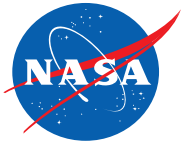
Advanced Stirling Convertor Durability Testing: Plans and Interim Results

Dave Meer and Sal Oriti

The U.S. Department of Energy (DOE), Lockheed Martin Corporation (LM), and NASA Glenn Research Center (GRC) have been developing the Advanced Stirling Radioisotope Generator (ASRG) for use as a power system for space science missions. In support of this program, NASA's Glenn Research Center (GRC) has been involved in testing Stirling convertors, including the Advanced Stirling Convertor (ASC), for use in the ASRG. This testing includes electromagnetic interference/compatibility (EMI/EMC), structural dynamics, advanced materials, organics, and unattended extended operation. The purpose of the durability tests is to experimentally demonstrate the margins in the ASC design. Due to the high value of the hardware, previous ASC tests focused on establishing baseline performance of the convertors within the nominal operating conditions. The durability tests present the first planned extension of the operating conditions into regions beyond those intended to meet the product spec, where the possibility exists of lateral contact, overstroke, or over-temperature events. These tests are not intended to cause damage that would shorten the life of the convertors, so they can transition into extended operation at the conclusion of the tests. This paper describes the four tests included in the durability test sequence: 1) start/stop cycling, 2) exposure to constant acceleration in the lateral and axial directions, 3) random vibration at increased piston amplitude to induce contact events, and 4) overstroke testing to simulate potential failures during processing or during the mission life where contact events could occur. The paper also summarizes the analysis and simulation used to predict the results of each of these tests.



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Objective / Outline

Durability Test Objective – Experimentally demonstrate margin in ASC design by operating outside the nominal operating parameters.

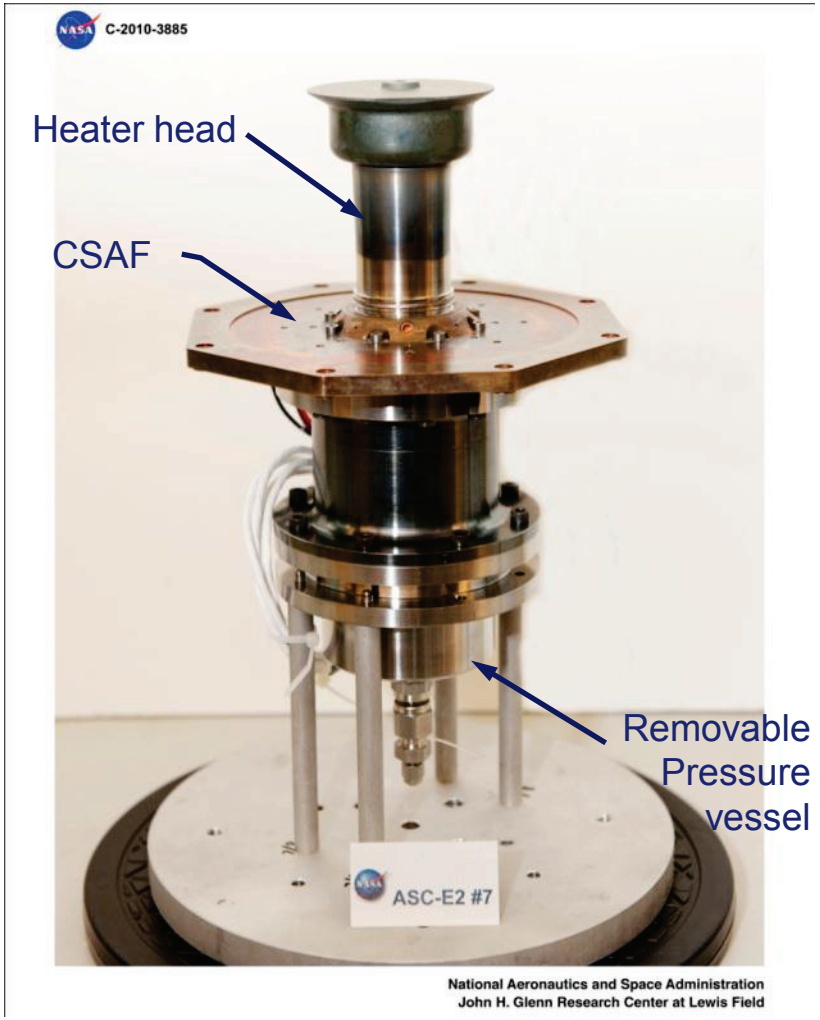
Outline:

