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CURRENT STATUS OF NASA’S NEXT-C ION PROPULSION SYSTEM DEVELOPMENT PROJECT

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NASA’s Evolutionary Xenon Thruster (NEXT) is a 7-kW class gridded ion thruster-based propulsion system that was initially developed from 2002 to 2012 under NASA’s In-Space Propulsion Technology Program to meet future science mission requirements. In 2015, a contract was awarded to Aerojet Rocketdyne, with subcontractor ZIN Technologies, to design, build and test two NEXT flight thrusters and two power processing units that would be available for use on future NASA science missions. Because an additional goal of this contract is to take steps towards offering NEXT as a commercialized system, it is called the NEXT-Commercial project, or NEXT-C. This paper reviews the capabilities of the NEXT-C system, status of the NEXT-C project, and the forward plan to build, test, and deliver flight hardware in support of future NASA and commercial applications. It also briefly addresses some of the potential applications that could utilize the hardware developed and built by the project.

I. INTRODUCTION

NASA has identified the need for a higher-power, higher-specific impulse, higher-thrust, and higher-throughput capable ion propulsion system (IPS) beyond the state-of-the-art NASA Solar Electric Propulsion Technology Application Readiness (NSTAR) IPS employed on the Deep Space 1 and Dawn Missions.¹⁻⁴ To address this need, the NASA’s Evolutionary Xenon Thruster (NEXT) IPS

development, led by NASA Glenn Research Center (GRC), was competitively selected in 2002. The NEXT IPS advanced technology was developed under the sponsorship of NASA’s In-Space Propulsion Technology Program, with Phase 2 close-out of the NEXT IPS development occurring in 2012. The IPS component technologies developed by the NEXT project are shown in Figure 1.

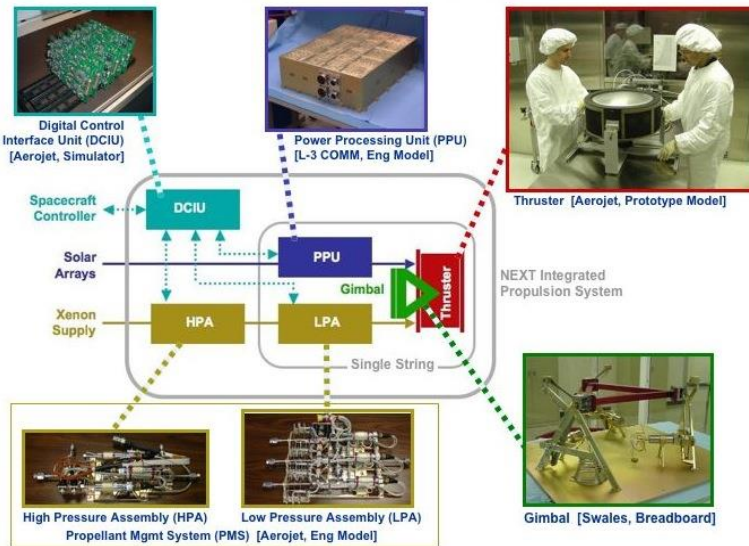


Fig. 1: Components addressed by the NEXT Technology Project conducted from 2002 to 2012.

The highest fidelity NEXT hardware planned was built by the government/industry NEXT team and included: an engineering model (referred to as prototype model) thruster, an engineering model power processing unit (PPU), engineering model (EM) propellant management assemblies, a prototype gimbal, and control unit simulators.⁵ Each of the units underwent extensive component-level testing, completed environmental testing (with the exception of the PPU), and was evaluated together in an integrated system test.⁶⁻⁹ Results from IPS component testing and integration testing can be found in Refs. 7-17.

In 2014, NASA GRC released a solicitation for the design, test, and manufacture of two NEXT thrusters and two NEXT PPUs. In April 2015, Aerojet Rocketdyne (AR), with subcontractor ZIN Technologies, was competitively selected for this contract, called the NEXT – Commercial (NEXT-C) project. The objectives of this contract are two-fold: 1) deliver two flight thrusters and two flight PPUs for use in future NASA missions, and 2) take steps to transition NEXT into a commercially available, off-the-shelf IPS for use by NASA, as well as other interested entities. Aerojet Rocketdyne is responsible for the overall project management, systems engineering, development test and fabrication/assembly of the thrusters, along with overall integrated system testing. ZIN Technologies is responsible for the development, fabrication/assembly, and test of the PPUs.

