

Pathfinding the Flight Advanced Stirling Convertor Design with the ASC-E3

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The Advanced Stirling Convertor (ASC) was initially developed by Sunpower, Inc. under contract to NASA Glenn Research Center (GRC) as a technology development project. The ASC technology fulfills NASA's need for high efficiency power converters for future Radioisotope Power Systems (RPS). Early successful technology demonstrations between 2003 to 2005 eventually led to the expansion of the project including the decision in 2006 to use the ASC technology on the Advanced Stirling Radioisotope Generator (ASRG). Sunpower has delivered 22 ASC convertors of progressively mature designs to date to GRC. Currently, Sunpower with support from GRC, Lockheed Martin Space System Company (LMSSC), and the Department of Energy (DOE) is developing the flight ASC-F in parallel with the ASC-E3 pathfinders. Sunpower will deliver four pairs of ASC-E3 convertors to GRC which will be used for extended operation reliability assessment, independent validation and verification testing, system interaction tests, and to support LMSSC controller verification. The ASC-E3 and -F convertors are being built to the same design and processing documentation and the same product specification. The initial two pairs of ASC-E3 are built before the flight units and will validate design and processing changes prior to implementation on the ASC-F flight convertors. This paper provides a summary on development of the ASC technology and the status of the ASC-E3 build and how they serve the vital pathfinder role ahead of the flight build for ASRG. The ASRG is part of two of the three candidate missions being considered for selection for the Discovery 12 mission.

Nomenclature

<i>ASC</i>	=	Advanced Stirling Convertor
<i>ASRG</i>	=	Advanced Stirling Radioisotope Generator
<i>CSAF</i>	=	cold-side adapter flange
<i>DOE</i>	=	Department of Energy
<i>GRC</i>	=	Glenn Research Center
<i>ILS/APS</i>	=	Internal Limit Sensor/ ASC Piston Sensor
<i>LMSSC</i>	=	Lockheed Martin Space Systems Company
<i>RPS</i>	=	Radioisotope Power System

I. Introduction

THE Advanced Stirling Convertor (ASC) development by Sunpower, Inc. began as a technology development contract to NASA Glenn Research Center (GRC). The initial ASC contract was one of ten technology contracts¹ awarded in 2003 that included a variety of conversion technologies and technology readiness levels that

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were intended to address NASA's need for high efficiency power conversion systems for future Radioisotope Power Systems (RPS). High efficiency systems are needed to reduce fuel requirements lowering system mass and to make best use of the small plutonium inventory in the U.S. for fueling non-solar NASA science missions. Between 2004 and 2005, Sunpower quickly demonstrated the performance capability of the ASC configuration, first with the Frequency Test Bed convertors (FTB) that demonstrated in the laboratory 36% efficiency (80 W_{AC} power output, 650°C T_{hot} and 30°C T_{cold}) and then with the ASC-1 at 38% efficiency (88 W_{AC} power output, 850°C T_{hot} and 90°C T_{cold}).² In order to operate at 850°C, the ASC-1 units were the first to utilize MarM-247 as the heater head material.

The positive results led to acceleration of the development of the ASC between 2005 and 2007 with the ASC-0 and ASC-1HS builds. Previous units utilized bolted joints, and the focus of the ASC-0 convertors was to develop the hermetic joints and processes using Inconel 718 for the heater head to allow quicker demonstration. The ASC-1HS (for Hermetically Sealed) then refined the design by demonstrating the seal of a MarM-247 heater head. Upon delivery to GRC, these convertors were put on extended operation.

Additionally, based on the continued successful performance demonstrations of the earlier ASC convertors by Sunpower, in 2006, NASA, the Department of Energy (DOE), and Lockheed Martin Space Systems Company (LMSSC) made the decision to switch from a lower efficiency Stirling convertor on the Stirling Radioisotope Generator (SRG 110) and adopted the Sunpower ASC technology as part of the newly named Advanced Stirling Radioisotope Generator (ASRG).³ A general layout of the current ASRG flight design is shown in Fig. 1 that identifies the position of one of a pair of ASCs that are positioned in dual-opposed configuration to minimize vibration, along with a General Purpose Heat Source (GPHS) mated to the heater head of each convertor.

