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

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
Redmond, Washington
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(FINAL)

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Prepared and approved by:

D. R. Johnson
Project Manager

THIS REPORT DOES NOT IDENTIFY "NEW TECHNOLOGY" ITEMS.

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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.
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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 photographs 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 desirable 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:

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

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 (GN₂) 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

FIRST 25,000 PULSES
(INITIAL PROGRAM)

SECOND 25,000 PULSES
(FOLLOW-ON PROGRAM)

THIRD 25,000 PULSES
(FOLLOW-ON PROGRAM)

LEGEND
○ SHORT PULSE TEST
◇ CHARACTERIZATION TEST

ACCUMULATED LIFE PULSES
VOYAGER 0.24fl T/VA SHORT PULSE TEST FLOW PLAN
FIRST 25,000 PULSES

RECEIVING INSPECTION

MODIFY T/VA FOR TESTS
- INSTALL PRESSURE TRANSDUCER

PREFIRE FUNCTIONAL TESTS
- VALVE RESPONSE
- GN₂ FLOW
- PROOF PRESSURE
- EXTERNAL LEAK
- INTERNAL LEAK
- HEATER RESISTANCE

T/VA CHARACTERIZATION TEST 1
- PULSE MODE @ Pₕ = 350 psia
- STEADY-STATE @ Pₕ = 350 psia
- STEADY-STATE @ P₂ = 150 psia

SHORT PULSE TEST 1
- P₂ = 220 psia
- ON TIME 10 TO 3 ms
- OFF TIME 60 sec.

SHORT PULSE TEST 5
- P₂ = 220 psia
- ON TIME 10 TO 3 ms
- OFF TIME 60 sec.

ABBREVIATED LIFE TEST 1
- 6,000 PULSES
- P₂ = 220 psia
- ON TIME 3.3 - 3.5 ms
- OFF TIME 30 sec.

SHORT PULSE TEST 4
- P₂ = 190 psia
- REVERSE ORDER
- ON TIME 3 TO 10 ms
- OFF TIME 60 sec.

SHORT PULSE TEST 3
- P₂ = 190 psia
- ON TIME 10 TO 3 ms
- OFF TIME 60 sec.

SHORT PULSE TEST 2
- P₂ = 220 psia
- REVERSE ORDER
- ON TIME 3 TO 10 ms
- OFF TIME 60 sec.

ABBREVIATED LIFE TEST 2
- 6,000 PULSES
- P₂ = 220 psia
- ON TIME 4 ms
- OFF TIME 30 sec.

SHORT PULSE TEST 6
- P₂ = 220 psia
- ON TIME 10 TO 3 ms
- OFF TIME 60 sec.

ABBREVIATED LIFE TEST 3
- 10,000 PULSES
- P₂ = 220 psia
- ON TIME
- OFF TIME 30 sec.

SHORT PULSE TEST 7
- P₂ = 220 psia
- ON TIME 10 TO 3 ms
- OFF TIME 60 sec.

ABBREVIATED LIFE TEST 4
- 6,000 PULSES
- P₂ = 220 psia
- ON TIME
- OFF TIME 30 sec.

POST FIRE FUNCTIONAL TESTS
- VALVE RESPONSE
- GN₂ FLOW
- PROOF PRESSURE
- EXTERNAL LEAK
- INTERNAL LEAK
- HEATER RESISTANCE

T/VA CHARACTERIZATION TEST 2
- PULSE MODE @ P₂ = 350 psia
- STEADY-STATE @ P₂ = 350 psia
- STEADY-STATE @ P₂ = 150 psia

SHORT PULSE TEST 8
- P₂ = 220 psia
- ON TIME 10 TO 3 ms
- OFF TIME 60 sec.

WRITTEN REPORT

POST FIRE T/VA DECON - TAMINATION
- GN₂ PURGES
- VACUUM BAKE

S/N 019 - 3.7 ms
S/N 020 - 3.7 ms
S/N 022 - 3.7 ms
VOYAGER 0.2 lb T/VA SHORT PULSE TEST FLOW PLAN
SECOND 25,000 PULSES

- Prefire Functional Tests
  - Valve Response
  - \( \text{N}_2 \) Flow
  - External Leak
  - Internal Leak
  - Heater Resistance

- T/VA Characterization Test 1 A
  - Pulse Mode at \( P_F \) 350 psia
  - Steady-State at \( P_F \) 350 psia
  - Steady-State at \( P_F \) 150 psia