II. NEXT-C SYSTEM CAPABILITIES

The NEXT IPS was designed for solar electric propulsion applications that experience variable input power as the available solar flux changes with distance from the sun throughout a typical deep-space science mission. The NEXT thruster has a nominal input power range of 0.5 to 6.9 kW input power, and utilizes 2-grid dished-out ion optics, capable of producing thrust levels of 25 to 235 mN and specific impulses of 1400 to 4220 seconds. The technical approach for NEXT continues the derating philosophy used for the NSTAR ion thruster. A beam extraction area of 1.6 times that of NSTAR allows for higher thruster input power while maintaining low discharge voltages and ion current densities, thus maintaining thruster longevity. Projected thruster and PPU performance parameters for the NEXT-C System are shown in Tables 1 and 2, respectively.

Table 1. NEXT-C Thruster Performance

Thruster Power Range, kW	0.5 – 6.9
Maximum Specific Impulse, s	4220
Thrust, mN	25-235
Maximum Thruster Efficiency	70%
Beam diameter, cm	36
Maximum Beam Current, A	3.52
Maximum Beam Voltage, V	1800
Mass (with harness), kg	<13.5

Table 2. NEXT-C PPU Performance

Input Power Range, kW	0.64 – 7.36
Peak Efficiency (High Voltage Bus)	>93.5%
Primary Power Input Voltage, V	80-160
Housekeeping Input Voltage, V	22-34
Housekeeping Power, W	<40
Mass, kg	<36

III. NEXT-C PROJECT STATUS

Following completion of the Preliminary Design Review (PDR) in February 2016, NEXT-C transitioned into its hardware development phase. AR and ZIN Technologies used the designs from the previous NEXT technology development phase as a baseline, and made modifications to improve manufacturability and commercialization as well as resolve any remaining issues with the original design. Both AR and ZIN have completed fabrication of their development hardware and both the thruster and PPU are presently under test.

III.I THRUSTER

In order to verify changes made to the thruster design did not adversely affect performance, AR planned to modify and test a thruster from the technology development phase. This modified version of the thruster, called Dev-C, is shown in Fig. 2. It incorporates relatively minor changes made to the original NEXT thruster design. No changes to plasma-wetted surfaces were made, in order to maintain the thruster performance and lifetime previously demonstrated during the technology development phase.^{2, 18}

Thermal and structural analyses were also completed on the Dev-C design to ensure that the thruster could meet the requirements with adequate margins. Testing phases include a hot-fire performance test, a random vibration test, a pyroshock test, as well as a final hot-fire performance test to verify that the hardware successfully completed structural testing. This testing would also

be used to collect data to validate the thermal and structural models.



Fig. 2: NEXT-C Dev-C thruster.

At present, the Dev-C thruster has successfully completed its first hot-fire performance test. Performance was characterized at several throttle points that span the throttle table, and included characterization of overall thruster performance, discharge performance, neutralizer performance and optics performance. A number of diagnostics were also used in the plasma plume to characterize beam current density profiles as well as charge species fractions. Performance was found to be consistent with data collected on previous NEXT thrusters. The thruster was also instrumented with numerous thermocouples in order to perform a thermal characterization test. This test was used to collect temperatures of various thruster components to ensure that the thruster was operating within acceptable limits as well as to provide data for thermal model validation. Following the hot-fire performance test, the thruster also successfully completed an abbreviated system integration test with the PPU (more detail provided in the following section).

III.II POWER PROCESSING UNIT (PPU)

After successful completion of PDR, ZIN Technologies fabricated a prototype PPU for the development phase.¹⁹ The purpose of this phase is to reduce risk by ensuring that the design can meet requirements, as well as to uncover any unexpected issues prior to the flight hardware design and operation. Planned testing for this phase includes a functional/performance test, a random vibration test, a pyroshock test, EMI/EMC characterization, and thermal vacuum testing. Various analyses have also been completed, including thermal and structural modeling as well as worst case analyses. Of

particular importance are the structural and thermal vacuum testing, as these tests were never performed on the original design from the technology development phase. Similar to the thruster development tests, this testing would also be used to collect data to validate the thermal and structural models.

At present, the prototype PPU, which is shown in Fig. 3, has completed a first round of each of the above tests. These tests were largely successful; however, a number of issues were uncovered during each part of the test campaign. AR and ZIN Technologies have been actively investigating root cause as well as potential solutions. To-date, almost all of these items have been resolved or have a clear path towards resolution. The prototype PPU will undergo a period where updates will be made to the hardware. The above tests will then be conducted once more to verify that the improvements have been successfully incorporated and that all requirements can be met, in order to minimize risk prior to the flight hardware phase.