- Introduction
- Background
- Start / Stop Cycle Test
- Centrifugal Acceleration Test
- Contact During Launch Vibration Test
- Overstroke Test
- Summary / Conclusions

Background

- Testing at Glenn Research Center - EMI/EMC, structural dynamics, advanced materials, organics, and unattended extended operation
- Limited quantity of high – value hardware limited testing that put the convertors at risk
- Extended operation testing at nominal operating conditions
- Designed with removable pressure vessels to allow for disassembly and inspection

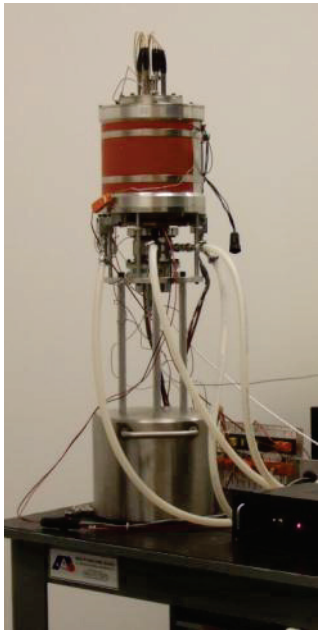
Durability tests validate convertor design beyond the nominal operational range.



Start / Stop Test

- Purpose – Demonstrate margin in start / stop cycles for flight
- Piston and displacer run on gas bearings that become fully charged above 3 mm piston amplitude
- Surfaces slide on Xylan coating until gas bearings become fully functional
- Exposed convertor to twice the number of start/stop cycles expected during flight preparation

# Cycles	Cold-end Temperature	Pressure Vessel Temperature	Orientation
67	23 °C	23 °C	Vertical
67	38 °C	46 °C	Vertical
67	52 °C	61 °C	Vertical
100	23 °C	23 °C	Horizontal



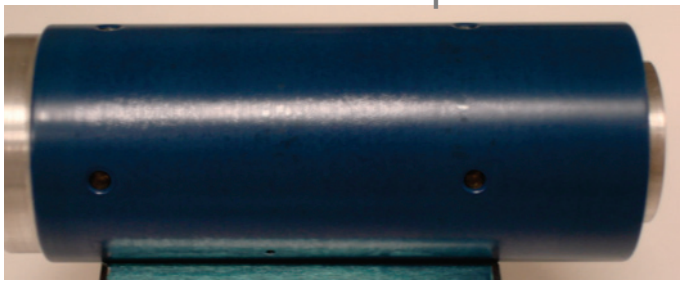
ASC-E2 #8 mounted in Sunpower test hardware in the vertical orientation for the start/stop test.

Start / Stop Test Results

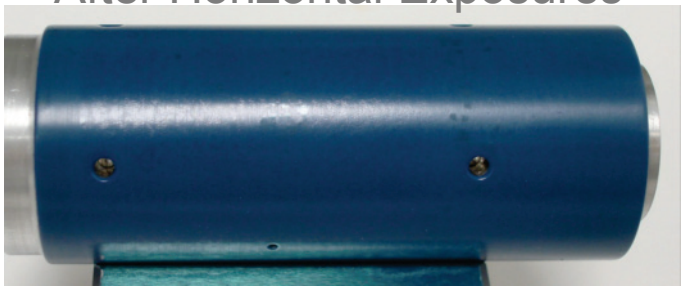
- Test completed using ASC-E2 #8 : September, 2011 at Sunpower
- Inspections performed after completion of vertical and horizontal testing
- No change in convertor performance or gas bearing performance
- No debris, only light buffing on piston surface oriented downward during horizontal testing

