Extended Operation of Stirling Convertors at NASA Glenn Research Center

International Energy Conversion Engineering Conference

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Salvatore Oriti
NASA Glenn Research Center
RPT – Thermal Energy Conversion Branch

Introduction

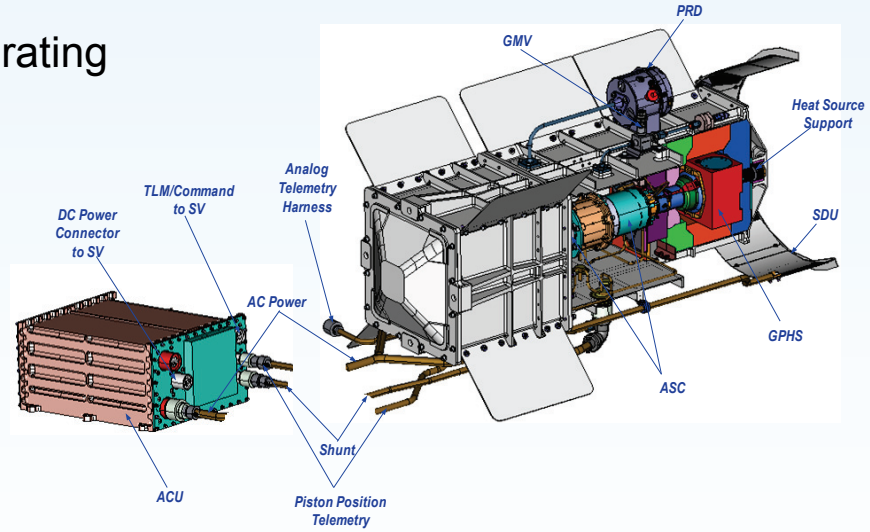
Advanced Stirling Radioisotope Generator (ASRG) being developed by Lockheed Martin, DOE, Sunpower, NASA GRC

- 4 times more efficient than thermoelectric conversion
- Requires ¼ amount of Pu-238 for same electrical power output
- Two Advanced Stirling Convertors (ASCs) operating up to 850 °C hot-end temperature
- 130 W_e from 2 heat source modules

(beginning-of-mission, current best estimate)

GRC Provides Technical Support for ASC Life and Reliability:

- Structural benchmark testing
- Vibration testing
- High-temperature materials
- Magnet life testing
- **Convertor extended operation**
  - **38 free-piston Stirling convertors, 18 ongoing**



ASRG Flight Unit Design

Image Courtesy of Lockheed Martin Space Systems

Ongoing Stirling Convertor Testing

Purpose:

- Generate performance data over tens of thousands of hours to observe long-term trends
- Support reliability database

Convertors	Nominal Operating Temperatures (Hot/Cold, °C)	Nominal Per-Convertor Power Output (W_e)	Convertor Output Voltage (V_{rms})	Supplier	Date Initiated	Per-Convertor Runtime (Hrs) *As of July 1, 2011*
TDC #13 & #14	650/80	65	85	Infinia	Jun 2003	60,000
TDC #15 & #16					Mar 2005	49,000
ASC-0 #3 & #4	650/90	75	25	Sunpower	Aug 2007	25,000
ASC-E #2 &# 3 (ASRG-EU)	625/70	65	11		Nov 2008	19,000
ASC-E #1 & #4	650/70	65	11		Dec 2009	10,000
ASC-E2 #1*	850/50	80	15		Mar 2010	6,200
ASC-E2 #2					Feb 2010	2,700
ASC-E2 #3 & #4					Aug 2010	800
ASC-E2 #5 & #6					Aug 2010	4,800
ASC-E2 #7					Nov 2010	2,100
ASC-E2 #8					Jun 2011	20