In contrast to the earlier technology demonstration convertors that were designed for stand-alone laboratory operation, the ASC-E (Engineering) was developed specifically to be integrated onto the electrically heated ASRG Engineering Unit (EU) that required development of the generator interfaces and other design and process updates to meet the system requirements. Leading up to the decision to adopt the Sunpower ASC technology on ASRG, the multi-disciplined GRC technical team that had supported DOE in the development of the SRG⁴ was directed by NASA Headquarters to shift support to Sunpower and accelerate ASC development. At the time, due to schedule considerations and the availability of the previous heater head fabrication vendor, it was decided to utilize Inconel 718 heater heads for the ASC-E design that limited operation to 650°C. Some of the technology advancements made with the ASC-E includes the integration of the heat collector interface, the cold-side adapter flange (CSAF) interface, and the development of an internal piston motion sensor. Sunpower developed the ASC-E under contract to GRC and in October 2007, GRC delivered two ASC-E convertors (Fig. 2) plus a spare on schedule to DOE and

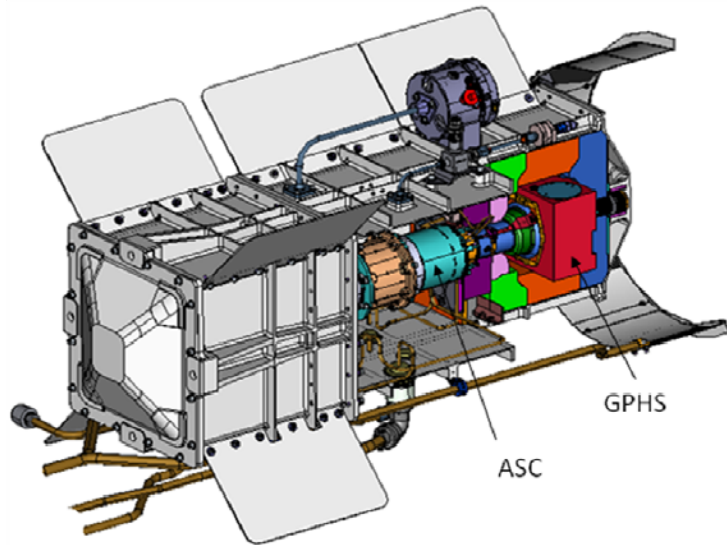


Figure 1. ASRG with two dual-opposed ASC convertors.



Figure 2. Pair of ASC-E units delivered by Sunpower and GRC to DOE and Lockheed Martin for integration onto ASRG EU.

LMSSC for integration onto the ASRG EU. The ASC-E convertors produced about 78 W_{AC} exceeding the specification of 75 W_{AC} at 60°C T_{cold} and 640°C T_{hot}. After completion of a variety of generator tests at LMSSC, the ASRG EU was delivered to GRC where it continues to operate.

Development of the ASC has progressed from the early technology demonstration convertors (ASC-1, ASC-0, and ASC-1HS), to the ASC-Es that were integrated into the ASRG EU, to the ASC-E2 that demonstrated key advancements used on the flight design. The general maturation of the ASC technology is illustrated in Fig. 3, identifying the order of the various convertor builds. To date, Sunpower has built and delivered 22 convertors under contract to GRC across several design generations. The convertors are being used for various purposes including extended operation evaluation, durability testing, and as support hardware for LMSSC's controller development. As of June 2012, GRC's Stirling Research Laboratory has accumulated over 220,000 hours of operation. Each of the ASC-Es integrated onto the ASRG EU has a total of over 26,000 hours. Currently, Sunpower has parallel contracts with GRC and LMSSC to deliver the ASC-E3s and the ASC-F (flight) respectively, based on the ASC-E2. The balance of this paper discusses the status and advancements of the ASC-E2, ASC-E3, and ASC-F.

II. ASC-E2 Development – Basis for Flight Design

Soon after delivery of the ASC-E, in November 2007 Sunpower and GRC in coordination with LMSSC kicked-off the development of the ASC-E2 that has become the basis of the current flight design. A significant aspect of the ASC-E2 was the development of the MarM-247 heater head assembly that required a redesign to provide a maximum of 850°C heater head temperature capability, meet 17 year design life, incorporate generator interface, and reflect process and fabrication vendor changes. While earlier heater heads used on the ASC-1 and ASC-1HS demonstration units utilized MarM-247 and performed at 850°C, the ASC-E2 heater head assembly design had additional structural requirements to support an axial load and lateral inertia loads of the GPHS during launch. The heater head assembly design developed for ASC-E2 utilized a composite of high thermal conductivity nickel in the heat collector and high strength MarM-247 to carry the structural loads. Additionally, Refrac System was selected to be Sunpower's fabrication vendor for production of the new heater head assembly as well as displacer assembly, requiring a variety of fabrication and joining development trials. While GRC personnel provided technical support to Sunpower in developing the ASC-E2 in several areas including organic materials, regenerators, structural dynamics testing, analysis, and reliability, working with Sunpower on the development of the new MarM-247 heater head assembly was an area of focus.^{5,6} In particular, GRC materials and structures experts performed materials

