

Advancement of eXploration Components for In-Space Servicing (AXCIS) Early Career Initiative (ECI) Project

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National Aeronautics and Space Administration (NASA) funded through NASA's Space Technology Mission Directorate (STMD) has been developing in-space servicing technologies via an Early Career Initiative (ECI) project, Advancement of eXploration Components for In-Space Servicing (AXCIS). The project developed a suite of gap technologies in partnership with commercial companies followed by component and system level environmental testing to raise the technology readiness levels for rapid integration into future servicing systems. Development of the AXCIS technologies enable design completion of an optimized servicing system posturing NASA, Department of Defense (DoD), and commercial companies to perform advanced servicing operations as the entire In-Space Servicing, Assembly, and Manufacturing (ISAM) community sets their sights on refueling, in-space servicing and Lunar/Martian surface operations. The purpose of this paper is to inform the ISAM community of the AXCIS project's results as the technologies developed are highly relevant to the field.

The AXCIS project is a two-year project set to end in September 2025. This paper covers technology development efforts performed in year one as well as functional and environmental test results collected during the second year of the project. This paper concludes with a brief summary of forward work that the AXCIS technologies could benefit from. The suite of technologies being developed under AXCIS includes a high accuracy Coriolis mass flow meter, xenon compressor, helium compressor, variable output regulator, and a seal-less (no dynamic seal), mechanically compliant fluid adapter. Environmental testing planned for the project includes functional, Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC), and vibration/shock testing at the component level as well as functional and Thermal Vacuum (TVAC) testing at the system level. Environmental testing is scheduled to begin in Quarter 3 of fiscal year 2025 and will conclude at the end of the project. All

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environmental testing will be performed following the General Environmental Verification Standard (GEVS), GSFC-STD-7000A.

The high accuracy Coriolis mass flow meter technology was selected for development as there is currently no capability for high accuracy fluid mass flow rate measurement utilizing space-rated electronics. The Coriolis flow meter measures, with high accuracy and reliability, mass flow rate using motion mechanics. It is used widely on the ground in various industries such as pharmaceutical, petroleum, chemical, and aerospace. The AXCIS project partnered with Chase Defense Partners and Emerson Micro Motion via fixed-firm price contract to develop this technology for use with propellants, gaseous helium, and gaseous xenon. Utilizing a 1989 analog transmitter design from Emerson Micro Motion as a baseline, NASA developed a flight forward transmitter design that incorporates flight-forward radiation hardened electronics for use with Emerson Micro Motion mass flow meter sensors that are available commercial-off-the-shelf (COTS). Chase Defense Partners and Emerson Micro Motion delivered the AXCIS Coriolis mass flow meter sensors to NASA in August 2024 and AXCIS has been performing characterization and accuracy testing through three design iterations of the NASA transmitter.

The xenon and helium compressor technologies were selected for development as there is currently no capability for mass efficient on-orbit high pressure gaseous helium and xenon transfer, nor has it been attempted. The AXCIS project partnered with Flight Works, Inc. via a Phase III Small Business Innovation Research (SBIR) contract to develop these technologies utilizing a positive displacement, multi-stage piston compressor design. Due to the schedule constraints of the project, a single stage Engineering Development Unit (EDU) compressor design capable of compressing both helium and xenon was selected for development. To simulate the second and third stage of the AXCIS EDU compressor, swappable mass simulators were installed where the pistons would normally be installed. The AXCIS project plans to use a spare EDU compressor to simulate the second stage during functional and TVAC testing. The AXCIS EDU compressor manufacturing and assembly was completed in April 2025 and is now undergoing characterization and performance testing utilizing gases such as nitrogen, argon, helium, carbon dioxide, and xenon.

The ability to perform large pressure regulator set point adjustments in space is a technology that remains underdeveloped. The variable output regulator (VOR) technology was selected for development to allow for adaptability in future in-space propellant and pneumatic gas servicing systems. The AXCIS project partnered with Premier Industries via fixed-firm price contract to develop a semi-custom ground regulator utilizing their existing COTS regulator product line. The NASA AXCIS team designed a motor assembly utilizing COTS parts and developed a flight forward printed circuit board design that incorporates radiation hardened electronics to control pressure set point adjustment. This motor assembly and custom electronics interface with the Premier Industries regulator, creating the AXCIS VOR. A prototype of the VOR was built and tested in late 2024/early 2025. Lessons learned from prototype testing are currently being implemented in the EDU version of the VOR which is scheduled for assembly, functional and environmental testing starting at the end of May 2025.

The seal-less, mechanically compliant fluid adapter is a technology being built to withstand hypergolic oxidizer (nitrogen tetroxide). It has no seals or soft goods, can move along any vector within a full hemisphere about the hinge for pitch, roll, and yaw, and could be adapted for use with any fluid interface or flexible joint under 500 psig. NASA is working with Quadrus Corporation on this technology development effort via SBIR Phase III. Work on the development of the adapter was already underway at the start of the AXCIS project however,

AXCIS joined the development effort to assist in component and system level environmental testing to further advance the technology. The prototype fluid adapter is currently being manufactured and will be implemented into the AXCIS test systems upon NASA receipt.

The AXCIS project team has designed an optimized servicing test system that integrates all the AXCIS technologies and allows for optimized servicing operations to be performed while under test. The team is currently building the test system on site at Kennedy Space Center with functional testing schedule to begin early June 2025. System level TVAC testing is scheduled at GSFC in July 2025. During TVAC testing, the AXCIS team will perform simulated servicing operations under hot and cold conditions at vacuum. These operations will include gaseous helium, carbon dioxide (xenon simulant), and xenon servicing operations, simulating transfers utilizing pressure balance and compression. Additionally, simulated propellant servicing operations will be demonstrated utilizing both pressure and pump fed transfer methods. Results from this system level TVAC testing will be included in this paper in addition to the EMI/EMC and vibration/shock component level test results.