**Short Pulse Test 3 A**
- \( P_F \) = 220 psia
- On Time 10 to 3 ms
- Off Time 30 sec.

**Abbreviated Life Test 2 A**
- 5,000 Pulses
- \( P_F \) = 220 psia
- On Time
- Off Time 30 sec.

**Abbreviated Life Test 3 A**
- 5,000 Pulses
- \( P_F \) = 220 psia
- Off Time 30 sec.

**Short Pulse Test 4 A**
- \( P_F \) = 220 psia
- On Time 10 to 3 ms
- Off Time 30 sec.

**Abbreviated Life Test 4 A**
- 5,000 Pulses
- \( P_F \) = 220 psia
- On Time
- Off Time 30 sec.

**Short Pulse Test 5 A**
- \( P_F \) = 220 psia
- On Time 10 to 3 ms
- Off Time 30 sec.

**Abbreviated Life Test 5 A**
- 5,000 Pulses
- \( P_F \) = 220 psia
- On Time
- Off Time 30 sec.

**Post Fire T/VA Decontamination**
- \( \text{N}_2 \) Purges
- Vacuum Bake

**T/VA Characterization Test 2 A**
- Pulse Mode at \( P_F \) 350 psia
- Steady-State at \( P_F \) 350 psia
- Steady-State at \( P_F \) 150 psia

\* S/N 021 = 10.0 ms
S/N 018 = 3.6 ms
S/N 019 = 3.7 ms
S/N 022 = 3.7 ms
VOYAGER 0.2 lbf T/VA SHORT PULSE TEST FLOW PLAN
THIRD 25,000 PULSES

Figure 24

* S/N 021 - 10.0 ms
  S/N 016 - 3.8 ms
  S/N 019 - 3.7 ms
  S/N 022 - 3.7 ms
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>
<thead>
<tr>
<th>Test Sequence</th>
<th>Propellant Feed Pressure (psia)</th>
<th>No. of Pulses</th>
<th>On Time (sec)</th>
<th>Off Time (sec)</th>
<th>Initial Temp. (°F)</th>
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<tr>
<td>1</td>
<td>350 ± 5</td>
<td>100</td>
<td>0.020</td>
<td>3.98</td>
<td>325 ± 25</td>
</tr>
<tr>
<td>2</td>
<td>350 ± 5</td>
<td>20</td>
<td>0.10</td>
<td>0.90</td>
<td>Existing</td>
</tr>
<tr>
<td>3</td>
<td>350 ± 5</td>
<td>1</td>
<td>200</td>
<td>—</td>
<td>Existing</td>
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<tr>
<td>4</td>
<td>150 ± 5</td>
<td>1</td>
<td>200</td>
<td>—</td>
<td>Existing</td>
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</tbody>
</table>

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

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

Table 2-2
SHORT PULSE WIDTH TEST DUTY CYCLES
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

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

*On Time (milliseconds)
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 ($P_e$) 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
Figure 3.4

T/VA FIRING TEST SETUP

THERMAL CONDITION SYSTEM

ALTITUDE CHAMBER

TO VACUUM PUMPS

GN₂ VAPOR TRAP

LIQUID TRAP

DEIONIZED WATER

REGULATED G₂ SOURCE

SIGHTGLASSES

ENABLE VALVE

PRESSURIZATION SOURCE

10µ FILTER

REGULATING SYSTEM

PRESSURIZATION VALVE

VENT

RELIEF

ISOLATION VALVE

TANK SELECT VALVE

FILL & DRAIN VALVE

VACUUM
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Range</th>
<th>Recording Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber pressure — Thruster</td>
<td>$P_c$</td>
<td>0 — 300 psia and 0 — 50 psia</td>
<td>—  X  X</td>
</tr>
<tr>
<td>Propellant feed pressure</td>
<td>$P_f$</td>
<td>0 — 400 psig</td>
<td>—  X  X</td>
</tr>
<tr>
<td>Propellant temperature</td>
<td>$T_f$</td>
<td>0 — 5 mv</td>
<td>—  —  X</td>
</tr>
<tr>
<td>Altitude chamber pressure</td>
<td>$P_a$</td>
<td>0 — 1 psia</td>
<td>—  —  X</td>
</tr>
<tr>
<td>Sightglass level</td>
<td>$HSG$</td>
<td>N/A</td>
<td>—  —  Manual</td>
</tr>
<tr>
<td>Valve voltage</td>
<td>$V_E$</td>
<td>0 — 30 vdc</td>
<td>—  X  X</td>
</tr>
<tr>
<td>Valve current</td>
<td>$I$</td>
<td>0 — 0.25 amps</td>
<td>—  X  X</td>
</tr>
<tr>
<td>Thruster heater voltage</td>
<td>$V_H$</td>
<td>0 — 30 vdc</td>
<td>—  —  —</td>
</tr>
<tr>
<td>Thrust chamber temperature</td>
<td>$T_C$</td>
<td>0 — 50 mv</td>
<td>X  —  X</td>
</tr>
</tbody>
</table>
AUTOMATIC TEST CONTROL SYSTEM
DIGITAL DATA ACQUISITION SYSTEM
HIGH-SPEED DIGITAL DATA SYSTEM
BLOCK DIAGRAM

