Performance testing of a 1 kW arcjet was conducted using catalytically decomposed hydrazine to examine engine and gas generator behavior and validate BPD Facility VP-1 for hydrazine operations. The MOD-B arcjet was used for the test and had a constrictor with a diameter of 0.71 mm and a length of 0.69 mm with an electrode gap of 0.4 mm. Hydrazine was fed to the gas generator at mass flow rates between 47 and 54 mg/s while the thruster operated at powers between 680 W and 1350 W. Comparison of MOD-B engine operation using a gas mixture to simulate hydrazine and catalytically decomposed hydrazine showed that the engine performance was basically the same. This demonstrated that the flight-oriented, regeneratively-cooled design adopted for the engine preheated the gaseous propellants to such a degree as to simulate hydrazine performance.

### NOMENCLATURE

**ARC**
- Atlantic Research Corporation - Liquid Propulsion

**ASTP-3**
- ESA Advanced Space Technology Program 3

**BPD**
- BPD Difesa e Spazio (Company)

**DC**
- Direct Current

**ESA**
- European Space Agency

**ESTEC**
- European Space Research and Technology Center

**GG**
- Gas Generator

**IPA**
- Isopropyl Alcohol

**LVDT**
- Linear Voltage Displacement Transducer

**MOD-B**
- Low Power Arcjet Used For Testing Described in This Paper

**NSSK**
- North-South Station Keeping

**PCU**
- Power Conditioning Unit

**PFS**
- Propellant Feed System

**PLC**
- Programmable Logic Controller

**RRC**
- OLIN Rocket Research Company

**SPT**
- Stationary Plasma Thruster

**SSPA**
- Studio di Sistema Propulsione ad Arcoggetto

**S1**
- Start-Up Unit Capacitor Charging Switch

**S2**
- Start-Up Unit Start Switch

**S3**
- Start-Up Unit Diode/Inductor By Pass Switch

**TRP**
- ESA Technology Research Program

**TZM**
- Molybdenum Alloy

**VP-1**
- Vacuum Facility No. 1 at BPD

**VP-2**
- Vacuum Facility No. 2 at BPD

**2%ThW**
- 2% Thoriated Tungsten Metal

### INTRODUCTION

Several electric propulsion subsystem technologies are presently under development in Europe for orbit maintenance of geostationary satellites; arcjets, ion engines and SPT thrusters. Low power arcjets (1 kW-class) can offer substantial propellant mass savings with respect to currently used chemical propulsion systems due to their higher specific impulse. Arcjet systems also have a lower dry mass and are less complex than ion engine and SPT systems while, based on specific impulse considerations alone, ion engine and SPT systems typically provide a larger propellant mass reduction. Arcjet thrusters also minimize spacecraft integration difficulties with monopropellant or bipropellant chemical systems which include hydrazine while ion engine and SPT systems require a separate propellant feed system. Arcjets also have a much smaller beam divergence angle than either ion or SPT engines easing satellite integration geometric constraints. In addition, SPT thrusters suffer from significantly higher material erosion rates than arcjets (or ion engines). In fact, insulator material is eroded from
SPT engines which, if deposited on the communication satellites antennas, could significantly inhibit the communication systems effectiveness. Therefore, electric propulsion systems based on arcjet thrusters are of particular interest and are presently being developed world-wide.

Laboratory and advanced development work on arcjet technology is ongoing in Italy, Germany, Japan, and the USA with system qualification complete in the USA. Arcjet engines offer specific impulse values of 450 to 600 s using hydrazine while operating power levels of 1 to 2 kW. An arcjet propulsion system will be used operationally starting this year on AT&Ts Telesat 4 commercial telecommunications satellites for North-South station keeping while ion engines will be used for NSSK by Japan and Europe onboard experimental satellites next year and in 1996 respectively. The advent of the usage of arcjet propulsion subsystems within dual-mode satellite propulsion systems for NSSK in the USA has demonstrated the acceptance of this technology for commercial applications. Dual-mode propulsion system usage has included Anik-E and Astra-1B with resistojets for NSSK while AT&Ts Telstar 4, Intelsat 8, EchoStar and Asiasat-2 are all baselined for near-term use with arcjets for NSSK.

