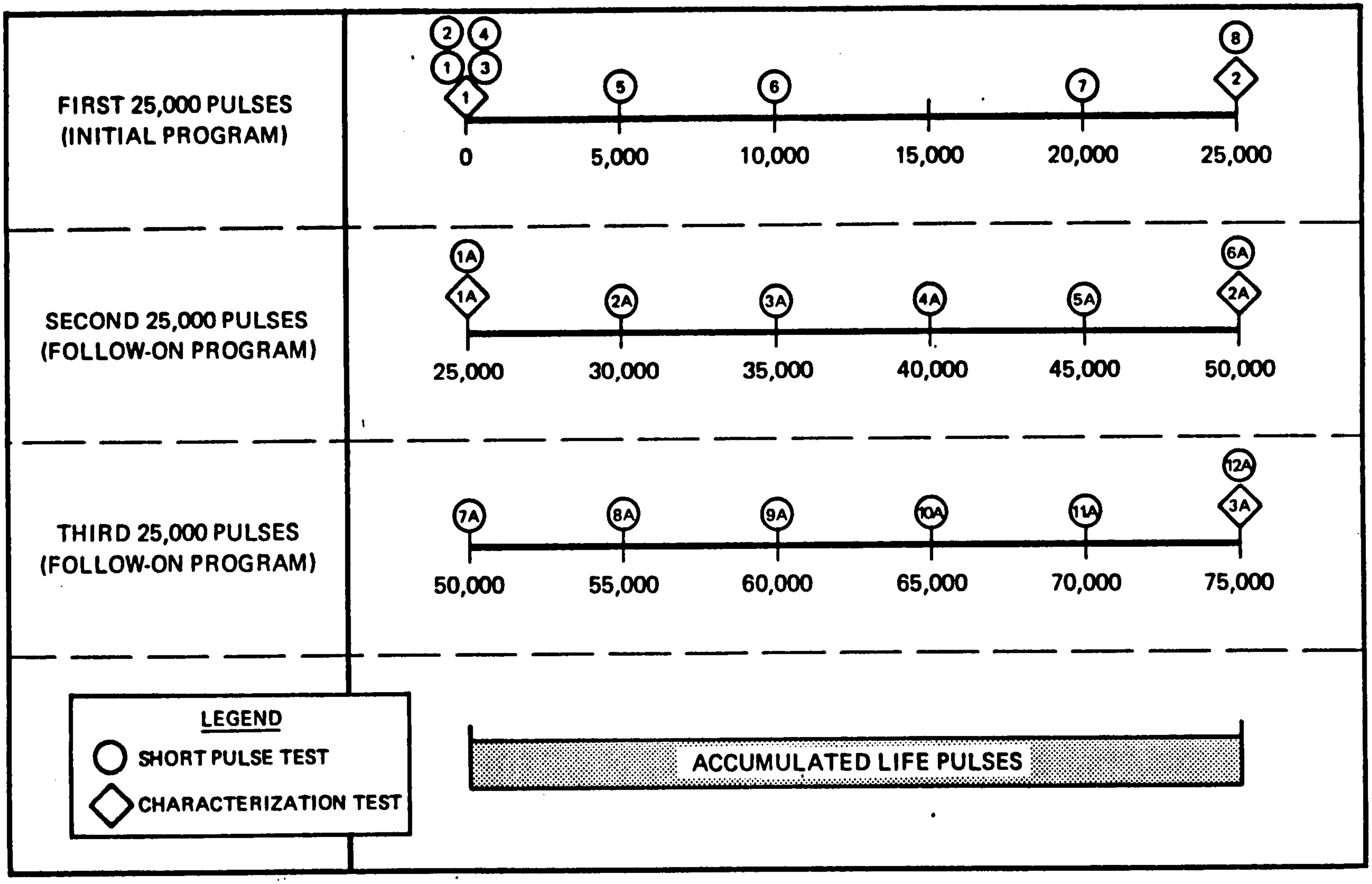

Figure 2-1

VOYAGER 0.2-lbf T/VA SHORT PULSE TEST FLOW PLAN
FIRST 25,000 PULSES

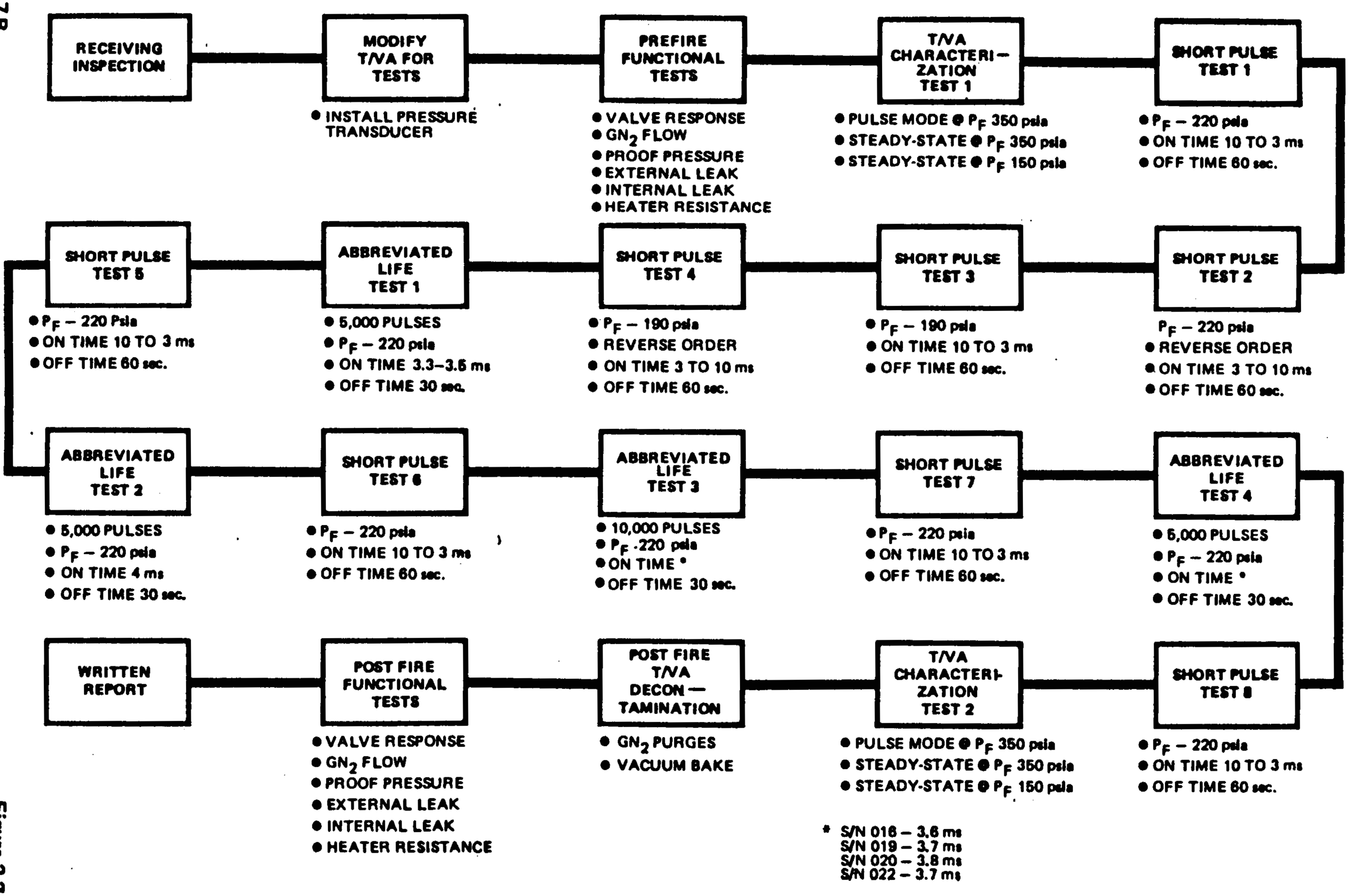

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Figure 2-2

VOYAGER 0.2 lbf T/VA SHORT PULSE TEST FLOW PLAN
SECOND 25,000 PULSES

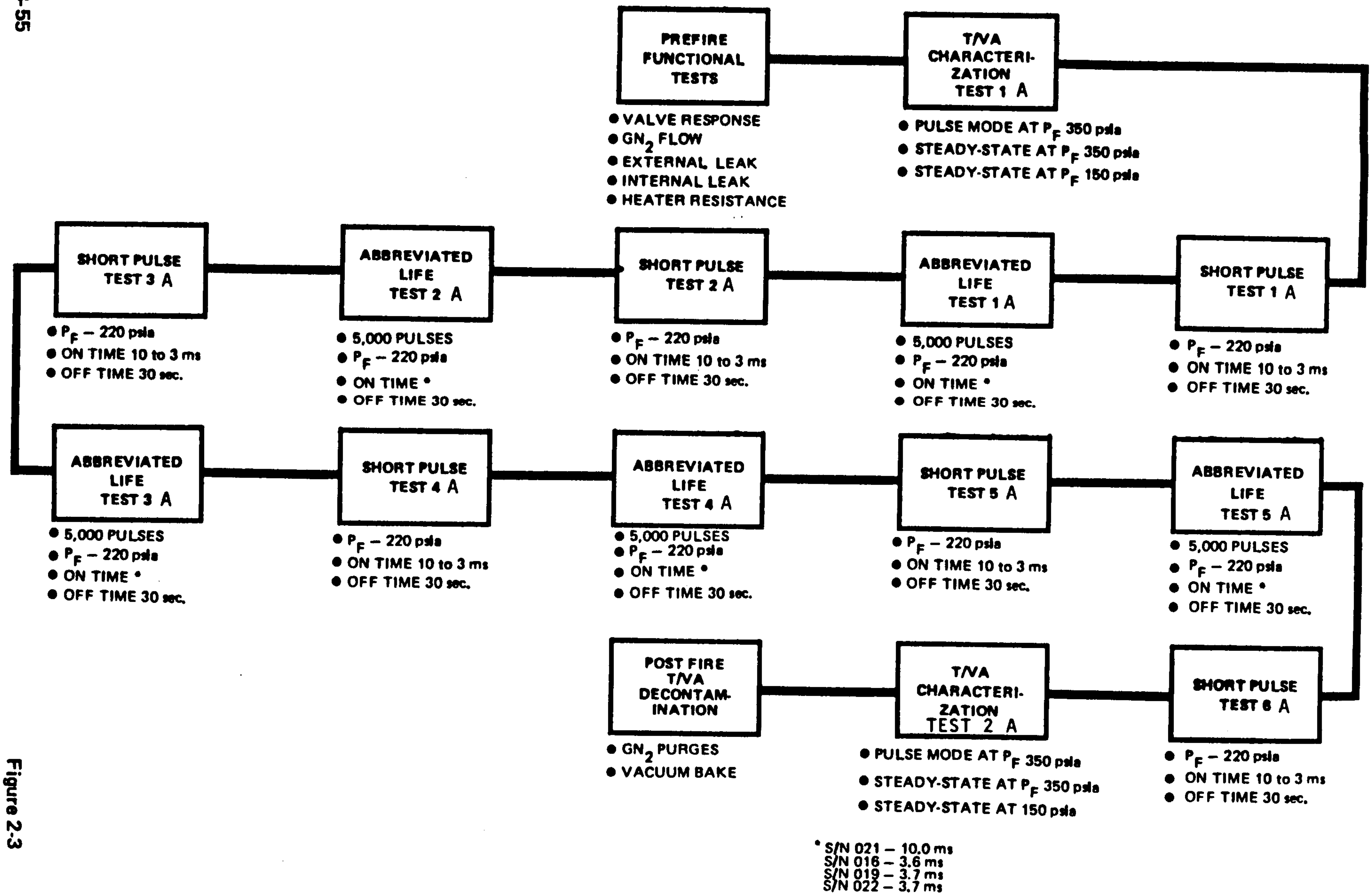

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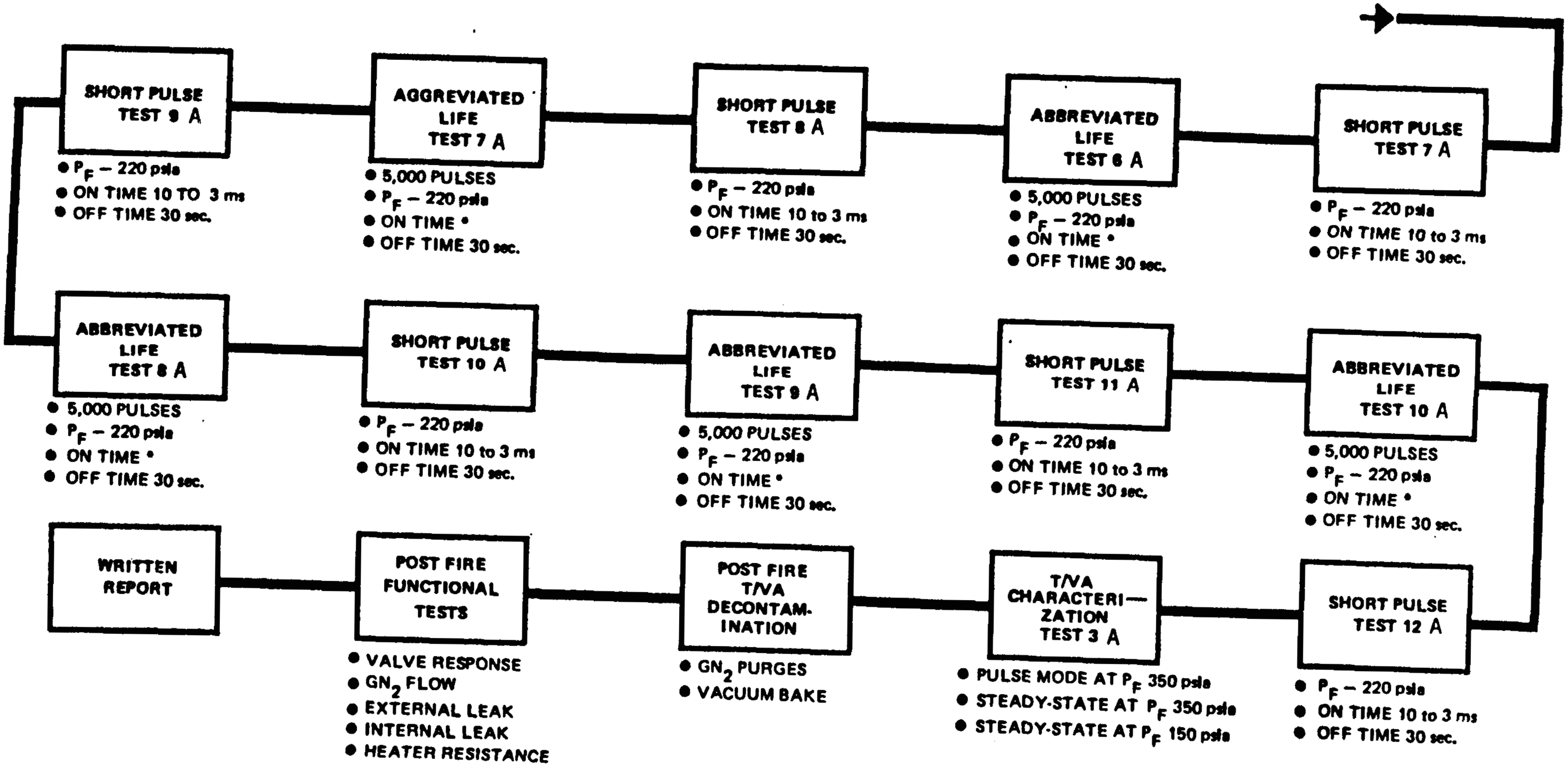
Figure 2-3

VOYAGER 0.2 lbf T/VA SHORT PULSE TEST FLOW PLAN
THIRD 25,000 PULSES



* S/N 021 – 10.0 ms
S/N 016 – 3.6 ms
S/N 019 – 3.7 ms
S/N 022 – 3.7 ms

Figure 2-4

Table 2-1

T/VA CHARACTERIZATION TEST DUTY CYCLE

Test Sequence	Propellant Feed Pressure (psia)	No. of Pulses	On Time (sec)	Off Time (sec)	Initial Temp. (°F)
1	350 ± 5	100	0.020	3.98	325 ± 25
2	350 ± 5	20	0.10	0.90	Existing
3	350 ± 5	1	200	—	Existing
4	150 ± 5	1	200	—	Existing

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The purpose of the characterization tests was to 1) determine the acceptability of the thruster valve assemblies (TVA's) for the test program, 2) establish TVA baseline performance, and 3) verify acceptable TVA performance after each 25,000 pulses.

2.6 SHORT PULSE WIDTH TESTS

The short pulse width test duty cycle is presented in Table 2-2.

Table 2-2

SHORT PULSE WIDTH TEST DUTY CYCLES

Test No.	Propellant Feed Pressure (psia)	No. of Pulses	On Times (ms)	Off Time (sec)	Initial Temp. (°F)
1	220 ± 5	10 ea	10, 9, 8, 7.5, 7, 6.5, 6, 5.5, 5, 4.5, 4, 3.5, 3	60	325 ± 25
2	220 ± 5	10 ea	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 9, 10	60	325 ± 25
3	190 ± 5	10 ea	10, 9, 8, 7.5, 7, 6.5, 6, 5.5, 5, 4.5, 4, 3.5, 3	60	325 ± 25
4	190 ± 5	10 ea	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 9, 10	60	325 ± 25
5—8	220 ± 5	10 ea	10, 8, 6, 5, 4.5, 4, 3.5, 3, 3, 3.5, 4, 4.5, 5, 6, 8	60	325 ± 25
1A—12A	220 ± 5	5 ea	10, 8, 6, 5, 4, 3.5, 3	30	Both heaters on

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The purpose of the short pulse width tests was to 1) establish a curve of impulse bit as a function of electrical pulse width, 2) determine impulse bit variations as a function of electrical pulse width, and 3) monitor TVA performance after each 5,000 pulses.

2.7 ABBREVIATED LIFE TEST

The abbreviated life test duty cycle is described in Table 2-3, and the electrical pulse width (on-time) represents an impulse bit that is 25 to 30 percent of the impulse bit of a 10-millisecond pulse. The "on-times" were determined from the curves generated by the short pulse width tests.

The purpose of this test was to determine the effect of 75,000 short pulses on thruster life.

Table 2-3

ABBREVIATED LIFE TEST DUTY CYCLES

Test No.	Propellant Feed Pressure (psia)	No. of Pulses	On Time (ms)	Off Time (sec)	Thruster Temp. (°F)
1	220 ± 5	5,000	*	30	325 ± 25
2	220 ± 5	5,000	*	30	325 ± 25
3	220 ± 5	10,000	*	30	325 ± 25
4	220 ± 5	5,000	*	30	325 ± 25
1A — 10A	220 ± 5	5,000	*	30	Both heaters on

*On Time (milliseconds)

Test No.	T/VA S/N 16	T/VA S/N 19	T/VA S/N 22	T/VA S/N 20	T/VA S/N 21
1	3.3	3.5	3.4	3.5	—
2	4.0	4.0	4.0	4.0	—
3	3.6	3.7	3.7	3.8	—
4	3.6	3.7	3.7	3.8	—
1A—10A	3.6	3.7	3.7	—	10.0

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3.0 TEST SETUP

3.1 TEST FIRING FIXTURE

The four thruster valve assemblies (T/VA's), S/N's 016, 019, 020, and 022, were installed on the test firing fixture as shown in Figures 3-1, 3-2 and 3-3.

Thermocouples were welded to the convergent section of the thrust chamber nozzle in order to provide thrust chamber temperature measurements. In order to provide thrust chamber pressure measurements the T/VA chamber pressure (P_c) tubes were connected to JPL-furnished Taber pressure transducers using specially prepared adapters to reduce the holdup volume. Transducers with a range of 0 to 300 psia were used for the characterization tests and transducers with a 0 to 50 psia range were used for the short pulse width and abbreviated life tests.

3.2 TEST CELL

The test cell setup is shown schematically in Figure 3-4.

The schematic shows the propellant system, pressurization system, propellant thermal conditioning system, water decontamination system and the altitude chamber. The altitude chamber will maintain an altitude of 200,000 feet minimum and much higher in most cases.

3.3 INSTRUMENTATION

The test parameters to be measured, calibration ranges, and method of recording data are listed in the test instrumentation Table 3-1.

The Automatic Test Control System (ATCS) is used to control the testing utilizing a preprogrammed disc. The ATCS is presented in Figures 3-5 and 3-6.

The Digital Data Acquisition System (DDS) is used to collect the high speed digital data and store it on magnetic tape. The DDS is presented in Figures 3-7 and 3-8.