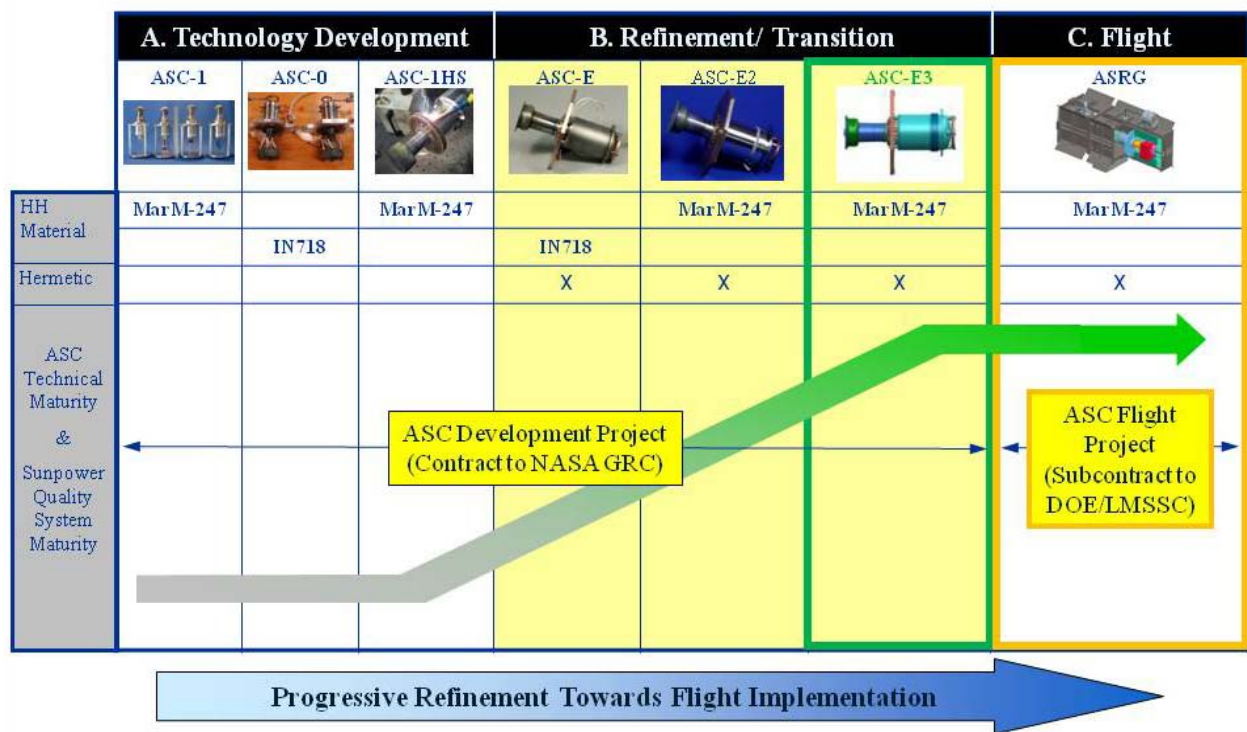


Figure 3. Advanced Stirling Convertor Evolution from Technology Development to Flight.

development and characterization testing, modeling and life prediction, as well as heater head component testing to support the design.⁷

Other advancements during the ASC-E2 build include the metallurgical bonding of the CSAF and the development of a new sensor to monitor the piston motion. Fig. 4 provides an illustration of the ASC configuration and overall size. The CSAF provides the heat rejection thermal interface and the structural interface between the central hub of the convertor called the transition assembly, and the ASRG generator housing. The previous ASC-E convertors utilized an interference fit for the CSAF to transition assembly joint, supported by fasteners. In preparation for the ASC-E2 build, a trade study was conducted on various attachment methods, and an electron beam weld was selected. Various electron beam weld trials were completed to confirm the weld parameters to be used on ASC-E2 and all production welds were completed successfully. A new piston sensor was also developed for the ASC-E2, called the Internal Limit Sensor (ILS), which was later renamed the ASC Piston Sensor (APS) for the ASC-E3 and ASC-F design. The new piston sensor design places the sensing coil on the exterior of the pressure vessel and thus eliminated two electrical feedthroughs in the pressure vessel boundary reducing production risk and improving overall reliability.

In addition to the design and process improvements, the ASC-E2 this was the first build that was completed under Sunpower's burgeoning Quality Management System developed in anticipation of the rigors of flight hardware production. An Engineering Review Board (ERB) consisting of GRC, Sunpower, and Lockheed personnel was responsible for the design review and approval and configuration control. Design rigors of geometric dimensioning and tolerancing (GD&T), upgrading to a 3-D design software, and upgrading of Sunpower's finite element analysis capabilities were all incorporated as part of the ASC-E2 project. Additionally, inspection capabilities and documentation were improved upon including the addition of a Coordinate Measuring Machine (CMM) and roundness tester dedicated to ASC production. A laser welder and other production capabilities were also added to support ASC-E2 manufacturing.