Fig. 3: NEXT-C Prototype PPU.

Along with the thruster, the PPU also completed an abbreviated system integration test. The PPU successfully powered the thruster at a variety of throttle levels, including the highest power throttle level. Preliminary data indicates that the newly incorporated PPU plume mode detection circuitry has the potential to provide telemetry to indicate when the thruster could be operating in this undesirable mode. Data also indicates that the efficiency requirement is being met at all evaluated throttle levels. A full system integration test will be conducted after the thruster and PPU successfully complete their component level tests.

IV. FLIGHT HARDWARE FORWARD PLAN

Fabrication of flight hardware will begin once confidence is gained that issues uncovered during development have been resolved and all documents for fabrication have been approved. A handful of risk reduction activities for the thruster are planned involving testing fabrication methods and techniques for critical components and processes prior to flight hardware fabrication. Due to the lack of qualification hardware, the flight hardware will be tested using a protoflight approach. The objective of the protoflight testing phase is to verify workmanship standards and ensure that all requirements have been met. Testing phases for both thruster and PPU include performance testing, random vibration testing, thermal vacuum testing, as well as system integration testing.

After successful completion of flight hardware fabrication and test, the two thruster/PPU pairs will be made available for any number of NASA missions. Presently, one pair will be delivered for the Double Asteroid Redirection Test (DART) mission led by the Applied Physics Laboratory (APL). Flight hardware is expected to have completed testing and been accepted by NASA in early 2019.

V. POTENTIAL APPLICATIONS

Due to the NEXT-C system's high power, wide throttleability, and high specific impulse operation, it is optimized for large delta-V, planetary science missions. The NEXT thruster was also designed for long-life, high throughput operation as demonstrated by the 50,000-hour Long Duration Test.¹⁸ Studies have also been performed that indicate the potential to run NEXT at higher thrust, lower specific impulse operation, which make the system more attractive for earth-orbiting and commercial applications.²⁰

Presently the first mission expected to use the NEXT system is the DART mission, led by APL and managed by the NASA Planetary Missions Office. DART is a planetary defense-driven test aimed at demonstrating kinetic impact of a small, near-Earth asteroid. DART will utilize the NEXT-C hardware as the primary propulsion system for the spacecraft. By using the NEXT-C system, DART is able to gain flexibility in the launch window as well as the mission timeline. Furthermore, the high specific impulse operation allows a reduction in required propellant which decreases the cost of the launch vehicle used to get into orbit. This is a general benefit of utilizing high specific impulse electric propulsion devices over chemical propulsion. Launch of the DART spacecraft is expected to occur in late 2020.

VI. CONCLUSIONS

The NEXT-C project, initiated in 2015, is aimed at providing two flight thruster/PPU pairs for use on NASA missions, as well as taking steps towards making the NEXT-C propulsion system available as a commercial off-the-shelf system for use by NASA and other users. The project leverages the design of the highly successfully NEXT technology development phase, which concluded in 2012. Presently, Aerojet Rocketdyne and its subcontractor ZIN Technologies are in the process of completing development testing on a prototype thruster and PPU, with delivery of flight hardware expected in early 2019. This hardware can then be utilized for a variety of applications, with one set of hardware already reserved for the primary propulsion system on the DART mission to be launched in 2020.

VII. REFERENCES

1. Brophy, J. R., Etters, M. A., Gates, J., Garner, C. E., Klatte, M., Lo, C. J., et al., "Development and Testing of the Dawn Ion Propulsion System", *42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2006-4319, Sacramento, CA, July 9-12, 2006.
2. Patterson, M. J. and Benson, S. W., "NEXT Ion Propulsion System Development Status and Performance", *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2007-5199, Cincinnati, OH, July 8-11, 2007.
3. Polk, J. E., Brinza, D., Kakuda, R. Y., Brophy, J. R., Katz, I., Anderson, J. R., et al., "Demonstration of the NSTAR Ion Propulsion System on the Deep Space One Mission", *27th International Electric Propulsion Conference*, IEPC-2001-075, Pasadena, CA, October 15-19, 2001.
4. Rayman, M. D., "The Successful Conclusion of the Deep Space 1 Mission: Important Results Without a Flashy Title", *Space Technology*, Vol. 23, No. 2-3, 2003, pp. 185-196.
5. Benson, S. W. and Patterson, M. J., "NASA's Evolutionary Xenon Thruster (NEXT) Ion Propulsion Technology Development Status in 2009", *31st International Electric Propulsion Conference*, IEPC-2009-150, Ann Arbor, MI, September 20-24, 2009.
6. Hoskins, W. A., Aadland, R. S., Meckel, N. J., Talerico, L. A., and Monheiser, J. M., "NEXT Ion Propulsion System Production Readiness", *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2007-5856, Cincinnati, OH, July 8-11, 2007.