Test instrumentation calibrations were performed to secondary standards traceable to the National Bureau of Standards. An accurate time base for the electrical pulse signal was

0.2 lbf T/VA SHORT PULSE TEST FIRING SETUP

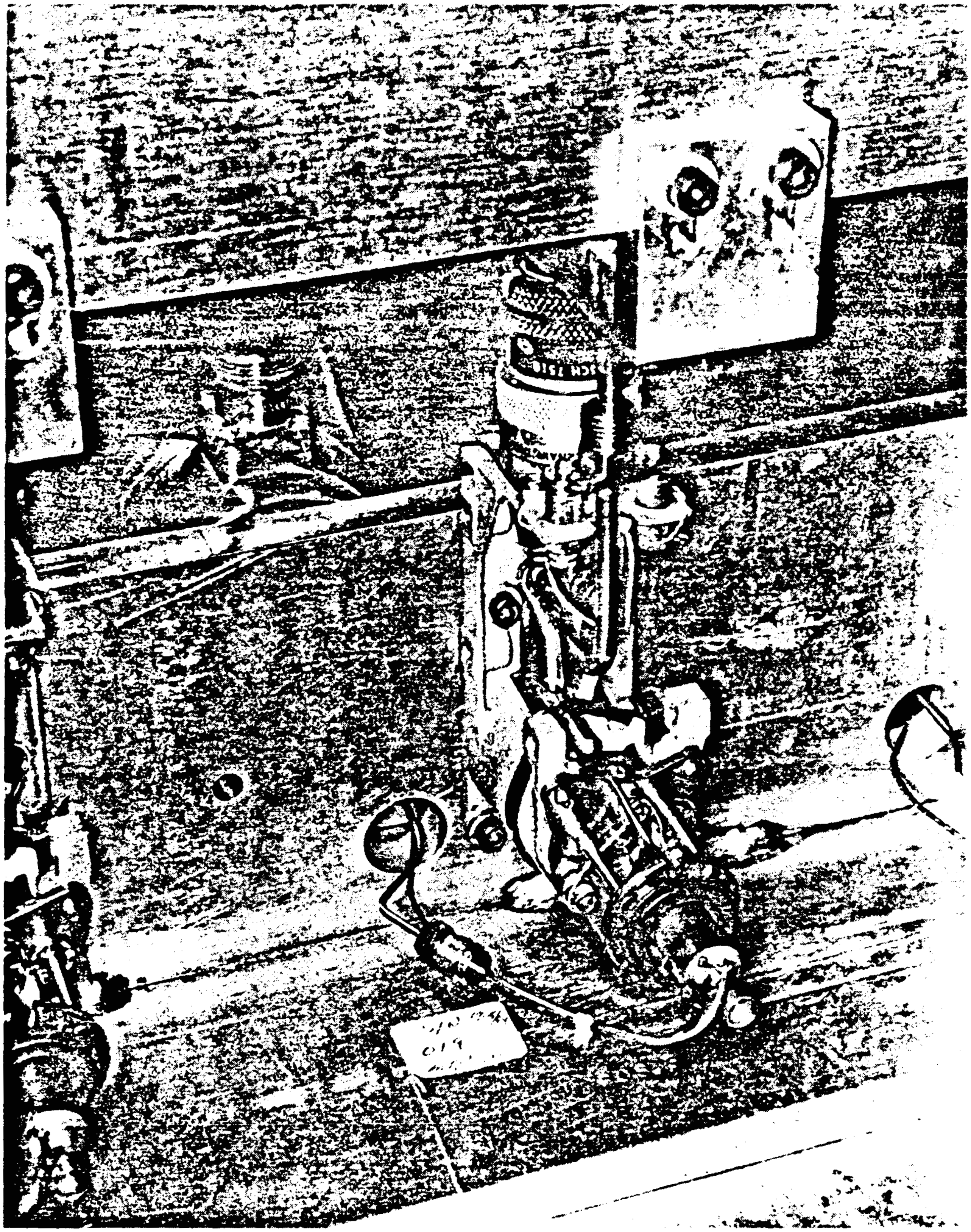

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Figure 3-1

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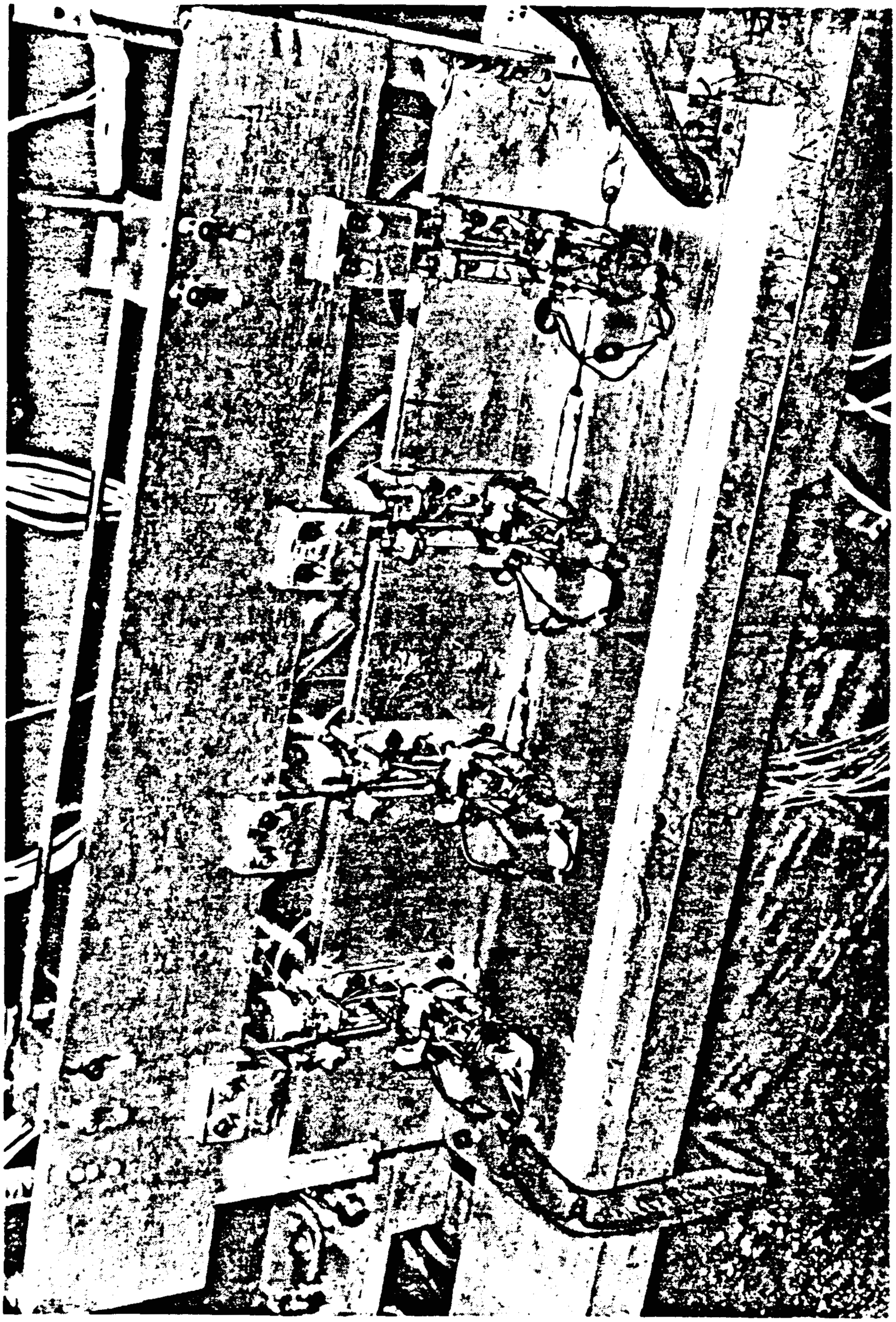

0.2 lbf T/VA SHORT PULSE TEST FIRING SETUP

Figure 3-2

0.2 lbf T/VA SHORT PULSE TEST SETUP

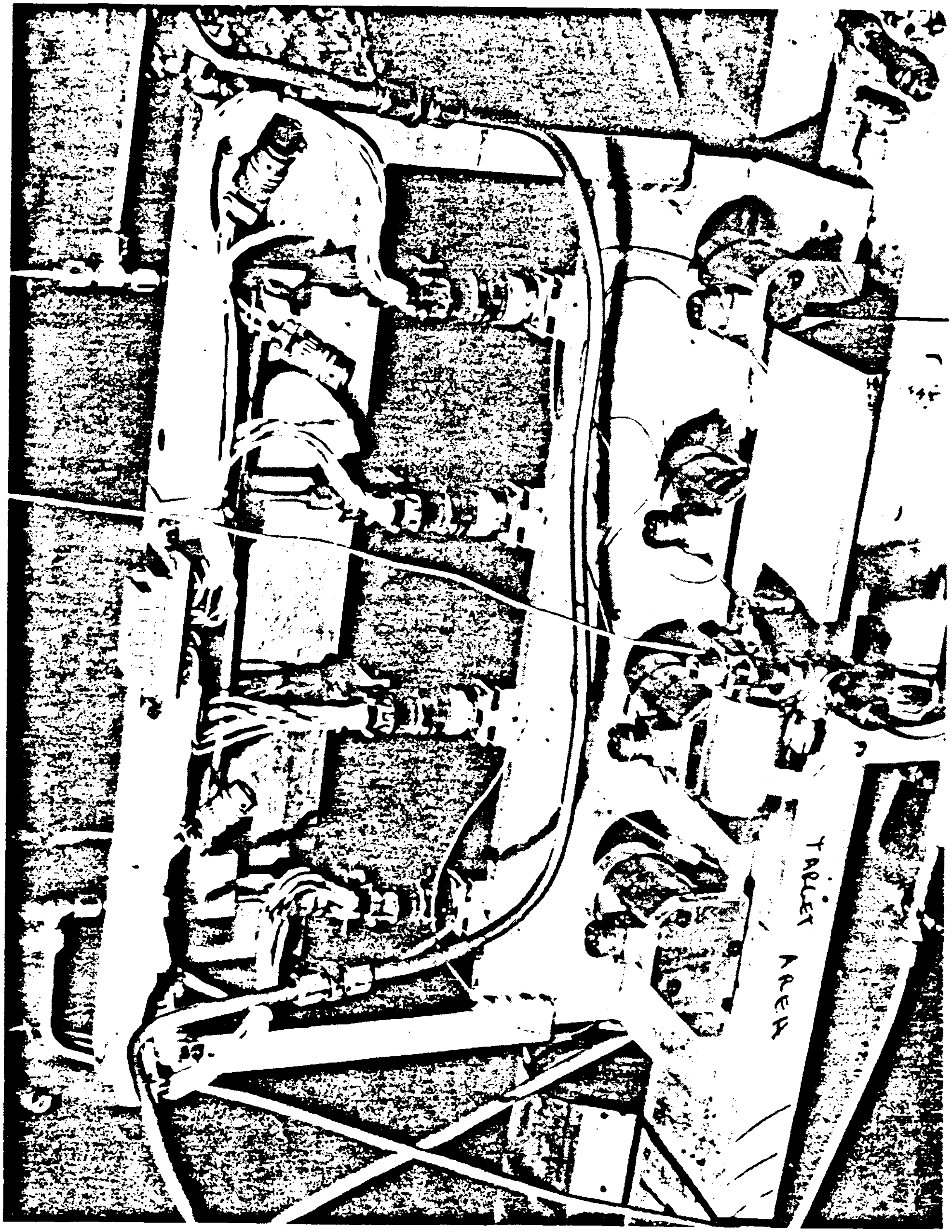

Figure 3-3

T/VA FIRING TEST SETUP

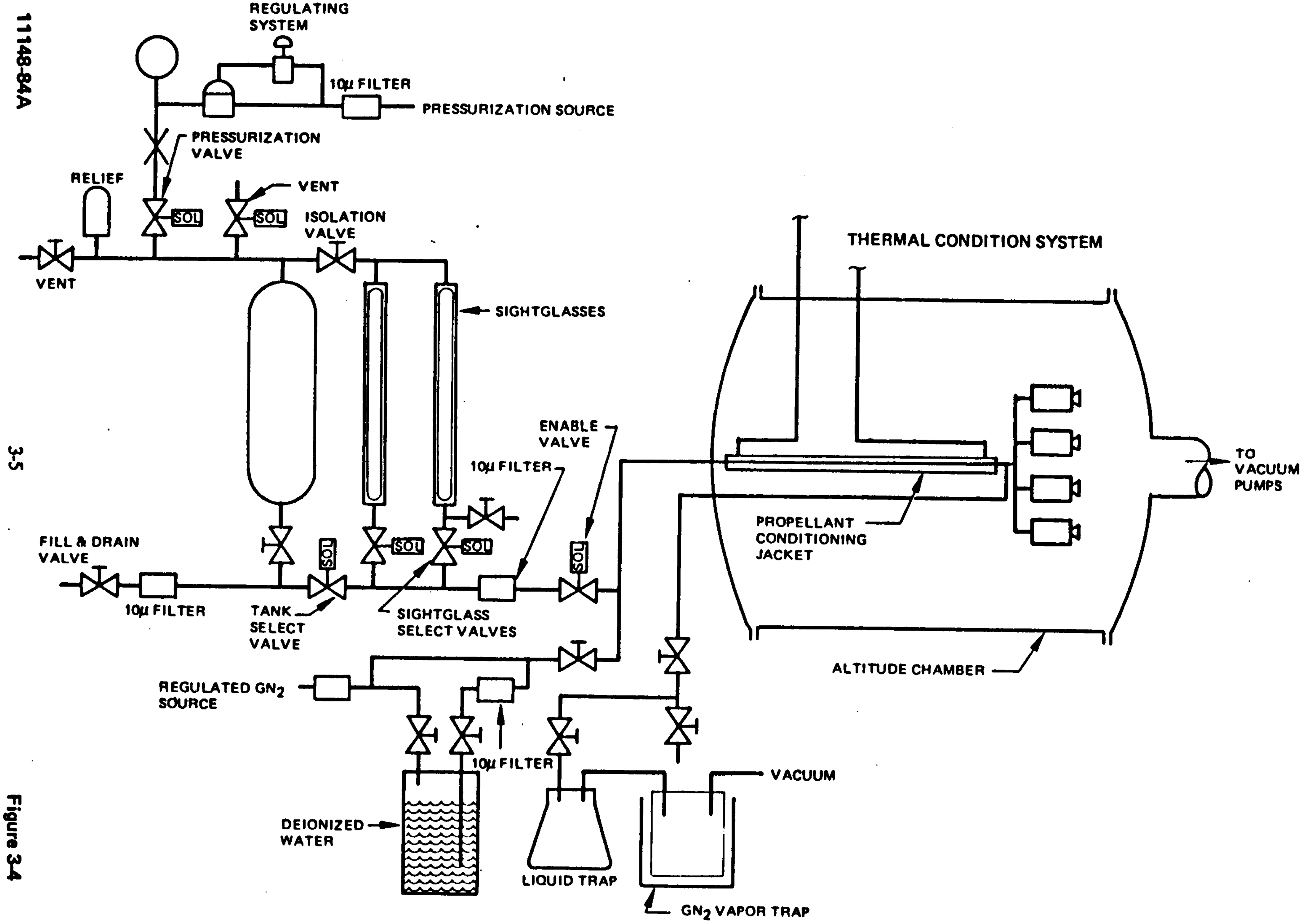

Figure 3-4

Table 3-1
TEST INSTRUMENTATION

Parameter	Symbol	Range	Recording Technique		
			SCR	Quick Look	DDS
Chamber pressure — Thruster	P_c	0 — 300 psia and 0 — 50 psia	—	X	X
Propellant feed pressure	P_f	0 — 400 psig	—	X	X
Propellant temperature	T_f	0 — 5 mv	—	—	X
Altitude chamber pressure	P_a	0 — 1 psia	—	—	X
Sightglass level	H_{SG}	N/A	—	—	Manual
Valve voltage	V_E	0 — 30 vdc	—	X	X
Valve current	I	0 — 0.25 amps	—	X	X
Thruster heater voltage	V_H	0 — 30 vdc	—	—	—
Thrust chamber temperature	T_C	0 — 50 mv	X	—	X

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AUTOMATIC TEST CONTROL SYSTEM

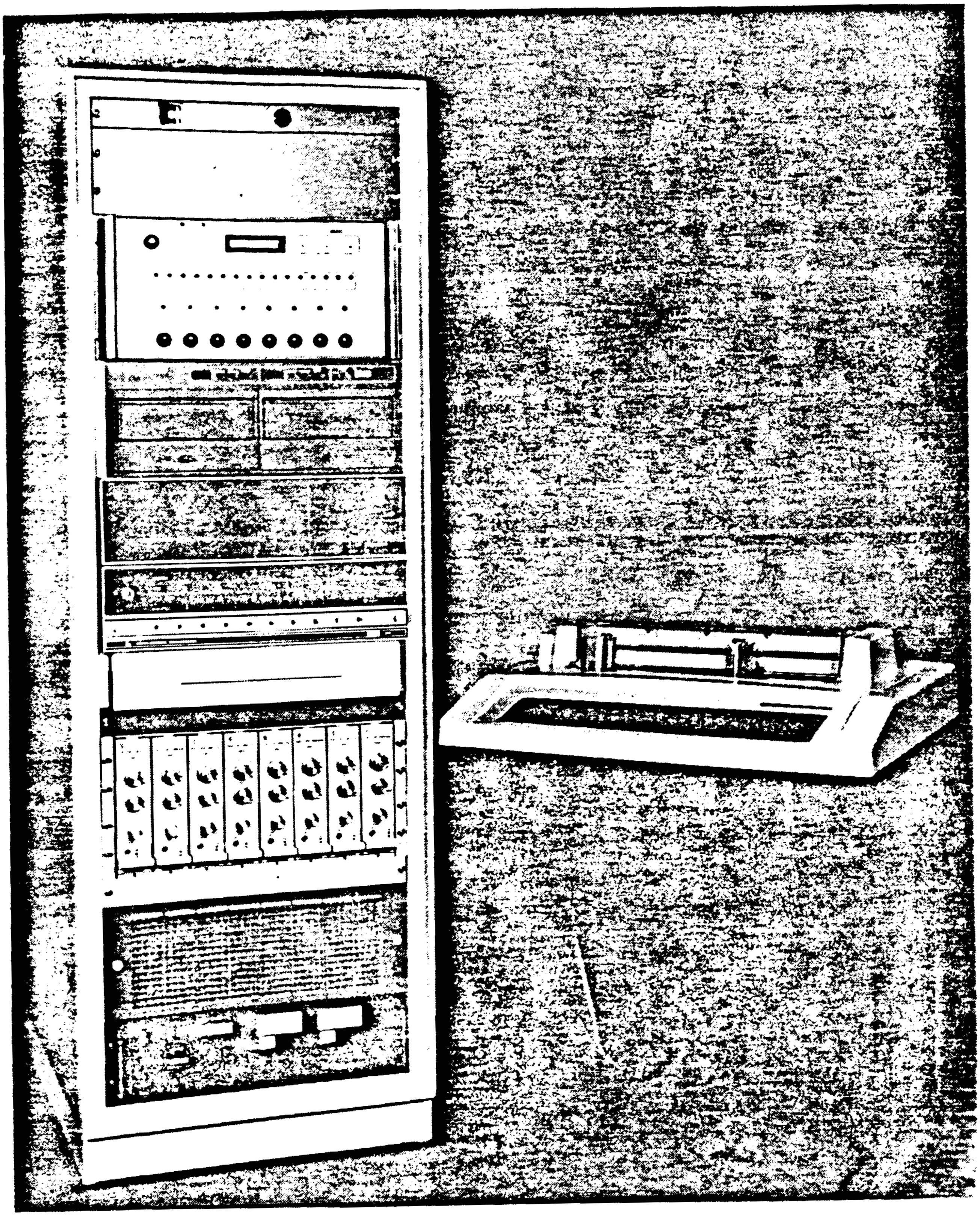

Figure 3-5

ATCS BLOCK DIAGRAM

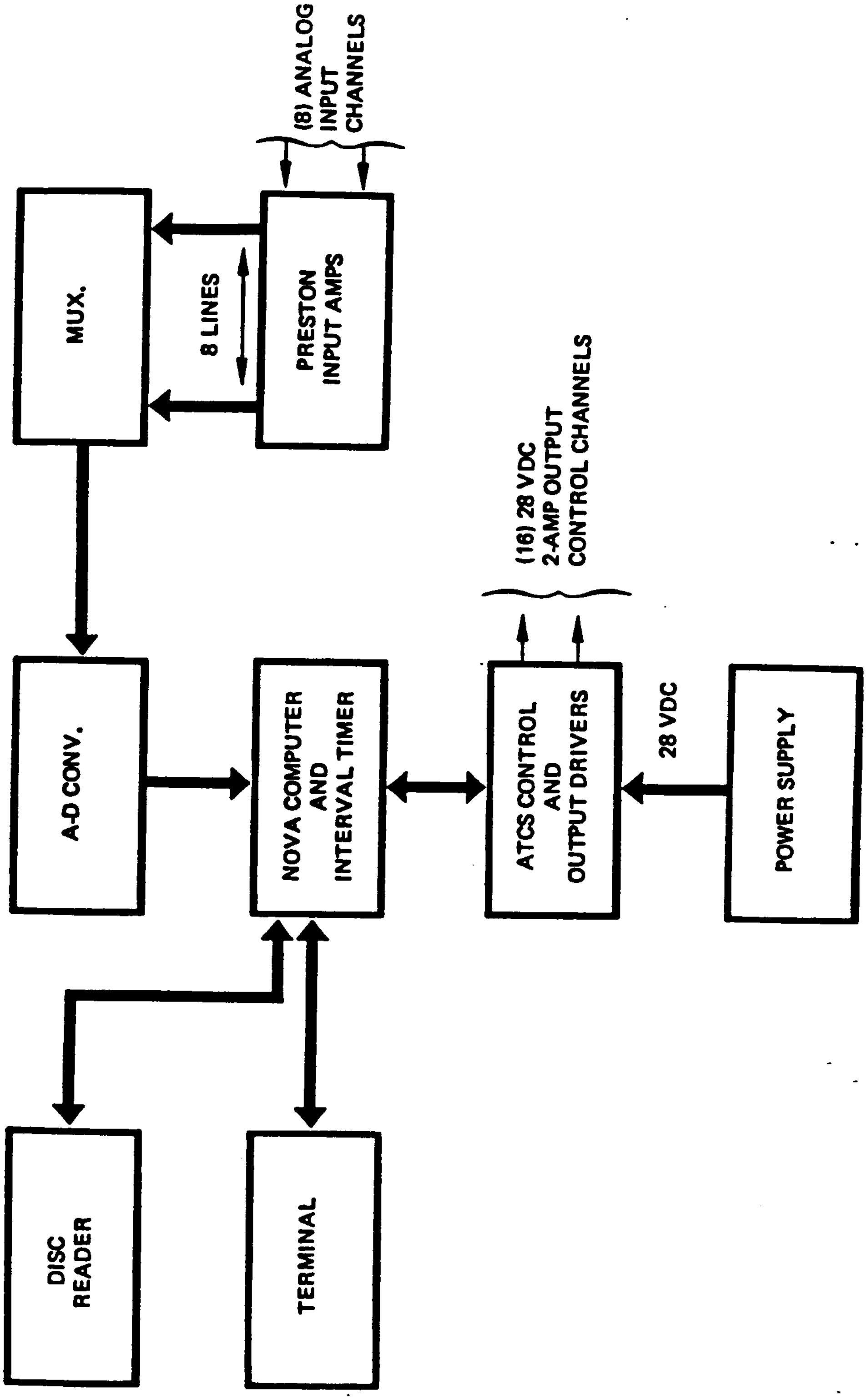

Figure 3-6

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DIGITAL DATA ACQUISITION SYSTEM