TEST DATA
DATA AMPLIFIERS

A/D
MUX

NOVA 1200 COMPUTER

TTY INTERFACE

START/STOP CONTROLLER
DISABLE START

MTU INTERFACE
MAGNETIC TAPE ADAPTER
MAGNETIC TAPE UNIT
MAGNETIC DATA TAPE

KEY:

_selector ANALOG DATA
_selector DIGITAL DATA
_selector CONTROL SIGNALS
_selector STATUS SIGNALS

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.

3.6 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\textsubscript{bit}) and specific impulse (I\textsubscript{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/\(^{\circ}\)F \( \times 10^6 \)
  - \( T \) = measured nozzle temperature, \(^{\circ}\)F.

- \( A_{tc} = A_{tm} \times C_d \times (1 + 2a \times (T-70)) \)
  
  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/\(^{\circ}\)F \( \times 10^6 \)
  - \( T \) = measured nozzle temperature, \(^{\circ}\)F
  - \( C_d \) = discharge coefficient = 0.9986

- \( C_{fss} = 1.55023 \times P_c^{0.0222886} \)
  
  where:
  - \( C_{fss} \) = steady-state thrust coefficient.
  - \( P_c \) = measured chamber pressure, psia
\[ C_{fpm} = \frac{3.178}{(T^0.06896 \cdot \int P_{cdt}^t/(23.07 + 0.0093681 \cdot T))} \]

where:

- \( C_{fpm} \) = pulse mode thrust coefficient
- \( T \) = chamber temperature, \(^\circ\)F
- \( \int P_{cdt} \) = time integral of chamber pressure, psia-sec

\[ F_v = P_c \cdot A_{tc} \cdot C_{fss} \]

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

\[ I_{bit} = \int P_{cdt} \cdot A_{tc} \cdot C_{fpm} \]

where:

- \( I_{bit} \) = pulse mode impulse bit, lbf-sec
- \( \int P_{cdt} \) = 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 temperature, \(^\circ\)F

\[ \dot{w} = RHO \cdot K \cdot D/(T \cdot 3785.4) \]

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.
\[ W_p = \text{RHO} \times K \times D(3785.4 \times N) \]

where:
- \( W_p \) = per pulse propellant consumption, lbm
- \( \text{RHO} \) = 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

\[ I_{sp_{ss}} = \frac{F_v}{\dot{w}} \]

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

\[ I_{sp_{pm}} = \frac{I_{bit}}{W_p} \]

where:
- \( I_{sp_{pm}} \) = pulse mode specific impulse, lbf-sec/lbm
- \( I_{bit} \) = pulse mode bit, lbf-sec
- \( W_p \) = pulse propellant consumption, lbm

\[ C_{ss}^* = \frac{P_c \times A_{tc}}{g/\dot{w}} \]

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

\[ C_{pm}^* = \int P_c \, dt \times A_{tc} \times g/\dot{w} \]

where:
- \( C_{pm}^* \) = pulse mode characteristic velocity, ft/sec
- \( \int P_c \, dt \) = time integral of chamber pressure, psia-sec


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

In addition, the following relationships are true:

- \( T_I = \text{response time from valve-on signal to 10\% of the average chamber pressure, msec.} \)
- \( T_R = \text{response time from valve-on signal to 90\% of the average chamber pressure, msec.} \)
- \( T_D = \text{decay time from valve-off signal to 10\% of the average chamber pressure, msec.} \)

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 omitted, 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

P_{f} = 220 psd

Figure 4-1
JPL MJS 0.2-LBF REA SHORT PULSE TEST 8

Figure 4-3

IMPULSE BIT VERSUS ELECTRICAL PULSE WIDTH

- ○ S/N 020
- ▲ S/N 016
- □ S/N 019
- ▼ S/N 022

P_t = 220 psia
JPL MJS 0.2-LBF REA SHORT PULSE TEST 1A

Impulse Bit Versus Electrical Pulse Width

Figure 4A

Electrical Pulse Width (Milliseconds)
JPL MJS 0.2-LBF REA SHORT PULSE TEST 1

AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH

\[ P_1 = 220 \text{ psi} \]

Average of S/Ns 016, 019, & 022

Electrical Pulse Width (Milliseconds) vs. Impulse Bit x 100 (LBF-SEC)
Figure 4-8
JPL MJS 0.2-LBF REA SHORT PULSE TEST 8

AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH

\( P_f = 220 \text{ psia} \)

Average of S/N's 015, 019, & 022

Figure 4.9
JPL MJS 0.2-LBF REA SHORT PULSE TEST 1A

AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH

AVERAGE OF S/N's 016, 019, 022

Pf = 220 psi

Figure 4-10
Figure 4-11
JPL MJS 0.2-LBF REA SHORT PULSE TEST 12A

AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ELECTRICAL PULSE WIDTH

AVERAGE OF S/N's 016, 013, 022

FP = 228 ps/4a

IMPULSE BIT X 100 (LBF-SEC)

ELECTRICAL PULSE WIDTH (MILLISECONDS)
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 TESTS

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

AVERAGE OF S/N's 619, 819, 822
PF = 229 ft/sec

- SHORT PULSE TEST 1 A
- SHORT PULSE TEST 8 A
- SHORT PULSE TEST 12 A

PERCENT OF IMPULSE BIT AT EPW=10 MSEC

ELECTRICAL PULSE WIDTH (MILLISECONDS)
JPL MJS 0.2-LBF REA SHORT PULSE TEST 1

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

$P_1 = 220 \text{ psl}$

IMPULSE BIT VARIATION (% DIFFERENCE)

Figure 4-15
JPL MJS 0.2-LBF REA SHORT PULSE TEST 5

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

P = 220 psia

S/N 020
S/N 016

S/N 019
S/N 022

ELECTRICAL PULSE WIDTH (MILLISECONDS)
Figure 4.17

JPL MJS 0.2-LBF REA SHORT PULSE TEST 8

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

P_f = 220 psia

S/N 828
S/N 818
S/N 818
S/N 822

IMULSE BIT VARIATION (% DIFFERENCE)

ELECTRICAL PULSE WIDTH (MILLISECONDS)
Figure 4.20

JPL MJS 0.2-LBF REA SHORT PULSE TEST 12A

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

- S/N 021
- S/N 016
- S/N 018
- S/N 022

IMPULSE BIT VARIATION (% DIFFERENCE)

ELECTRICAL PULSE WIDTH (MILLISECONDS)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust —</td>
<td>3</td>
<td>0.093 — 0.258</td>
<td>0.093 — 0.258</td>
<td>0.093 — 0.258</td>
<td>0.093 — 0.258</td>
<td>0.093 — 0.258</td>
<td>0.093 — 0.258</td>
</tr>
<tr>
<td>Swayline</td>
<td>4</td>
<td>0.093 — 0.102</td>
<td>0.093 — 0.102</td>
<td>0.093 — 0.102</td>
<td>0.093 — 0.102</td>
<td>0.093 — 0.102</td>
<td>0.093 — 0.102</td>
</tr>
<tr>
<td>Specific</td>
<td>3</td>
<td>0.250 — 0.340</td>
<td>0.250 — 0.340</td>
<td>0.250 — 0.340</td>
<td>0.250 — 0.340</td>
<td>0.250 — 0.340</td>
<td>0.250 — 0.340</td>
</tr>
<tr>
<td>Impulse —</td>
<td>4</td>
<td>0.250 — 0.101</td>
<td>0.250 — 0.101</td>
<td>0.250 — 0.101</td>
<td>0.250 — 0.101</td>
<td>0.250 — 0.101</td>
<td>0.250 — 0.101</td>
</tr>
<tr>
<td>Swayline</td>
<td>(ms/sec/ampere)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Roughtness—</td>
<td></td>
<td>5.00 — 7.00</td>
<td>5.00 — 7.00</td>
<td>5.00 — 7.00</td>
<td>5.00 — 7.00</td>
<td>5.00 — 7.00</td>
<td>5.00 — 7.00</td>
</tr>
<tr>
<td>Swayline</td>
<td>(%)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Rise response —</td>
<td></td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Swayline</td>
<td>(%)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Delay response —</td>
<td></td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Swayline</td>
<td>(%)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Impulse —</td>
<td>(%)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Responsivity</td>
<td>(%)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Rise response —</td>
<td>(%)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
<tr>
<td>Swayline</td>
<td>(%)</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
<td>3.00 — 5.00</td>
</tr>
</tbody>
</table>
JPL MJS 0.2-LBF REA SHORT PULSE TEST

AVERAGE IMPULSE BIT OF THREE TEST REAS VERSUS ACCUMULATED LIFE

IMULSE BIT X 100 (LBF-SEC)