Rapid evolution of the low power arcjet development program in Italy to provide European product availability is important to enable realization of a competitive European dual-mode propulsion system. To that end, low power arcjet (0.5 - 2.0 kW) technology development is being conducted at BPD with support from Centospazio within the ESA ASTP-3 Program and with Italian national funding from ASI (SSPA Program) and Centrospazio have installed dedicated facilities to conduct arcjet technology development within the TRP and ASTP-3 programs. Testing of low power arcjets is presently under way at both BPD and Centospazio. The activities at Centospazio are focused on engine modelling and engine operating envelope definition and parametric performance mapping using nitrogen, hydrogen and mixtures of these gases. The test activities at BPD have included parametric performance mapping using nitrogen, hydrogen, ammonia and mixtures of these gases but is now centered toward testing on catalytically decomposed hydrazine and endurance testing.

This paper describes initial low power arcjet parametric test activities using catalytically decomposed hydrazine as the propellant. The MOD-B arcjet was used for these tests along with a gas generator supplied by OLIN Rocket Research Company (RRC). Following a description of the apparatus and facilities, the test procedures are reviewed. Then the results of gas generator acceptance testing at RRC are summarized followed by a discussion of the parametric test results.

**APPARATUS AND FACILITIES**

The MOD-B arcjet design, gas generator configuration and test facilities are reviewed below.

**MOD-B ENGINE DESCRIPTION**

Low power arcjet parametric testing with catalytically decomposed hydrazine was conducted using the MOD-B engine which is shown in Fig. 1. This engine was designed for low cost flexibility in engine geometry changes while trying to better mimic the thermal characteristics of flight-oriented engines than other laboratory model arcjets. Variations in the constrictor dimensions, nozzle area ratio and shape, injector number and diameter, cathode configuration and anode heat rejection scheme are easily implemented with simple parts changeout. Constrictor and nozzle geometry variations are enabled by replacement of the low cost nozzle insert while the heat rejection scheme is easily varied by changing the dimensions of the anode cap. The gas injection scheme can be varied by substitution of the gas injector insert with another having a different number of slots and/or with different diameters. Cathode geometry variations are achieved by the replacing the cathode. In order to try and mimic the thermal characteristics of flight-oriented arcjets, the heat absorbed at the anode attachment point is constrained to the forward section of the engine by the heat radiation from the anode cap surface, the small cross-sectional area of the engine body piece and by the relatively low thermal conductivity graphite gasket used to seal the anode cap to the engine body.

The MOD-B configuration used for the parametric tests included a 2% thoriated tungsten (2%ThW) nozzle insert with a 0.71 mm-diameter and 0.69 mm-long constrictor. The conical nozzle had a 20° half-angle and an area ratio of 100. The propellant was tangentially injected into the plenum chamber through four, 0.5 mm diameter injectors with a semicircular cross-section. The injectors were milled into a molybdenum insert. The cathode was a 3 mm-diameter, 2%ThW rod with a 15 mm-long, 2 mm-diameter front section. The cathode
ended with a conical tip which had an included angle of 60° and a tip radius of 0.3 mm. The cathode was inserted through the rear of the engine and held by a Swagelok connector. The electrode gap was set at 0.4 mm. To eliminate potential problems from the unequal thermal expansion of different materials within the engine, a stainless steel spacer ring was placed within the rear assembly nut to maintain the sealing pressure at the graphite gasket. The compression spring compensated for the different thermal expansions between the boron nitride insulator and the TZM outer engine body and insured continuous contact between the insulator, gas injection insert and anode piece. Hydrazine was injected near the rear of the engine to provide some regenerative cooling of the engine and pre-heating of the propellant.

GAS GENERATOR CONFIGURATION

The BPD requirements for the gas generator (GG) are given Table 1. A laboratory model GG was procured from ARC which met these requirements. In addition, a flight-type unit was procured from RRC which focused on the low flow rate condition. The GG supplied by RRC was used with the MOD-B arcjet for the tests described in this paper and is a version of design qualified for previous hydrazine arcjet thruster flight programs conducted successfully by RRC. The arcjet system developed by RRC includes the arcjet thruster assembly, power conditioning unit and interconnecting power cable. The complete system is shown in Fig. 2 while Fig. 3 identifies the key parts and components of the arcjet thruster assembly. The RRC supplied GG is based on the GG within this system. Propellant is supplied to the arcjet assembly through the fluid resistor inlet. The fluid resistor regulates the flow rate to within the desired values over the propellant feed pressure blowdown range. The device has a high flow impedance. It therefore produces a large pressure differential between the spacecraft feed system and the thruster assembly. The thruster control valve is a series-redundant, dual seat valve which controls propellant flow to the gas generator in an on-off mode. The hydrazine is catalytically and thermally decomposed in the catalyst bed of the gas generator. The decomposition gases then flow through the delivery tube into the arcjet body. In the test stand at BPD, a motorized needle valve takes the place of the fluid resistor to ensure that the system can be properly purged at the conclusion of the test sequence. The GG outlet is connected to the MOD-B propellant inlet as shown in Fig. 4.

