Development Status and Performance Metrics of the Advanced NEXT Ion Propulsion System

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Robert E. Thomas[1] and Marcelo C. Gonzalez.[2]
NASA Glenn Research Center, Cleveland, OH, 44135, USA

Rittu R. Samuel[3]
HX5 LLC, Cleveland, OH, 44135, USA

James J. Bontempo[4]
Voyager Technologies, Cleveland, OH, 44130, USA

Keith D. Goodfellow[5] and Chayse A. Aubuchon.[6]
L3Harris, Redmond, WA, 98052, USA

and

Michael J. Patterson[7]
Desert Works Propulsion, Carrizozo, NM, 88301, USA

The Advanced NEXT ion propulsion system is a derivative of the NEXT-C flight design, incorporating modifications that support increased thrust-to-power ratios without significantly altering the system's mass or volume. The primary design modifications are described, which include changes to the discharge cathode assembly, ion optics, and the power processing unit (PPU). A system integration test, conducted using an engineering model thruster and a prototype model PPU, verified functionality across the entire throttle range, measured steady-state efficiencies, and evaluated fault management. The thruster demonstrated efficiencies comparable to those of the NEXT-C system, while maintaining adequate performance margins at all test conditions. A thrust of 330 mN was demonstrated, which represents a 40% increase over the NEXT-C maximum. The PPU operated stably at all ten throttle levels, effectively managed arc faults, and maintained an efficiency between 92%

[1] Research Engineer, Electric Propulsion Systems Branch, robert.e.thomas@nasa.gov.
[2] Electrical Engineer, Power Management and Distribution Branch, marcelo.c.gonzalez@nasa.gov.
[3] Research Engineer, Electric Propulsion Systems Branch, ritz.s.raju@nasa.gov.
[4] Electrical Engineer, Space Solutions, jim.bontempo@voyagertechnologies.com.
[5] Chief Engineer, Arcjet and Ion Thruster Systems, keith.goodfellow@l3harris.com.
[6] Project Manager, Space Advanced Programs, chayse.aubuchon@l3harris.com.
[7] Chairman, mjpatterson@desertworkspropulsion.com.

and 95%. Ongoing and future work includes detailed evaluation of ion optics performance, subcomponent life testing, and environmental qualification of the PPU.

Nomenclature

J_b = beam current, A
V_{bps} = beam power supply voltage, V

I. Introduction

Gridded ion thrusters are a mature electric propulsion technology, with extensive flight heritage in geostationary orbit keeping and deep space science missions.[1-7] One implementation of the technology is NASA's Evolutionary Xenon Thruster (NEXT), which was developed under the agency's In-Space Propulsion Technology Program and was led by the NASA Glenn Research Center (GRC). This development effort advanced the technology readiness of the thruster, power processing unit (PPU), and xenon feed system, including the completion of environmental tests and a 51,184 hour thruster wear test.[8,9] To facilitate commercial adoption and address the risk of limited utilization following initial mission deployments, NASA initiated the NEXT-Commercial (NEXT-C) flight project in 2015.[10-12] The project developed a flight-qualified thruster and PPU in collaboration with industry participants Aerojet Rocketdyne (now L3Harris) and ZIN Technologies (now Voyager Technologies). The effort culminated in the delivery of these units to the Johns Hopkins University Applied Physics Laboratory, where the system was briefly operated as part of a technology demonstration during the Double Asteroid Redirection Test (DART) mission.[13]

The NEXT ion propulsion system was optimized to meet the specific demands of planetary science missions, selecting conservative values for the beam current density, internal operating voltages, and power density to meet service life requirements. While this "derated" approach proved effective for long-duration deep space missions, it limited the system's applicability for broader use. Many potential commercial missions, particularly those in near-Earth space, prioritize high thrust-to-power ratios and have less stringent throttling and lifetime requirements. To address this difference in mission needs, the Advanced NEXT (AdvNEXT) program was initiated with the U.S. Space Force, to adapt the technology for a broader range of mission applications.

Prior to the initiation of the AdvNEXT program, a series of tests were conducted to characterize the thruster's extended operating envelope.[14-16] These investigations demonstrated that the thruster could operate at input powers up to twice the 7 kW design limit established under the original NEXT program. However, stable operation at these elevated power levels was only achievable at high total accelerating voltages, where ion transparency through the grids is maximized. At the low beam voltage and high beam current conditions necessary to achieve high thrust-to-power ratios, the thruster exhibited a strongly peaked beam current density profile. This led to direct ion impingement on the accelerator grid and a steep reduction in the engine's current extraction capability.[17] The AdvNEXT Annex 01 effort was initiated in early 2020, with an initial focus on eliminating the current density peak to allow for operation at the throttle levels of interest.

The Annex 01 effort focused exclusively on thruster development. A series of hardware modifications were experimentally evaluated to mitigate the current density peak. These included changes to the magnetic circuit, ion optics geometry, and propellant plenum. The implementation of a discharge baffle was ultimately selected as the preferred solution.[18] The program's scope was subsequently broadened to support the development of high-fidelity models of the thruster and power processing unit, leveraging the continued involvement of the core private-sector team from the NEXT-C project. These activities form the basis of this paper, which is organized as follows. Section II presents the throttle table developed for the AdvNEXT program. Section III describes the propulsion system architecture, highlighting design differences compared to the heritage NEXT-C configuration. Sections IV and V provide an overview of the system integration test and discuss the performance data. The final sections summarize the key findings and discuss planned future work for the program.