Sunpower completed eight ASC-E2s. The convertors all went through a suite of tests at Sunpower as part of the production process that allowed checkout of performance characteristics throughout the build that incrementally added final production components and welded joints. Once the convertors were completed and hermetically sealed (convertors #1-#6), they went through Workmanship level vibration testing at GRC (Fig. 5). Afterwards, the convertors were returned to Sunpower for final performance mapping. A significant aspect of the ASC-E2 build was to improve the accuracy of performance assessments for the convertors that is made complicated by a non-measurable specification called "net heat input" that is the available heat from the GPHS provided to the ASC. In order to determine ASC efficiency accurately, all losses in the test system including insulation, housing, electric heaters and wiring, supports, etc. must be considered. Wilson⁸ provides a summary of the efforts that

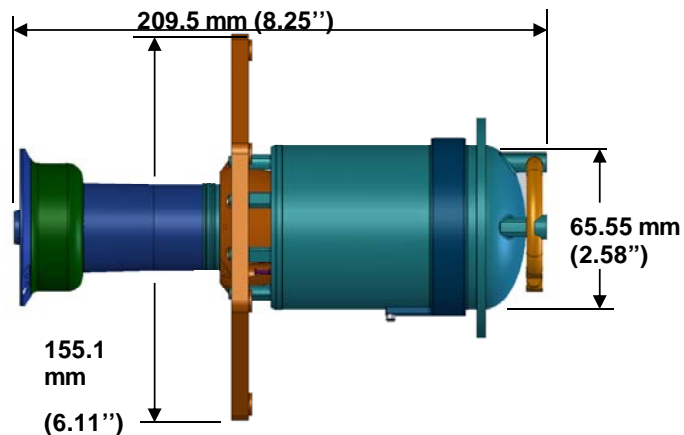


Figure 4. Illustration of the ASC flight configuration.

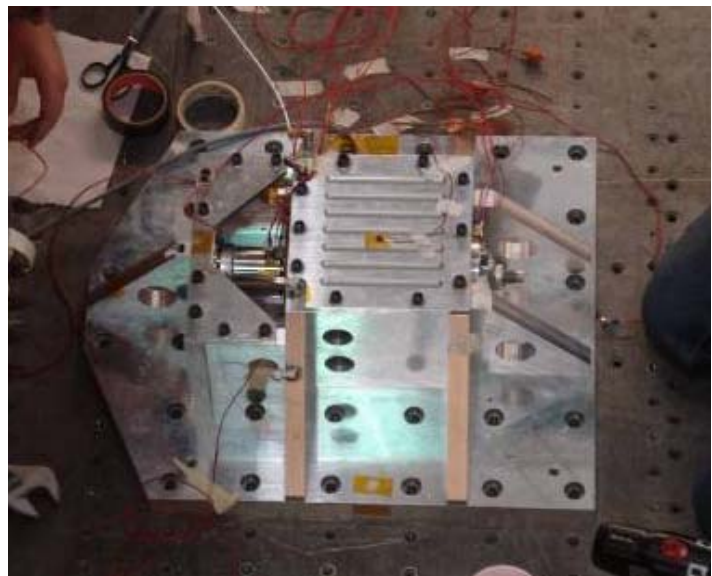


Figure 5. ASC-E2 #2 preparing for Workmanship level vibration testing at GRC's Structural Dynamics Laboratory

went into developing a high fidelity methodology for determining ASC net heat input and convertor efficiency.

The first three pairs of ASC-E2s were delivered by Sunpower to GRC at varying times between February 2010 and July 2010, with a representative unit shown in Fig. 6. The last pair of convertors, ASC-E2 #7 and #8, was delivered in a non-hermetic specialized configuration for the purpose of conducting durability testing. They utilized GRC designed pressure vessels with bolted joints that would allow periodic inspections as part of several planned durability tests. See later section on durability testing. The plan is for ASC-E2 #7 and #8 to eventually be returned to Sunpower for re-work and completion to the baseline hermetically sealed configuration. The ASC-E2 build included many significant technology advancements, technical challenges, lessons learned, and improvements to Sunpower's infrastructure. The ASC-E2 is the baseline for all future ASC convertors including the ASC-F units.

III. ASC-E3 Pathfinders and ASC-F Flight Units

As illustrated in Fig. 3, the original intent was to complete the technology development phase with ASC-E3 prior to commencement of flight production. However, the technology maturation plan has been compressed in order to support the candidate Discovery 12 mission opportunity. Sunpower has recently started fabrication of the ASC-E3 (Engineering design #3) convertors for GRC and, in parallel, is developing the ASC-F (Flight) convertors for Lockheed Martin's ASRG flight project. This circumstance of parallel convertor builds with the initial two pairs of ASC-E3 convertors leading the way allow for a unique opportunity to use the ASC-E3s as pathfinders for the design and process changes that are part of the ASC-F.