FACILITIES AND INSTRUMENTATION

The parametric tests with hydrazine were performed in Facility VP-1 of BPD's Electric Propulsion Laboratory. This facility is described in detail elsewhere and summarized below. The facility is based on a 4.0 m-long, 1.6 m-diameter water-cooled, stainless steel vacuum chamber connected to a vacuum plant composed of a four-stage, Roots blower-based pumping group. The vacuum system provided a pumping speed of 58,000 m³/hr at an inlet pressure of 10⁻² mbar. Bellows were used to damp vibrations through the connecting pipes. A capacitance manometer with an accuracy of ±0.15% of the reading was used to measure the vacuum chamber pressure.

The propellant feed system (PFS) provided a controlled flow of hydrazine to the arcjet/GG assembly. The hydrazine delivery system is shown in Fig. 5. Pressurization of the hydrazine tank is remotely established and maintained. The propellant tank and feed lines up to the thrust stand flexure are temperature conditioned with water jackets to prevent thermal transients which could cause flow measurement errors and create GG operation problems. A mass flowmeter made by Micro Motion is used to measure the flow rate. The meter is calibrated on a flow bench with water an has an uncertainty of ± 1.1%. A Precision Needle Valve connected with a Planetary reducer and energized by a DC motor is used to regulate the hydrazine flow rate instead of the fluid resistor. The hydrazine used for the tests was high purity grade from ERNO (Germany) according to MIL-P-26536 D. The feed system is under the control of the Programmable Logic Controller (PLC) for safety reasons. During the tests all the analog signals from the measurement transducers are acquired, using an HP 44713 A card, by an HP 3852 A DAS and elaborated with the personal computer, HP 200 series Mod. 16.

The power supply system, Fig. 6, was composed of a main power supply and a start up circuit connected in parallel. This system was moved from Facility VP-2 and installed in Facility VP-1 for these tests. The start-up system was composed of a high voltage/low current power supply unit, a 5 µF capacitor bank, a diode block and a 1.4 µH inductor. The matching of the electrical characteristic of the main power supply and the engine was accomplished by a 0 to 11 ohm ballast resistor in series with the thruster. The
variable ballast resistor was also used to reduce the current spike during the capacitor bank discharge and to compensate for the main power supply ramp-up time. The inductor was connected to increase the capacitor bank discharge time and to cut current oscillations during the ignition transient. A by-pass switch was also installed to avoid diode and inductor overheating. Referring to Fig. 6, the capacitor bank was charged by closing switch S1 while switches S2 and S3 were open. Then, the arc was ignited by opening switch S1 and closing switch S2. As soon as the arc was stable, switch S3 was closed to by-pass the diodes and inductor. The start up and run voltages were measured by voltage probes with attenuation factors of 1000 and 100, respectively. The probes had an accuracy of ±3%. A calibrated shunt, in series with the anode current feedline, was used to measured the arcjet current. The current was measured with an accuracy of ±0.5%.

The thrust balance, Fig. 7, was a parallelogram, swing arm-type device. The engine was mounted along the support beam by means of a thermally isolated clamp interface. The thrust was calculated by measuring the support beam displacement using a linear variable displacement transducer (LVDT). The thrust balance calibration was performed by correlating the LVDT output to the displacements caused by sequential application of four known weights. The weights simulated a thrust range of 0.068 to 0.282 N. The sensitivity of the thrust balance was 0.14 N/V. The least squares linear fits indicated that the standard error of the measurement was about ±2 mN corresponding to approximately 1% of the reading. The thrust measurement was affected by a thermal drift of the zero point. Tests indicated that thermal drift was mainly caused by the thermal elongation of the thruster support beam. A comparison of the calibration curves before and after a test indicated that the thermal drift affected the calibration zero offset only. Therefore, the thrust measurements were performed by turning off the engine after each cycle and recording the zero drift. Then the thrust was corrected by subtracting the zero-drift from the measured values.

Temperatures on the body of the engine and GG and on various components of the thrust stand were measured by means of K-type thermocouples. The anode temperature was measured by means of an optical pyrometer with a wavelength range from 0.8 to 1.1 μm and a listed accuracy of ±1 °C. The pyrometer had a spot size of 5 mm at a distance of 1 m.

