TEST PROGRAM FOR STIRLING RADIOISOTOPE GENERATOR HARDWARE AT NASA GLENN RESEARCH CENTER. E. J. Lewandowski[1], S. M. Oriti[1], and M. D. Dolloff[1], [1]NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135.

Introduction: Stirling-based energy conversion technology has demonstrated the potential of high efficiency and low mass power systems for future space missions. This capability is beneficial, if not essential, to making certain deep space missions possible. Significant progress was made developing the flight Advanced Stirling Radioisotope Generator (ASRG), a 140-watt radioisotope power system. A variety of flight-like hardware, including Stirling convertors, controllers, and housings, was designed and built under the ASRG project, and this hardware will now go on test at the NASA Glenn Research Center (GRC) as part of the new Stirling Radioisotope Generator (SRG) project to support future Stirling-based power system development. While future flight hardware may not be identical to the hardware developed under the ASRG project, many components will likely be similar, and system architectures may have heritage to ASRG. Thus the importance to future Stirling-based power systems of testing the ASRG hardware cannot be understated. This testing will include extended operation to establish an extensive reliability database and characterization testing to quantify subsystem and system performance and better understand system interfaces. This abstract details the test program for Stirling radioisotope generator hardware that is already underway at NASA GRC. It explains the rationale behind the tests being conducted and how these tests will meet the stated objectives.

Test Objectives: There are several objectives for ASRG hardware testing in support of the SRG project. First, extended operation of highest-pedigree ASCs will establish a database of component and convertor performance and reliability. Having high hours of reliable operation for Stirling convertors fills an important gap in the data. This data can be used to validate component models which can be the basis for models of future SRG components. Demonstrated long-life extended operation builds confidence that any major failure modes have been identified and addressed.

A second objective is to demonstrate steady-state and dynamic performance of an integrated Stirling system converting heat to conditioned spacecraft bus power. This includes benchmarking convertor, controller, and generator system performance in a flight-like environment under typical mission operation scenarios, including beginning of mission, end of mission, and diurnal Martian environmental testing. Tests will quantify efficiency, power, power quality, short-term and long-term convertor and controller stability, temperature sensitivity of the convertor, and DC bus voltage sensitivity of the controller [1].

A third objective is to validate convertor, controller, convertor-controller interface, and controller-spacecraft bus interface requirements. This activity will inform future Stirling power system requirement development and requirements flowdown and improve requirements definition, especially with the complex interfaces in Stirling power systems.

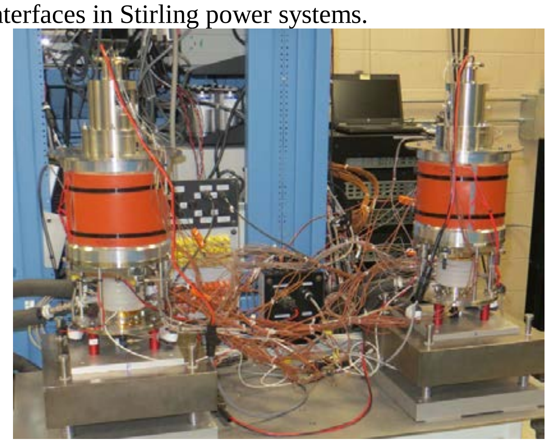

Figure 1. ASC-E3 #3 and #4 under test in NASA GRC's Stirling Research Laboratory (SRL).

Convertor testing: Convertor testing that had been planned under the ASRG project largely continues under the SRG project, although with slightly different objectives. Because demonstrating high reliability is so critical to any space power system, and this invariably necessitates years of testing, this work will continue. Multiple high pedigree convertors will be put on test under a flight-like test profile, with the goal of accumulating a significant number of failure-free years of operation (Figure 1).

The typical convertor test profile begins with performance mapping, where convertor performance is characterized at certain specific operating points. This is followed by extended operation, which may include both horizontal and vertical operation as expected during ground operations. After typically 5,000 to 10,000 hours of operation, the convertors undergo a flight acceptance and launch simulation vibration test, simulating the vibration expected to be experienced by flight convertors. The convertors will then return to extended operation and continue to operate at varying operating conditions throughout the test, so that they see the range of operating conditions expected during a mission. Some convertors will be tested in air, some in vacuum, and some will be tested as part of a generator system with a digital controller.