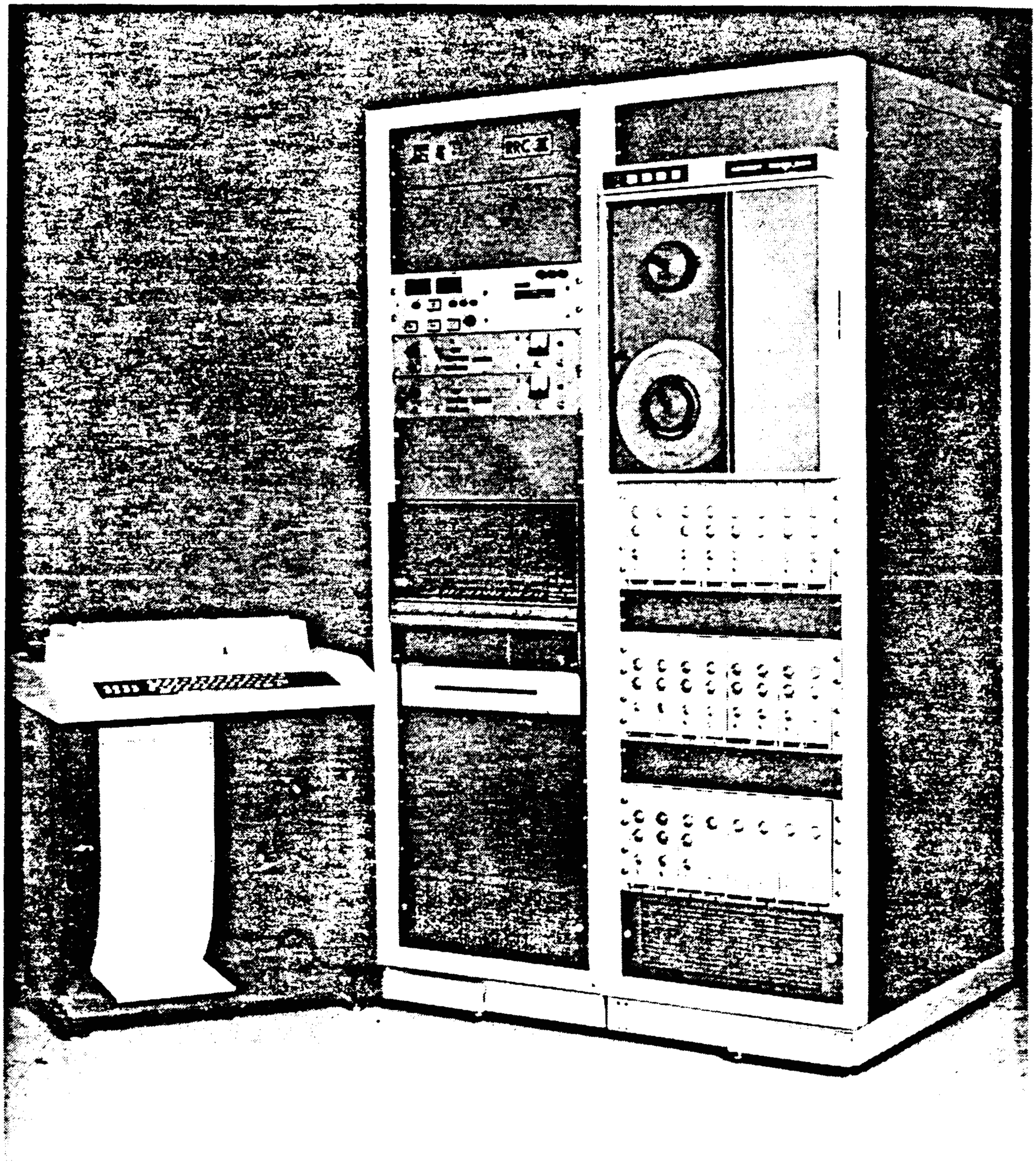


Figure 3-7

HIGH-SPEED DIGITAL DATA SYSTEM
BLOCK DIAGRAM

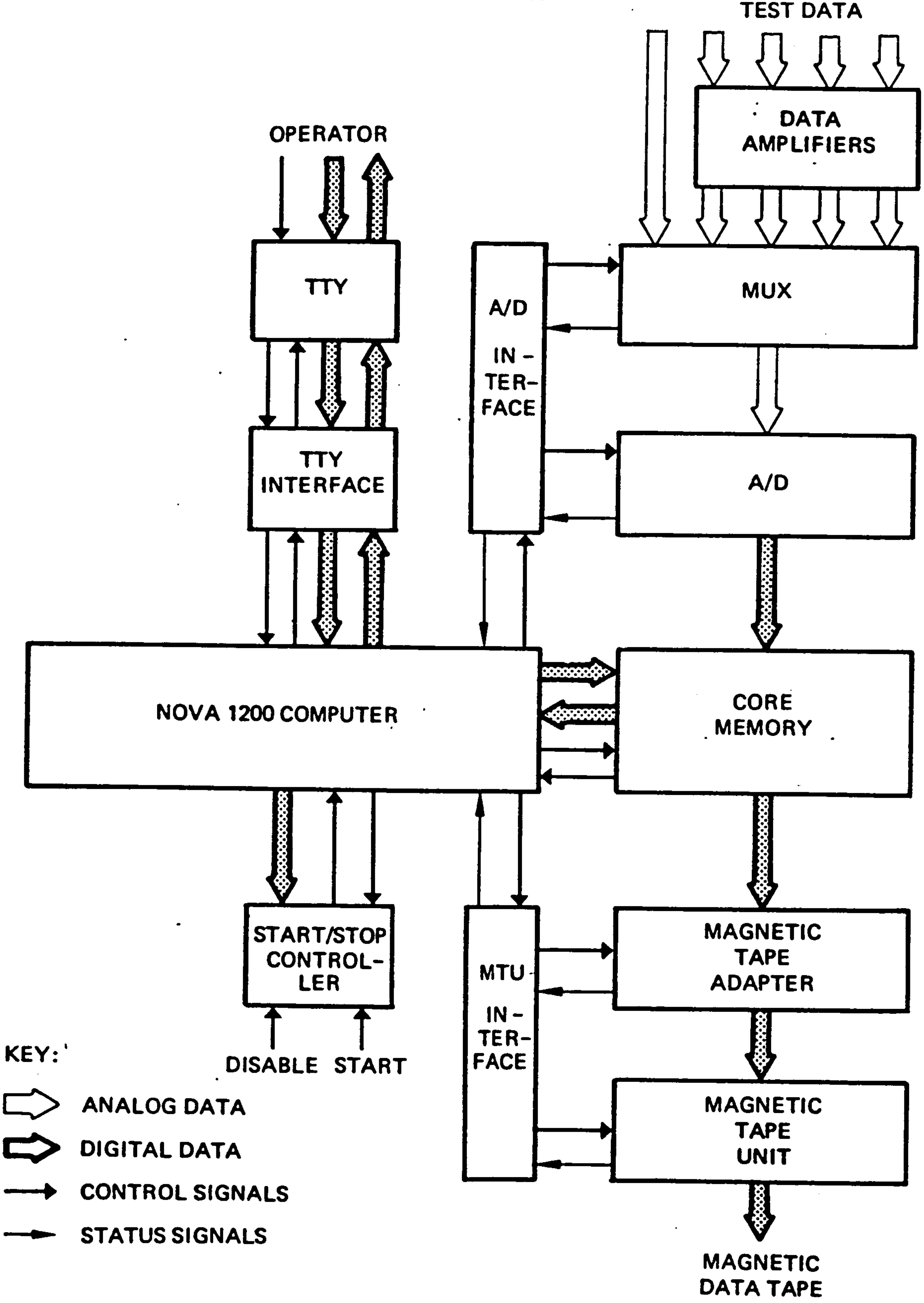


Figure 3-8

difficult to obtain because the Automatic Test Control System (ATCS) was designed to operate at one millisecond intervals and this testing required control of the electrical pulse in one-tenth of a millisecond intervals. In order to accomplish this the ATCS was modified to speed up the time base electronically by a factor of ten; i.e., for each one second of real time the ATCS time base registers 10 seconds. Therefore, a 35 millisecond input to the ATCS would result in a 3.5 millisecond output command to the valve drivers. The ATCS output pulse width commands were calibrated. The pulse widths had a tendency to drift and had to periodically be recalibrated.

3.4 DATA REDUCTION

The raw test data contained on the DDS magnetic tape is processed on a computer that has been programmed to reduce the raw data into engineering data such as impulse bit (I_{bit}) and specific impulse (I_{sp}). This data is then displayed on computer printout sheets.

The following is a summary of the equations used in the computer program MJSDAT.

- $a = (0.641667E-05) + (0.229905E-08)T - (0.104312E-11)T^2 + (0.37630E-15)T^3$

  where:

  a = the coefficient of thermal expansion for Haynes 25, in/in/°F * 10^6
  T = measured nozzle temperature, °F.

- $A_{tc} = A_{tm} * C_d * (1 + 2a * (T-70))$

  where:

  A_{tc} = corrected throat area, sq. in.
  A_{tm} = measured throat area, sq. in.
  a = the coefficient of thermal expansion for Haynes 25, in/in/°F * 10^6
  T = measured nozzle temperature, °F
  C_d = discharge coefficient = 0.9986

- $C_{fss} = 1.55023 * P_c^{0.0222886}$

  where:

  C_{fss} = steady-state thrust coefficient.
  Pc = measured chamber pressure, psia

- $C_{fpm} = 3.178/(T^{0.06896} \bullet \int P_c dt^{1/(23.07 + 0.0093681 * T)})$

  where:

  C_{fpm} = pulse mode thrust coefficient
  T = chamber temperature, ^{o}F
  $\int P_c dt$ = time integral of chamber pressure, psia-sec

- $F_v = P_c * A_{tc} * C_{fss}$

  where:

  F_v = steady-state vacuum thrust, lbf
  P_c = chamber pressure, psia
  A_{tc} = corrected throat area, sq. in.
  C_{fss} = steady-state thrust coefficient

- $I_{bit} = \int P_c dt * A_{tc} * C_{fpm}$

  where:

  I_{bit} = pulse mode impulse bit, lbf-sec
  $\int P_c dt$ = time integral of chamber pressure, psia-sec
  A_{tc} = corrected throat area, sq. in.
  C_{fpm} = pulse mode thrust coefficient

- $RHO = 8.70038 - (0.411411E-02)T$

  where:

  RHO = density of 99% Hydrazine, lbm/gal
  T = propellant temperaure, ^{o}F

- $\dot{w} = RHO * K \bullet D/(T \bullet 3785.4)$

  where:

  $\dot{w}$ = steady-state propellant flow rate, lbm/sec
  RHO = density of 99% Hydrazine, lbm/gal
  K = sightglass calibration constant, cc/cm
  D = observed propellant drop in sightglass, cm
  T = time that sightglass valve was open, sec.

- $W_p = RHO \bullet K * D/(3785.4 \bullet N)$

  where:

  W_p = per pulse propellant consumption, lbm
  RHO = density of 99% Hydrazine, lbm/gal.
  K = sightglass calibration constant, cc/cm
  D = observed propellant drop in sightglass, cm
  N = number of pulses over which drop in sightglass level is observed

- $I_{sp_{ss}} = F_v/\dot{w}$

  where:

  $I_{sp_{ss}}$ = steady-state specific impulse, lbf-sec/lbm
  F_v = steady-state vacuum thrust, lbf
  $\dot{w}$ = steady-state propellant flow rate, lbm/sec

- $I_{sp_{pm}} = I_{bit}/W_p$

  where:

  $I_{sp_{pm}}$ = pulse ode specific impulse, lbf-sec/lbm
  I_{bit} = pulse mode bit, lbf-sec
  W_p = pulse propellant consumption, lbm

- $C^*_{ss} = P_c * A_{tc} \bullet g/\dot{w}$

  where:

  C^*_{ss} = steady-state characteristic velocity, ft/sec
  P_c = chamber pressure, psia
  A_{tc} = corrected throat area, sq. in.
  g = gravitational constant = 32.174 ft/sec/sec
  $\dot{w}$ = steady-state propellant flow rate, lbm/sec

- $C^*_{pm} = \int P_c dt * A_{tc} * g/W_p$

  where:

  C^*_{pm} = pulse mode characteristic velocity, ft/sec
  $\int P_c dt$ = time integral of chamber pressure, psia-sec

A_{tc} = corrected throat area, sq. in.
g = gravitational constant = 32.174 ft/sec/sec
W_p = pulse propellant consumption, lbm

In addition, the following relationships are true:

- TI = response time from valve-on signal to 10% of the average chamber pressure, msec.
  TR = response time from valve-on signal to 90% of the average chamber pressure, msec.
  TD = decay time from valve-off signal to 10% of the average chamber pressure, msec.

  where the average chamber pressure is the peak chamber pressure attained for pulse widths less than 60 milliseconds, and is the average chamber pressure at 500 milliseconds after valve-on signal for steady state firings.

- The time of integration for all pulses fired in the short pulse test duty cycles is the time from valve-on signal to the time of the valve-off signal plus 6 seconds.

4.0 TEST RESULTS

4.1 GENERAL

The test results presented herein do not include the results of every test due to the copious amount of data generated by this test program. The results presented are clearly sufficient to fulfill the requirements of the purpose and scope of this program. The Jet Propulsion Laboratory has been furnished copies of all of the computer data and RRC has the original data and copies on file.

The short pulse test results have been limited to short pulse tests 1, 5, 8, 1A, 6A and 12A. These tests are representative of the entire test program including the start and finish. In some cases the results of T/VA S/N's 020 and 021 have been ommitted, especially when an average of the T/VA's is used. In this case an average of three T/VA's, S/N's 016, 019 and 022, is used to plot the results. The reason T/VA S/N 020 is not included is because of partial flow blockage after 13,000 pulses (this problem was due to previous firing history and not short pulse test exposures). T/VA S/N 021 was installed in place of S/N 020 after 25,000 short pulses but was not included in the averaged data because it was not subjected to short pulses of 4 milliseconds or less during life testing. S/N 021 was operated at a standard duty cycle of 10-millisecond pulses.

The overall test-to-test curve shift of the short pulse test presentations is due to the slight drift of the ATCS pulse command signal. This signal was calibrated periodically.

4.2 DETERMINATION OF IMPULSE BIT AS A FUNCTION OF ELECTRICAL PULSE WIDTH

4.2.1 Impulse Bit as a Function of Electrical Pulse Width

Curves of impulse bit versus electrical pulse width for the individual T/VA's are presented in Figures 4-1 through 4-6; short pulse tests 1, 5, 8, 1A, 6A and 12A respectively.

Curves of the average impulse bit of the three T/VA's S/N 016, 019 and 022 versus electrical pulse width are presented in Figures 4-7 through 4-12; short pulse tests 1, 5, 8, 1A, 6A and 12A respectively.

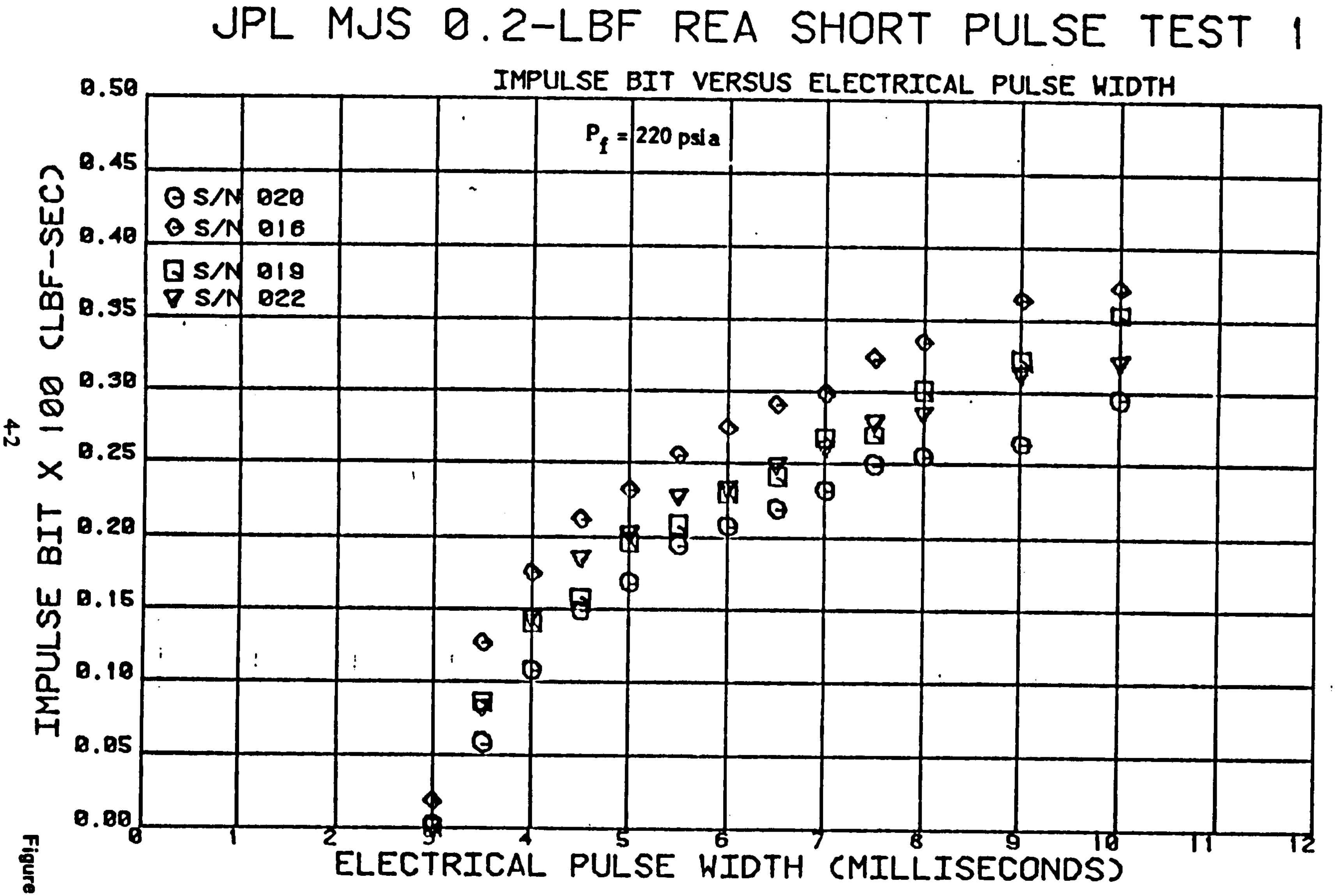

JPL MJS 0.2-LBF REA SHORT PULSE TEST 1
IMPULSE BIT VERSUS ELECTRICAL PULSE WIDTH
P_f = 220 psia
S/N 020
S/N 016
S/N 019
S/N 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
ELECTRICAL PULSE WIDTH (MILLISECONDS)

Figure 4-1

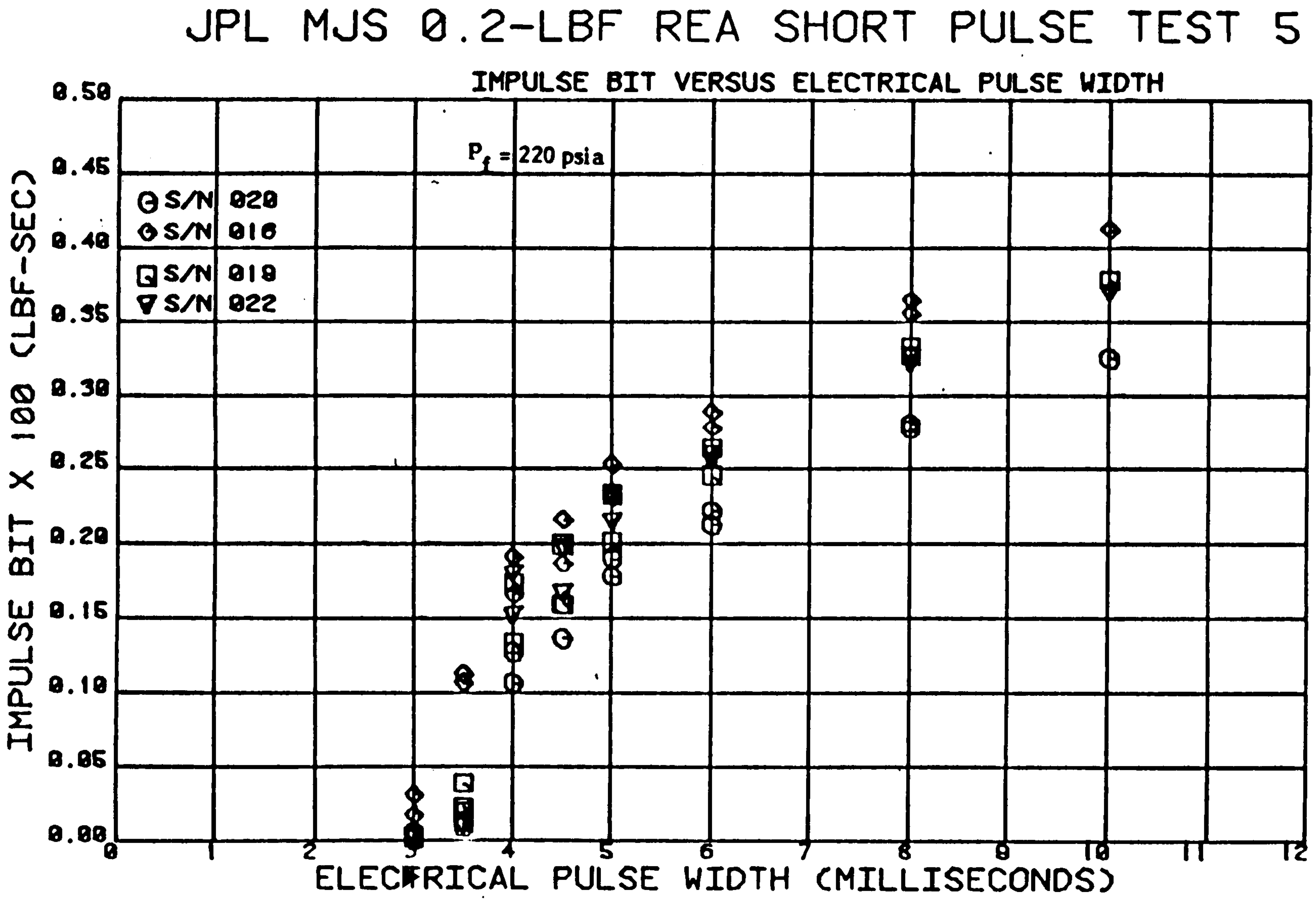

JPL MJS 0.2-LBF REA SHORT PULSE TEST 5
IMPULSE BIT VERSUS ELECTRICAL PULSE WIDTH
P_f = 220 psia
S/N 020
S/N 016
S/N 019
S/N 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
ELECTRICAL PULSE WIDTH (MILLISECONDS)