RESULTS AND DISCUSSION

The test procedures are described below followed by a summary of the GG acceptance tests conducted at RRC and a description of the MOD-B/GG parametric test results.

TESTING PROCEDURES

The procedures included preparing the engine/gas generator assembly for the test cycle; test stand integration; leak testing the system; calibration of the thrust stand; execution of the test; system purging; engine/gas generator component check; and safety status. These steps are described in more detail below.

Engine/GG Assembly Preparation All of the metallic parts were cleaned with alcohol (IPA) and dried with nitrogen. The engine piece parts were then assembled. Prior to positioning the cathode in the engine body, a preliminary leak check was conducted to verify proper engine assembly. The electrode gap was set by inserting the cathode rod into the engine until the cathode tip touched the converging cone of the anode, then pulling back the cathode by the desired gap setting. The gap was measured by means of a micrometer with a resolution of 5 x 10⁻³ mm. A leak check of the assembled engine was made by pressurizing the engine to 4 bar with compressed air. Leaks were detected using a liquid leak detector. The resistance between the cathode and anode was checked for infinite impedance. The engine was then attached to the thrust stand interface and connected to the GG. The thermocouples for monitoring the GG were then installed.

Test Stand Integration The MOD-B engine/GG assembly was then mounted within the test stand of Facility VP-1 as was shown in Fig. 7. This included mounting the assembly on the thrust balance support and making all of the mechanical, electrical and fluid connections. The engine/GG assembly was mounted along the main axis of the thrust stand support bar and aligned horizontally with the point of load application on the calibration weight loading bar. Following engine alignment, the cathode and anode current feed cables were connected. To prevent unexpected arc discharges, the exposed cathode current feed connections were covered with a high temperature resistant insulator. The propellant feed connection was then made.

Engine/Gas Generator Assembly Leak Test A schematic of the propellant feed and purge lines in
the vicinity of the vacuum chamber is shown in Fig. 8. The hydrazine was filtered using a 6 micron absolute filter upstream of the propellant valve, while two 15 micron absolute filters were installed in the purge lines. The flexible propellant feed line is connected to fuel inlet of the gas generator. The pressure transducer has been connected to the gas generator pressure tap using a coiled tube in order to minimize the connection stiffness and its effects on the thrust measurement. The propellant feed line was pressurized to 20 bar with filtered nitrogen to check for leaks in the line connections. No visible leakage was allowed. The pressure was then slowly vented to atmospheric pressure.

Thrust Balance Calibration. Prior to sealing the vacuum chamber and activating the vacuum plant, the thrust measurement balance was aligned to insure accurate and reliable thrust measurements. The alignment controls included:

* Address the DAS software to remove the thrust balance locking mechanism and lift the calibration weights away from the loading bar.

* Control the alignment of the loading bar in the horizontal direction and within the vertical plane of the engine support bar.

* Control the loading and unloading of the weights on the loading bar. Repeat the activity several times to guarantee proper weight application on the bar and seating within the retainer.

* Control the alignment of the LVDT transducer bore within the transducer core with weights applied and removed. The bore must situated near to the center of the core for best performance.

* Lock thrust balance in place and close the vacuum chamber.

After the final pressure was reached in the vacuum chamber, the thrust balance was calibrated. A least squares linear fit was used to determine the thrust balance force versus LVDT voltage correlation. The calibration was repeated until a correlation coefficient of better than 0.9998 was obtained.

Test Execution. High purity grade hydrazine (from ERNO, Germany) was used for testing. The propellant temperature was maintained at 20 ± 5 °C by a water heat exchanger around the feed line. In order to avoid hydrazine combustion due to the adiabatic compressibility of the hydrazine vapors, the feed line was filled and pressurized in increments of 4 bar/min in two steps; 4 bar and 18 bar. The catalyst bed was heated to 90 °C before activating the hydrazine flow through the gas generator/propellant valve. Hydrazine flow was established by opening the inlet valve. The test sequence started at the nominal mass flow rate and current; then, the current was varied in steps of 2 A in the range 8 - 14 A. After ignition, the engine reached steady-state operation and thermal equilibrium before data was collected. The engine power and mass flow rate were then turned off in order to check the thrust balance zero point drift. Data were recorded by the DAS using a sampling rate of 2 s during the start up and 10 s during the test. Data were printed every 60 s. The thrust values were corrected by subtracting the zero-shift measured at the end of each cycle.