**ASC-E2 #1 delivery delayed due to heater head manufacturing flaw*

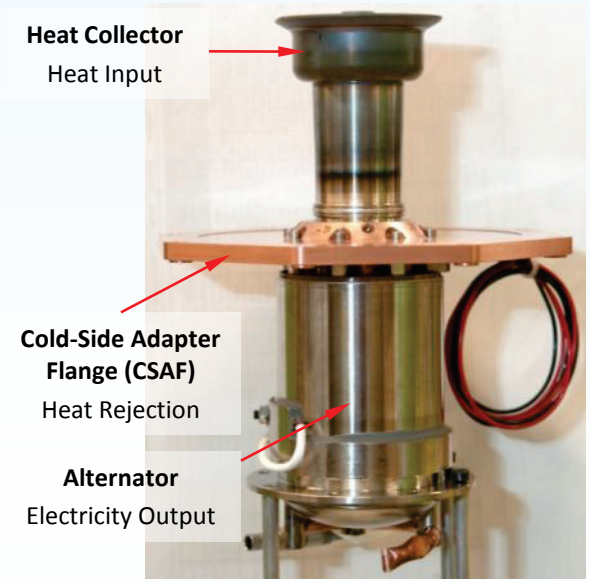
Discovery 12 proposed missions : 7 years + 3 years max storage (87,000 hours)
Outer planet missions : 17 years (150,000 hours)

Convertor Test Station

Example ASC-E2 Test Station

Test Rack

- Operator controls
- Data acquisition
- Software protection
- Hard-wired protection
- Automated error notification via email and text messaging
- UPS and generator backup



ASC-E2

Test Methodology

- **24/7 Operation**
- **Data acquisition**:

  2-second – All parameters recorded once every two seconds, for transient or 24-hr period evaluation

  5-min – Each parameter's 2-second data averaged over 5-minute period, recorded once per hour, for long-term performance data evaluation
- **Maintain constant operating conditions (during extended operation):**

Parameter	Control Methods
Hot-end temperature	PID control, thermocouple feedback Constant heat input, heater power feedback
Cold-end temperature	Circulator with fluid temperature PID control
Alternator housing temperature	Auxiliary surface heaters Fluid heat exchanger
Piston amplitude	AC Bus power supply voltage setpoint Zener-diode controller DC output setpoint ASC Controller Unit (ACU, flight method)