Before Test

After Vertical Exposures

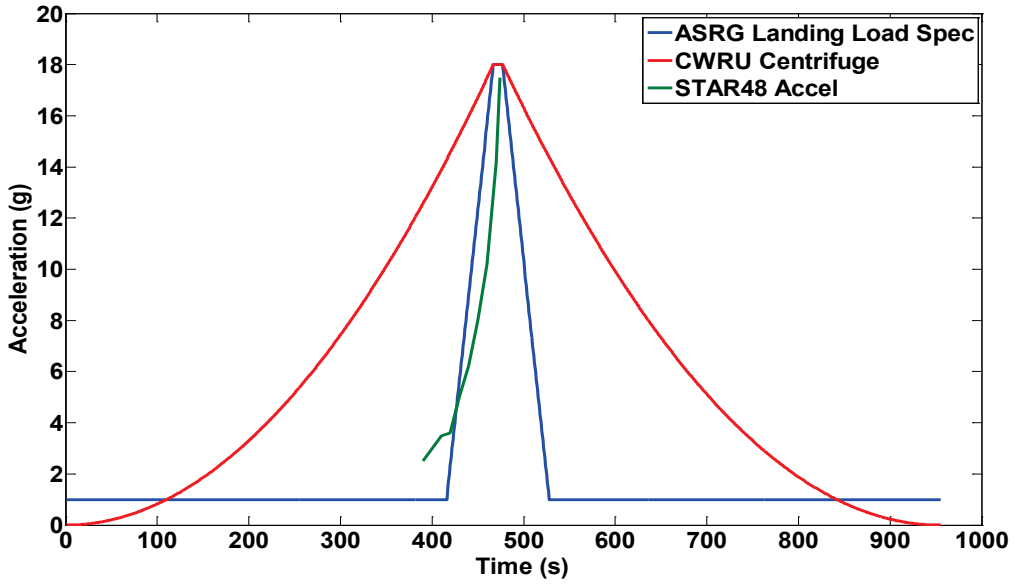


After Horizontal Exposures



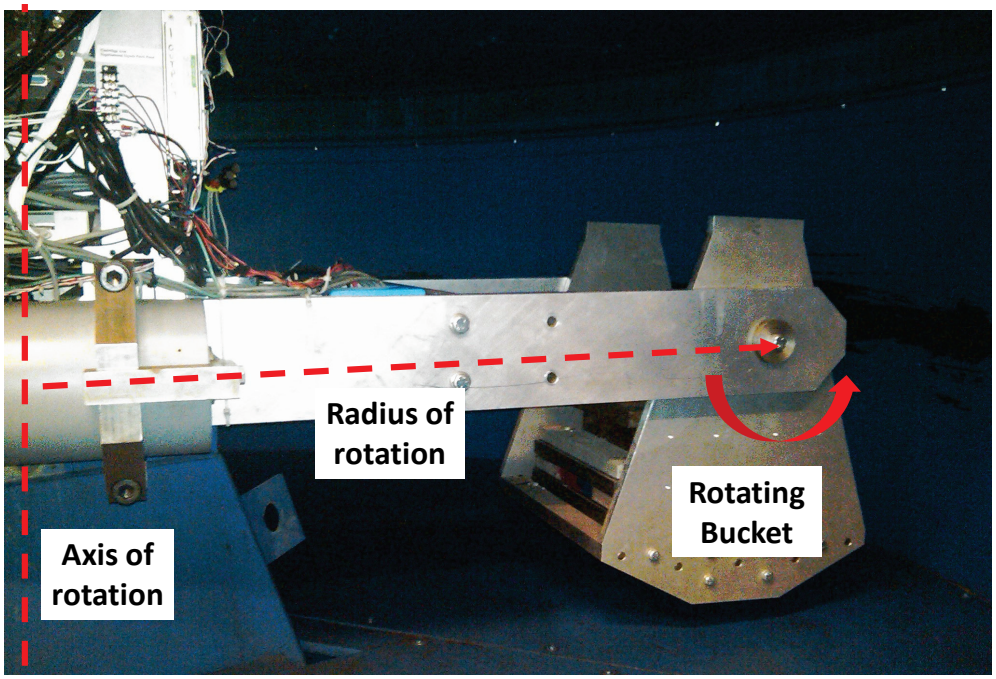
Centrifugal Acceleration Test

- Purpose – Assess and characterize the response of the ASC piston and displacer assemblies when exposed to static acceleration due to STAR48 burn and planetary surface landing.
- Launch Load – Star 48 spin-stabilized upper stage
- Landing Load
- Perform tests >= 18 g level
  - Axial, heater head out
  - Axial, heater head in
  - Lateral
    - 8 g -> 12 g -> 18 g
    - Intermediate inspections