7. Patterson, M. J., Foster, J., McEwen, H., Pencil, E., Van Noord, J., and Herman, D., "NEXT Multi-Thruster Array Test - Engineering Demonstration", *42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2006-5180, Sacramento, CA, July 9-12, 2006.
8. Snyder, J. S., Anderson, J. R., Van Noord, J. L., and Soulas, G. C., "Environmental Testing of the NEXT PM1 Ion Engine", *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2007-5275, Cincinnati, OH, July 8-11, 2007.
9. Soulas, G. C., Patterson, M. J., Pinero, L., Herman, D. A., and Snyder, J. S., "NEXT Single String Integration Test Results", *45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2009-4816, Denver, CO, August 2-5, 2009.
10. Aadland, R. S., Frederick, H., Benson, S. W., and Malone, S. P., "Development Results of the NEXT Propellant Management System", *JANNAF 2nd Liquid Propulsion Subcommittee and 1st Spacecraft Propulsion Subcommittee Joint Meeting*, JANNAF 2005-0356DW, Monterey, CA, December 5-8, 2005.
11. Crofton, M. W., Pollard, J. E., Beiting, E. J., Spektor, R., Diamant, K. D., Eapen, X. L., et al., "Characterization of the NASA NEXT Thruster", *45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2009-4815, Denver, CO, August 2-5, 2009.
12. Diamant, K. D., Pollard, J. E., Crofton, M. W., Patterson, M. J., and Soulas, G. C., "Thrust Stand Characterization of the NASA NEXT Thruster", *46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit*, AIAA-2010-6701, Nashville, TN, July 25 - 28, 2010.
13. Herman, D. A., Pinero, L. R., and Sovey, J. S., "NASA's Evolutionary Xenon Thruster (NEXT) Component Verification Testing", *44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2008-4812, Hartford, CT, July 21-23, 2008.
14. Herman, D. A., Soulas, G. C., and Patterson, M. J., "Performance Evaluation of the Prototype-Model NEXT Ion Thruster", *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2007-5212, Cincinnati, OH, July 8-11, 2007.
15. Pinero, L. R., Hopson, M., Todd, P. C., and Wong, B., "Performance of the NEXT Engineering Model Power Processing Unit", *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2007-5214, Cincinnati, OH, July 8-11, 2007.
16. Pinero, L. R., Hopson, M., Todd, P. C., and Wong, B., "Performance of the NEXT Engineering Model Power Processing Unit", *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2007-5214, Cincinnati, OH, July 8-11, 2007.
17. Snyder, J. S., O'Connell, M. R., Fernandez, J. P., Wang, G., McNabb, R. S., and Crumb, D., "Vibration Test of a Breadboard Gimbal for the NEXT Ion Engine", *42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA-2006-4665, Sacramento, CA, July 9-12, 2006.
18. Shastry, R., Herman, D. A., Soulas, G. C., and Patterson, M. J., "End-of-test Performance and Wear Characterization of NASA's Evolutionary Xenon Thruster (NEXT) Long-Duration Test", *50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference*, AIAA-2014-3617, Cleveland, OH, July 28-30, 2014.
19. Aulisio, M. V., Pinero, L. R., White, B. L., Hickman, T. A., Bontempo, J. J., Hertel, T. A., et al., "Status of the Development of Flight Power Processing Units for the NASA's Evolutionary Xenon Thruster - Commercial (NEXT-C) Project", *52nd AIAA/SAE/ASEE Joint Propulsion Conference*, AIAA-2016-4519, Salt Lake City, UT, July 25-27, 2016.
20. Patterson, M. J., Soulas, G. C., Young, J. A., and Crofton, M. W., "Expanded Throttling Capabilities of the NEXT Thruster", *49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference*, AIAA-2013-3891, San Jose, CA, July 14 - 17, 2013.