ACCUMULATED LIFE (1000 PULSES)
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 (GN₂) 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.
Figure 4-23
<table>
<thead>
<tr>
<th>S/N</th>
<th>T/VA</th>
<th>G\textsubscript{N}2 Flow (ml/min)</th>
<th>ATP</th>
<th>Pre-Fire 5 psig</th>
<th>10 psig</th>
<th>Post-Fire 5 psig</th>
<th>10 psig</th>
<th>Valve Opening Response Time (ms)</th>
<th>Pre-Fire</th>
<th>Post-Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>155</td>
<td>189</td>
<td>263</td>
<td>186</td>
<td>275</td>
<td>5.0</td>
<td>296</td>
<td>3.5</td>
<td>3.8</td>
<td>3.2</td>
</tr>
<tr>
<td>19</td>
<td>160</td>
<td>181</td>
<td>268</td>
<td>161</td>
<td>275</td>
<td>5.5</td>
<td>254</td>
<td>3.5</td>
<td>3.0</td>
<td>5.2</td>
</tr>
<tr>
<td>20</td>
<td>173</td>
<td>178</td>
<td>293</td>
<td>28</td>
<td>36</td>
<td>5.5</td>
<td>30</td>
<td>4.0</td>
<td>6.0</td>
<td>4.1</td>
</tr>
<tr>
<td>22</td>
<td>160</td>
<td>160</td>
<td>263</td>
<td>150</td>
<td>289</td>
<td>6.0</td>
<td>243</td>
<td>4.5</td>
<td>6.0</td>
<td>4.0</td>
</tr>
<tr>
<td>21</td>
<td>168</td>
<td>185</td>
<td>275</td>
<td>184</td>
<td>280</td>
<td>5.5</td>
<td>184</td>
<td>3.3</td>
<td>4.1</td>
<td>5.5</td>
</tr>
</tbody>
</table>
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 plus 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
# 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 Beach

<table>
<thead>
<tr>
<th>Constituents</th>
<th>MJS77 Hydrazine Specification</th>
<th>Analysis of Drum No. H-5300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrazine (percent by weight)</td>
<td>98.5 min</td>
<td>99.4</td>
</tr>
<tr>
<td>Water (percent by weight)</td>
<td>0.5 to 1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Particulate (mg/l)</td>
<td>1.0 max</td>
<td>0.2</td>
</tr>
<tr>
<td>Chloride (percent by weight)</td>
<td>0.0005 max</td>
<td>0.002</td>
</tr>
<tr>
<td>Aniline (percent by weight)</td>
<td>0.005 max</td>
<td>0.002</td>
</tr>
<tr>
<td>Iron (percent by weight)</td>
<td>0.002 max</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nonvolatile Residue (percent by weight)</td>
<td>0.005 max</td>
<td>0.001%</td>
</tr>
<tr>
<td>Carbon Dioxide (percent by weight)</td>
<td>0.005 max</td>
<td>0.002</td>
</tr>
<tr>
<td>Other Volatile Carbonaceous Material, i.e., UDH, MH, Alcohol (percent by weight)</td>
<td>0.02 max</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ammonia (percent by weight)</td>
<td>0.4 max</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Visual Observations and Remarks:**

---

**ORIGINAL PAGE OF POOR QUALITY**
**ROCKET RESEARCH COMPANY**  
**HYDRAZINE ANALYTICAL FORM**  
**FOR HYDRAZINE MEETING MIL - P - 26536, AMENDMENT 1**

- **Sampled:** 6-5-84  
- **Originator:** R. MEHL  
- **Due:** 6-5-84  
- **Sample ID:** DRUM H 8300  
- **Charge No.:** 131522-3300  
- **Control No.:** 03653