Figure 4-2

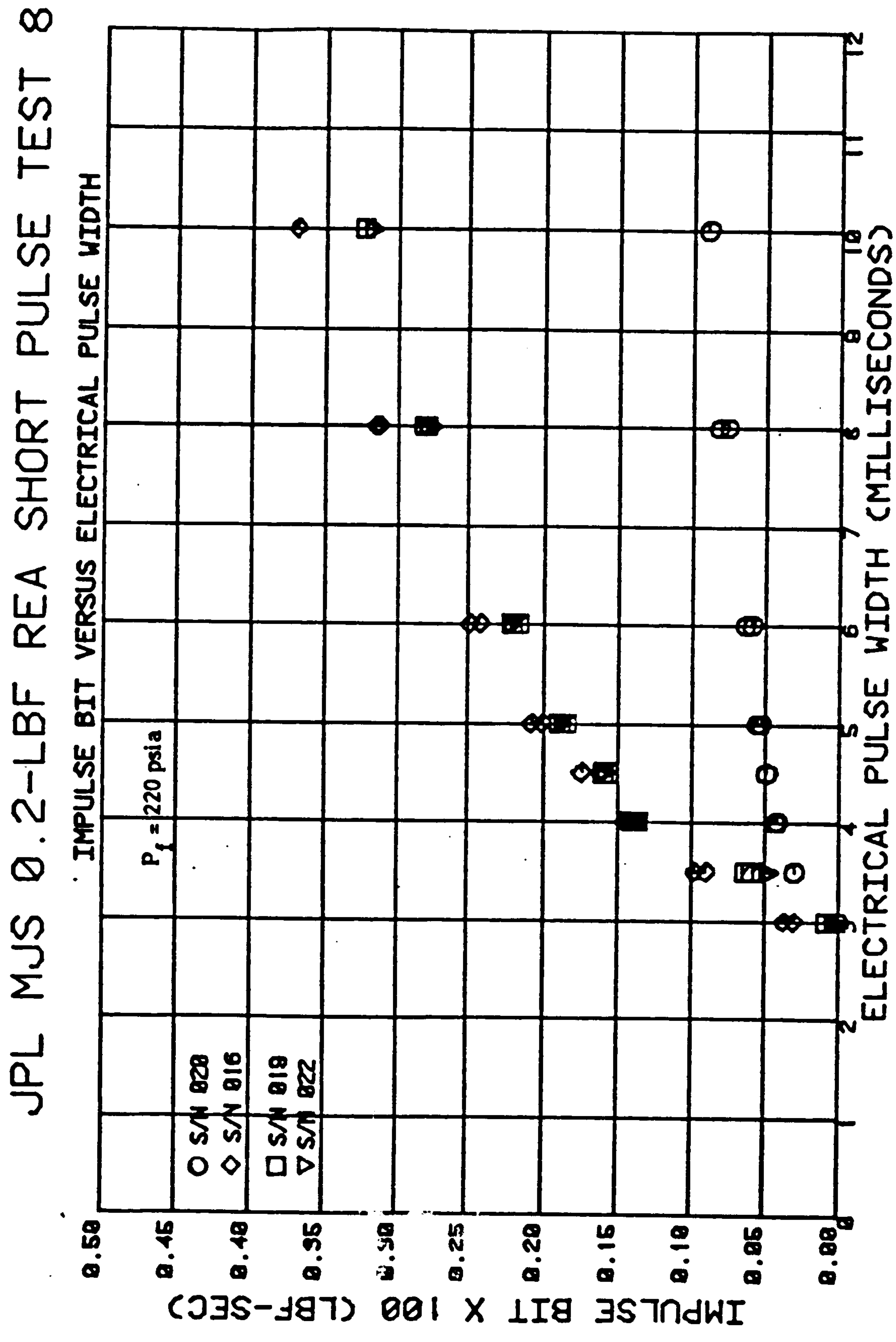

JPL MJS 0.2-LBF REA SHORT PULSE TEST 8
IMPULSE BIT VERSUS ELECTRICAL PULSE WIDTH
P_f = 220 psia
○ S/N 020
◇ S/N 016
□ S/N 019
▽ S/N 022
IMPULSE BIT X 100 (LBF-SEC)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
ELECTRICAL PULSE WIDTH (MILLISECONDS)
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 4-3

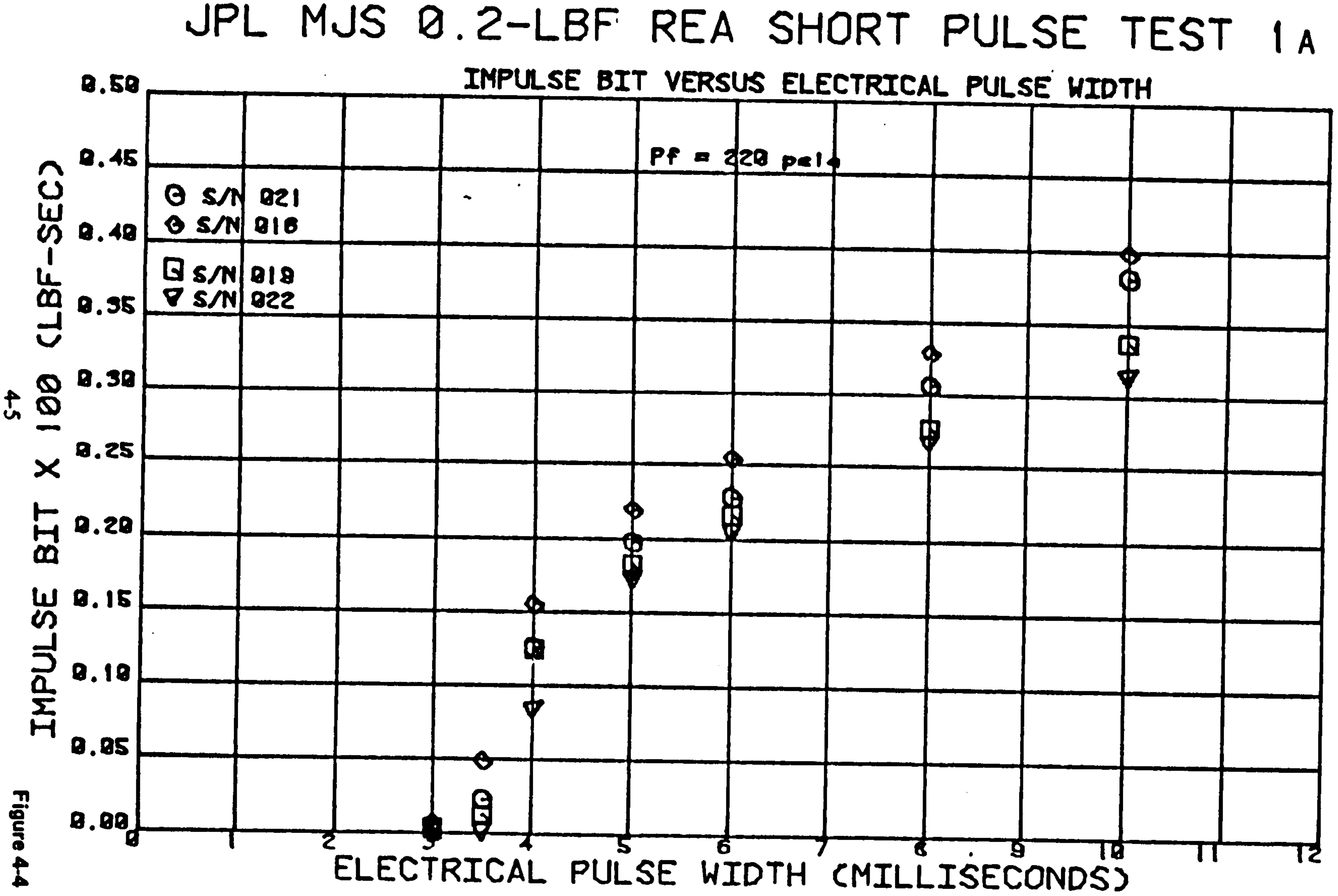

JPL MJS 0.2-LBF REA SHORT PULSE TEST 1A
IMPULSE BIT VERSUS ELECTRICAL PULSE WIDTH
Pf = 220 psia
⊖ S/N 021
◇ S/N 016
◻ S/N 019
▽ S/N 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
ELECTRICAL PULSE WIDTH (MILLISECONDS)

Figure 4-4

JPL MJS 0.2-LBF REA SHORT PULSE TEST 6A

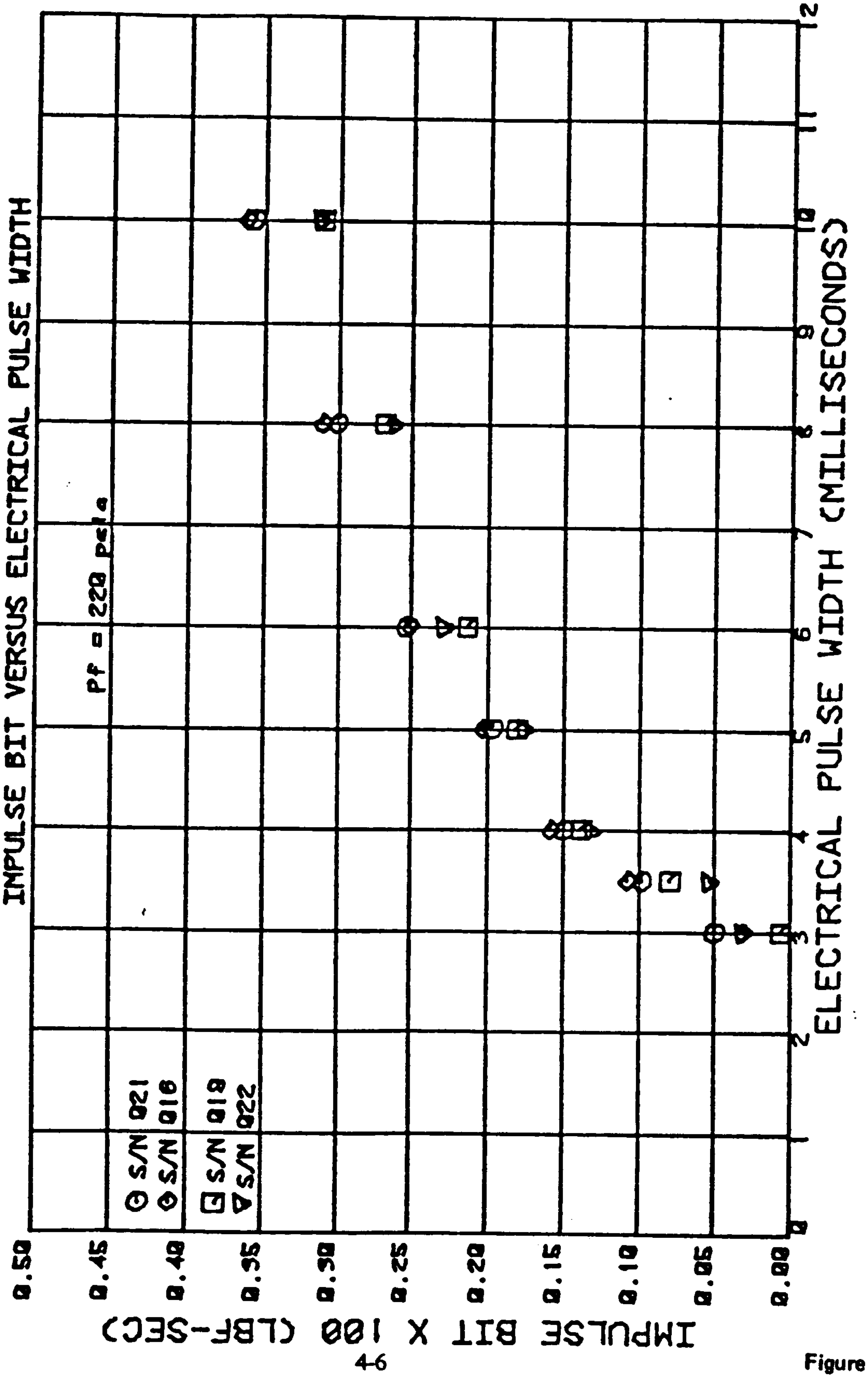


Figure 4-5

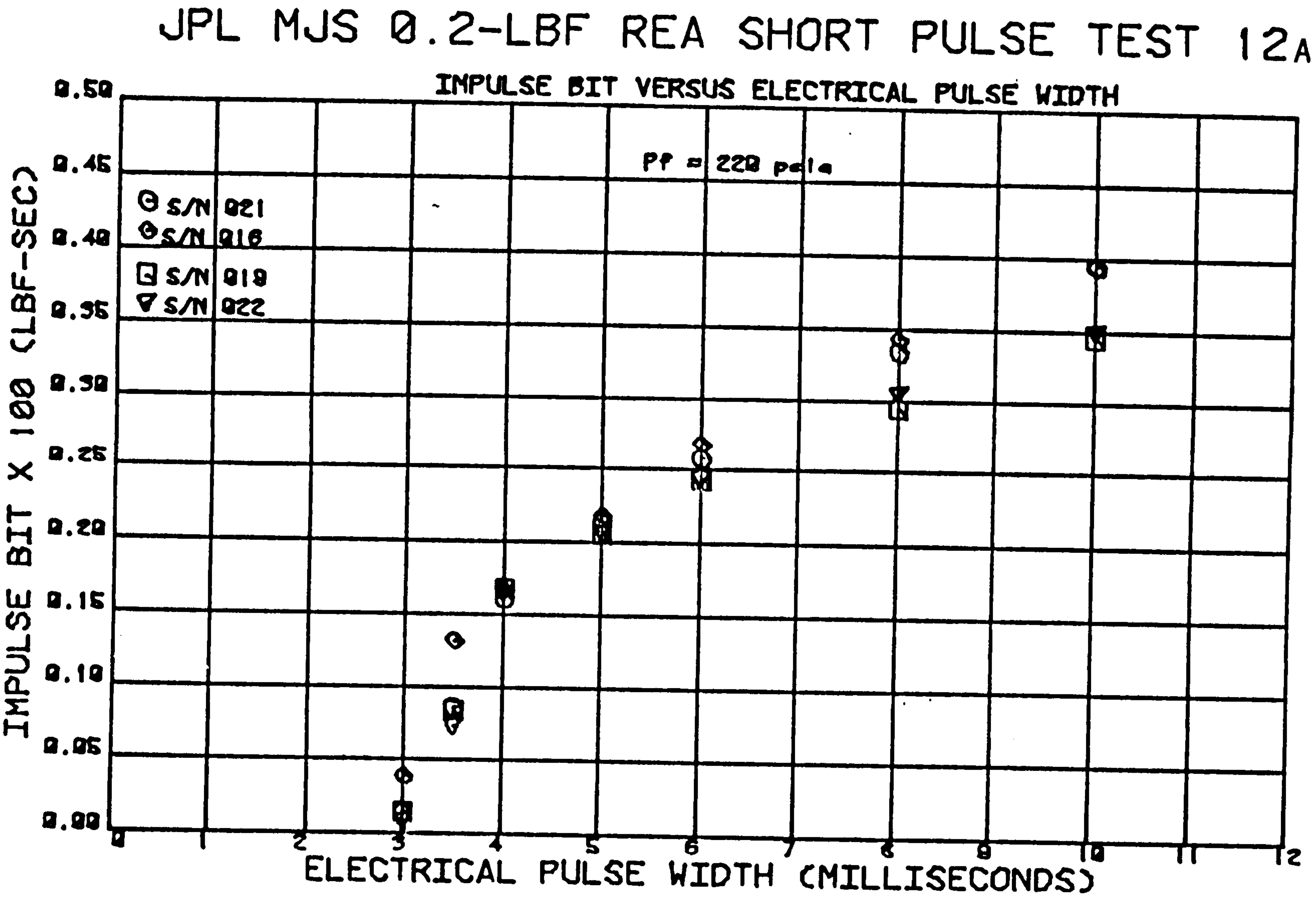
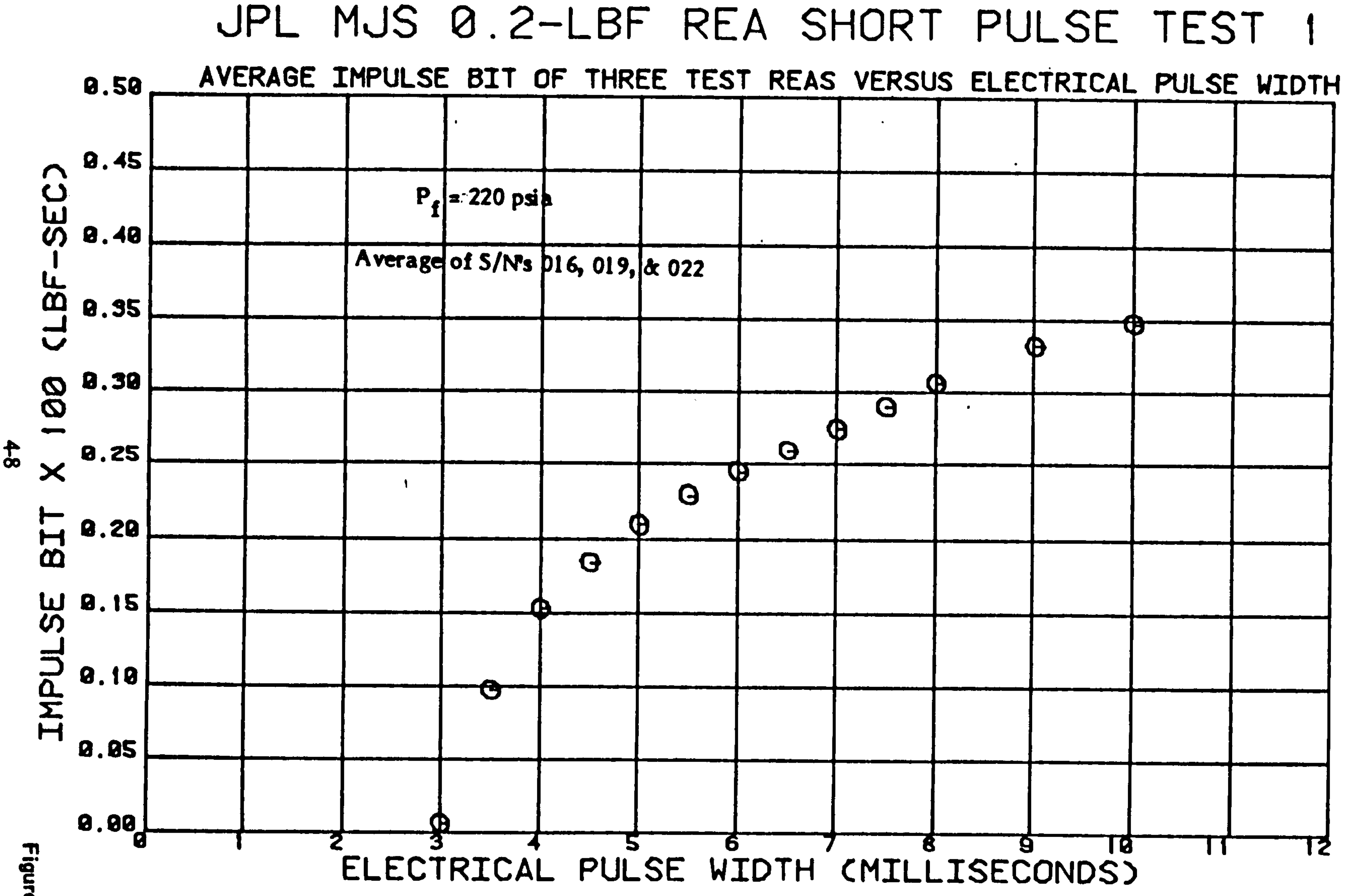

JPL MJS 0.2-LBF REA SHORT PULSE TEST 12A
IMPULSE BIT VERSUS ELECTRICAL PULSE WIDTH
Pf = 220 psia
⊖ S/N 021
◇ S/N 016
⊡ S/N 019
▽ S/N 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
ELECTRICAL PULSE WIDTH (MILLISECONDS)