- **Off-nominal operation included:**

  Performance mapping

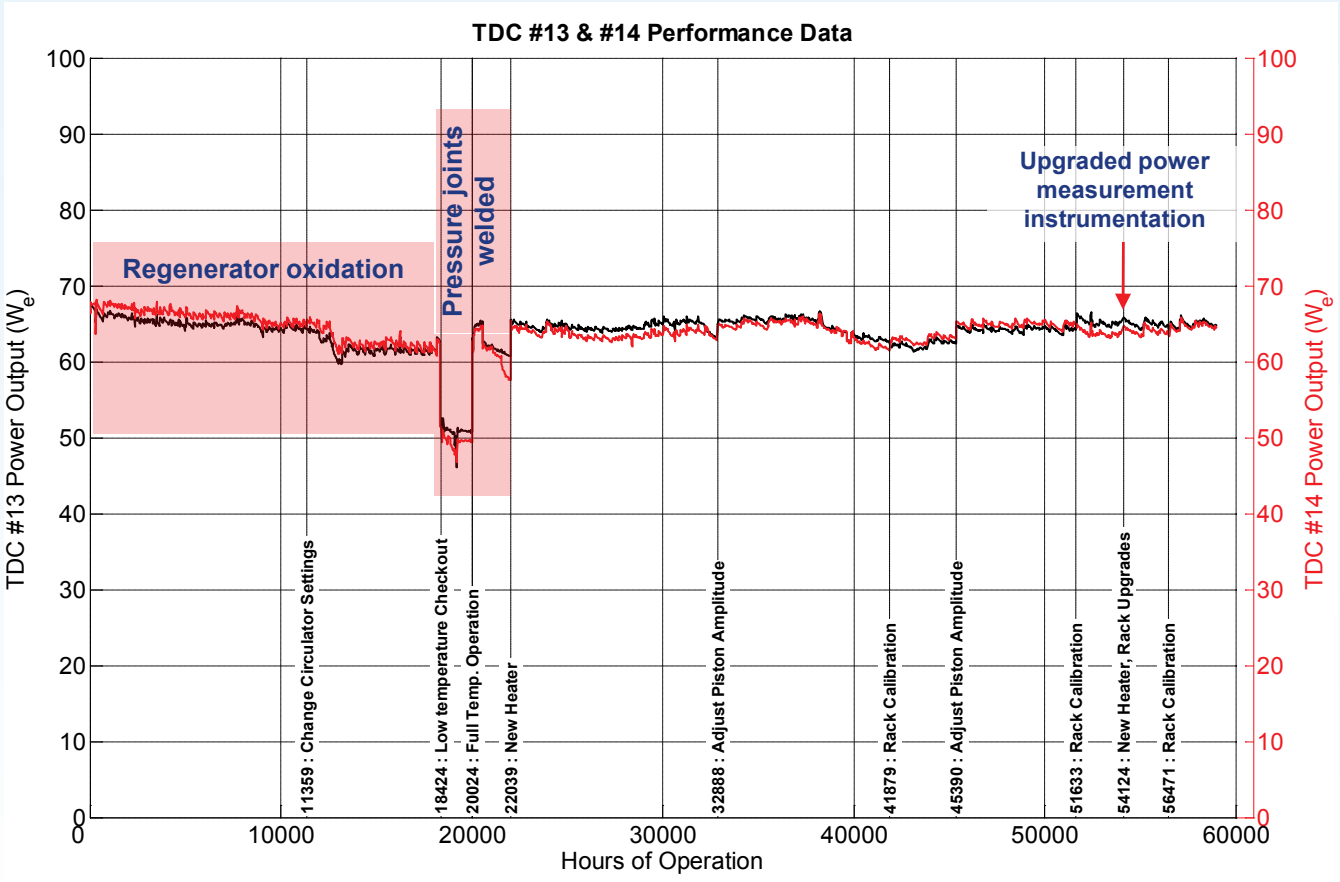
  Operating frequency variation

  Heat input variation

  Controller variation

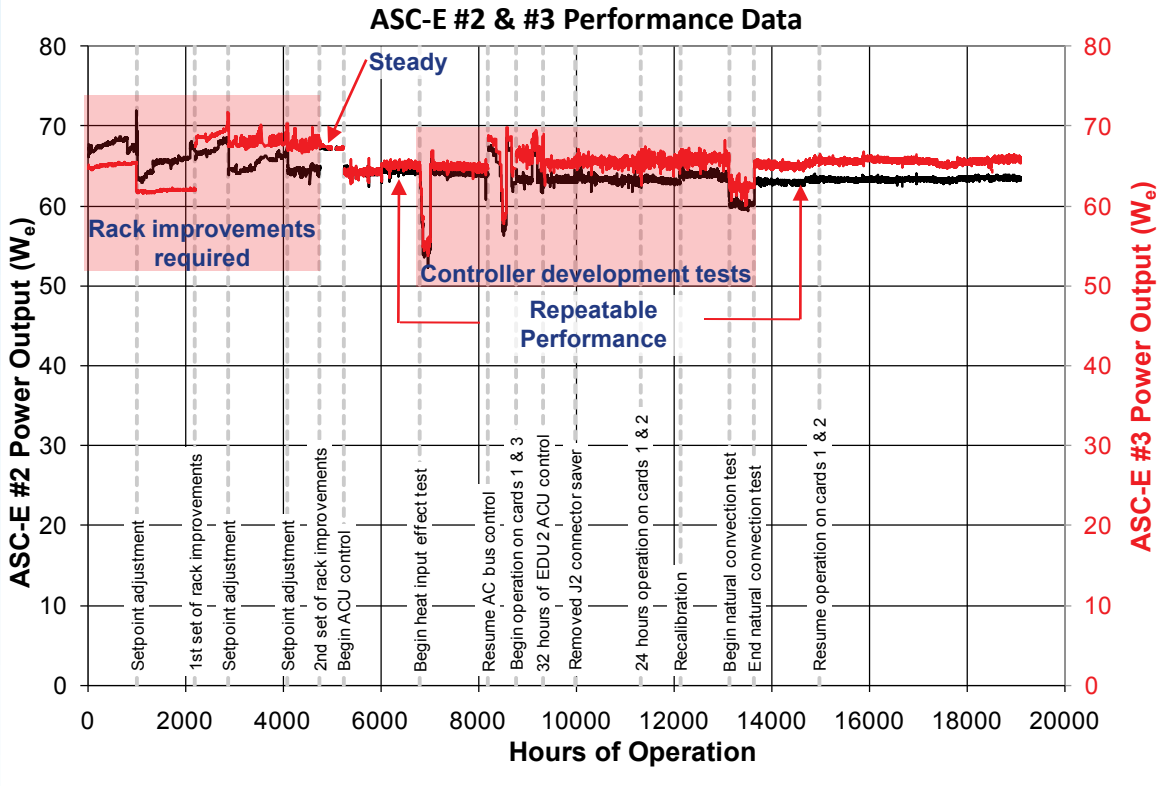
  Individual temperature variation

Technology Demonstration Convertors (TDCs) #13, #14