**Disposition of Sample:** DESTROY

<table>
<thead>
<tr>
<th>ANALYSES REQUESTED</th>
<th>CHECK</th>
<th>ACCEPTABLE VALUES</th>
<th>RESULTS</th>
<th>CHK.</th>
<th>ACCEPTABLE VALUES</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NONPROPELLANT</td>
<td></td>
<td></td>
<td>HIGH PURITY</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>GRADE</td>
<td>% BY WEIGHT</td>
<td>ppm</td>
<td>GRADE</td>
<td>% BY WEIGHT</td>
</tr>
<tr>
<td><strong>N₂H₄</strong></td>
<td></td>
<td>98.50 min.</td>
<td>N/A</td>
<td>%</td>
<td>98.50 min.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>H₂O</strong></td>
<td></td>
<td>1.00 max.</td>
<td>N/A</td>
<td>%</td>
<td>0.00 max.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>NH₃</strong></td>
<td></td>
<td>0.40 max.</td>
<td>N/A</td>
<td>%</td>
<td>0.40 max.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Total Organics</strong></td>
<td></td>
<td>0.020 max.</td>
<td>200 ppm</td>
<td></td>
<td>0.020 max.</td>
<td>26 ppm</td>
</tr>
<tr>
<td>Excluding Aniline</td>
<td></td>
<td><strong>Aniline</strong></td>
<td>0.50 max.</td>
<td>N/A</td>
<td><strong>Ammonia</strong></td>
<td>0.85 ppm</td>
</tr>
<tr>
<td><strong>Total Nonvolatiles (NVR)</strong></td>
<td></td>
<td>0.0020 max.</td>
<td>20 ppm</td>
<td></td>
<td>0.00125 % Fe max.</td>
<td>13 ppm</td>
</tr>
<tr>
<td><strong>Particulate</strong></td>
<td></td>
<td>1 mg/L max.</td>
<td>N/A</td>
<td>mg/L</td>
<td>1 mg/L max.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Corrosivity</strong></td>
<td></td>
<td>0.00125 % Fe max.</td>
<td>12.5 ppm</td>
<td></td>
<td>0.00125 % Fe max.</td>
<td>0.05 ppm</td>
</tr>
<tr>
<td><strong>Chloride</strong></td>
<td></td>
<td>0.0005 max.</td>
<td>5 ppm</td>
<td></td>
<td>0.0005 max.</td>
<td>0.2 ppm</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td></td>
<td>0.0002 max.</td>
<td>2 ppm</td>
<td></td>
<td>0.0002 max.</td>
<td>0.2 ppm</td>
</tr>
<tr>
<td><strong>CO₂</strong></td>
<td></td>
<td>0.0030 max.</td>
<td>30 ppm</td>
<td></td>
<td>0.0030 max.</td>
<td>5 ppm</td>
</tr>
<tr>
<td><strong>Silicon (OPTIONAL)</strong></td>
<td></td>
<td>0.000005 max.</td>
<td>0.05 ppm</td>
<td></td>
<td>0.000005 max.</td>
<td>8.2 ppm</td>
</tr>
</tbody>
</table>

**0.2 ppm**

**F(31/82)**

**Completed And Reviewed:**

- **Signature:** J. Mars
- **Date:** 6-7-84
**HYDRAZINE ANALYTICAL FORM**

**FOR HYDRAZINE MEETING MIL-P-26536, AMENDMENT 1**

**Compiled:** 8-17-86  **Originator:** MIL ALVAREZ  **Approval:**

**Due Date:** 8-20-86  **Sample ID:** N4H4 SYSTEM SAMPLE CH.4 SYSTEM CERT.

**Received:** 8-17-86  **Charge No.:** 1647-3-4600  **Control No.:** 63609

**Disposition of Sample:** DESTROY

<table>
<thead>
<tr>
<th>ANALYSES REQUESTED</th>
<th>CHK.</th>
<th>ACCEPTABLE VALUES MONOPROPELLANT GRADE % BY WEIGHT ppm</th>
<th>RESULTS</th>
<th>ACCEPTABLE VALUES HIGH PURITY GRADE % BY WEIGHT ppm</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2H4</td>
<td></td>
<td>98.50 min. N/A</td>
<td>%</td>
<td>98.50 min. N/A</td>
<td>99.19 %</td>
</tr>
<tr>
<td>H2O</td>
<td></td>
<td>1.00 max. N/A</td>
<td>%</td>
<td>1.00 max. N/A</td>
<td>0.70 %</td>
</tr>
<tr>
<td>NH3</td>
<td></td>
<td>0.40 max. N/A</td>
<td>%</td>
<td>0.40 max. N/A</td>
<td>0.11 %</td>
</tr>
<tr>
<td>Organic Trace</td>
<td></td>
<td>0.020 max. 200 ppm</td>
<td></td>
<td>0.020 max. 200 ppm</td>
<td>3.5 ppm</td>
</tr>
<tr>
<td>Aniline</td>
<td></td>
<td>0.50 max. N/A</td>
<td>%</td>
<td>0.005 max. 60</td>
<td>15 ppm</td>
</tr>
<tr>
<td>Total Non-volatiles (NVR)</td>
<td>0.0020 max. 20 ppm</td>
<td>ppm</td>
<td>0.0010 max. 10</td>
<td>2 ppm</td>
<td></td>
</tr>
<tr>
<td>Particulates</td>
<td></td>
<td>0.0005 max. 5</td>
<td>ppm</td>
<td>0.0005 max. 5</td>
<td>0.5 ppm</td>
</tr>
<tr>
<td>Corrosivity</td>
<td></td>
<td>0.00125 % Fe max. 12.5 ppm</td>
<td>ppm</td>
<td>0.00125 % Fe max. 12.5 ppm</td>
<td>0.8 ppm</td>
</tr>
<tr>
<td>Chloride</td>
<td></td>
<td>0.0005 max. 6</td>
<td>ppm</td>
<td>0.0005 max. 5</td>
<td>0.5 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td>0.0002 max. 2</td>
<td>ppm</td>
<td>0.0002 max. 2</td>
<td>0.5 ppm</td>
</tr>
<tr>
<td>CO2</td>
<td></td>
<td>0.0030 max. 30</td>
<td>ppm</td>
<td>0.0030 max. 30</td>
<td>5 ppm</td>
</tr>
<tr>
<td>Silicon (optional)</td>
<td></td>
<td>0.000005 max. 0.05 ppm</td>
<td>ppm</td>
<td>0.000005 max. 0.05 ppm</td>
<td>0.05 ppm</td>
</tr>
</tbody>
</table>