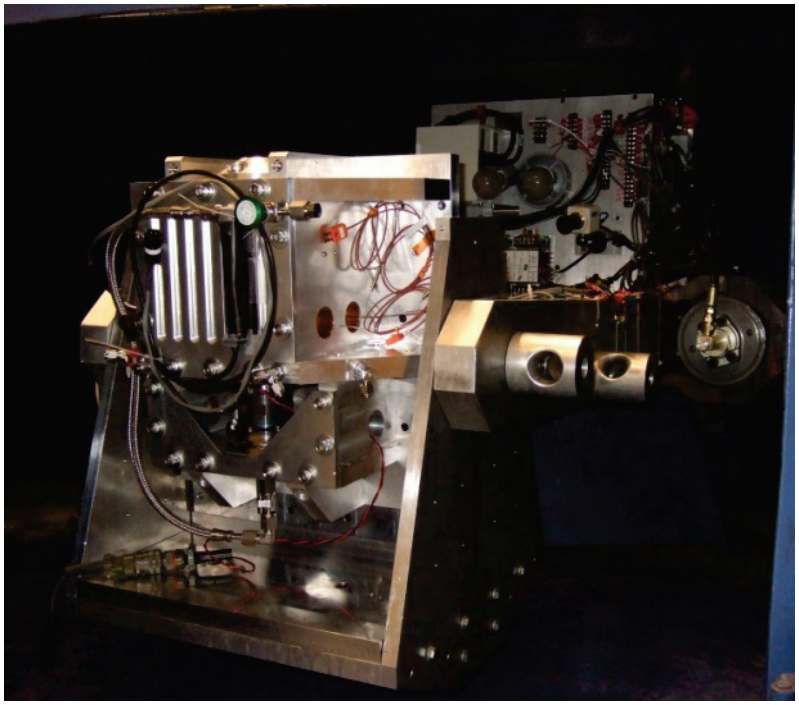


Centrifugal Acceleration Test Status

- Test completed March-May, 2012



Centrifuge arm from side.



Convertor installed in centrifuge

Centrifugal Acceleration Test Results

- Completed all planned exposures (2 axial, 3 lateral)
- Inspection performed after each lateral exposure
- No wear or debris generation after any exposure
- Some buffing marks were observed, similar to start/stop test
- Observed expected temporary reductions in power output as acceleration was applied
  - 18g lateral caused largest reduction : 56%
- Observed temporary shifts in piston and displacer centers of oscillation
- Convertor output and piston center of oscillation returned to normal after centrifugal acceleration was removed