II. Advanced NEXT Throttle Table

The throttle table that was developed for the AdvNEXT program is shown in Fig. 1. The table defines ten discrete operating points, each characterized by a unique combination of beam current (J_b) and beam supply voltage (V_{bps}). While the thruster and power processing unit are capable of operating over a continuous range of current and voltage values within the limits outlined in the table, the discrete throttle points serve as a practical construct for system characterization and mission analysis. In practice, the operational capability is bounded by a control volume defined by the throttle table limits. The upper left boundary corresponds to the maximum power output capability of the power processing unit. Operation beyond this limit would require modifications to the beam and discharge supplies, resulting in changes to the physical envelope of the unit relative to the heritage NEXT-C design. The right boundary is governed by the perveance limit of the ion optics. This represents a condition where, at lower beam supply voltages or higher beam currents, the required current exceeds the extraction capacity of the ion optics, given the total applied voltage and acceptable accelerator electrode voltages. The throttle points presented in the table are adapted from those used in the NEXT-C project and were chosen to deliver performance metrics, such as thrust, specific impulse, and input power, that are suitable for missions operating in near-Earth environments.

J_b, A	V_{bps}, V			
	1200	1100	1000	900
6.00	**2B**			
5.80		**1A**		
5.50			AN45C	**AN45A**
3.50	**AN37**		AN3.5A	AN3.5C
1.50	**AN14**		AN13	**AN1.5B**

Figure 1. Advanced NEXT throttle table.

The AdvNEXT system is capable of operating at beam currents up to 6.00 A, exceeding the 3.52 A maximum of the NEXT-C system. However, its maximum beam voltage is limited to 1200 V, compared to 1800 V for NEXT-C. This combination results in higher thrust and an improved thrust-to-power ratio, albeit with a modest reduction in specific impulse. Figure 2 plots the thrust-to-power ratio as a function of specific impulse for various commercially available electric propulsion systems. AdvNEXT addresses the performance gap between Hall thrusters and traditional gridded ion thrusters by operating at elevated current densities, enabling thrust-to-power ratios approaching 45 mN/kW. This performance makes AdvNEXT well suited for near-Earth commercial missions requiring higher thrust than NASA's existing gridded ion thrusters.

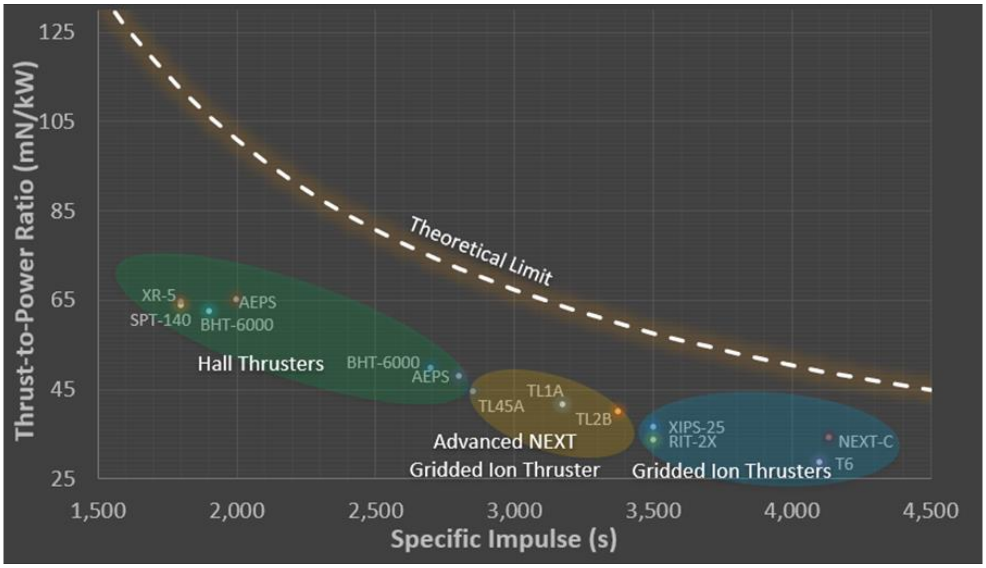


Figure 2. Thrust-to-power ratio vs. specific impulse for various electric propulsion systems.

III. System Description

The following subsections present an overview of the two primary propulsion system elements currently under development: the thruster and the PPU.

A. Thruster

The AdvNEXT thruster design builds upon the NEXT-C architecture. The design philosophy is to utilize heritage components wherever practical, to reduce future hardware maturation and qualification costs. References 12 and 19 provide descriptions of the flight and prototype model NEXT designs. Of the major thruster subassemblies, the plasma screen, discharge chamber, and neutralizer cathode are largely unchanged from the heritage design. The power cable harness will be modified to accommodate increased current levels and elevated thermal loads from the engine. The two primary design updates involve the ion optics and the discharge cathode.