**Analysis Completed And Reviewed:**

**Signature:** J. Miles  **Date:** 8-20-86
**ROCKET RESEARCH COMPANY**

**HYDRAZINE ANALYTICAL FORM**

**FOR HYDRAZINE MEETING MIL - P - 26536, AMENDMENT 2**

---

**Date Received:** 6-14-85  
**Charge No.:** 151539-4300  
**Control No.:** 03828  
**Sample ID:** N2Hy chamber RESAMPLE

---

**Acceptable Values**

**Monopropellant**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptable Value</th>
<th>Results</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>N\textsubscript{2}H\textsubscript{4}</td>
<td>98.50 min.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>H\textsubscript{2}O</td>
<td>1.00 max.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>NH\textsubscript{3}</td>
<td>0.40 max.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Trace Organics Excluding Aniline</td>
<td>0.020 max.</td>
<td>V</td>
<td>200 ppm</td>
</tr>
<tr>
<td>Aniline</td>
<td>0.50 max.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Total Nonvolatiles (NVR)</td>
<td>0.0020 max.</td>
<td>X</td>
<td>20 ppm</td>
</tr>
<tr>
<td>Particulate</td>
<td>1 mg/L max.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Corrosivity</td>
<td>0.00125 % Fe max.</td>
<td>X</td>
<td>12.5 ppm</td>
</tr>
<tr>
<td>Chloride</td>
<td>0.0005 max.</td>
<td>X</td>
<td>5 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0002 max.</td>
<td>X</td>
<td>2 ppm</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>0.0030 max.</td>
<td>X</td>
<td>30 ppm</td>
</tr>
<tr>
<td>Silicon (Optional)</td>
<td>0.0000005 max.</td>
<td>X</td>
<td>0.05 ppm</td>
</tr>
</tbody>
</table>

**High Purity Grade**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptable Value</th>
<th>Results</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>N\textsubscript{2}H\textsubscript{4}</td>
<td>99.00 min.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>H\textsubscript{2}O</td>
<td>1.00 max.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>NH\textsubscript{3}</td>
<td>0.40 max.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Organic Excluding Aniline</td>
<td>0.005 max.</td>
<td>V</td>
<td>50 ppm</td>
</tr>
<tr>
<td>Aniline</td>
<td>0.005 max.</td>
<td>X</td>
<td>50 ppm</td>
</tr>
<tr>
<td>Total Nonvolatiles (NVR)</td>
<td>0.0010 max</td>
<td>X</td>
<td>10 ppm</td>
</tr>
<tr>
<td>Particulate</td>
<td>1 mg/L max.</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Corrosivity</td>
<td>0.00125 % Fe max.</td>
<td>X</td>
<td>12.5 ppm</td>
</tr>
<tr>
<td>Chloride</td>
<td>0.0005 max.</td>
<td>X</td>
<td>5 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0002 max.</td>
<td>X</td>
<td>2 ppm</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>0.0030 max.</td>
<td>X</td>
<td>30 ppm</td>
</tr>
<tr>
<td>Silicon (Optional)</td>
<td>0.0000005 max.</td>
<td>X</td>
<td>0.05 ppm</td>
</tr>
</tbody>
</table>

---

Signature:  
Date: 4-17-85

---

1636 A (2/85)
**ROCKET RESEARCH COMPANY**

**HYDRAZINE ANALYTICAL FORM**

**FOR HYDRAZINE MEETING MIL-P-26536, AMENDMENT 2**

---

**Sample:** 7-26-85  
**Originator:** MEZ HUAREZ  
**Approval:** [Signature]  
**Due:** 7-26-85  
**Sample ID:** HYHY System Sample  
**Charge No.:** 131467-3520  
**Control No.:** 03864  
**Position of Sample:** DESTROY