Figure 4-6



JPL MJS 0.2-LBF REA SHORT PULSE TEST 1

AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH

Figure 4-7

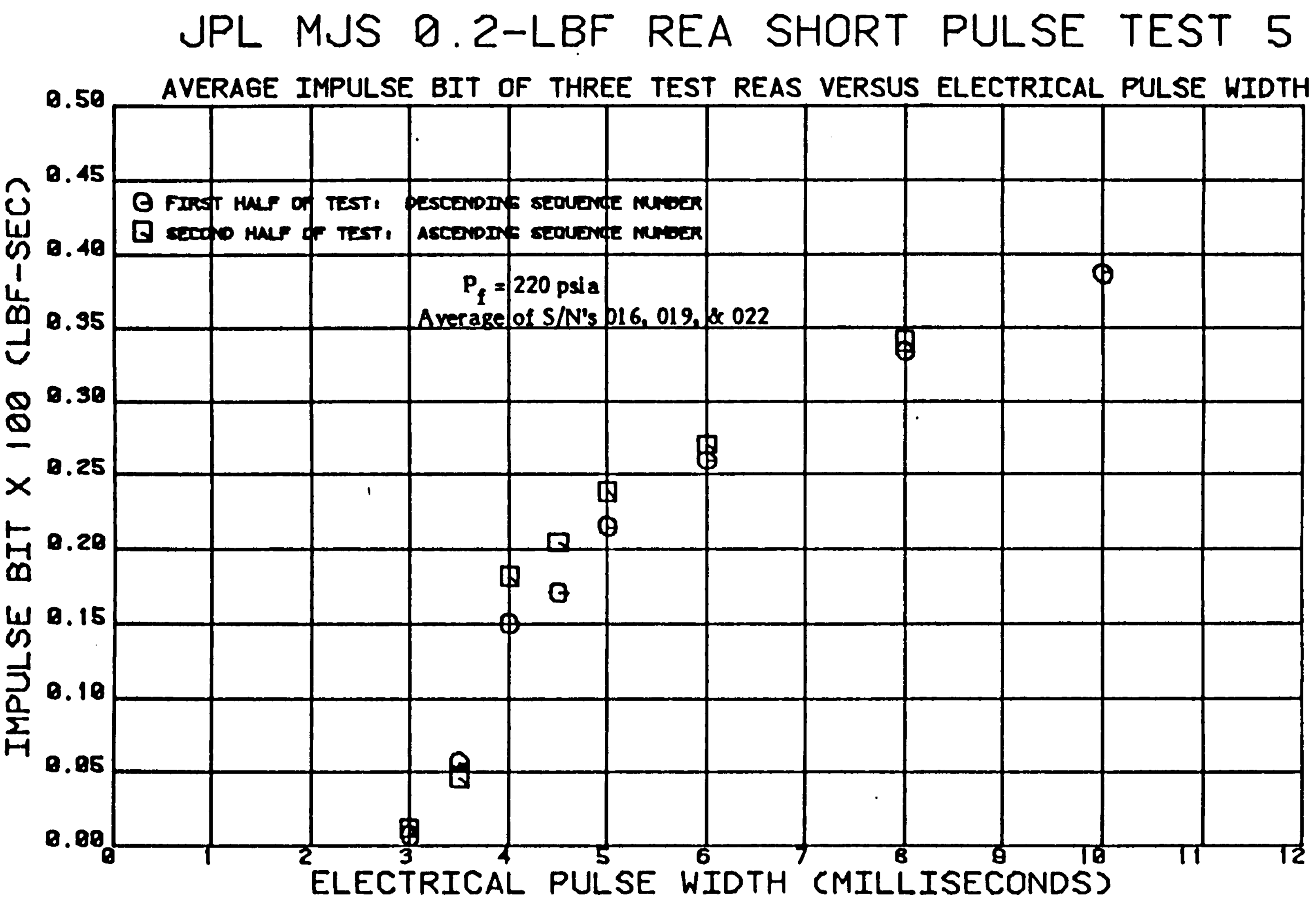

JPL MJS 0.2-LBF REA SHORT PULSE TEST 5
AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH
○ FIRST HALF OF TEST: DESCENDING SEQUENCE NUMBER
□ SECOND HALF OF TEST: ASCENDING SEQUENCE NUMBER
P_f = 220 psia
Average of S/N's 016, 019, & 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
ELECTRICAL PULSE WIDTH (MILLISECONDS)

Figure 4-8

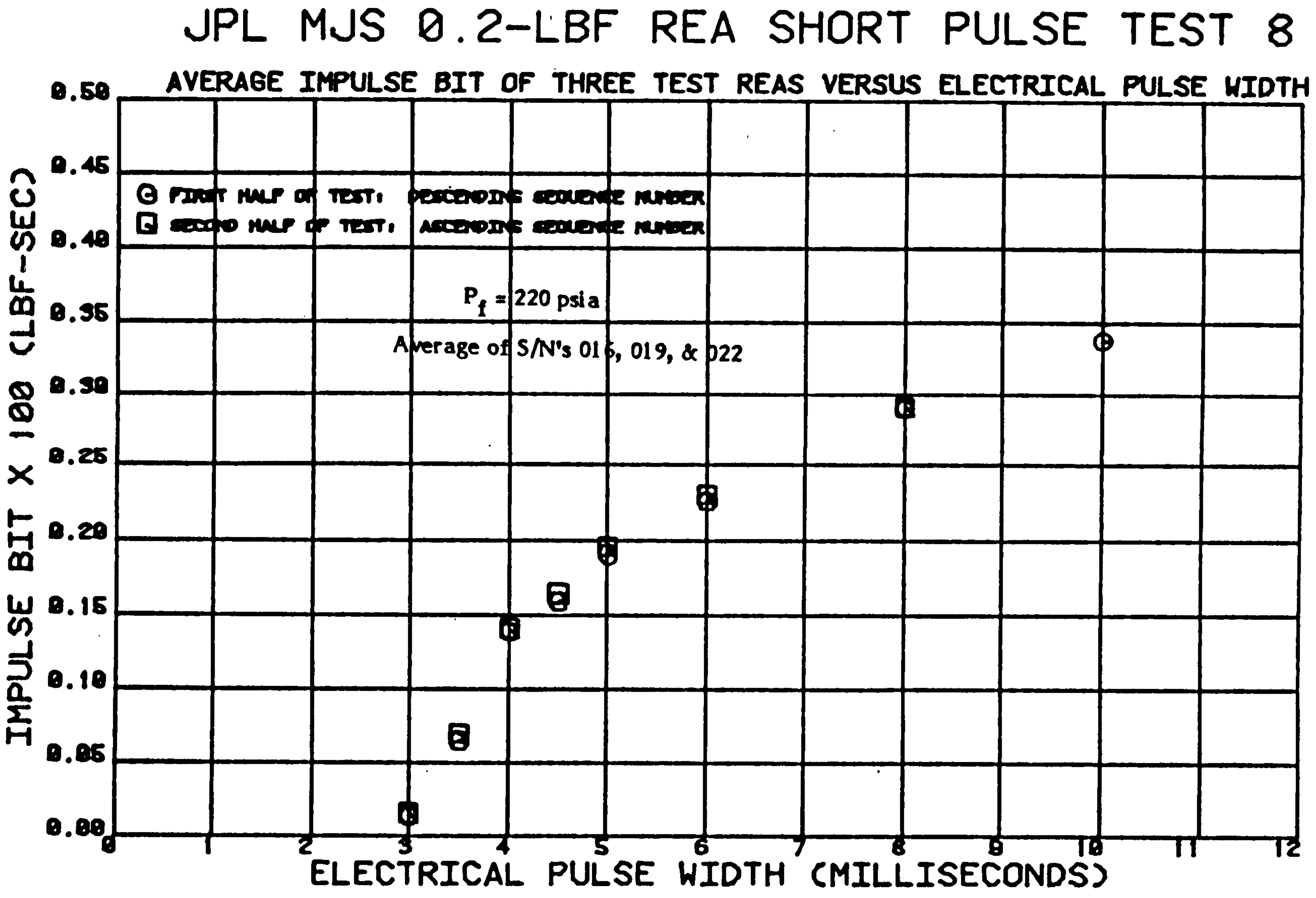

JPL MJS 0.2-LBF REA SHORT PULSE TEST 8
AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH
FIRST HALF OF TEST: DESCENDING SEQUENCE NUMBER
SECOND HALF OF TEST: ASCENDING SEQUENCE NUMBER
P_f = 220 psia
Average of S/N's 016, 019, & 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
ELECTRICAL PULSE WIDTH (MILLISECONDS)

Figure 4-9

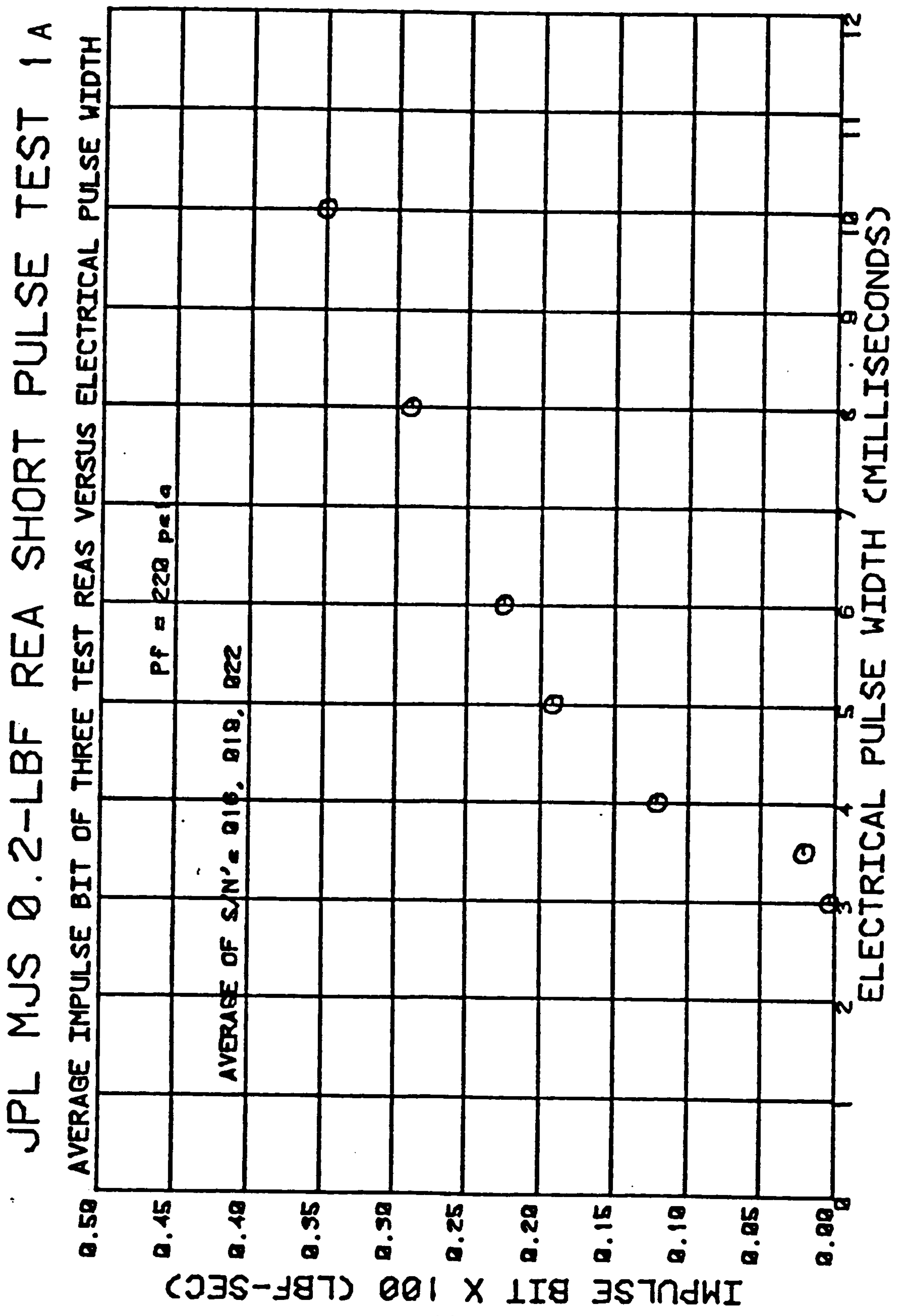
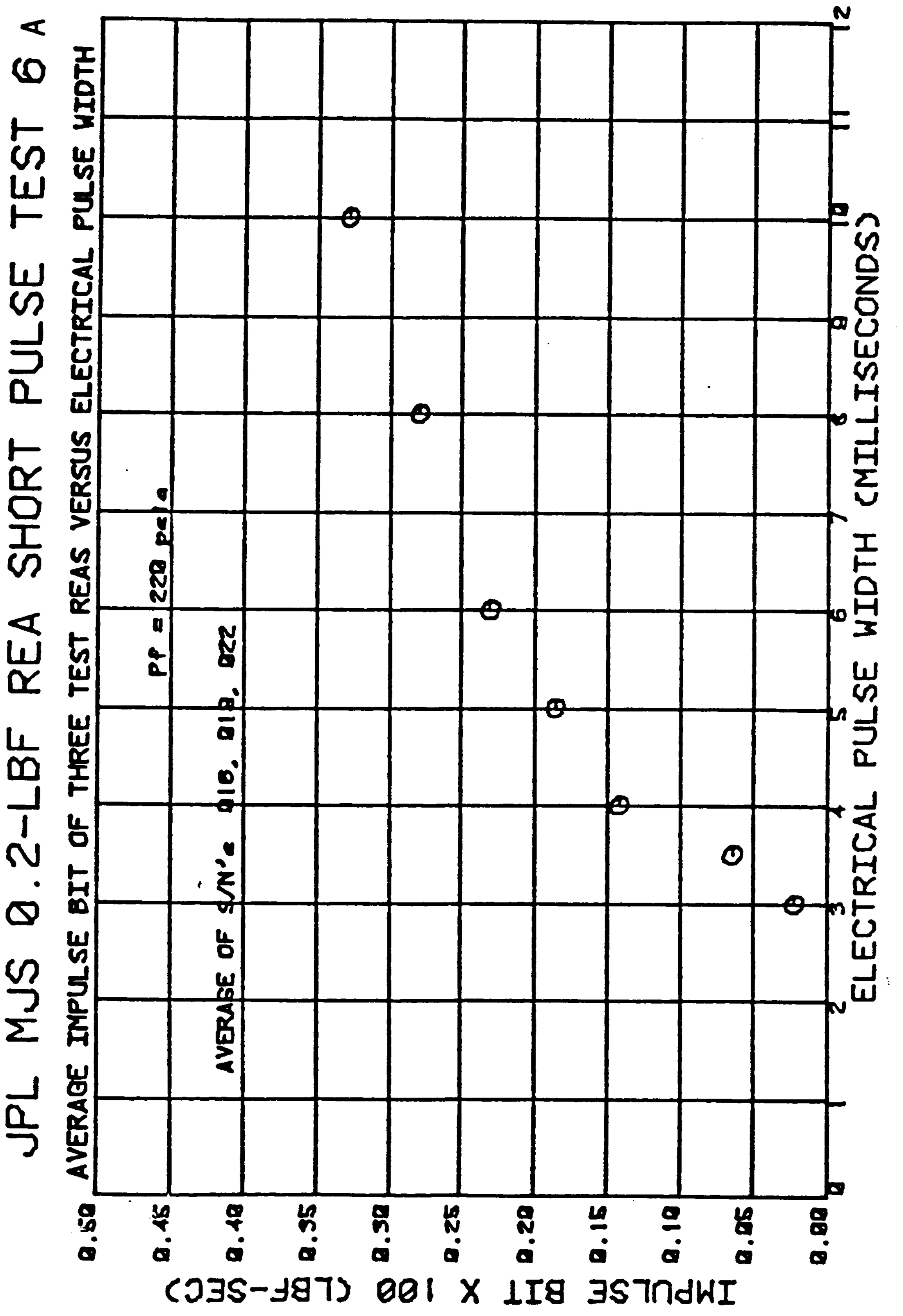

JPL MJS 0.2-LBF REA SHORT PULSE TEST 1A
AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH
Pf = 220 psia
AVERAGE OF S/N's 016, 019, 022
ELECTRICAL PULSE WIDTH (MILLISECONDS)
0
1
2
3
4
5
6
7
8
9
10
11
12
IMPULSE BIT X 100 (LBF-SEC)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

Figure 4-10



JPL MJS 0.2-LBF REA SHORT PULSE TEST 6 A
AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH
Pf = 220 psia
AVERAGE OF S/N's 016, 019, 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
ELECTRICAL PULSE WIDTH (MILLISECONDS)
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 4-11

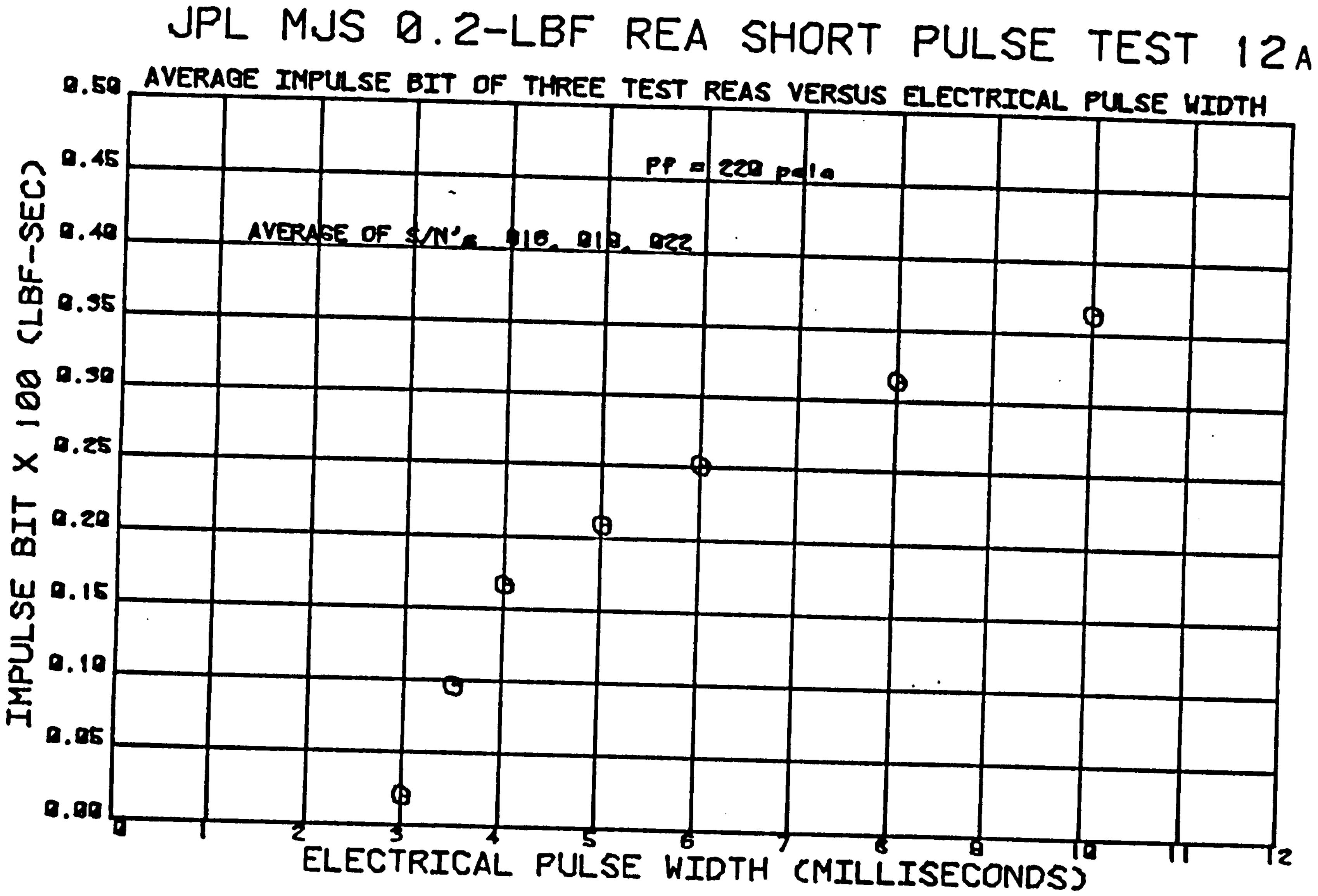

JPL MJS 0.2-LBF REA SHORT PULSE TEST 12A
AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH
Pf = 220 psia
AVERAGE OF S/N's 016, 018, 022
IMPULSE BIT X 100 (LBF-SEC)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
ELECTRICAL PULSE WIDTH (MILLISECONDS)

Figure 4-12

4.2.2 Impulse Bit as a Percent of the Impulse Bit of a 10-Millisecond Pulse

Curves of impulse bit as a percent of the impulse bit of a 10-millisecond pulse are presented in Figures 4-13 and 4-14. These curves represent the average of the three test T/VA's S/N 016, 019 and 022. Short pulse tests 1, 5, and 8 are presented in Figure 4-13 and short pulse tests 1A, 6A, and 12A are presented in Figure 4-14.

4.3 DETERMINATION OF PULSE-TO-PULSE IMPULSE BIT VARIATIONS AS A FUNCTION OF ELECTRICAL PULSE WIDTH

Plots of pulse-to-pulse impulse bit variations versus electrical pulse width are presented in Figures 4-15 through 4-20; short pulse tests 1, 5, 8, 1A, 6A and 12A respectively.

Five short pulses were performed at each data point. The pulse-to-pulse variations was determined by taking the difference between the highest and lowest impulse bit of the five pulses and dividing by the average.

The maximum pulse-to-pulse variation occurs at 3.5 milliseconds and decreases dramatically as the pulse width increases.