The intention is that the ASC-E3 and -F convertors will be built to the same design and processing documentation and the same flight ASC product specification. The current plan is to phase the ASC-E3 build into an initial "developmental" set (the first two pairs), followed by a "flight-like" set (the last two pairs). This plan allows the reduction of risk by using the initial two pairs of ASC-E3 to validate design and processing changes prior to implementation on the ASC-F, and to develop and verify the cleanliness and planetary protection procedures that are being implemented for flight. As hardware for the first two pairs is being produced, the flight requirements and documentation will be finalized. The documents for the early ASC-E3 are all part of the same "set" as the flight documentation, but as documents are updated, they are given distinct revision numbers that allow traceability for all the hardware. The plan is for the last two pairs of ASC-E3 to be produced using the final flight approved documents so that these convertors will be fully representative of the flight convertors and can undergo extended operation and independent validation and verification testing at GRC. In total, four pairs of ASC-E3 and four pairs of ASC-F convertors are planned.



Figure 6. Completed ASC-E2 - Baseline for Flight Design

A Joint Configuration Control Board (CCB) with membership from GRC, DOE, Lockheed Martin, and Sunpower was created in January 2011 that has the responsibility to review and approve Sunpower's ASC design documentation to maintain configuration control for the ASC-F build and the ASC-E3 build. The CCB reviews all ASC drawings, process specifications, process documents, and test procedures. As of this writing, there is an ASC-E3 Material Review Board (MRB) and an ASC-F MRB that work very closely together to review nonconformances and approve corrective actions and disposition of hardware. The ASRG Project Office is in the process of chartering a Joint MRB, modeled after the Joint CCB, that will have oversight for the ASC-F and the third and fourth pairs of ASC-E3.

After successful completion of the ASC-E3 Long Lead Production Readiness Review (PRR) held in November 2010, production of the three critical long lead subassemblies was initiated: The heater head assembly and displacer assembly produced by a subcontract team led by Refrac Systems, Inc. and the transition assembly. A second PRR for the entire ASC-E3 convertor was held in April 2011 resulting in authority to proceed for the first two ASC-E3 pathfinding pairs starting June 2011. At the time of the PRRs, requirements and design details not fundamental to

the ASC design were not finalized for the flight design so the initial E3 convertors have proceeded with “TBR” notation on some design and process details. This circumstance was accepted to allow the initial ASC-E3 pathfinder production to commence ahead of the equivalent flight production process.

The ASC-F design has also gone through several reviews, first as part of the ASRG Final Design Review (FDR) held July 2011, then at the ASC-F FDR Closeout held February 2012. While various long-lead hardware commenced production earlier, ASC-F convertor-level build and processing approval was provided by LMSSC after the Manufacturing Readiness Review (MRR) held April 2012 pending approvals of design documents by the CCB. Meanwhile, Sunpower was in the process of relocating to a new larger facility made necessary by the growing staff and increased production requirements for the ASRG flight project. Sunpower completed the relocation on schedule in July 2011. One of the primary drivers for the relocation was the flight cleanliness requirements that necessitate build-up and processing in a clean room environment. The plan is for the first ASC-E3 pair to pathfind the flight design and process changes as early as possible without clean room processing in order to identify potential developmental issues. The second ASC-E3 pair will then serve as the first hardware to undergo production in the new Sunpower clean room facility following new production procedures, inspection techniques, and cleaning methods.⁹

IV. Advancements and ASC-E3 Status

Sunpower has completed the initial components for the first two pairs of ASC-E3. As explained earlier, these components proceeded prior to finalization of all production documents. The remainder of the hardware for ASC-F and ASC-E3 are in production and to improve on production and tracking efficiency, rather than handle all hardware as ASC-E3 or -F specific, Sunpower is utilizing "common inventory" for many of the longer lead components and subassemblies. This entails producing flight-worthy parts that are entered into bonded storage inventory and that are doled out for the future builds when the parts are needed.

The ASC-F design is very similar to the ASC-E2 baseline in terms of overall configuration. However, every design and process document has been updated and some new ones created for the ASC-F. Much of the design refinements, documentation details, and analysis updates are necessary due to the new ASC flight requirements flowed down to Sunpower from LMSSC's ASRG specifications including materials and processing requirements, nondestructive inspection requirements, and LMSSC, NASA, and industry standards being applied to the updated ASC-F specification. The details of these updates are beyond the scope of this paper and are part of the ASC-E3 PRR, ASRG FDR, and ASC-F FDR Closeout reviews. Below are some of the advancements and design updates. As intended, several refinements and improvements were the result of early lessons learned from the production of initial ASC-E3 pathfinder hardware.