---

### Acceptable Values

<table>
<thead>
<tr>
<th>Analyses Requested</th>
<th>Monopropellant Grade</th>
<th>High Purity Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% by Weight</td>
<td>ppm</td>
</tr>
<tr>
<td>N₂H₄</td>
<td>98.50 min.</td>
<td>N/A</td>
</tr>
<tr>
<td>H₂O</td>
<td>1.00 max.</td>
<td>N/A</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.40 max.</td>
<td>N/A</td>
</tr>
<tr>
<td>Organics (excluding Aniline)</td>
<td>0.020 max.</td>
<td>200 ppm</td>
</tr>
<tr>
<td>Aniline</td>
<td>0.50 max.</td>
<td>N/A</td>
</tr>
<tr>
<td>Total Nonvolatiles (NVR)</td>
<td>0.0020 max.</td>
<td>20 ppm</td>
</tr>
<tr>
<td>Particulate</td>
<td>1 mg/L max.</td>
<td>N/A</td>
</tr>
<tr>
<td>Corrosivity</td>
<td>0.00125 % Fe max.</td>
<td>12.5 ppm</td>
</tr>
<tr>
<td>Chloride</td>
<td>0.0005 max.</td>
<td>5 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0002 max.</td>
<td>2 ppm</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.0030 max.</td>
<td>30 ppm</td>
</tr>
<tr>
<td>Silicon (optional)</td>
<td>0.000005 max.</td>
<td>0.05 ppm</td>
</tr>
</tbody>
</table>

---

**Analysis Completed And Reviewed:**  
**Signature:** A. Fidler  
**Date:** 7-26-85  
**Reviewed:** [Signature]  
**Date:** 7-26-85  

---

**Page is of Poor Quality**
### ROCKET RESEARCH COMPANY

**HYDRAZINE ANALYTICAL FORM**

**FOR HYDRAZINE MEETING MIL – P – 26536, AMENDMENT 2**

- **Date Sampled:** 11-22-85
- **Ornator:** J. MEHL
- **Approval:** By MEHL
- **Date Due:**
- **Sample ID:** NUMBER #4 FUEL SYSTEM
- **Date Received:**
- **Charge No.:** 131568-2100
- **Control No.:** 04050
- **Position of Sample:** DESTROY

### RESULTS

<table>
<thead>
<tr>
<th>ANALYSES REQUESTED</th>
<th>MONOPROPELLANT GRADE</th>
<th>RESULTS</th>
<th>ACCEPTABLE VALUES HIGH PURITY GRADE</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% by weight ppm</td>
<td></td>
<td>% by weight ppm</td>
<td></td>
</tr>
<tr>
<td>N₂H₄</td>
<td>98.50 min. N/A</td>
<td></td>
<td>99.00 min. N/A</td>
<td>99.0 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>1.00 max. N/A</td>
<td></td>
<td>1.00 max. N/A</td>
<td>0.81 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₃</td>
<td>0.40 max. N/A</td>
<td></td>
<td>0.40 max. N/A</td>
<td>0.19 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>trace Organics Excluding Aniline</em></td>
<td>0.020 max. 200 ppm</td>
<td></td>
<td>0.005 max. 50 ppm Nine DETECTED</td>
<td></td>
</tr>
<tr>
<td>Aniline</td>
<td>0.50 max. N/A</td>
<td></td>
<td>0.005 max. 50 ppm</td>
<td>11.0 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Nonvolatiles (NVR)</td>
<td>0.0020 max. 20 ppm</td>
<td></td>
<td>0.0010 max 10 ppm</td>
<td>0.9 ppm</td>
</tr>
<tr>
<td>Particulate</td>
<td>1 mg/L max. N/A</td>
<td>mg/L</td>
<td>1 mg/L max. N/A</td>
<td>0 mg/L</td>
</tr>
<tr>
<td>Corrosivity</td>
<td>0.00125 % Fe max. 12.5 ppm</td>
<td></td>
<td>0.00125 % Fe max. 12.5 ppm</td>
<td>0.4 ppm</td>
</tr>
<tr>
<td>Chloride</td>
<td>0.0005 max. 5 ppm</td>
<td></td>
<td>0.0005 max. 5 ppm</td>
<td>0.4 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0002 max. 2 ppm</td>
<td>0.7 ppm</td>
<td>0.0002 max. 2 ppm</td>
<td>0.7 ppm</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.0030 max. 30 ppm</td>
<td></td>
<td>0.0030 max. 30 ppm</td>
<td>5 ppm</td>
</tr>
<tr>
<td>Silicon (OPTIONAL)</td>
<td>0.000005 max. 0.05 ppm</td>
<td></td>
<td>0.000005 max. 0.05 ppm</td>
<td>- ppm</td>
</tr>
</tbody>
</table>

---

**Completed And Reviewed:**

Signature: J. MEHL

Date: 12-10-85