The ion optics assembly consists of a pair of multi-aperture electrodes, the screen and accelerator grids, which extract, focus, and accelerate ions produced in the discharge chamber. The heritage design uses 36 cm active beam diameter grids that are fabricated from molybdenum. The AdvNEXT operating conditions generate higher current densities on the grids, which necessitate the use of an alternative material to meet the targeted operational life of approximately 25,000 hours. A carbon-based material was selected based on its significantly lower sputter yield compared to molybdenum. A material trade study was conducted to compare several carbon grades. The evaluation considered performance impacts, manufacturability, and structural characteristics. Thermomechanical analyses were carried out for both the grids and their support structures. The selected material demonstrated positive safety margins under the expected mechanical loads during launch and under thermal expansion and stress conditions during operation. Predicted variations in the grid gap due to thermal expansion were also found to be within acceptable limits. The electrode geometry and active beam diameter were retained from the heritage design. At the time of writing, the ion optics assembly is nearing completion and will be tested in the upcoming phase of the program.

The discharge cathode supplies the electrons required to ionize the neutral propellant and establish a stable plasma discharge. The two primary modifications to this assembly are a change in the cathode orifice diameter and the addition of a baffle structure, which is physically integrated into the keeper assembly. The cathode orifice has been redesigned to handle discharge currents up to 80% higher than the heritage design. The baffle was incorporated to create a more uniform current density distribution across the ion optics and to eliminate an off-center current concentration. Baffle structures are a common design feature in divergent field engines and were also investigated in early ring-cusp designs.[20,21] Figure 3 shows a two-dimensional near-field current density map, obtained 3 cm downstream of the thruster exit plane, highlighting the off-center current density concentration when no baffle is used. This region as viewed from the front of the engine is in the third quadrant of the accelerator electrode, displaced vertically below the thruster horizontal centerline by 3.5 cm, and displaced 3 cm laterally from the thruster vertical centerline. While this peak current was consistently observed at all operating conditions, its effect on performance became pronounced only at beam currents exceeding five amperes. Figure 4 shows a comparison of perveance margin with and without the baffle, demonstrating a clear improvement in electrostatic performance, particularly at elevated beam current conditions.

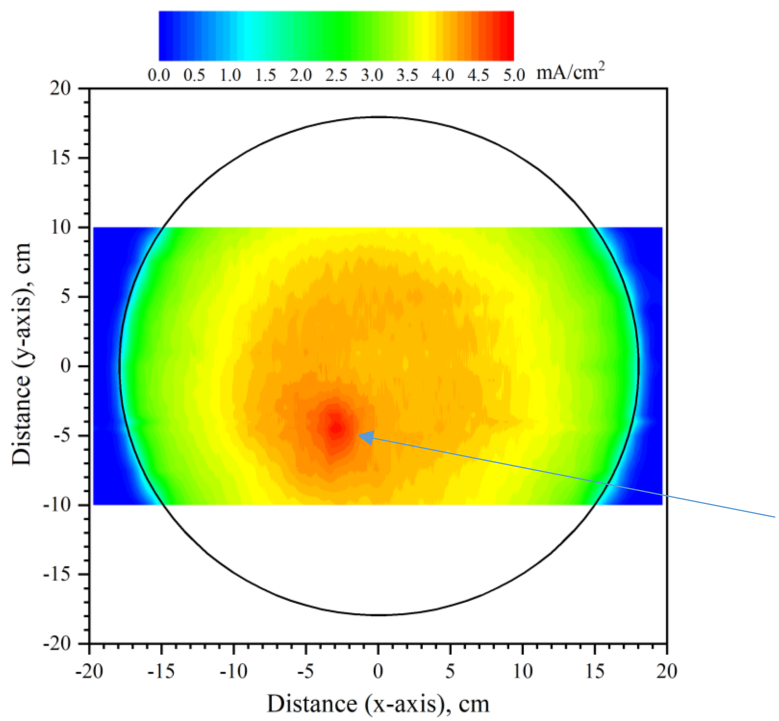


Figure 3: Near field current density map obtained at a beam current of 3.52 A demonstrating an off-center current density concentration without the use of a discharge baffle.

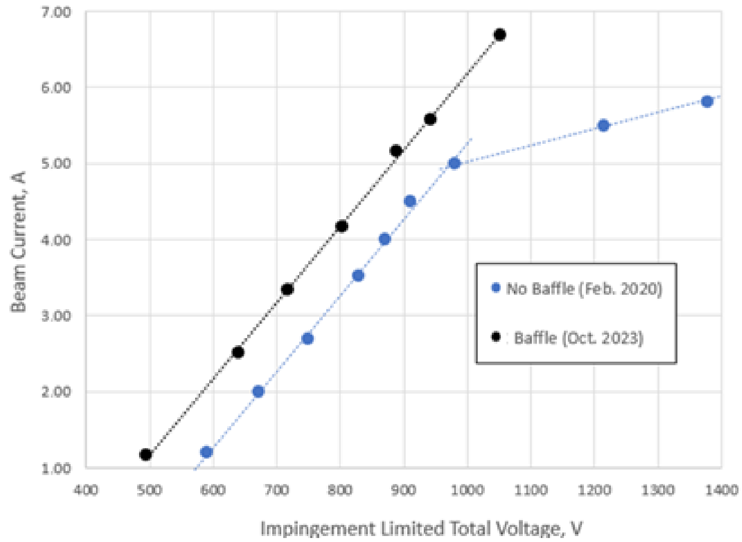


Figure 4: Beam current vs. perveance limited total voltage with and without the use of a discharge baffle.