4.4 THRUSTER LIFE

4.4.1 Characterization Tests

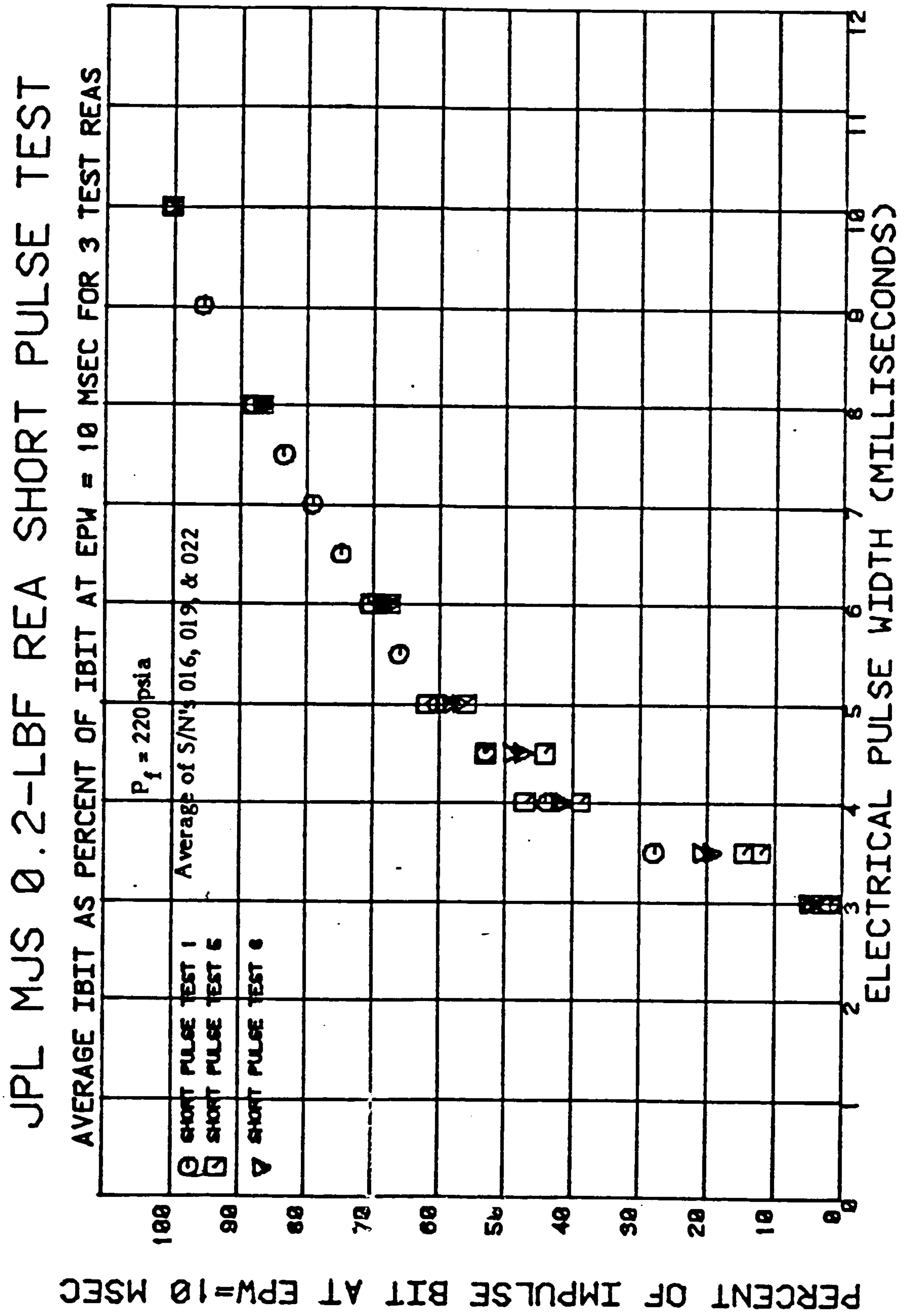
The characterization test summary in Table 4-1 presents the performance of the T/VA's at several points throughout the 75,000 pulse life testing.

There was no significant performance change throughout the life testing except in the case of T/VA S/N 020. This T/VA experienced partial flow blockage after 12,000 pulses but this is attributed to previous firing history and not the exposure to short pulse testing.

4.4.2 Short Pulse Tests

The short pulse test plots of impulse bit versus accumulated life is presented in Figures 4-21 and 4-22. Figure 4-21 is a plot of the average of the three T/VA's S/N 016, 019 and 022 and Figure 4-22 is a plot of the individual T/VA's including serial number 020.

There is no significant change in impulse bit throughout the life testing. The test-to-test variation is due to the slight drift of the ATCS pulse width command signal.



JPL MJS 0.2-LBF REA SHORT PULSE TEST

AVERAGE IBIT AS PERCENT OF IBIT AT EPW = 10 MSEC FOR 3 TEST REAS

Figure 4-13

JPL MJS 0.2-LBF REA SHORT PULSE TESTS

AVERAGE IBIT AS PERCENT OF IBIT AT EPW = 10 MSEC FOR 3 TEST REAS

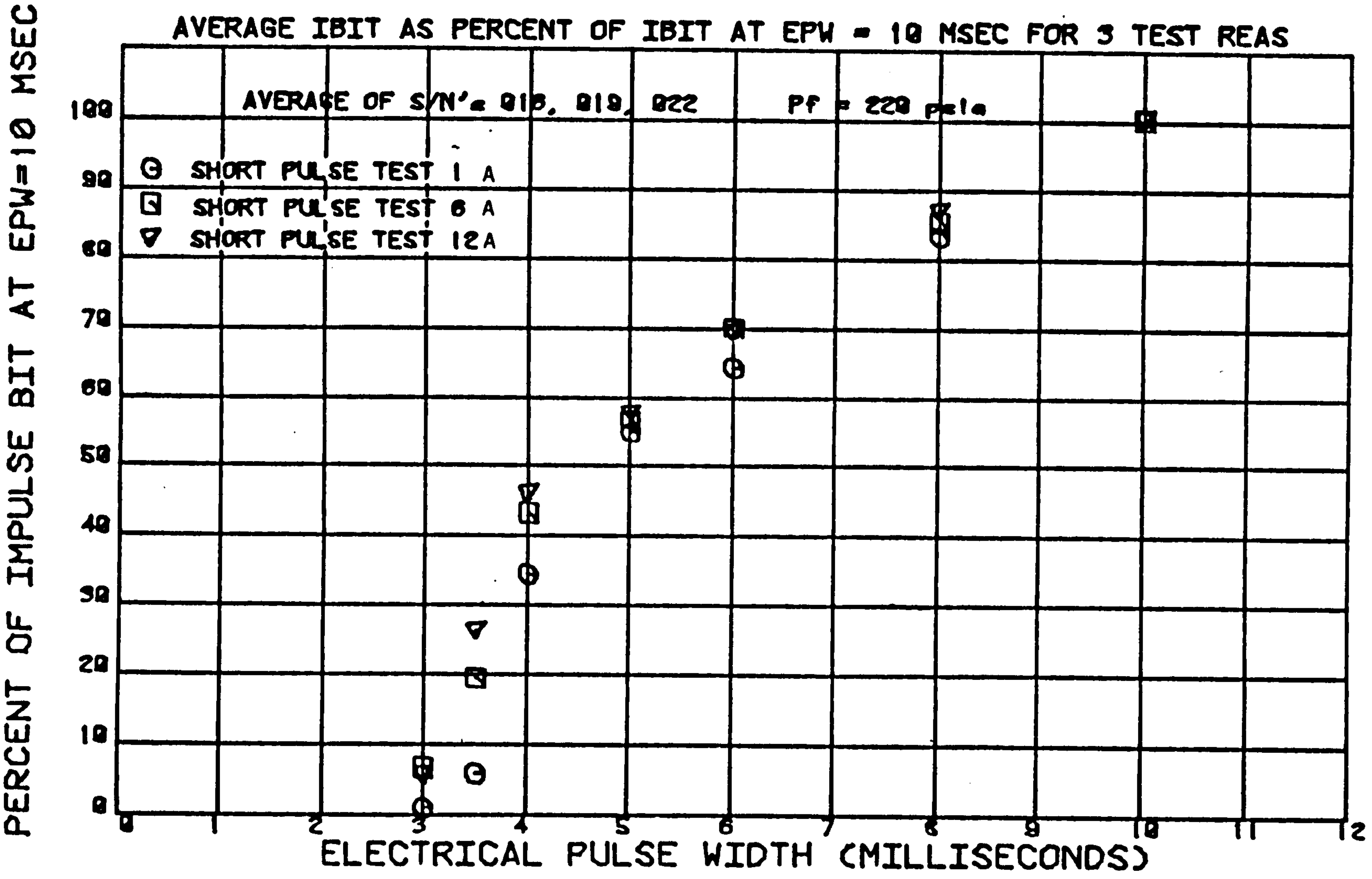
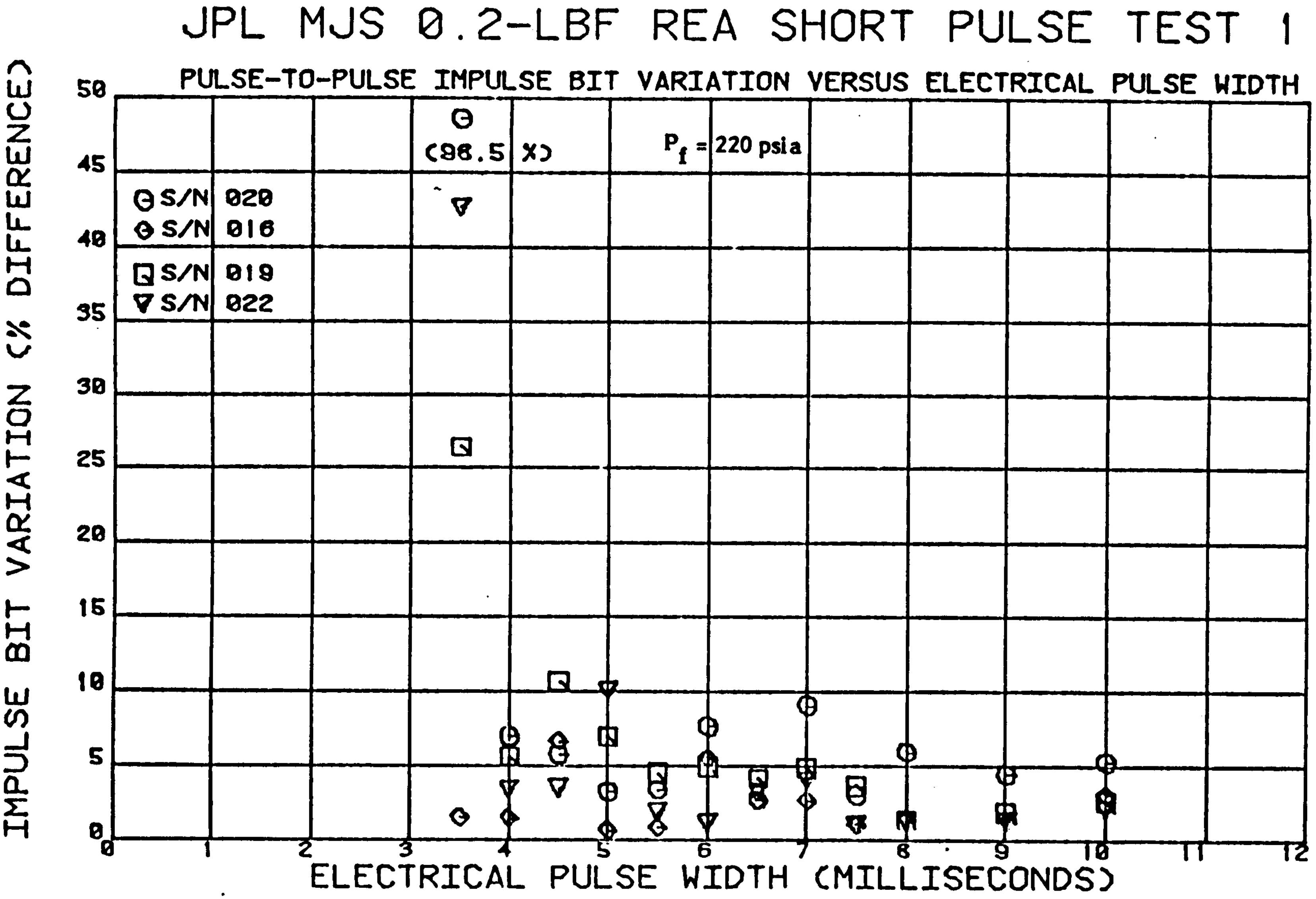