Purging of Engine/Gas Generator Assembly. Purging was required only if the vacuum tank (gas generator) was vented to atmospheric pressure. At the completion of the test when all arcjet temperatures were below 200 °C, the propellant line was purged with nitrogen at 2 bar, through the propellant valve, until there were no further signs of hydrazine decomposition, as indicated by the catalyst bed thermocouple. When all temperatures were below 37 °C, the vacuum pumps were turned off and the chamber was backfilled with nitrogen to 1 mbar pressure until all temperatures reached ambient. The vacuum pumps were then restarted and the chamber was evacuated. After the chamber was evacuated the pumps were shut off and the chamber was backfilled with air.

Engine/Gas Generator Component Check. The engine and GG were disassembled at the end of the test. The component conditions and critical dimensions were controlled and documented.

Safety Status. Dedicated documents were written in order to contemplate the immediate actions in the event of a hazardous condition in the plant and the procedures to re-establish a safe environment for the propellant feed system and facility were developed. During normal test operations, it was only necessary to depressurize the hydrazine lines if the time of a test shut-down was less than 24 hours. Otherwise, it was necessary to force the liquid hydrazine back into the storage bottle and evacuate the hydrazine vapor in the lines through the catalytic vent and gas treatment plant.
ACCEPTANCE TESTS AT RRC

After fabrication, the gas generator received a full acceptance test at RRC. The GG was run at three pressure blocks under vacuum with the GG outlet orificed to simulate an attached arcjet. A schematic of the set-up used for testing at RRC is shown in Fig. 9. A Precision Needle Valve connected with a Planetary reducer and energized by a DC motor was used in order to regulate the hydrazine flow rate instead of the fluid resistor. This is because the large pressure drop created by the fluid resistor makes purging and decontaminating the unit very difficult. Initially the feed pressure was set at 250 psia and then the needle valve was adjusted until the mass flow rate was approximately 50 mg/s. The feed pressure was later changed to 210 and then 300 psia for other tests. Data plots were collected for each of the three pressure blocks. Figures 10 and 11 show representative data for the 250 psia case. The data points are plotted each 100 ms and each point represents an average value within a 20 ms band. Figure 12 shows the location of the thermocouples on the gas generator.

RESULTS OF PARAMETRIC TESTS AT BPD

Parametric testing of the MOD-B arcjet/GG assembly was conducted in BPD Facility VP-1. During performance mapping, the flow and thrust measurements were sampled over a 20 s period just prior to the end of the run and averaged by the computer. Post-shutdown zeros were acquired in a similar manner and used to reduce the data. This process was used to eliminate thermal drift error from the thrust measurements. The nominal vacuum pressure during firing was approximately 0.002 mbar. Figure 4 also showed the thermocouple locations for the gas generator and the arcjet. The parametric test matrix which was performed is shown in Table 2. Test cycles were run using a duty cycle of 1 hour on and ½ hour off. The start-up and shut-down sequences of the arcjet and power supply system were manually commanded. A preliminary parametric test was made (see Table 2; sequence IA-4A) in order to verify the proper operation of the test stand, the data acquisition system and to calibrate the needle valve around the nominal flow rate to be investigated. The voltage-current characteristic for this test is shown in Figure 13. Then, two sets of parametric test data were collected (see Table 2; sequences IB-4B and IC-4C) in order to investigate the performance of the arcjet/gas generator assembly around nominal flow rates of 50 mg/s and 55 mg/s, respectively. Plots of voltage vs. current, specific impulse vs. specific power, and thrust and efficiency vs. power are shown in Figs. 14, 15, 16 and 17, respectively. A typical temperature-time history during arcjet/GG operation, recorded during the sequence IC, is shown in Fig. 18.

The data reported in Figs. 14, 15, 16 and 17 shows some scatter. The scatter resulted since it was the difficult to stabilize the hydrazine flow rate due to the test stand configuration. In addition, at the start of each test cycle, the GG was subjected to a transient where the mass flow rate was well above the design limits (more then one order of magnitude) resulting in significant unit overheating. Both of these effects were caused by the large distance between the needle valve (flow restrictor) and GG inlet in our facility (approximately 1 m) which created a large ullage volume. The over limit mass flow rate resulted since when the GG inlet valve was closed, the pressure upstream and downstream of the needle valve equalized at 18 bar. Then, when the inlet valve was opened, the 18 bar downstream pressure caused a flow surge through the GG until the needle valve opening reestablished the proper pressure drop. In addition, this resulted in a large quantity of hydrazine in between the needle valve and GG inlet which had to be purged through the GG by flowing nitrogen through the needle valve. As a result, a large quantity of hydrazine had to pass through the GG at low (below design limit) flow rates during purging. Since continued operation in this configuration would eventually lead to unit failure, future tests will adopt a different test stand set-up.