While the incorporation of the baffle assembly enables stable operation at the desired conditions, its use introduces several potential concerns. The presence of the baffle increases both the discharge impedance and the discharge voltage, which may accelerate erosion of surfaces held at or near cathode potential. Additionally, the baffle itself may experience significant erosion, particularly on upstream surfaces that are directly exposed to the plasma generated by the discharge cathode. These effects can be mitigated through the selection of low sputter yield materials, by adjusting the electrical potential of the baffle to operate at or near the keeper potential, and by moderating the propellant flow rate to reduce the discharge voltage.

B. Power Processing Unit

The AdvNEXT PPU is based on the heritage NEXT-C design demonstrated on the DART mission. The block diagram shown in Fig. 5 shows the six interconnected DC-DC converters that are used to power the thruster. The voltage-controlled Beam Supply (also known as the Screen Supply) is the highest-power supply in the PPU, providing up to 6.0 A at 1200 VDC (7.2 kW). The Beam Supply dominates the overall efficiency of the PPU, as it supplies approximately 88% of the PPU's total power output. The AdvNEXT propulsion system is optimized for modest specific impulse (3300 seconds) and high thrust (330 mN) in an 8-kW class design. Compared to the NEXT-C PPU, this requires that the beam supply maximum voltage is decreased from 1800 V to 1200 V (-33%), but its maximum current is increased from 3.5 A to 6.0 A (+71%). The maximum beam power is increased from 6.3 kW to 7.2kW (+14%).

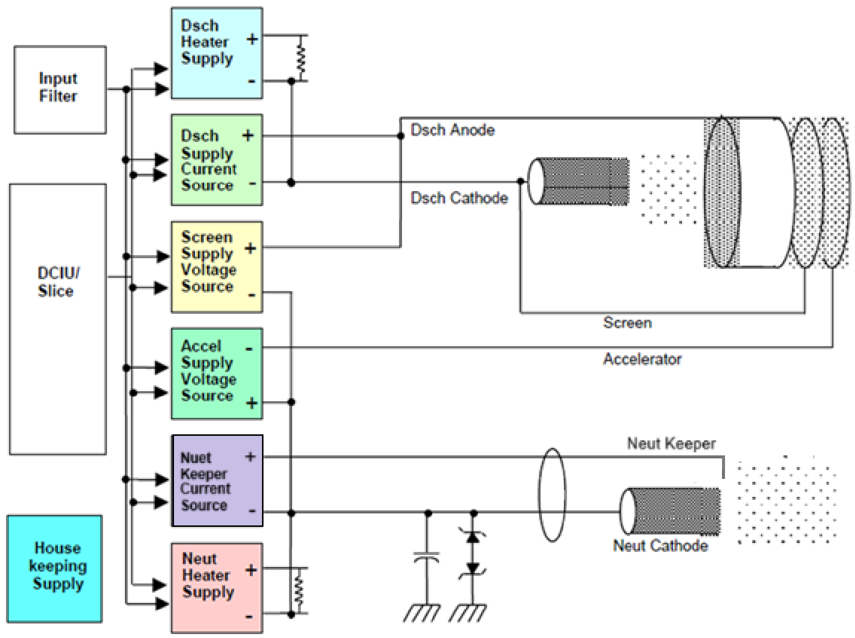


Figure 5. Block diagram of the AdvNEXT PPU.

The PPU discharge supply uses DC voltage and current to generate ions in the thruster. The NEXT-C discharge supply provides an output up to 35 V, 24 A (840 W) to generate the ions to operate the thruster at its highest power level. However, the AdvNEXT PPU requires significantly more beam current, which means that significantly more discharge current is required. The AdvNEXT discharge supply can output up to 35 V, 40 A, 1400 W (67% higher than NEXT-C).

The heritage NEXT-C PPU operates directly from an 80 to 160 Vdc unregulated solar array power bus, which changes its input voltage as the spacecraft travels away from the sun. This was a major challenge in the PPU design, as the low input voltage drove the maximum current of the power transistors and maximum converter duty cycle, while the high input voltage drove the maximum voltage rating of the power transistors and output rectifiers. In contrast, the AdvNEXT PPU is designed for near-Earth missions, operating from a regulated 100 ± 5 Vdc spacecraft power bus. Since the input power is more tightly controlled, the maximum power output of the PPU was increased from 7 kW to 8.2 kW. The regulated input power allows the AdvNEXT PPU to output higher beam and discharge power in the same mass (34.5 kg), volume (50.80 cm x 40.89 cm x 13.97 cm; 29,019 cm^3), and form factor as the heritage NEXT-C PPU. The balance of the power supplies (Neutralizer, Neutralizer Cathode Heater, Discharge Cathode Heater, Accelerator Grid) have the same technical specifications as NEXT-C. The AdvNEXT output power is shown in Table 1.

Table 1. AdvNEXT PPU output power.