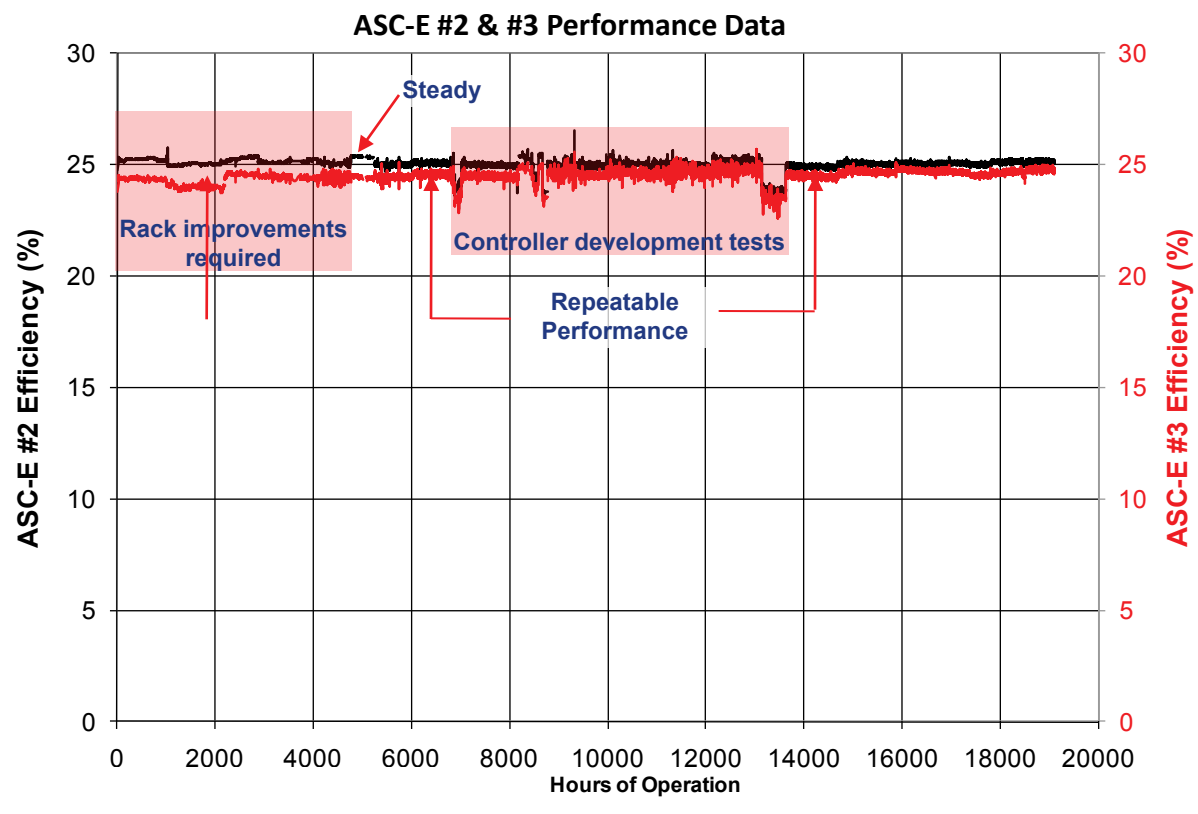
- Longest-running convertor pair (60,000 hours each)
- Pressure joints welded at 19,000 hours, but helium fill tube remains
- Periodic charge pressure adjustments required, manifests as “saw-tooth” output
- Zener diode controller hardware drift required adjustment to maintain piston amplitude