The convertor can survive 18g centrifugal acceleration

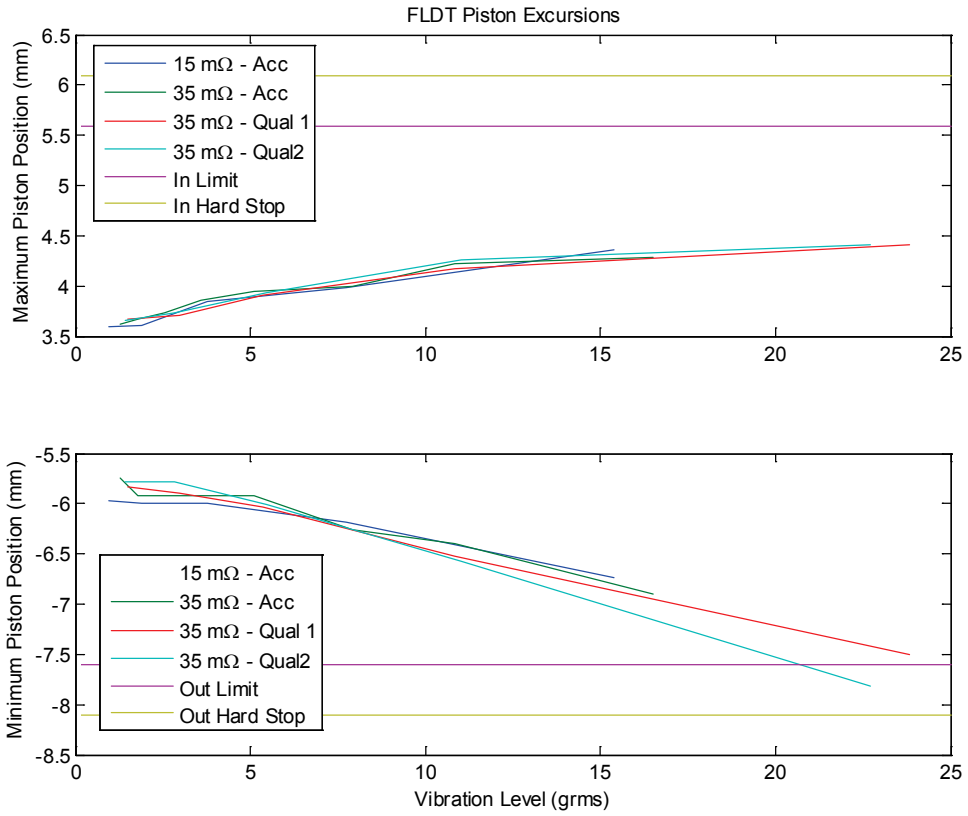
A temporary loss of power should be anticipated

Contact During Launch Test

- Purpose – Verify convertor can operate after potential internal contact during launch vibration

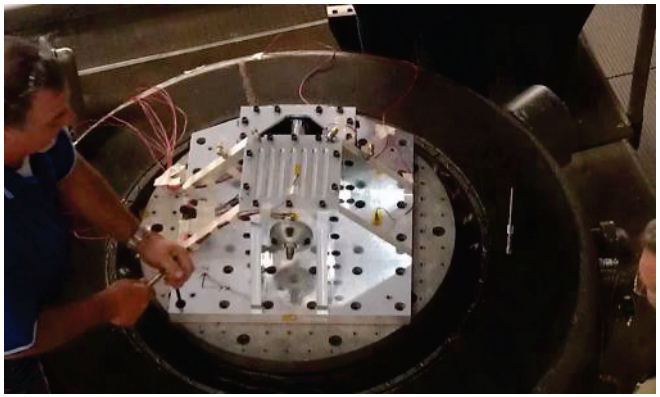
Previous vibration testing results on ASC-E #1:

- Qualification-level random vibration testing with prototype controller (EDU1)
- The piston exceeded outer limit (0.5 mm from hard stop) once
- Lateral random vibe exposure exceeds gas bearing strength resulting in temporary output power variation



Contact During Launch Plans and Status

- Plan : Quantify effects of different vibration levels on Xylan surfaces
  - Phase 1 Workmanship – all axes
    Inspection
  - Phase 2 Qualification – lateral axes
    Inspection
  - Phase 3 Qualification – axial with contacts
    Inspection
- Status
  - Phase 1 complete
  - Loss of non-flight position sensor during final lateral exposure has put test on hold



Convertor installed on shaker table for lateral vibration exposure

Overstroke Test

- This testing intends to simulate conditions which may cause an overstroke
  - Controller card switchover
  - Ground operation error that may lead to temporary disconnection of the load after fueling
- If controller requires 1 msec to detect and switchover – simulations show up to 3 contact events
- Structural analysis has provided upper limits on maximum collision velocity to prevent permanent deformation
  - Magnet can / cylinder: 1.43 m/s
  - Piston / displacer: 4.85 m/s
  - APS core / bumper: 1.14 m/s
  - Displacer / heater head: 0.75 m/s

Conclusions

- ASC Durability Tests – A series of four tests designed to experimentally demonstrate margin in ASC design by operating outside the nominal operating parameters.
  - Start / stop test demonstrated margin for anticipated start/ stop cycle in September, 2011
  - Centrifugal acceleration test demonstrated margin for launch/landing stages in May, 2012
  - Contact during launch test to verify convertor can operate after potential internal contact during launch vibration started June, 2012
  - Overstroke test to demonstrate robustness to overstroke in late 2012