	Neutralizer Keeper		Neutralizer Heater		Discharge		Discharge Heater		Screen		Accel	
Input Voltage	95 to 105 Volt DC High Power Bus, 22 to 34 Volt DC Low Power Bus											
Output Voltage (VDC)	8	32	3	24	15	35	3	24	275	1200	115	525
Output Current (ADC)	1	3	3.5	8.5	4	40	3.5	8.5	1	6.0	0	0.04
Controlled Output	Current		Current		Current		Current		Voltage		Voltage	
Max Power Out (W)	96		204		1400		204		7200		21	
Min Efficiency (%) at Max Power Out @ TL2B (W)	> 93.5% @ 8200 W											

IV.System Integration Testing

A system integration test (SIT) was conducted using an engineering model thruster and a prototype model PPU. The objectives of the test were to demonstrate system functionality across the full AdvNEXT operating envelope, evaluate steady-state efficiencies, identify potential PPU issues, verify fault management capabilities, and reduce risk in preparation for future flight unit testing. The PPU was subjected to calibration and functional testing on a resistive load prior to its integration with the thruster. The thruster test results presented in this study were obtained during two separate test campaigns: one using commercially available power supplies and the other using the prototype model PPU. Testing prior to the SIT was performed with a power console composed of six commercial power supplies, whose basic design is described in Ref. 22. This testing phase included cathode flow sensitivity studies, assessments of electrostatic operating margins, charge state measurements, and background pressure evaluations. These tests were used to determine input parameters, such as mass flow rates and operating voltages, which were subsequently applied during integration testing with the PPU. Thruster data showed variations of only a few percent between the commercial power console and the PPU, indicating that the choice of power source had negligible effect on thruster performance.

A. Test Setup

The system integration test was completed at NASA GRC. An engineering model 6 (EM6) thruster was used for testing, and was primarily composed of engineering model subassemblies, except for the ion optics, which are a flight pathfinder set from the NEXT-C project. In terms of fit and function, the engine is similar to the unit used in the long duration life test.[9] The thruster was mounted in Vacuum Facility 16 (VF16), a 2.7 m diameter × 8.5 m long chamber evacuated with ten cryopumps. The facility has a base pressure of 2.0×10^{-7} torr, and the Xe corrected facility pressure during operation at the maximum power input condition (2B) was 5.8×10^{-6} torr. A data acquisition system monitored ion engine and facility operation. A high-purity xenon feed system delivered propellant to the discharge cathode, neutralizer cathode, and discharge chamber main plenum through individual commercial mass flow controllers. Thruster and vacuum facility telemetry were written to a data file at a rate of 1 Hz during thruster operation.

The PPU was operated in ambient conditions and mounted to a cold plate for waste heat rejection. The PPU was instrumented with thermocouples to monitor component temperatures and support design evaluation. Electrical outputs from the PPU were routed through a breakout box (BoB), enabling independent, calibrated measurements of output voltages and currents. Oscilloscopes captured voltage and current transients during thruster ignition and arc ("recycle") events. A laptop connected to the PPU using an RS-485 connector controlled the PPU and logged digital telemetry, including all output voltages and currents from individual power supplies, as well as input values from the high- and low-voltage power inputs. All verification measurements were taken as close to the PPU terminals as possible to minimize voltage drop errors. A schematic and photograph of the test configuration are provided in Figs. 6 and 7, respectively.

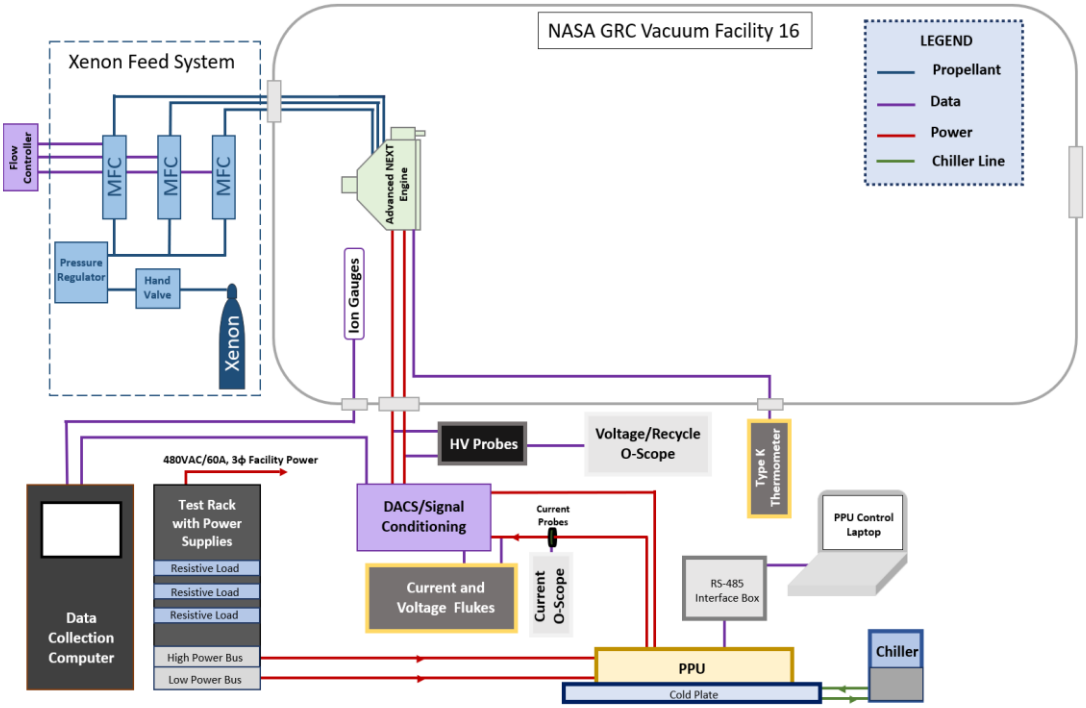


Figure 6. System integration test setup.