Figure 4-14



JPL MJS 0.2-LBF REA SHORT PULSE TEST 1

PULSE-TO-PULSE IMPULSE BIT VARIATION VERSUS ELECTRICAL PULSE WIDTH

Figure 4-15

JPL MJS 0.2-LBF REA SHORT PULSE TEST 5

PULSE-TO-PULSE IMPULSE BIT VARIATION VERSUS ELECTRICAL PULSE WIDTH

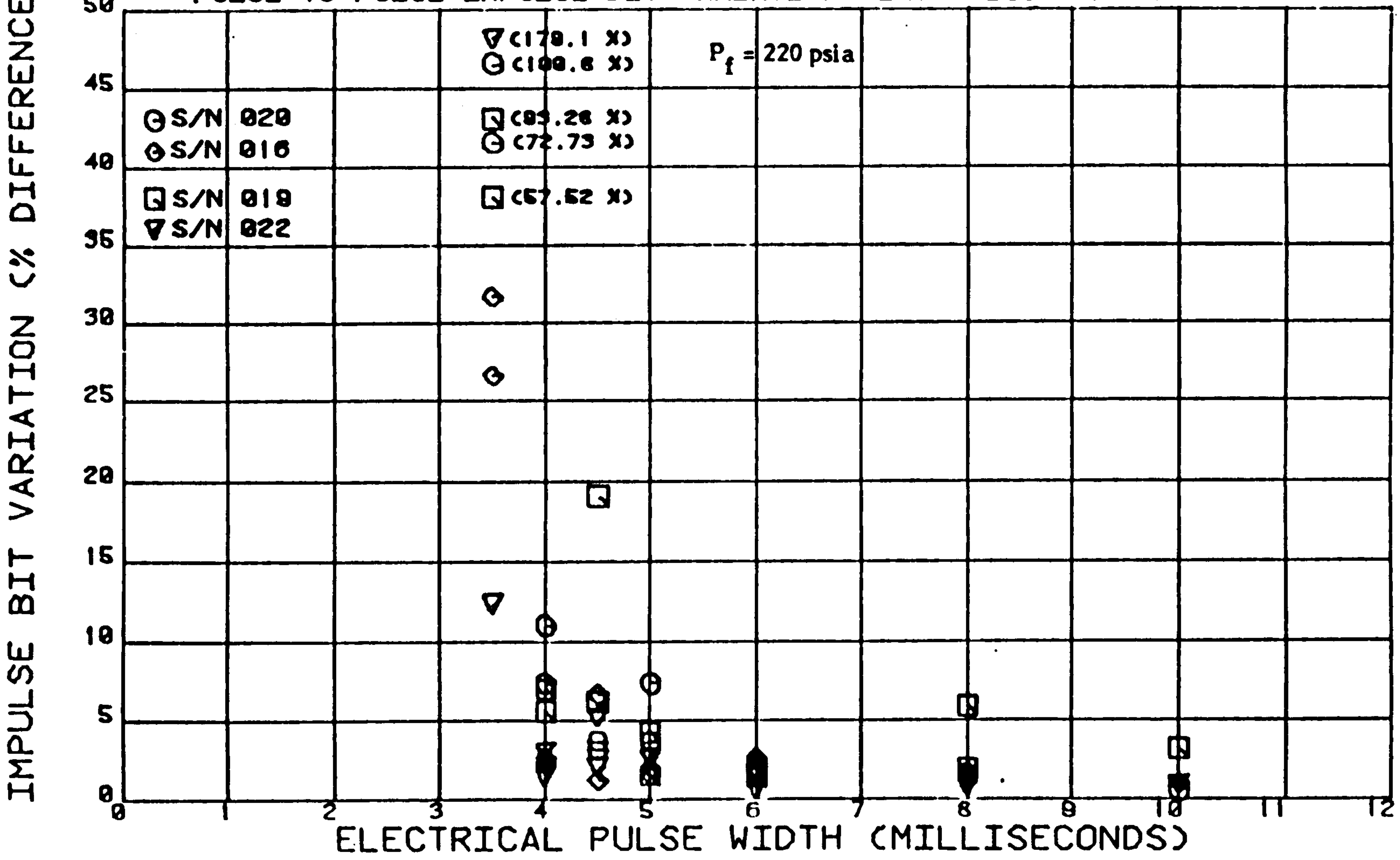


Figure 4-16

JPL MJS 0.2-LBF REA SHORT PULSE TEST 8

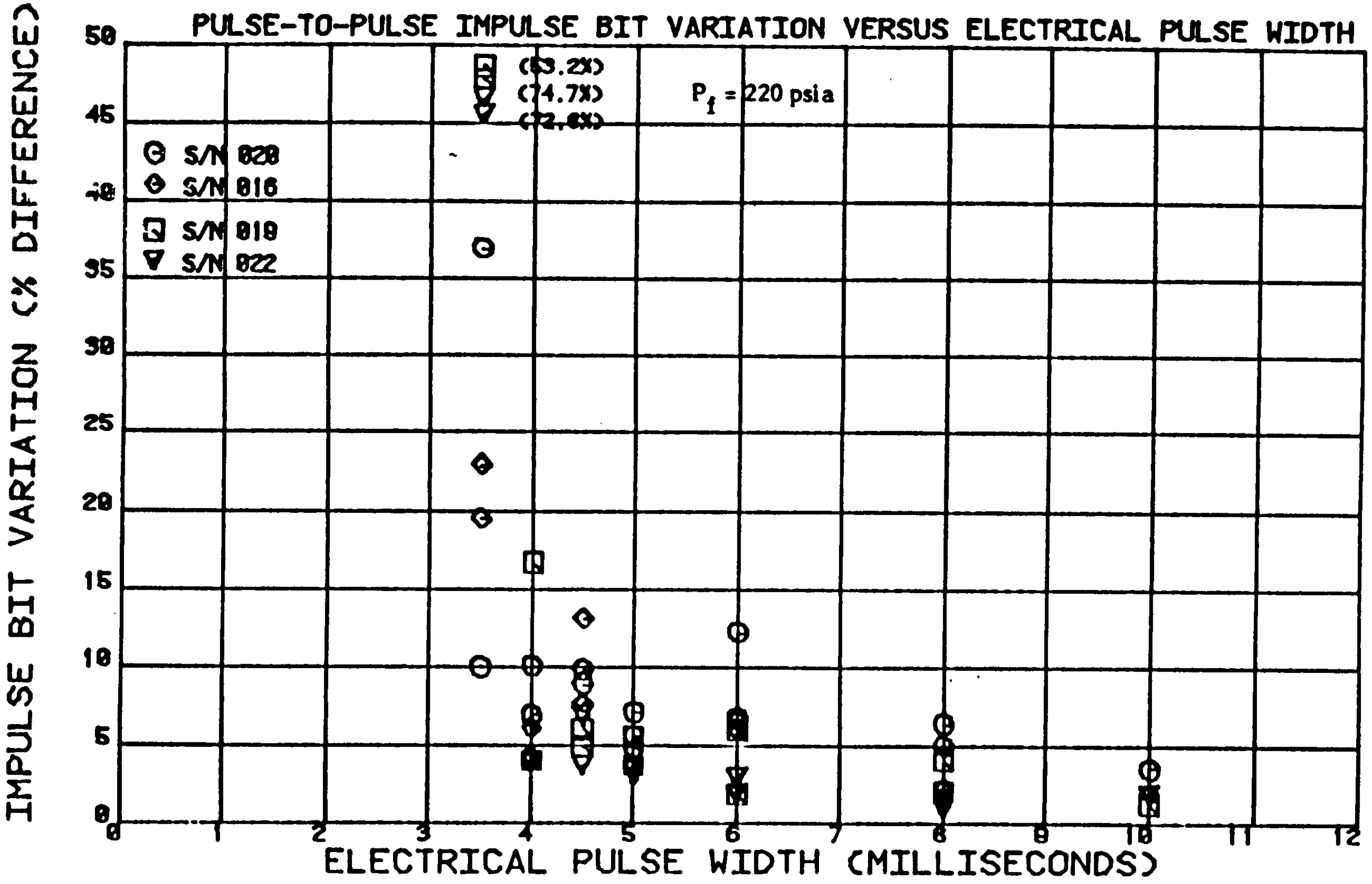


Figure 4-17

JPL MJS 0.2-LBF REA SHORT PULSE TEST 1 A

PULSE-TO-PULSE IMPULSE BIT VARIATION VERSUS ELECTRICAL PULSE WIDTH

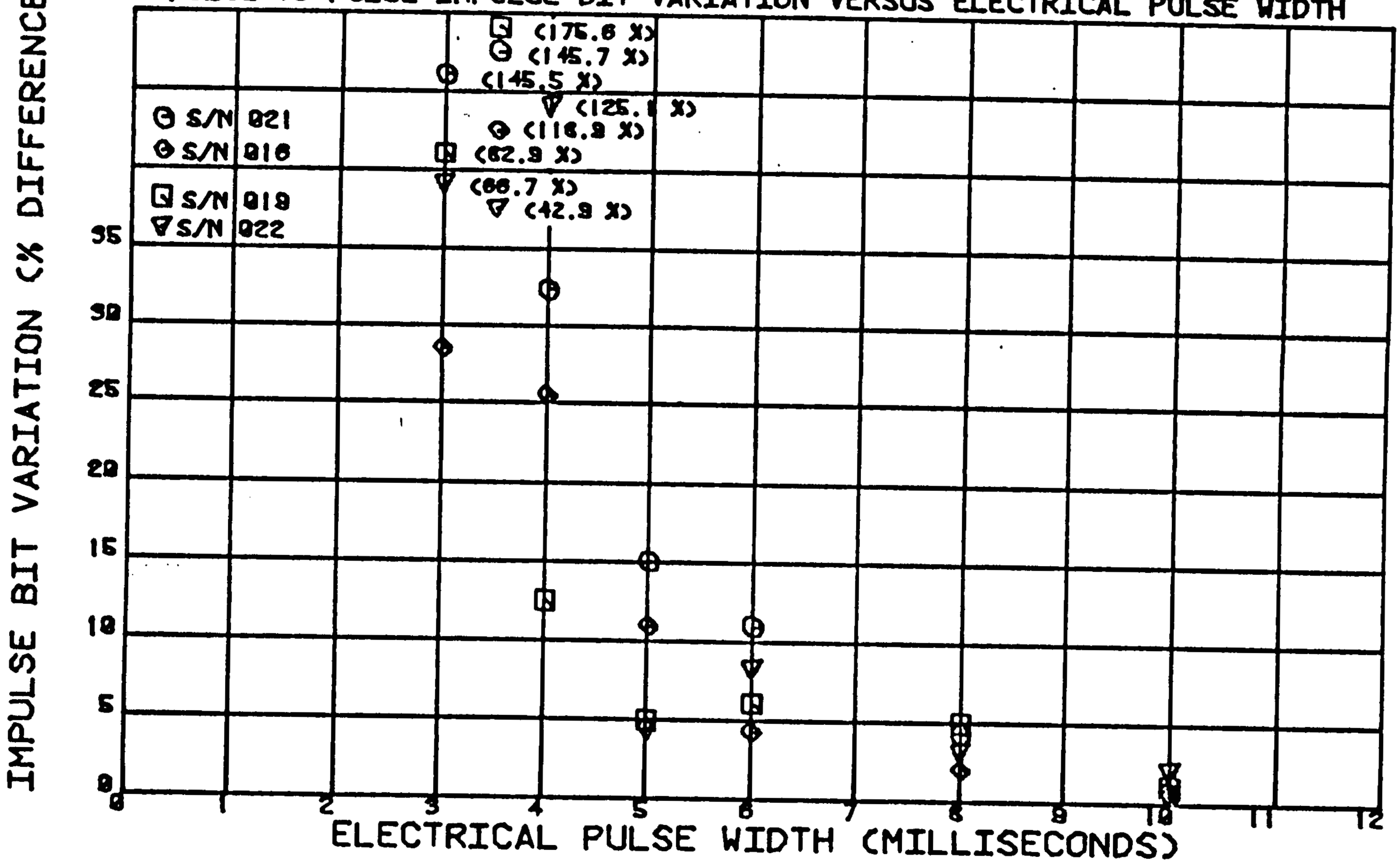


Figure 4-18

JPL MJS 0.2-LBF REA SHORT PULSE TEST 6A

PULSE-TO-PULSE IMPULSE BIT VARIATION VERSUS ELECTRICAL PULSE WIDTH

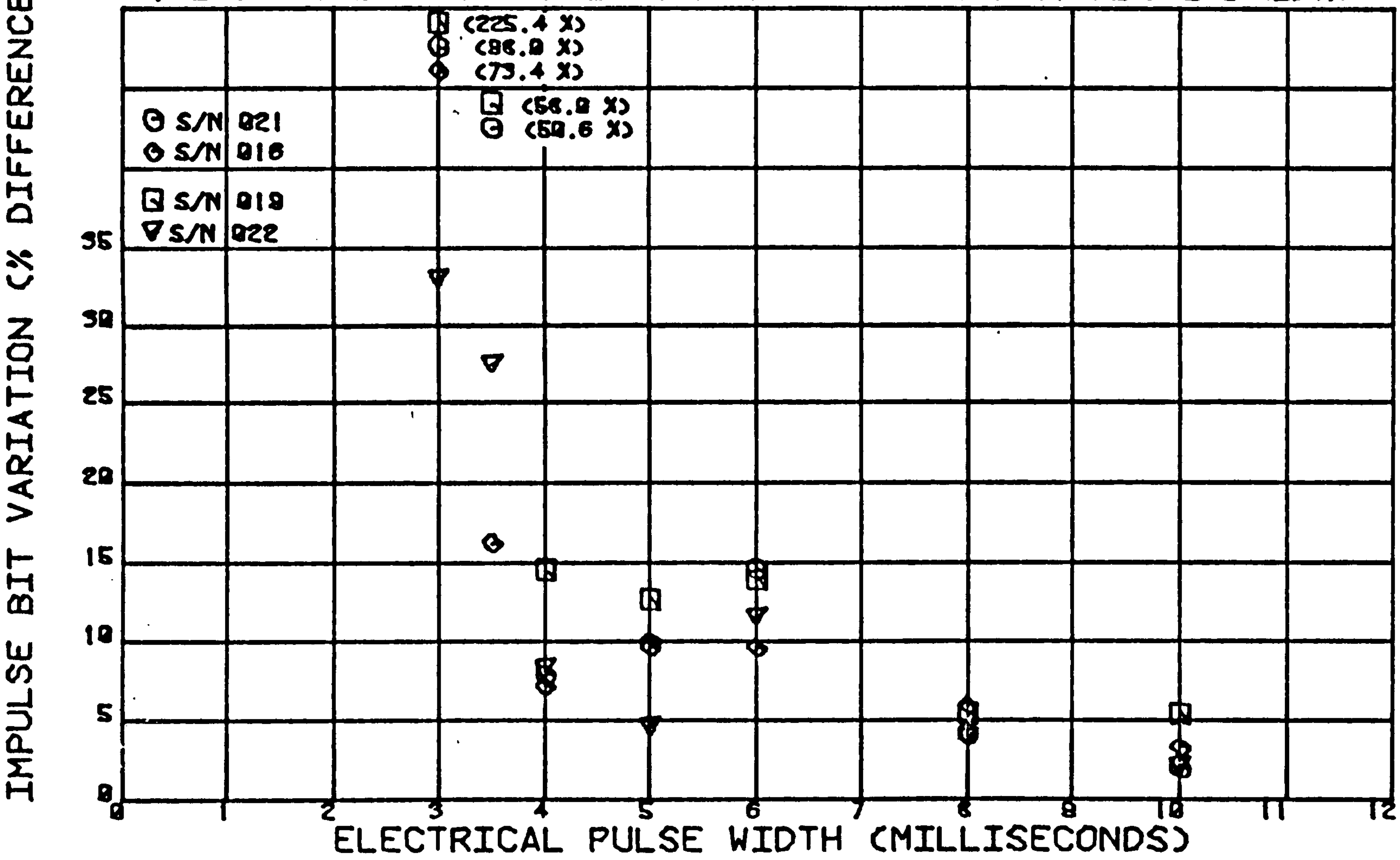


Figure 4-19

JPL MJS 0.2-LBF REA SHORT PULSE TEST 12A

PULSE-TO-PULSE IMPULSE BIT VARIATION VERSUS ELECTRICAL PULSE WIDTH

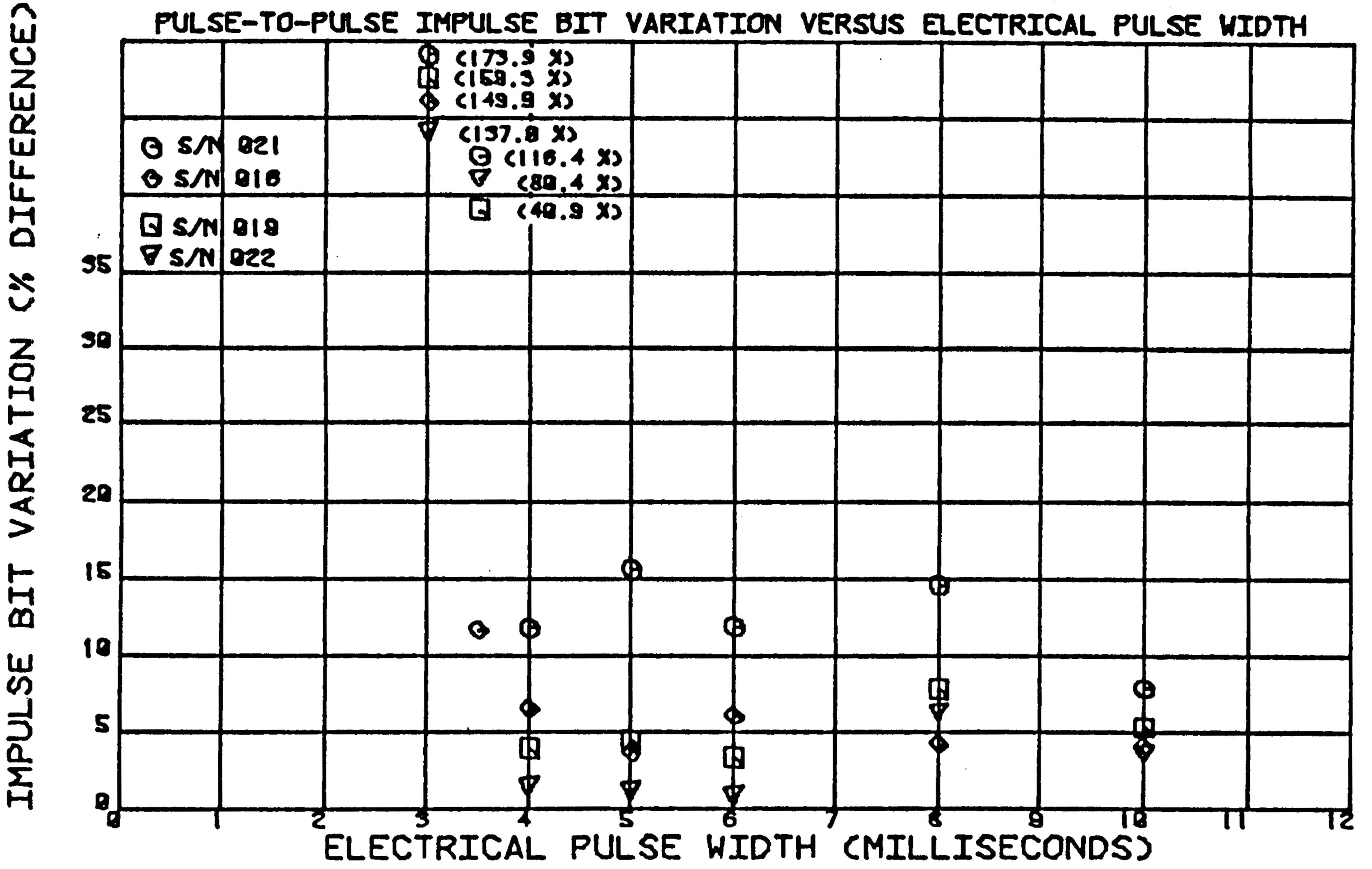


Figure 4-20

Table 4-1
CHARACTERIZATION TEST SUMMARY

Parameter	Character-ization Test Seq.	Original ATP Criteria	T/VA S/N 016						T/VA S/N 019					
			Orig ATP	CT-1	CT-2	CT-1A	CT-2A	CT-3A	Orig ATP	CT-1	CT-2	CT-1A	CT-2A	CT-3A
Thrust — Steady state (lbf)	3	0.207—0.228	0.218	0.225	0.220	0.230	0.226	0.225	0.222	0.220	0.209	0.218	0.216	0.212
	4	0.0888—0.102	0.095	0.101	0.096	0.102	0.103	0.101	0.098	0.097	0.092	0.099	0.101	0.101
Specific Impulse — Steady state (lbf-sec/lbm)	3	220 min	229	237	236	237	235	237	234	235	233	234	233	233
	4	210 min	221	232	228	228	227	229	227	229	239	224	225	227
Roughness — Steady state (%)	3 & 4	± 50% max	10.0	2.9	6.5	5.1	5.2	5.4	84.0	15.5	6.6	3.9	4.1	4.7
Rise response — Steady state (ms)	3	45 max to 10%	21	27	23	24	25	24	18	23	26	25	27	26
		175 max to 90%	45	124	76	78	82	81	37	82	91	83	93	91
	4	45 max to 10%	24	25	25	28	28	27	20	26	27	30	28	30
		175 max to 90%	30	74	78	75	79	79	46	74	87	81	93	86
Decay response — Steady state (ms)	3	200 max to 10%	100	133	132	125	131	131	102	134	130	120	126	128
	4	200 max to 10%	128	149	149	149	155	154	121	143	148	153	153	157
Impulse Bit Repeatability — Pulse mode (%)	1	± 15% max	0.6	0.3	0.5	0.2	0.3	0.6	0.5	0.4	0.5	0.6	0.1	0.4
	2	± 15% max	0.2	0.4	0.2	0.6	0.2	0.4	0.7	0.2	0.3	2.1	0.7	0.2
Centroid Repeatability — Pulse mode (%)	1	± 10% max	0	0.4	0.8	0.8	0.8	0.4	0.8	0.4	0.8	0.4	0	1.6
	2	± 20% max	0.6	0.4	0.4	0.8	0.8	0.8	0.6	0.8	0.4	0.9	0.4	0.4
Rise response — Pulse mode (ms)	1	30 max to 10%	19	17	20	20	20	20	16	19	21	21	22	22
	2	30 max to 10%	17	20	21	21	21	21	14	22	23	22	23	22
	1	80 max to 90%	38	35	38	37	38	38	30	36	40	39	40	41
	2	80 max to 90%	37	62	62	60	64	64	31	67	65	69	67	66
Decay Response — Pulse mode (ms)	1	1200 max to 10%	160	220	250	197	198	202	160	210	200	211	212	219
	2	1200 max to 10%	100	130	130	130	134	133	100	140	130	125	146	130

Parameter	Character-ization Test Seq.	Original ATP Criteria	T/VA S/N 022						T/VA S/N 020			T/VA S/N 021		
			Orig ATP	CT-1	CT-2	CT-1A	CT-2A	CT-3A	Orig ATP	CT-1	CT-2	Orig ATP	CT-1A	CT-2A
Thrust — Steady state (lbf)	3	0.207—0.228	0.217	0.214	0.203	0.213	0.210	0.211	0.224	0.215	0.060	0.218	0.227	0.229
	4	0.0888—0.102	0.094	0.095	0.089	0.097	0.098	0.096	0.098	0.098	0.030	0.095	0.100	0.100
Specific Impulse — Steady state (lbf-sec/lbm)	3	220 min	233	235	232	233	232	233	232	239	234	232	237	239
	4	210 min	223	228	223	225	224	226	226	235	216	222	228	230
Roughness — Steady state (%)	3 & 4	± 50% max	26.2	12.0	12.8	7.3	7.2	7.8	22.0	4.4	6.7	70.8	9.3	9.1
Rise response — Steady state (ms)	3	45 max to 10%	18	27	27	25	25	24	18	33	58	17	24	25
		175 max to 90%	37	118	139	88	76	84	40	155	185	36	77	90
	4	45 max to 10%	18	26	31	29	29	27	20	37	83	18	28	28
		175 max to 90%	58	71	86	86	83	87	47	90	229	49	76	81
Decay response — Steady state (ms)	3	200 max to 10%	95	123	124	127	126	124	92	156	168	101	123	134
	4	200 max to 10%	130	141	149	145	144	149	118	141	202	119	149	153
Impulse Bit Repeatability — Pulse mode (%)	1	± 15% max	1.2	0.6	1.2	0.3	0.2	0.4	0.6	0.3	0.4	0.6	0.5	0.4
	2	± 15% max	0.8	0.9	0.6	0.3	0.7	0.4	0.2	0.2	1.3	0.4	0.7	0.5
Centroid Repeatability — Pulse mode (%)	1	± 10% max	0	0.4	1.3	0.9	0	0.9	1.8	0.3	1.2	0	2.0	1.3
	2	± 20% max	1.2	0.8	0.4	0	0.4	0.4	0.6	1.0	1.1	0.6	0.9	0.4
Rise response — Pulse mode (ms)	1	30 max to 10%	16	20	20	21	22	20	17	23	26	16	19	20
	2	30 max to 10%	14	21	21	21	21	20	15	24	30	14	20	23
	1	80 max to 90%	28	40	40	41	42	42	29	48	80	28	39	39
	2	80 max to 90%	31	68	74	64	67	67	31	75	86	30	62	68
Decay Response — Pulse mode (ms)	1	1200 max to 10%	130	270	220	202	243	198	130	350	600	127	193	208
	2	1200 max to 10%	90	140	120	123	122	124	80	160	250	96	127	146

T-1, Characterization test prior to short pulse testing.
T-2, Characterization test after 25,000 pulses.
T-1A, Characterization test after 25,000 pulses (start of follow-on program).
T-2A, Characterization test after 50,000 pulses.
T-3A, Characterization test after 75,000 pulses.

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OF POOR QUALITY

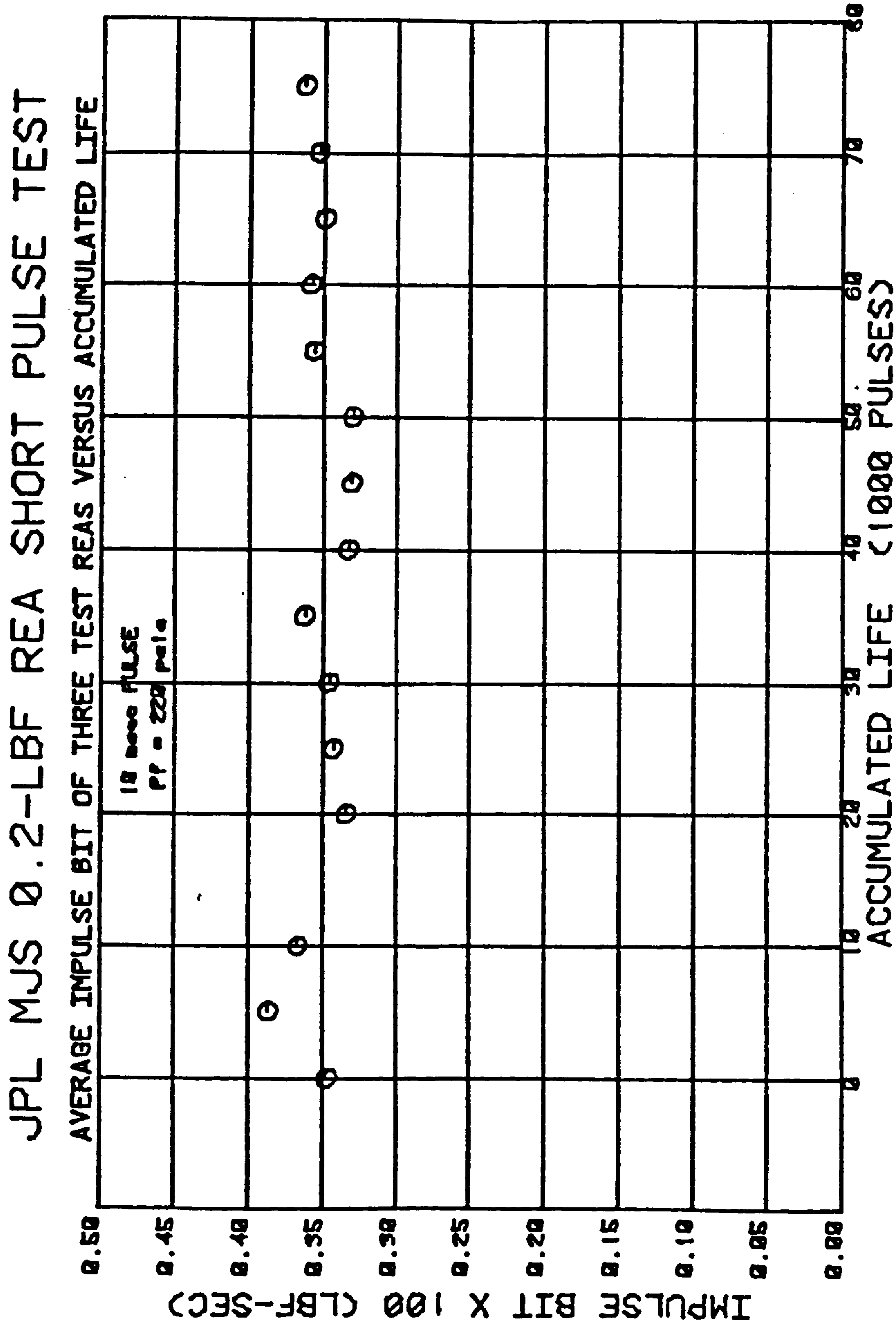
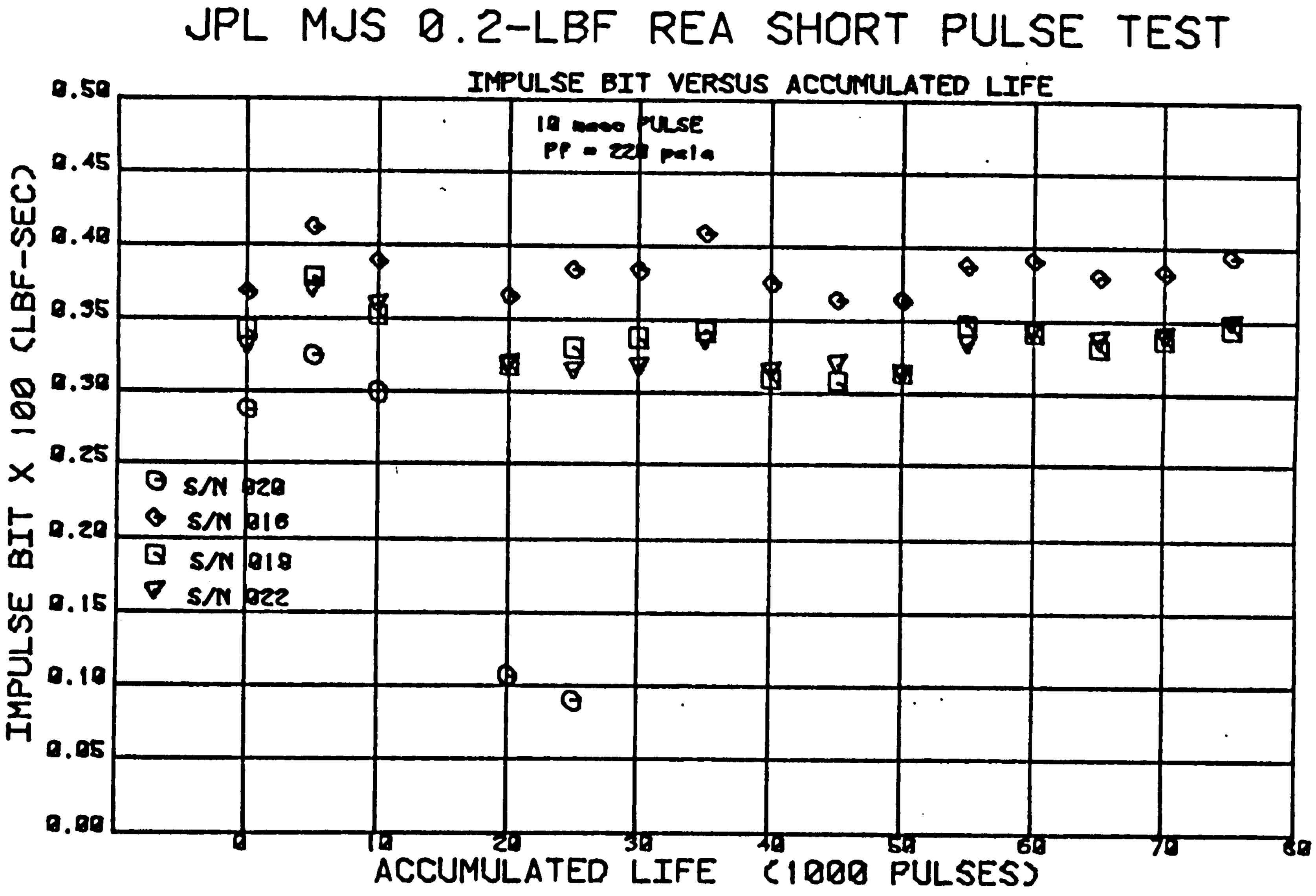

JPL MJS 0.2-LBF REA SHORT PULSE TEST
AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ACCUMULATED LIFE
10 msec PULSE
Pf = 220 psia
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
IMPULSE BIT X 100 (LBF-SEC)
0
10
20
30
40
50
60
70
80
ACCUMULATED LIFE (1000 PULSES)

Figure 4-21



JPL MJS 0.2-LBF REA SHORT PULSE TEST

Figure 4-22

4.5 TYPICAL PULSE SHAPES

Curves of thruster chamber pressure versus time for pulses with electrical pulse widths of 3.5 to 10 milliseconds are presented in Figure 4-23. Note the delay in chamber pressure indication and the long tailoff.