ASRG EU (ASC-E #2, #3)



- Fully hermetically sealed before delivery (pressure joints and pinched fill tube)
- 19,000 hours each (13,000 on Lockheed Martin controller)
- Test rack improvements required during initial operation
- Tests conducted for Lockheed Martin in support of controller development and flight system development
- Good repeatability on ASC controller unit (ACU) with consistent operating conditions

ASRG EU (ASC-E #2, #3)

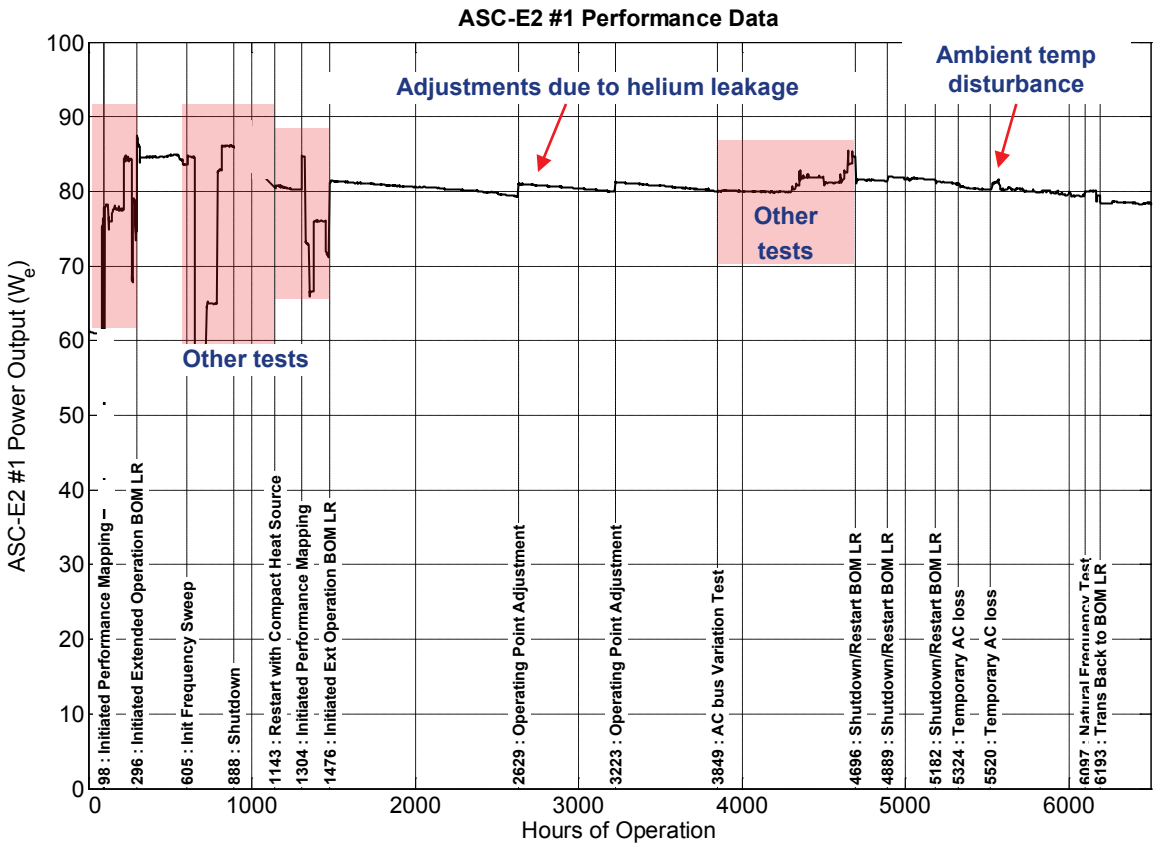


Efficiency =

Alternator output power/Heater power