A. Cold Side Adapter Flange Attachment

As discussed earlier, the previous ASC-E2 design utilized an electron beam weld for the CSAF to transition joint. For schedule and cost reasons, the ASC-E2 used a simpler Sunpower CSAF design that approximated the stiffness anticipated in a flight CSAF. For the ASC-F and -E3, LMSSC is responsible for the CSAF design and production, and qualification of the attachment joint to the transition assembly. The flight CSAF design is more complicated than that of the ASC-E2 as it has features to enhance thermal performance. Considerable effort went into producing the flight CSAF components and qualifying the weld. However, during weld trials prior to ASC-E3 production, it was found that the electron beam weld may not be compatible with the flight CSAF design without significant development. After assessment, LMSSC concluded that a mechanical interference-fit joint that is supported by existing CSAF fasteners is acceptable for meeting the structural loading and heat transfer requirements and that the electron beam weld can be eliminated. The first pair of ASC-E3 production was on hold while this issue was resolved, and immediately resumed production once the decision to baseline the interference fit joint was made. Several production CSAF/transition assemblies have been joined successfully to date. Thermal performance has been verified through a dedicated thermal vacuum test at LMSSC as well as through initial operations of the ASC-E3 first pair at Sunpower. Structural performance has been verified through vibration testing of an ASC mockup assembly at GRC.

B. Heater Head Assembly Non-Destructive Inspection

Several lessons learned during the ASC-E2 build have been included in the ASC-F and -E3 heater head assemblies including fabrication and processing improvements. Most notable of the changes is after the heater head assemblies are completed by Refrac, they undergo several quality checks at Sunpower and GRC. In addition to performing detailed CMM inspection, Sunpower performs bubble leak testing as well as proof pressure testing.

GRC had been developing non-destructive inspection (NDI) techniques for the heater head assembly that has become part of the flight hardware process.

After evaluating several NDI techniques, GRC's x-ray Microfocus Computed Tomography (CT) system was selected as most suitable for identifying imperfections in the thin wall and taper region of the heater head assembly. The GRC system is considered to be one of the best in the United States and offers the resolution and sensitivity necessary to detect nonconforming features in the head. CT creates a three-dimensional model of the inspected object through computer processing and reconstructing a very large series of high-resolution two-dimensional x-ray images taken of the object around a single axis of rotation. Optimization of the GRC CT system was performed using several representative parts including an initial roughly machined "calibration standard." Plans are to conduct a more thorough probability of detection study using a more precisely machined calibration standard made from an ASC MarM-247 heater head with many accurate minute target features. It has been verified that CT is capable of detecting critical flaw size features in the heater head assembly. All ASC-E3 and ASC-F heater head assemblies are undergoing CT inspection.

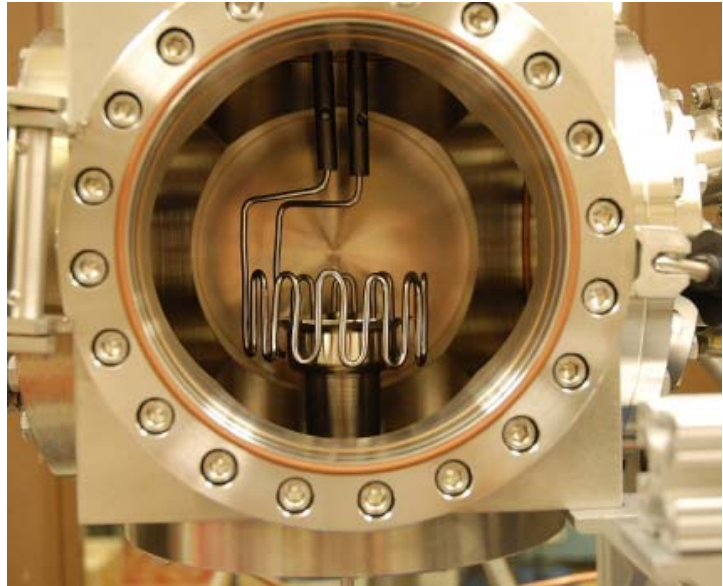


Figure 7. Heater Head Assembly High Temperature Leak Test Setup located at GRC

The second screening technique that the heater head assemblies will go through at GRC is the high temperature leak test. The GRC setup was originally used to verify that the helium working fluid of the convertor would not permeate at representative pressures and temperatures through the heater head assembly. The setup was then updated to allow verification that the production heater heads do not leak helium. The vacuum chamber for this test (Fig. 7) utilizes a very tight crushed metallic seal between the heater head assembly open end and the actively cooled mounting flange. The heater head is pressurized with helium and heated with a radiant heater to the maximum head temperature. The system has a residual gas analyzer and vacuum pressure gage for leak detection.

