Small Radioisotope Power System at NASA Glenn Research Center

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Outline

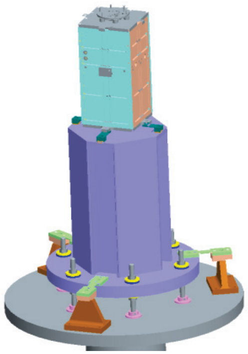
- Background
- Project objectives
- Advanced Stirling Convertor – Lunar (ASC-L) with passive balancer
- Simulated lunar lander test stand
- Single convertor controller (SCC)
- SCC design effort
  - Mathematical model
  - Dynamic engine/alternator simulator
- SCC testing
- Future plans

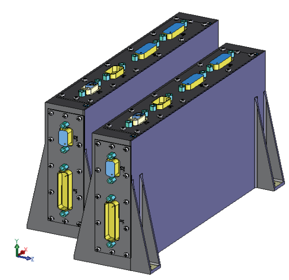
Background

- Small Radioisotope Power System (RPS) kick off in April 2009
- Advanced technology development; not part of flight project
- Integrated product team: The Johns Hopkins University/Applied Physics Lab (JHU/APL), Sunpower, Inc., and NASA GRC
- Preliminary design review: February 2010
- Engineering design review: September 2010

Project Objectives

- Targeted for International Lunar Network (ILN).
  - 9 year life – 6 year mission/3 years storage
  - Studying the feasibility of implementing a multiple node seismometer network to investigate the internal lunar structure
- Analyze the effectiveness of a passive balancer on minimizing vibration produced by a Stirling convertor
- Characterize the effect of Stirling convertor vibration on a lunar lander
- Characterize the performance of the SCC
- Integrate SCC with ASC-L, balancer, and lunar lander test stand to demonstrate system performance



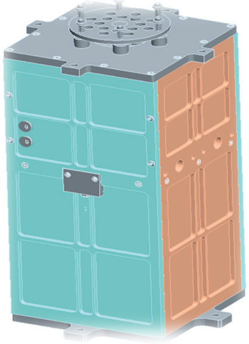


ASC-L

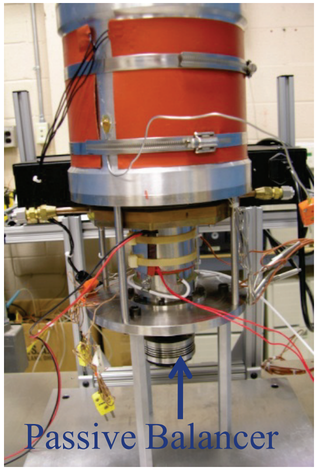
- Sunpower developmental convertor built to extend the current convertor capabilities to address some lunar requirements
- **Design**
  - Based on ASC-E2 with limited changes and intended for single-convertor configuration:
    - Substitute of higher temperature magnets, higher temperature epoxy used to bond the magnets, and integration of a passive balancer
    - No interconnect tube or mass needed for operation
    - Decreased alternator efficiency (~1.7 %) due to higher temperature magnets
  - Temps: T_{hot} = 850°C, T_{reject} = 47°C – 147°C; T_{PV} = 55°C – 155°C
  - Rejection temperature range based on simulations of expected lunar day/night temperatures. PV temperature assumed to be ~8 °C higher than T_{reject}
  - Convertor operated at high rejection temperature for performance mapping only. Nominal operation is 90 °C rejection temperature.

ASC-L

- **Quality**
  - Considered a developmental convertor
  - Due to schedule and budget constraints, the full ASC-E2 quality system not implemented
  - Workmanship test not performed
  - Limited design changes: Most organics, ILS and piston materials not changed for higher temperature operation
    - Deemed acceptable for short term operation ~100 hours at 147 °C rejection temperature.
- **Testing**
  - Completed testing at Sunpower and delivered to GRC 5/26/11
  - Performance mapping will be performed at GRC
    - Sunpower mechanical hardware used allows the high rejection temperature