- 25% conversion efficiency demonstrated at the system level on flight-like controller
- Repeatable and constant conversion efficiency over 19,000 hours of operation

ASC-E2 #1



BOM = Beginning of Mission

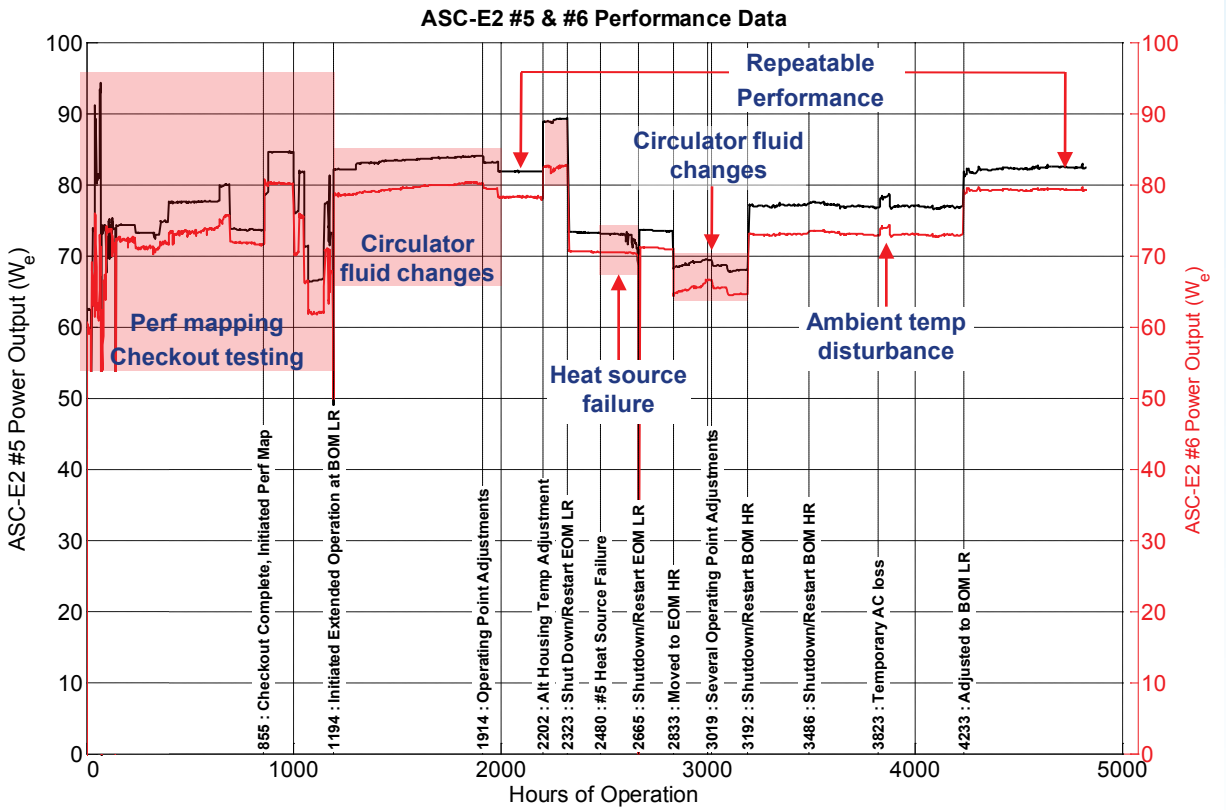
EOM = End of Mission

LR = Low Rejection

HR = High Rejection

- Fully hermetically sealed before delivery (pressure joints and pinched fill tube)
- 6,200 hours – majority at 850 °C
- Known heater head flaw and helium leakage
- AC bus voltage requires adjustment to negate helium leakage