Figure 7. PPU, power rack, and BoB setup for the system integration test.

V. Test Results

A. Thruster Performance

Thruster testing primarily focused on steady-state performance characterization, with particular emphasis on the discharge behavior due to the inclusion of the baffle assembly. Figure 8 shows the discharge current and discharge voltage as functions of beam current. The discharge current exhibited an approximately linear relationship with beam current, with magnitudes comparable to the heritage NEXT-C system for beam currents below 3.50 A. The maximum observed discharge current of 36 A is within the output limits of the PPU (40A maximum). The discharge impedance was found to be strongly influenced by the discharge cathode flow rate. Flow settings were selected to moderate the discharge voltage, striking a balance between discharge efficiency and thruster lifetime. At the lowest beam current levels, the discharge voltage was approximately 30 V, decreasing to 25–26 V at higher beam currents. Spatially resolved measurements of ion charge states, obtained in prior tests, showed that the doubles-to-single ion ratio remained below 10% across all test conditions. First-order lifetime estimates suggest that these values are consistent with the engine's service lifetime requirements, particularly when carbon-based ion optics are employed.[18] Discharge losses, shown in Fig. 9, ranged from 150 to 170 W/A, which is consistent with heritage NEXT performance and indicative of efficient discharge operation.[23]

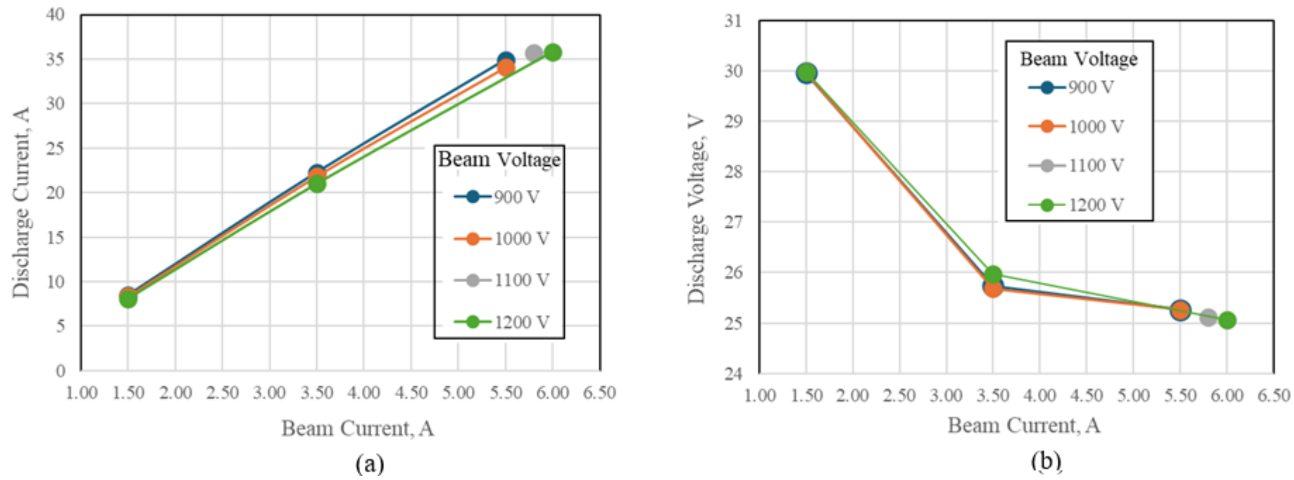


Figure 8. (a) Discharge current and (b) discharge voltage as a function of beam current.

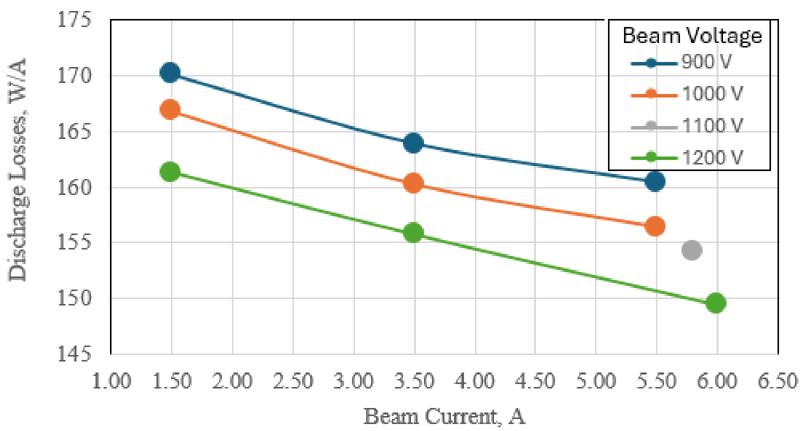


Figure 9. Discharge losses as a function of beam current.