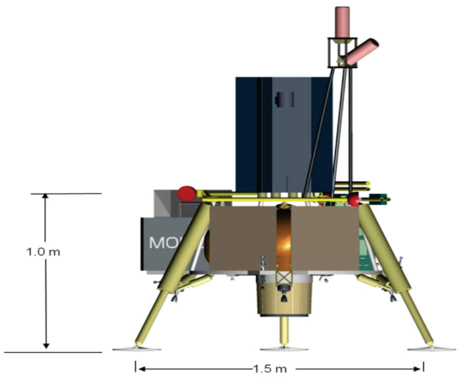


GRC Mechanical Hardware



ASC-L w/ Sunpower Mechanical Hardware

Lunar Lander Simulated Test Stand

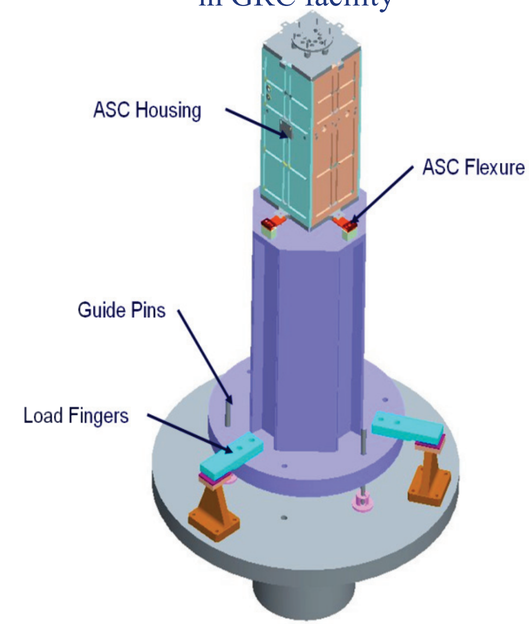


Conceptual design for ILN lander

- Simulate dynamics of a potential lander
- Load cells used for force measurement.
  - Measure force at the interface between the ASC and the lander
  - Measure force at the interface between the lander and the planetary surface


Lunar lander test stand in GRC facility

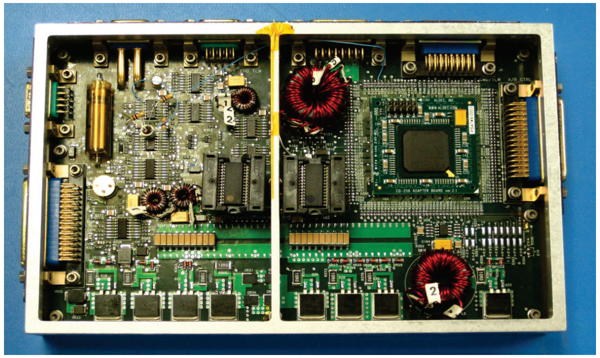
- Replicate dynamic behavior of conceptual lunar lander avoiding ASC frequency of 102.2 Hz and first two harmonics
- Provide isolation up to 20 Hz for the potential seismometer instrumentation
- Designed with adjustable stiffness and damping
  - Sorbothane pads
- Weight ~385 lbs



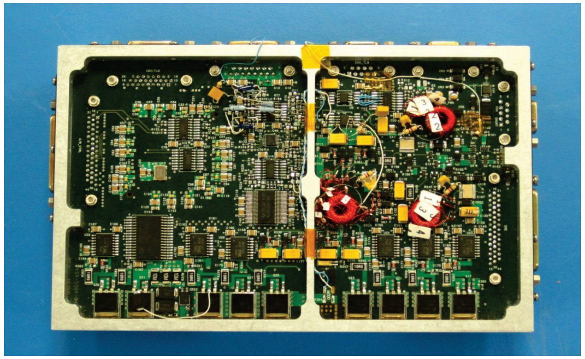
Final design for lunar lander test stand

SCC - Overview

- Two identical controller boards packaged in separate chassis
- **Mass**
  - 1 box: 1.135 kg
  - 2 boxes: 2.27 kg
- **Volume**
  - 8.67 x 5.45 x 2.57 inches
  - Custom DC/DC converter minimizes mass and volume
- **Efficiency**
  - ~92%
  - DC Power out of SCC/AC Power into SCC
  - Measured (5/25/11)