SUMMARY AND CONCLUSIONS

Parametric testing using the MOD-B arcjet and a gas generator supplied by RRC was performed to examine the performance of the engine/GG assembly and validate BPD Facility VP-1 for hydrazine operations. The MOD-B arcjet geometry used for the test was characterized by a constrictor diameter of 0.71 mm and a length of 0.69 mm with an electrode gap of 0.4 mm. Hydrazine was fed to the gas generator at mass flow rates between 47 and 54 mg/s while the thruster operated at power between 680 W and 1350 W. A comparison of the parametric tests performed on the MOD-B arcjet with a gas mixture to simulate hydrazine and catalytically decomposed hydrazine was made, see Fig. 19. This comparison shows that the performance is basically the same. This is due to the particular design of the MOD-B engine in that the gas inlet is in the rear in order to provide additional cooling of the engine and pre-heating of
the propellant. The preheating of the propellant has increased the performance of the mixture to match the performance of engine operation on hydrazine.

The configuration of the thrust balance inside the vacuum chamber at BPD did not permit the positioning of the arcjet, gas generator and needle valve (including planetary reducer and DC motor) on the same mounting fixture without a severe increase in thrust stand alignment error. This test configuration resulted in large spikes and excessive mass flow when the valve was first opened. Furthermore, oscillation in chamber pressure or engine "sineing" occurred which can reduce the life of the gas generator. Future testing will use a modified test stand set-up to minimize the ullage volume between the needle valve and GG inlet valve.

ACKNOWLEDGMENTS

The authors would like to extend their gratitude to W. Smith, S. Yano, R. Smith and R. Roberts of OLIN Rocket Research Company and J. Gidley, C. Schmidt and M. Roy of ARC Liquid Propulsion for sharing their extensive experience and providing detailed advice on gas generator implementation. The authors would also like to thank M. Magnanini and D. Monaco for operating the facilities and assistance in conducting the tests and C. Parca, R. Sangiorgi and S. Biagiioni for help in system assembly and decontamination.

The activities described in this paper were sponsored by ESA/ESTEC under ASTES-3 Program Contract no. 7632/88/NL/PH within the ASTP-3 program. The contract technical officer for ESA/ESTEC was G. Saccoccia.

REFERENCES


Table 1. Initial Requirements for Gas Generator.

<table>
<thead>
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<th>PARAMETER</th>
<th>VALUE</th>
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<tr>
<td>Overall Hydrazine Flow Rate Range</td>
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<td>Nominal Low Hydrazine Flow Rate</td>
<td>45 mg/s</td>
</tr>
<tr>
<td>Nominal High Hydrazine Flow Rate</td>
<td>200 mg/s</td>
</tr>
<tr>
<td>Chamber Pressure Range</td>
<td>0.5 - 5 bar</td>
</tr>
<tr>
<td>Ammonia Dissociation Range</td>
<td>90 - 100%</td>
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<tr>
<td>Maximum On/Off Cycles</td>
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<td>Maximum Single On Time</td>
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<td>Minimum Bed Life (Goal)</td>
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Table 2. Test Data Set Points For PCU/MOD-B Arcjet Parametric Tests

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<tr>
<th>Sequence No.</th>
<th>Propellant Flow Rate [mg/s]</th>
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<tr>
<td>1A</td>
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</tr>
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<tr>
<td>2B</td>
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Figure 1. Schematic of MOD-B Arcjet.

Figure 2. RRC MR-508 System.
Figure 3. Schematic of MR-508 Arcjet Assembly.

Figure 4. Integrated MOD-B Arcjet/Gas Generator Assembly and Temperature Measurement Points
Figure 5. Hydrazine Feed System of BPD Facility VP-1.

By-pass switch S3

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Figure 15. MOD-B Arcjet/GG Isp/Specific Power Characteristics - Parametric Tests.
Figure 16. MOD-B Arcjet/GG Thrust/Power Characteristics - Parametric Tests.

Figure 17. MOD-B Arcjet/GG Efficiency/Power Characteristics - Parametric Tests.
Figure 18. MOD-B Arcjet/GG Typical Temperature/Time Characteristics (Sequence 1C) - Parametric Tests.

Figure 19. MOD-B Isp/Specific Power Characteristics - Comparison of Simulated Hydrazine and Hydrazine Operation.