The electrostatic performance of the thruster is summarized in Table 2. Perveance limits were determined by plotting the accelerator current as a function of total voltage, with the limiting condition defined by a slope of 0.02 mA/V. Electron back-streaming limits were identified by reducing the magnitude of the accelerator voltage until the beam power supply current increased by 1 mA, indicating the onset of electron back-streaming. These electrostatic margins are primarily governed by the magnitude of the accelerator voltage; increasing this voltage improves margin but can lead to increased erosion of the accelerator grid. The minimum observed back-streaming margin was 60 V, which exceeds the corresponding value from the heritage NEXT system. At all throttle points, the thruster exhibited ample perveance margin, which is expected to increase over time as the accelerator grid apertures enlarge from direct impingement and sputter erosion. Ion optics modeling is underway to evaluate grid lifetime and end-of-life operating margins.

Table 2. Electron back-streaming and perveance margins for the AdvNEXT engine.

Throttle Level	Beam Current, A	Beam Voltage, V	Electron Back-streaming Margin, V	Perveance Margin, V
AN1.5B	1.50	900	98	524
AN13	1.50	1000	90	624
AN14	1.50	1200	80	824
AN3.5C	3.50	900	90	358
AN3.5A	3.50	1000	79	458
AN37	3.50	1200	60	658
AN45A	5.50	900	168	268
AN45C	5.50	1000	155	368
1A	5.80	1100	139	439
2B	6.00	1200	125	520

Table 3 summarizes engine performance across the ten AdvNEXT throttle levels. Thrust values were calculated from thruster telemetry and corrected using semi-empirical models to account for losses associated with multiply ionized xenon species and plume divergence effects. The engine achieved a maximum thrust of 330 N, corresponding to a 40% increase over the performance of the NEXT-C system. Specific impulse spans from 2500 to 3400 seconds, with a maximum thruster efficiency of 67%. Collectively, these results indicate substantial performance gains relative to the heritage NEXT-C system.

Table 3. Thruster performance data for operating conditions with the AdvNEXT throttle table.

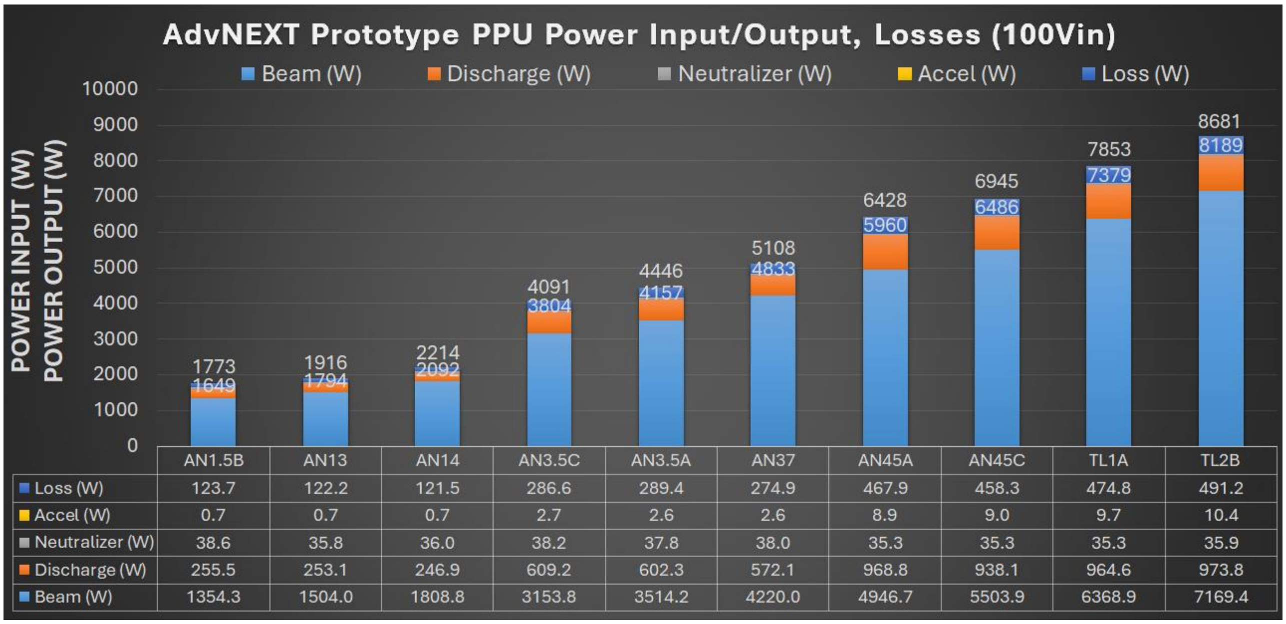
Throttle Level	Beam Current, A	Beam Voltage, V	Thrust. mN	Specific Impulse, s	Thruster Efficiency	Thrust/Power, mN/kW
AN1.5B	1.50	900	71	2,530	54%	43
AN13	1.50	1000	75	2,668	55%	42
AN14	1.50	1200	82	2,930	57%	40
AN3.5C	3.50	900	166	2,964	64%	44
AN3.5A	3.50	1000	175	3,134	65%	42
AN37	3.50	1200	192	3,424	67%	40
AN45A	5.50	900	261	2,919	63%	44
AN45C	5.50	1000	276	3,085	64%	43
1A	5.80	1100	306	3,251	66%	42
2B	6.00	1200	330	3,401	67%	40

B. PPU Performance

The PPU successfully operated at all ten AdvNEXT throttle levels. The test accomplishments include:

- The Neutralizer Heater and Discharge Heater supplies were able to successfully complete the thruster cathode conditioning cycle.
- The Neutralizer and Discharge supply ignition pulse circuit was shown to successfully ignite the Neutralizer cathode and Discharge cathode.
- The PPU was shown to be tolerant of the accelerator supply surge current (1.4A) during application of high voltage (Beam and Accelerator supply) to the thruster.
- The PPU successfully executed the arc extinction "recycle" sequence in response to over-current events, demonstrating robust fault tolerance.