FPGA Side of Board



Housekeeping Supply Side of Board

SCC - Overview

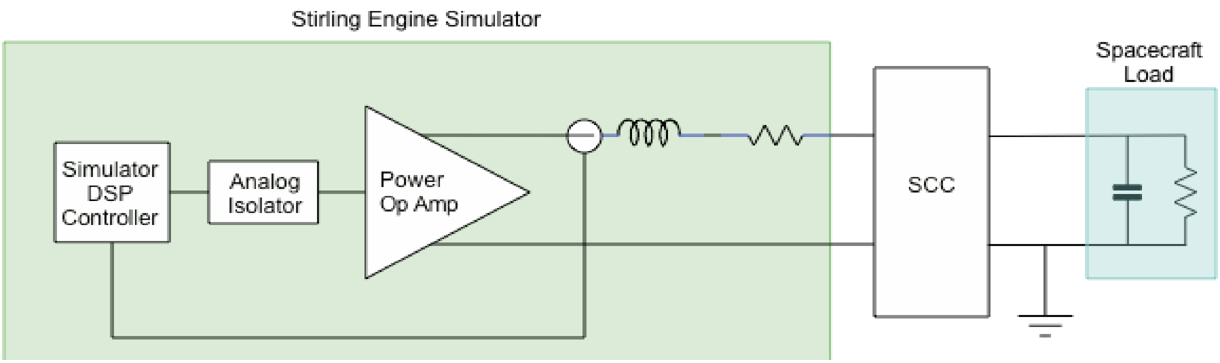
- **Component Selection**
  - All parts used have flight equivalent
  - Flight qualified parts are >100 krad total ionizing dose (TID)
  - 54% of flight target RTAX 2000 FPGA used
- **Harnessing**
  - Separate harnessing for each board to allow for hot swap
  - 8 AWG wire used on alternator harness
    - Reduce line losses
    - Less mass than several wires in parallel
- **Communication**
  - TIA/EIA-422
- **Delivered to GRC Friday 5/27/11**

SCC Design Effort – Mathematical Model

- System dynamic model (SDM) developed by NASA GRC.
  - Contains non-linear sub-models for Stirling-cycle thermodynamics, gas dynamics, piston and displacer dynamics, alternator electromagnetics, and external thermal effects
- APL developed a linear model based on SDM
  - Simpler and more appropriate for control system design
  - Vital to SCC design
  - Main analytic tool to support simulations
  - Aided in component selection, control law & fault tolerance development
- GRC verified the APL linear model simulations with the SDM non-linear model

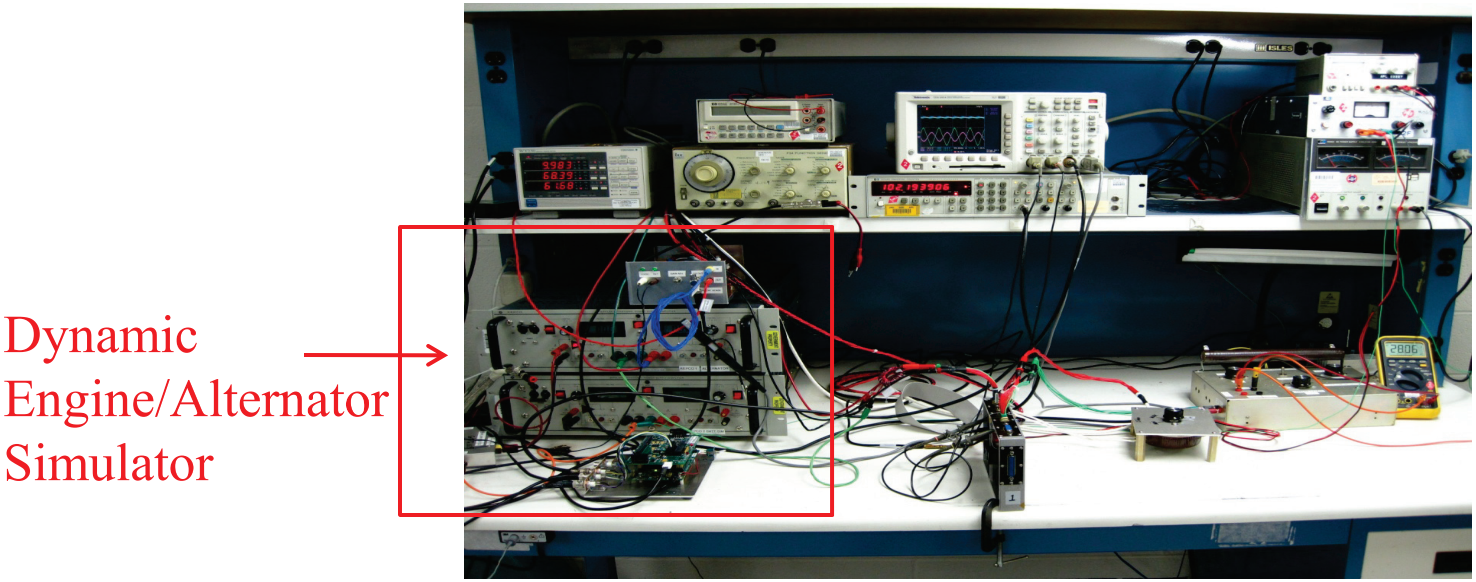
SCC Design Effort – Dynamic Engine/Alternator Simulator