Hermeticity is a crucial requirement of the ASC convertor that is required to operate for 17 years and the application of CT NDI and high temperature leak testing of the heater head assembly at the subassembly level, prior to integration onto a convertor, provides confidence that the hermeticity requirement will be met.

C. Alternator Design Update

After completion of the ASC-E2 builds, as a result of LMSSC system assessments, a decision was made to specify an increase in the output voltage of the ASC-F. Sunpower avoided cascading design changes by only revising the alternator coil design. Several trial assemblies were produced. To gain operational performance data with the new alternator design, ASC-E2 #7 and #8 were re-worked to include the new coil/outer stator. This pair originally planned for durability testing had the bolted pressure vessel design that made access to the outer stator easier. While one of the units was used for initial durability testing, this pair of convertors was provided to LMSSC to support controller operational verification as the electrical characteristics with the updated alternator is most flight like.

D. Completed Regenerator Production Transfer

Production methods for the high-temperature capable, oxidation resistant regenerator were developed at GRC. For earlier convertors the regenerators were produced at GRC with a gradual transfer of capabilities and responsibilities to produce the regenerators to Sunpower. In preparation for the ASC-E3 and -F builds, Sunpower demonstrated in-house production capabilities and has assumed complete responsibility for regenerator production. Sunpower regenerators have been installed and operated in the ASC-E3 first pair successfully.

E. ASC Durability Testing

Durability testing is intended to stress the convertors beyond what is expected in application and experimentally demonstrate the existing margins in the design. The suite of four durability tests includes: 1) repeated starting and stopping of the convertor, 2) exposing the convertor to a large static g-load on a centrifuge, 3) random vibration testing at higher piston amplitudes to incite a number of piston and/or displacer contact events, 4) temporarily disable control allowing a limited number of contact events through a controller switch over or other equivalent event. To date, the first two durability tests have been completed.

As discussed previously, ASC-E2 #7 and #8 were intended for durability testing. Later, circumstances required the pair to undergo rework in order to update the alternator to the flight design after which they were reallocated to support a higher priority need at LMSSC for controller development. Before transferring the convertors to LMSSC, ASC-E2 #8 was able to complete the first of the four durability tests in September 2011 at Sunpower with support from GRC personnel. The objective was to characterize any potential degradation on the internal convertor surfaces during startup and shutdown of a convertor before the self-pressurizing gas bearings are activated. The testing was conducted with the convertor motored in horizontal and vertical orientations and in a range of operating temperatures. The convertor was exposed to 300 start/stop cycles total representing over twice the maximum cycles expected in a flight unit. Post-test disassembly and inspection as well as gas bearing flow tests indicate no evidence of wear or gas bearing degradation.

GRC Stirling test personnel completed the second of the durability tests at Case Western University's centrifuge facility in May 2012. As the ASC-E2 #7 and #8 convertors were no longer available, ASC-E2 #2 was reworked and prepared for durability testing. The rework included installation of the bolted pressure vessel that would allow repeated disassembly for post-test inspections as well as installation of more accurate FLDT piston and displacer position sensors. The centrifuge test was performed at several g-loads with the operating convertor in lateral loading, and axial loading orientations relative to the centrifuge, with disassembly and inspections performed in between. The most demanding of the tests exposed the convertor to 18-g in the lateral direction acting against the gas bearings. This test was also an over-test in that the spin-up time of the centrifuge facility took significantly longer than the projected duration of a static load of reentry and landing or of a boost thruster during a mission. Inspection revealed no significant degradation or wear of the running surfaces. Very minor "polishing" of the surfaces was noted confirming that lateral contact did occur as expected. Operation of the convertor after the centrifuge testing also confirmed nominal performance.

F. Status of ASC-E3 First and Second Pair

As the first hardware to be built and processed based on the new flight design, a variety of issues were identified and resolved including technical issues that required design updates, processing issues that required refinement, and human errors. Non-conformances are handled by the ASC-E3 MRB. The initial assembly of ASC-E3 first pair components was completed and Sunpower successfully operated ASC-E3 #2 on March 13, 2012, demonstrating first operation of the flight-like design. As planned, the initial operation configuration (Fig. 8) utilized non-production test piston, displacer, and back pressure vessel (alternator housing) and was the first in a series of tests that allow assessment of the convertor in between progressive assembly steps including welding of the head, pressure vessel sleeve, dome, and hermetic sealing of the fill tube weld. On April 12, 2012 ASC-E3 #1 was operated for the first time and was followed by focused shakedown/characterization testing that allowed unit #1 to catch up to unit #2 so that the pair could continue production more efficiently in parallel. While final performance verification testing has not been performed yet, tests to date across a range of required conditions with nominal performance results indicate the convertors will validate the performance estimates and flight design updates. As of this writing, the first pair of ASC-E3 has completed the final installation of all internal components to be followed by the pressure vessel dome and fill tube welds. Plans then call for Workmanship testing and final performance verification testing, followed by continuous detailed performance mapping with delivery to GRC Fall 2012. GRC will perform acceptance testing and then configure the convertors in a dual opposed configuration and deliver them to LMSSC for controller verification testing.