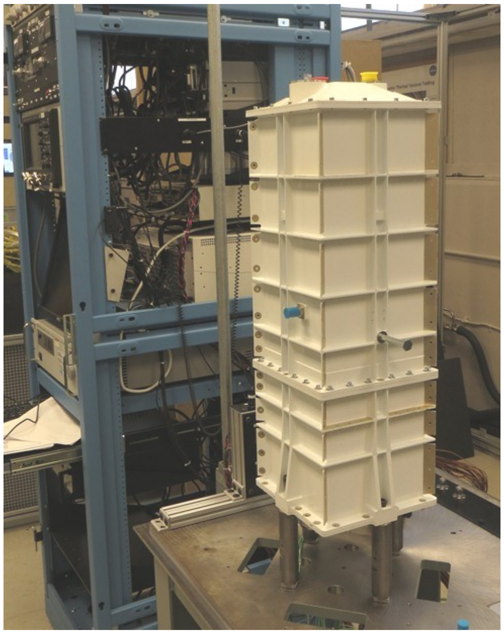

Figure 2. The ASRG EU2 Generator Housing Assembly being set up for test in the SRL.

Generator system testing: While much testing of Stirling convertors has been conducted over the past decade, limited system level testing has been done. To date, the highest fidelity generator system testing was conducted with the ASRG Engineering Unit (EU). After completing a series of system-level tests to qualification level thermal and dynamic environments at Lockheed Martin, the ASRG EU ran for over 33,000 hours at NASA GRC. This included 15,378 hours of operation with a first-generation controller, Engineering Development Unit (EDU) 1. The ASRG EU was taken off of test in 2013 for disassembly and inspection.

To take the ASRG to flight, many changes were made to the convertor and controller designs since the ASRG EU was built in 2007. It will be important to any future Stirling-based flight project to be able to leverage flight-like pedigree system-level test heritage. To that end, a high-fidelity engineering unit, the ASRG EU2, is being assembled at NASA GRC (Figure 2). The ASRG EU2 will consist of the first pair of ASC-E3 convertors, Lockheed Martin's EDU 4 controller (a 4th generation controller), and an aluminum flight-like housing [2].

This test program does not intend to complete fabrication of the ASRG Qualification Unit (QU) or to test the ASRG EU2 to the full suite of qualification tests. Qualification tests are mission specific, and the EU2 was not designed to be able to meet the requirements of all qualification tests.

Special system tests. The ASRG EU2 presents an opportunity to conduct system-level tests that are of special interest to missions. One of these tests is to characterize the disturbance force generated by oscillating internal parts of the convertors. Parameter sensitivities and levers available to reduce disturbance force will be quantified. Another test will be to characterize generator performance with one convertor non-operational, under different dynamic mounting dynamics.

Extended operation testing. After completion of performance, demonstration, and characterization testing, the ASRG EU2 will continue on extended operation. Besides generating long-life data, this testing will provide an opportunity to quantify any performance degradation. Some potential minor degradation modes have been hypothesized, but for the most part have not been quantified empirically. Convertor and generator performance will be accurately measured regularly at certain operating points to monitor for any changes in performance. Operating conditions during this phase will mimic expected flight conditions to the extent possible, including thermal environment variation and vacuum.

Interface testing. The interface between the controller and the convertor is complex, containing bidirectional energy flows influenced by many factors. Completely capturing and quantifying the interface requirements when considering all aspects of a space mission, including startup, fueling, test, integration, launch, and so forth, is challenging. This test program will include tests to better understand interfaces for future power systems.

Controller testing. Controller-only tests are planned to assess power quality and other controller metrics. These tests will be conducted with active electronic convertor simulators in place of actual convertors to allow for ease of testing and to allow for a wider range of inputs. A test of two generators on one bus will be conducted if two controllers become available.

Conclusion: The Stirling radioisotope generator hardware test program at NASA GRC plays a vital role in the future development of Stirling-based power systems. Under the ASRG project, significant progress was made towards the development of a flight-qualified radioisotope power system. The test program described here will provide data on the performance and reliability of the ASRG hardware, at the system, sub-system, and component level.

References:

[1] Lewandowski, E. J. et al. (2010) "Testing to Characterize the Advanced Stirling Radioisotope Generator Engineering Unit," *AIAA-2010-6693*.

[2] Oriti, S. M. (2012) "Test Hardware Design for Flight-like Operation of Advanced Stirling Convertors (ASC-E3)," *AIAA-2012-4254*.