- Uses a mix of custom designed circuits, commercial equipment, and an off the shelf digital signal processor (DSP) development system
- Includes the linear model of the ASC and therefore includes dynamics of the convertor mechanisms beyond the alternator electrical inductance and resistance
  - Simplified dynamic equations implemented using a DSP
- Input: Alternator current
- Output: back emf voltage, displacer position, piston position
- SCC development would not have been as effective without this tool
- Eliminates start and stop time of operating a convertor
- Eliminates risk of operating a convertor during controller development



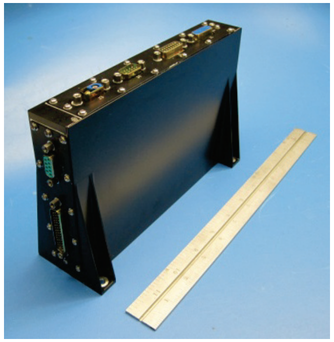
SCC Design Effort – Dynamic Engine/Alternator Simulator

- Used to solve non-linearity and noise related problems in sensing alternator current resulting in stable convertor output power
- Testing results on the dynamic engine/alternator simulator match those of testing with an actual convertor
- Can be reprogrammed to mimic other types of ASCs by changing the linear model implemented in the DSP and the physical alternator inductance and resistance components

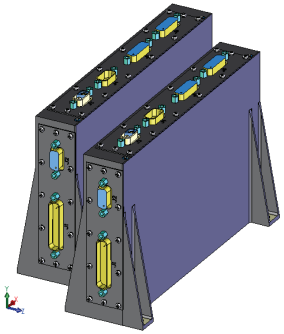


SCC- Fault Detection and Commanding

- Fault detection and recovery
  - Failure modes effects analysis (FMEA) completed
  - Detects fault and autonomously recovers
  - Autonomous switchover to backup controller prevents convertor internal damage
- Hot swap
  - Command switchover to allow replacement of failed controller board



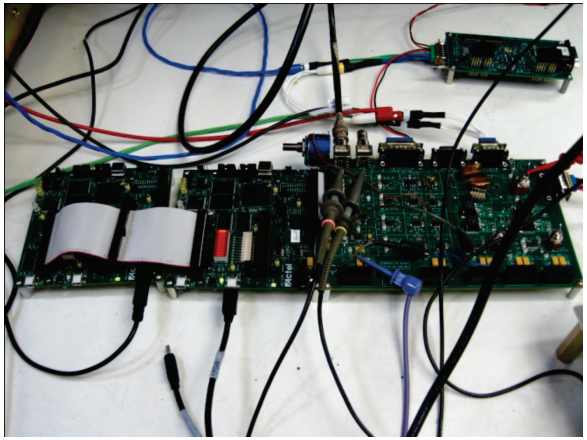
One SCC EM board in chassis



Redundant SCC configuration

SCC – Testing

- SCC testing sequence:
  - Operated SCC **breadboards** with engine simulator
  - Operated SCC **breadboards** with ASC-1 #4
  - Operated SCC engineering model **(EM) board 1/2** with engine simulator
  - Operated SCC **EM board 1/2** with ASC-1 #4
- **First attempt at each full power convertor operation was successful**



SCC Breadboards

SCC – Testing

- SCC tests with ASC-1 #4
  - Varied DC bus voltage – power output stable
  - Operation on a shunt resistor to demonstrate fueling configuration
  - Tested over and under the acceptable DC bus voltage range to demonstrate power transfer from spacecraft to shunt and recovery

JHU/APL SCC Test Facility

Future Plans

- Performance map of ASC-L with AC bus power supply at GRC
- Operate SCC with ASC-L at GRC
- Performance map of ASC-L with SCC
- Operate SCC, ASC-L with passive balancer and lunar lander test stand as a system
- Complete fault tolerance and CMD/TLM on SCC
  - Demonstrate hot swap
  - Demonstrate fault detection and recovery
    - Switch from the active controller card to the backup
- EMI and vibe testing of ASC-L while being controlled by the SCC
- Extended operation of the SCC with ASC-L with passive balancer and lunar lander test stand

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