4.6 FUNCTIONAL TESTS

All of the initial functional tests were satisfactory and there was no significant functional changes at the conclusion of the short pulse life testing, except for T/VA S/N 020 which experienced partial flow blockage.

Table 4-2 presents the results of the T/VA gas (GN_2) flow and the valve opening response testing.

4.7 HARDWARE FAILURES

4.7.1 T/VA S/N 020 Experienced Partial Flow Blockage

T/VA S/N 020 experience partial flow blockage after 13,000 pulses during life testing. This unit was disassembled and inspected. It was determined that the blockage was in the thruster injector capillary tube. The injector was sectioned and a material buildup was found at the downstream end of the capillary tube.

An analysis of the material was performed at JPL and was determined to be composed of iron, nickel and chromium; the constituents of stainless steel. It was further determined that the metals were dissolved as carbazates or hydrazides in hydrazine used during previous testing.

The deposition occurred prior to the short pulse testing and the observed flow reduction was caused by a particle, probably a piece of the deposition, which broke free and lodged in smaller flow area of the deposition buildup.

4.7.2 Thruster Heater Failures

There were four thruster heater element failures but the heaters on the T/VA's used in this test program all had the small (1 mil) elements wire. The flight units have a different heater with a 2.5-mil element or they have a resistor in series with the element.

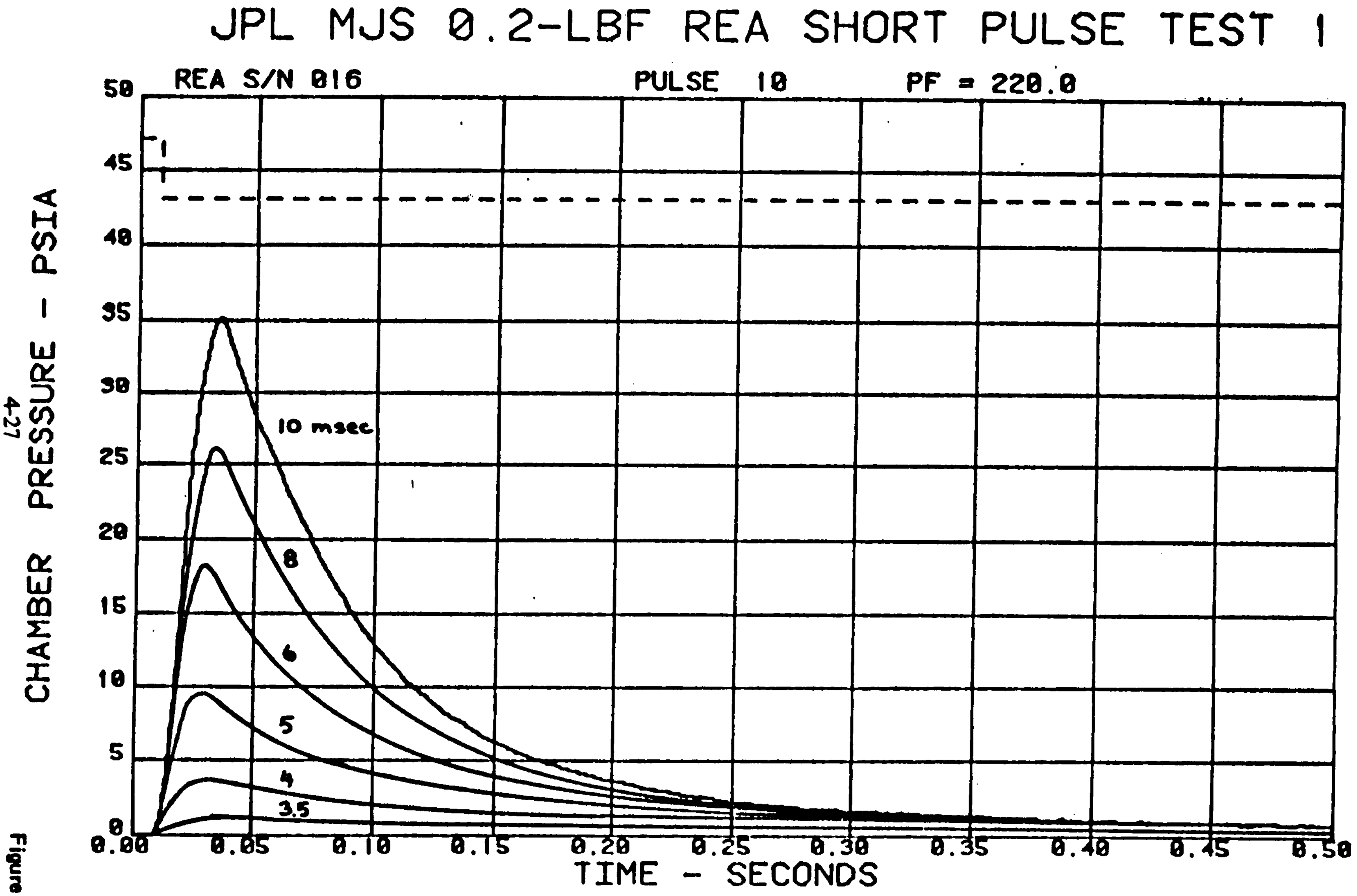

JPL MJS 0.2-LBF REA SHORT PULSE TEST 1
REA S/N 016
PULSE 10
PF = 220.0
CHAMBER PRESSURE - PSIA
TIME - SECONDS
50
45
40
35
30
25
20
15
10
5
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
10 msec
8
6
5
4
3.5

Figure 4-23

Table 4-2

T/VA GN_2 FLOW AND VALVE RESPONSE TESTS

T/VA S/N	T/VA GN_2 Flow (ml/min)						Valve Opening Response Time (ms)					
	ATP		Pre-Fire		Post-Fire		Pre-Fire			Post-Fire		
	5 psig	10 psig	5 psig	10 psig	5 psig	10 psig	22 vdc	29.5 vdc	34 vdc	22 vdc	29.5 vdc	34 vdc
16	155	263	189	275	186	296	5.0	3.5	3.5	5.2	3.8	3.2
19	160	268	181	275	161	254	5.5	3.5	3.0	5.2	4.0	3.8
20	173	293	178	245	28	36	5.5	4.0	3.0	6.0	4.1	3.5
22	160	263	160	268	150	243	6.0	4.5	3.9	6.0	4.0	3.8
21	168	275	185	280	184	289	5.5	4.1	3.3	5.5	4.0	3.2

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5.0 CONCLUSIONS

- The limiting electrical pulse width is approximately 3.0 milliseconds. At pulse widths of 3.0 ms or less the valve will not unseat and no impulse will be obtained.
- Pulse widths of 3.5 milliseconds provide an impulse bit of approximately 20 percent of the impulse provided by a 10 millisecond pulse, but there is a wide variation in pulse-to-pulse and unit-to-unit impulse.
- Pulse widths of 4.0 milliseconds provide an impulse bit of approximately 45 percent of the impulse provided by a 10-millisecond pulse and the pulse-to-pulse and unit-to-unit variation is approximately plus or minus 10 percent.
- Pulse widths of 5.0 milliseconds provide an impulse bit of approximately 55 percent of the impulse provided by 10-millisecond pulse and the pulse-to-pulse and unit-to-unit variation is approximately pluse or minus 8 percent.
- Seventy-five thousand (75,000) short pulses of 4 milliseconds and shorter cause no performance degradation. Three units showed no effect. One unit exhibited partial flow reduction after 13,000 pulses but this is attributed to the previous testing history.
- There is no significant risk associated with short pulse operation. This is supported by: 1) a successful demonstration test program was completed, 2) 410,000 pulses were accumulated on one T/VA during the Voyager qualification test, and 3) 75,000 short pulses represents less than 1 percent of the qualified hydrazine throughput capability.
- The disassembly and sectioning of the injector on T/VA S/N 019 and/or 016 would support the contention that the flow blockage of T/VA S/N 020 is due to previous testing history if a low degree of deposition was discovered.
- The Voyager T/VA's should be considered flight qualified for short pulse operation at pulse widths of 4 milliseconds or greater.

APPENDIX A

HYDRAZINE ANALYSES

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Analysis Report for
Sample of MJS77 Hydrazine

Date Sampled: 1-31-84 Request No.:

Type of Sample Container: 250 ml glass bottle

Date of Analysis: 2-2-84 & 2-20-84 Request No.:

Chem Lab Log Book I.D.: 37-79

Analysis by (Name): Lois L. Taylor and Ray Haack

Constituents	MJS77 Hydrazine Specification	Analysis of Drum No. H-8300
Hydrazine (percent by weight)	98.5 min	99.4
Water (percent by weight)	0.5 to 1.0	0.6
Particulate (mg/l)	1.0 max	0.2
Chloride (percent by weight)	0.0005 max	<0.0002
Aniline (percent by weight)	0.005 max	<0.002
Iron (percent by weight)	0.002 max	<0.0001
Nonvolatile Residue (percent by weight)	0.005 max ASH	0.001% 0.0007
Carbon Dioxide (percent by weight)	0.005 max	0.002
Other Volatile Carbonaceous Material, i.e., UDMH, MMH, Alcohol (percent by weight)	0.02 max	<0.01
Ammonia (percent by weight)	0.4 max	0.03

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Visual Observations and Remarks:

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ROCKET RESEARCH COMPANY
HYDRAZINE ANALYTICAL FORM
FOR HYDRAZINE MEETING MIL – P – 26536, AMENDMENT 1

e Sampled: 6-5-84 Orignator: R. MEHL Approval:

e Due: 6-8-84 Sample ID: DRUM H 8300

Date Recieved: ____ Charge No.: 131522-3300 Control No.: 03553

osition of Sample: DESTROY

eck Upper ox For All →	☐				Check Upper Box For All →	☒		
ANALYSES REQUESTED	CHK.	ACCEPTABLE VALUES MONOPROPELLANT GRADE % BY WEIGHT	ppm	RESULTS	CHK.	ACCEPTABLE VALUES HIGH PURITY GRADE % BY WEIGHT	ppm	RESULTS
N_2H_4		98.50 min.	N/A	%		98.50 min.	N/A	99.10 %
H_2O		1.00 max.	N/A	%		~~1.00 max.~~ .5 TO 1.0%	N/A	0.72 %
NH_3		0.40 max.	N/A	%		0.40 max.	N/A	0.18 %
e Organics Excluding Aniline		0.020 max.	200	ppm		~~0.020 max.~~ 50	~~200~~	26 ppm
Aniline		0.50 max.	N/A	%		~~0.005 max.~~ 80	~~50~~	8 ppm
tal Nonvolatiles (NVR)		0.0020 max.	20	ppm		~~0.0010 max.~~ 20.0	~~10~~	13 ppm
Particulate		1 mg/L max.	N/A	mg/L		1 mg/L max.	N/A	0 mg/L
Corrosivity		0.00125 % Fe max.	12.5	ppm		~~0.00125 %~~ Fe max. 5.0	~~12.5~~	1 ppm
Chloride		0.0005 max.	5	ppm		0.0005 max.	5	0.2 ppm
Iron		0.0002 max.	2	ppm		~~0.0002 max.~~ 3	~~2~~	0.2 ppm
CO_2		0.0030 max.	30	ppm		~~0.0030 max.~~ 25	~~30~~	5 ppm
Silicon (OPTIONAL)		0.000005 max.	0.05	ppm		~~0.000005 max.~~ .05	0.05	less Than .05 ppm
ARBON)						50 PPM MAX		9.2 ppm

is Completed And Reviewed:

Signature J Maro Date 6-7-84

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ROCKET RESEARCH COMPANY
HYDRAZINE ANALYTICAL FORM
FOR HYDRAZINE MEETING MIL – P – 26536, AMENDMENT 1

mpled: 8-17-84 Orignator: MEL ALVAREZ Approval:

Date Due: 8-20-84 Sample ID: N2H4 SYSTEM SAMPLE CH. #4 (SYSTEM CERTIFICATI

Date Recieved: 8-17-84 Charge No.: 13522-3300 ~~13523~~-4000 Control No.: 63609

Disposition of Sample: DESTROY

heck Upper Box For All →	☒				☒	← Check Upper Box For All		
ANALYSES REQUESTED	CHK.	ACCEPTABLE VALUES MONOPROPELLANT GRADE % BY WEIGHT	ppm	RESULTS		ACCEPTABLE VALUES HIGH PURITY GRADE % BY WEIGHT	ppm	RESULTS
N_2H_4		98.50 min.	N/A	%		98.50 min.	N/A	99.19 %
H_2O		1.00 max.	N/A	%		1.00 max.	N/A	.70 %
NH_3		0.40 max.	N/A	%		0.40 max.	N/A	.11 %
Trace Organics ding Aniline		0.020 max.	200	ppm		0.020 max.	200	3,5 ppm
Aniline		0.50 max.	N/A	%		0.005 max.	50	15 ppm
otal Nonvolatiles (NVR)		0.0020 max.	20	ppm		0.0010 max.	10	2 ppm
Particulate		1 mg/L max.	N/A	mg/L		1 mg/L max.	N/A	0 mg/L
Corrosivity		0.00125 % Fe max.	12.5	ppm		0.00125 % Fe max.	12.5	.8 ppm
Chloride		0.0005 max.	5	ppm		0.0005 max.	5	0.5 ppm
Iron		0.0002 max.	2	ppm		0.0002 max.	2	0,1 ppm
CO_2		0.0030 max.	30	ppm		0.0030 max.	30	5 ppm
Silicon (OPTIONAL)		0.000005 max.	0.05	ppm		0.000005 max.	0.05	Not detected less than .05 ppm

nalysis Completed And Reviewed:

Signature ______ Date 8-20-84

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ROCKET RESEARCH COMPANY
HYDRAZINE ANALYTICAL FORM
FOR HYDRAZINE MEETING MIL – P – 26536, AMENDMENT 2

te Sampled: 6-14-85 Orignator: ELLIS Approval: Steven P. Ellis

te Due: 6-17-85 Sample ID: N2Hy chamber #4 RESAMPLE

Date Recieved: 6-14-85 Charge No.: 131539-4300 Control No.: 03828

Disposition of Sample: Destroy

heck Upper Box For All →	☐				☐	← Check Upper Box For All		
ANALYSES REQUESTED	CHK.	ACCEPTABLE VALUES MONOPROPELLANT GRADE % BY WEIGHT	ppm	RESULTS		ACCEPTABLE VALUES HIGH PURITY GRADE % BY WEIGHT	ppm	RESULTS
N_2H_4		98.50 min.	N/A	%	X	99.00 min.	N/A	99.01 %
H_2O		1.00 max.	N/A	%	X	1.00 max.	N/A	0.83 %
NH_3		0.40 max.	N/A	%	X	0.40 max.	N/A	0.16 %
ace Organics Excluding Aniline		0.020 max.	200	ppm	X	0.005 max.	50	29 ppm
Aniline		0.50 max.	N/A	%	X	0.005 max.	50	28 ppm
Total Nonvolatiles (NVR)		0.0020 max.	20	ppm	X	0.0010 max	10	6 ppm
Particulate		1 mg/L max.	N/A	mg/L	X	1 mg/L max.	N/A	0 mg/L
Corrosivity		0.00125 % Fe max.	12.5	ppm	X	0.00125 % Fe max.	12.5	1.1 ppm
Chloride		0.0005 max.	5	ppm	X	0.0005 max.	5	0.1 ppm
Iron		0.0002 max.	2	ppm	X	0.0002 max.	2	0.5 ppm
CO_2		0.0030 max.	30	ppm	X	0.0030 max.	30	5 ppm
Silicon (OPTIONAL)		0.000005 max.	0.05	ppm		0.000005 max.	0.05	ppm

ysis Completed And Reviewed:

Signature J. Maro Date 6-17-85

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ROCKET RESEARCH COMPANY
HYDRAZINE ANALYTICAL FORM
FOR HYDRAZINE MEETING MIL – P – 26536, AMENDMENT 2

Sampled: 7-26-85 Orignator: MEL ALVAREZ Approval: 7/26/85

Due: 7-26-85 Sample ID: N_2H_4 SYSTEM SAMPLE CH.#3 (CERTIFICATION)

te Recieved: 7-26-85 Charge No.: 131467-3520 Control No.: 03866

sition of Sample: DESTROY L/N 80539

ck Upper For All	☐				☐	Check Upper Box For All		
NALYSES EQUESTED	CHK.	ACCEPTABLE VALUES MONOPROPELLANT GRADE % BY WEIGHT	ppm	RESULTS 6432 ARF		ACCEPTABLE VALUES HIGH PURITY GRADE % BY WEIGHT	ppm	RESULTS
N_2H_4		98.50 min.	N/A	99.22 %		99.00 min.	N/A	99.22 %
H_2O		1.00 max.	N/A	0.71 %		1.00 max.	N/A	0.71 %
NH_3		0.40 max.	N/A	0.07 %		0.40 max.	N/A	0.07 %
rganics Excluding Aniline		0.020 max.	200	6 ppm		0.005 max.	50	6 ppm
Aniline		0.50 max.	N/A	14 PPM		0.005 max.	50	14 ppm
Total Nonvolatiles (NVR)		0.0020 max.	20	3 ppm		0.0010 max	10	3 ppm
Particulate		1 mg/L max.	N/A	0.0 mg/L		1 mg/L max.	N/A	0 mg/L
Corrosivity		0.00125 % Fe max.	12.5	1.7 ppm		0.00125 % Fe max.	12.5	1.7 ppm
Chloride		0.0005 max.	5	0.2 ppm		0.0005 max.	5	0.2 ppm
Iron		0.0002 max.	2	0.5 ppm		0.0002 max.	2	0.5 ppm
CO_2		0.0030 max.	30	8 ppm		0.0030 max.	30	8 ppm
Silicon OPTIONAL)	N/A	0.000005 max.	0.05	— ppm	N/A	0.000005 max.	0.05	— ppm

sis Completed And Reviewed:

Signature A. Fields Date 7-26-85

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ROCKET RESEARCH COMPANY
HYDRAZINE ANALYTICAL FORM
FOR HYDRAZINE MEETING MIL – P – 26536, AMENDMENT 2

D :e Sampled: 11-22-85 Orignator: R. MEHL Approval: Ray Mehl

D :e Due: ____________ Sample ID: CHAMBER #4 FUEL SYSTEM

Date Recieved: ____________ Charge No.: 131568-2100 Control No.: 0405D

D..position of Sample: DESTROY

heck Upper lox For All →	☒	NO RGM			☒	← Check Upper Box For All		
ANALYSES REQUESTED	**CHK.**	**ACCEPTABLE VALUES MONOPROPELLANT GRADE**		**RESULTS**		**ACCEPTABLE VALUES HIGH PURITY GRADE**		**RESULTS**
		% BY WEIGHT	**ppm**			**% BY WEIGHT**	**ppm**	
N_2H_4		98.50 min.	N/A	%		99.00 min.	N/A	99.0 %
H_2O		1.00 max.	N/A	%		1.00 max.	N/A	0.81 %
NH_3		0.40 max.	N/A	%		0.40 max.	N/A	0.19 %
...ce Organics Excluding Aniline		0.020 max.	200	ppm		0.005 max.	50	NONE DETECTED ppm
Aniline		0.50 max.	N/A	%		0.005 max.	50	11.0 ppm
Total Nonvolatiles (NVR)		0.0020 max.	20	ppm		0.0010 max	10	7 ppm
Particulate		1 mg/L max.	N/A	mg/L		1 mg/L max.	N/A	0 mg/L
Corrosivity		0.00125 % Fe max.	12.5	ppm		0.00125 % Fe max.	12.5	0.9 ppm
Chloride		0.0005 max.	5	ppm		0.0005 max.	5	0.4 ppm
Iron		0.0002 max.	2	0.7 ppm		0.0002 max.	2	0.7 ppm
CO_2		0.0030 max.	30	ppm		0.0030 max.	30	5 ppm
Silicon (OPTIONAL)	N/A	0.000005 max.	0.05	ppm	N/A	0.000005 max.	0.05	— ppm
	NO RGM							

sis Completed And Reviewed:

Signature J. Mars Date 12-10-85

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