ASC-E2 #5, #6



BOM = Beginning of Mission

EOM = End of Mission

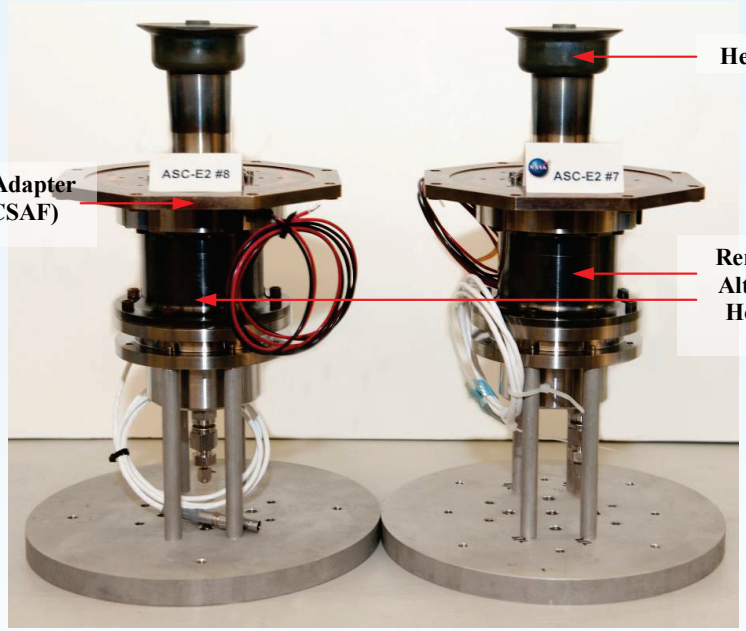
LR = Low Rejection

HR = High Rejection

- Fully hermetically sealed before delivery (pressure joints and pinched fill tube)
- 4,800 hours – all at 850 °C
- Steady when maintaining constant conditions

ASC-E2 #7 & #8

- **Slated for durability testing**
  Stress components to above-nominal levels
- **Removable alternator housings for inspection**



ASC-E2 #7& #8 with removable alternator housings

Test Description	Purpose
Start/Stop Cycling *August 2011*	Cycle the convertor repeatedly through start/stop cycle to exacerbate any possible wear induced before gas bearings become fully functional
Centrifugal Acceleration *September 2011*	Expose operating convertor to 30 g static load using a centrifuge facility to observe response in moving components
Contact Events During Launch	Simulate a limited number of contact events during off-nominal launch by adjusting piston amplitude
Piston Overstroke	Simulate a limited number of contact events with desired relative velocities between the piston and displacer with short-term controller disconnection

Conclusion

GRC is supporting life and reliability database for free-piston Stirilng conversion via extended convertor operation

Ongoing convertor operation:

- **18 convertors (4 TDCs from Infinia, 14 ASCs from Sunpower)**
- **350,000 total convertor hours of operation**
- **218,000 on Infinia units and 132,000 on Sunpower units**

Demonstrating steady convertor performance requires precise maintenance of operating conditions

Sources of disruption :

- **Investigative tests**
  - Varying operating frequency, hot-end temp, cold-end temp
- **Hot end control method**
  - Constant heat input mode requires more user-adjustment than constant temperature mode
  - Long-term transients in hot end insulation were observed
- **Support facility**
  - Open-bath circulator fluid concentration drifting
  - Nuisance shutdowns (instrumentation failure, EMI, power outages)
  - Ambient temperature fluctuations due to room HVAC

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