Figures 10 and 11 show the PPU input power, output power, and efficiency during the AdvNEXT Prototype PPU System Integration Test at all ten throttle levels. The Prototype PPU operated at all ten throttle levels over the 95 to 105 V input range. The PPU output 8.2 kW at over 94% efficiency at TL2B conditions. The PPU rejected less than 500 W to the cold plate throughout the test.



	AN1.5B	AN13	AN14	AN3.5C	AN3.5A	AN37	AN45A	AN45C	TL1A	TL2B
Loss (W)	123.7	122.2	121.5	286.6	289.4	274.9	467.9	458.3	474.8	491.2
Accel (W)	0.7	0.7	0.7	2.7	2.6	2.6	8.9	9.0	9.7	10.4
Neutralizer (W)	38.6	35.8	36.0	38.2	37.8	38.0	35.3	35.3	35.3	35.9
Discharge (W)	255.5	253.1	246.9	609.2	602.3	572.1	968.8	938.1	964.6	973.8
Beam (W)	1354.3	1504.0	1808.8	3153.8	3514.2	4220.0	4946.7	5503.9	6368.9	7169.4

Figure 10. PPU input and output powers for the ten different AdvNEXT throttle levels.

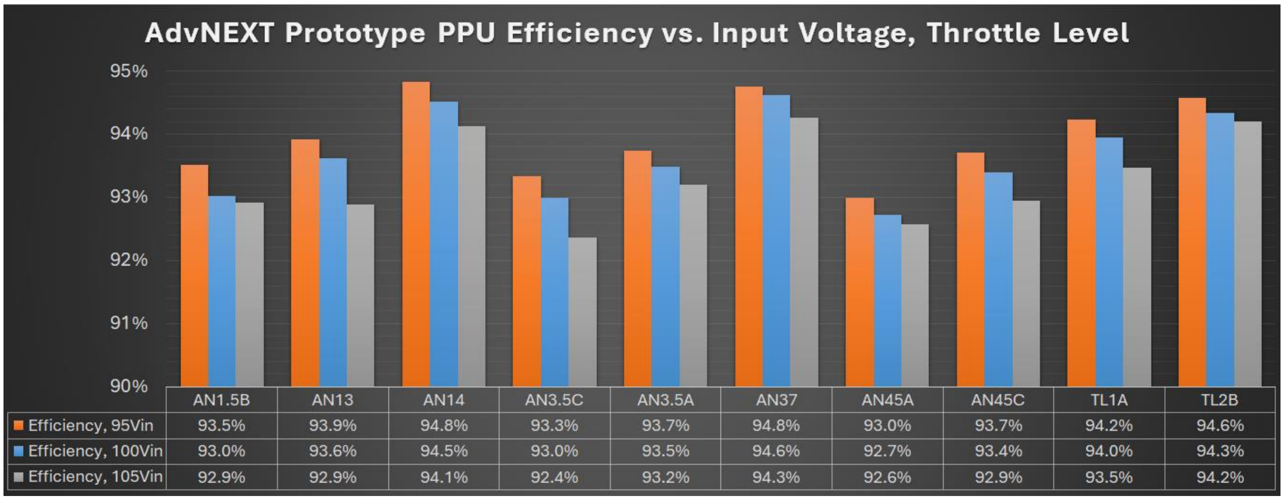


Figure 11. PPU efficiency data for the ten different AdvNEXT throttle levels.

VI. Future Work

Several near-term activities are planned to advance the development of both the thruster and the PPU. As previously noted, fabrication of the carbon-based ion optics is nearing completion, and this assembly will be integrated with the EM6 thruster for full performance characterization. In parallel, subcomponent testing is scheduled. The cathode and baffle assembly will undergo thermal testing to assess internal emitter temperatures under relevant discharge conditions. A 2,000-hour wear test is also planned to evaluate the temporal performance of the assembly and to identify potential life-limiting mechanisms. The prototype PPU will undergo environmental qualification, including tests for electromagnetic compatibility (EMC), pyrotechnic shock, random vibration, and thermal vacuum. Completion of these environmental tests is anticipated by early 2026, at which point the PPU is expected to achieve TRL 6.

VII. Summary

The AdvNEXT ion propulsion system enhances the performance of the heritage NEXT-C design by delivering improved thrust-to-power capability while maintaining comparable mass and volume. System-level integration testing of the thruster and PPU confirmed stable operation at beam currents up to 6.0 A and thruster input powers of 8.2 kW. Thruster data indicated efficient performance within the PPU's output capabilities, with adequate output current and electrostatic margins maintained under all test conditions. A calculated thrust of 330 mN represents a 40% increase over the NEXT-C maximum. The PPU operated stably across all ten defined AdvNEXT operating conditions, demonstrated effective fault management, and maintained efficiency levels between 92% and 95%. Ongoing and planned work includes detailed ion optics performance evaluation, life testing of key subcomponents, and environmental qualification of the PPU.

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