Similar to the first pair, the second ASC-E3 pair has also been invaluable as pathfinders as the first hardware to begin assembly and processing in Sunpower's new clean room facility. Assembly and production of the high precision ASC components requires tactile skills and experience. The clean room processes and required facility garb makes processing more difficult and time consuming. For the first two pairs of ASC-E3 convertors, Sunpower is able to redline the design and process documentation to make adjustments as deemed necessary prior to formal document revision and CCB review. Many cleanroom related process documents are expected to undergo revision as an outcome of the initial processing with ASC-E3 second pair. Upon delivery to GRC, the second pair hardware will undergo acceptance testing and extended operation testing.

One notable improvement in the testing of ASC-E3 and flight convertors is the adoption of the common performance mapping test setup design that will be used for all future performance mapping tests. The common test setup was designed taking into account lessons learned from convertor testing, insulation loss testing, and net heat input modeling for the ASC-E2 convertors. In addition to minimizing overall heat leaks, the new test setup is anticipated to reduce variability from convertor to convertor. Further, for the ASC-E3 convertors, Sunpower will deliver each convertor to GRC installed in its individual test setup so that GRC acceptance testing can be done without a tear down and build up of the insulation and test setup, again, minimizing variation in data.

G. Status of ASC-F Flight Convertors

Collins⁹ provides an overview of the ASC flight project accomplishments including a status of the ASC-F convertors. In summary, many of the components and subassemblies for the initial ASC-F pair are complete or nearing completion. As the initial flight convertors lag the ASC-E3 second pair by a couple of months, it is anticipated that convertor assembly will begin in the clean room shortly. This initial pair of ASC-F convertors is planned for integration onto an ASRG qualification test generator with later convertors slated for potential flight generators.

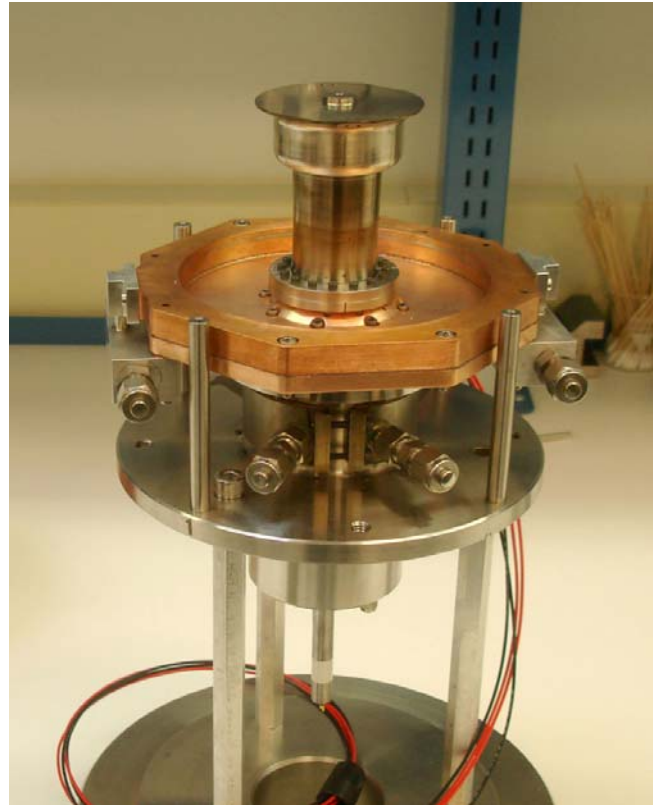


Figure 8. Non-Hermetic Configuration of ASC-E3 #2 for First Operation

V. Summary

The ASC began as a technology development project in 2003 and based on the break-through performance demonstrated by the early convertors, the development was accelerated including demonstration of a pair of convertors on the ASRG EU. The ASC-E2 included significant design updates required to meet the flight requirements and serves as the baseline for the flight configuration. The ASC-E3 is being built to the flight documentation and the first two pairs serve as critical pathfinders for the flight requirements driven design and processing updates. The first pair of ASC-E3 is nearing completion and preliminary results indicate performance projections will be met. The second ASC-E3 pair has initiated assembly in the clean room in Sunpower's new facility paving the way ahead of the flight convertor builds. Meanwhile, Sunpower has made significant transformative changes by relocating, training, building infrastructure, adding staffing, and adding capabilities all in preparation for building the ASC flight convertors. Sunpower along with support from GRC, LMSSC, and DOE are poised to begin assembly of ASC-F convertors for integration onto ASRGs to support the potential Discover 12 mission.

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