Advanced Stirling Convertor (ASC-E2) Characterization Testing

Testing has been conducted on Advanced Stirling Convertor (ASC-E2) convertors at NASA Glenn Research Center in support of the Advanced Stirling Radioisotope Generator (ASRG) Project. This testing has been conducted to understand sensitivities of convertor parameters due to environmental and operational changes during operation of the ASRG in missions to space. This paper summarizes test results and explains in terms of operation of the ASRG during space missions.

Advanced Stirling Convertor (ASC-E2) Characterization Testing

Presented at the International Energy Conversion Engineering Conference

July 30 – August 1, 2012

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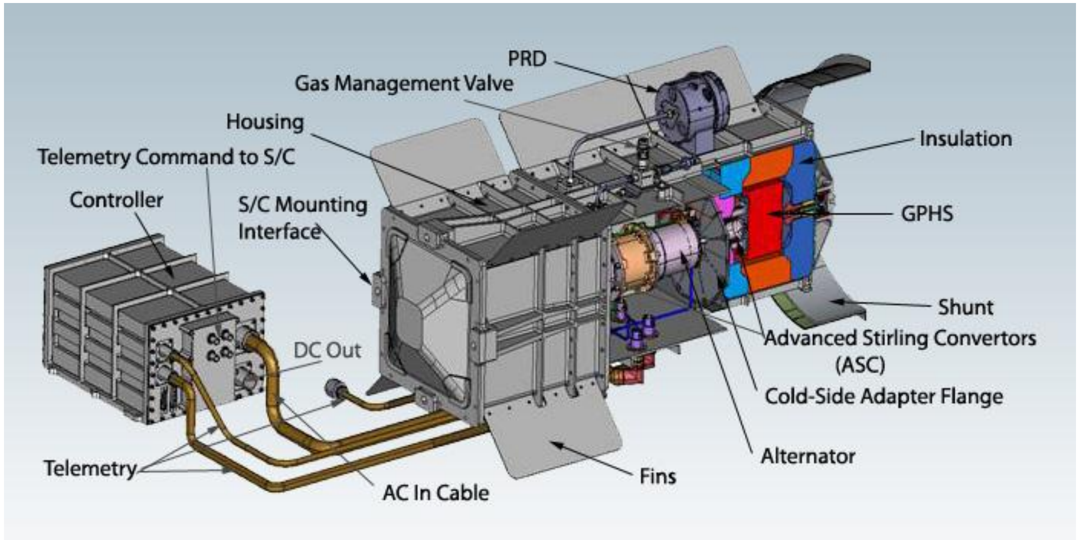
Outline

- Introduction
- Purpose of Tests
- Test Results
  - AC Bus Test
  - Argon Venting During Launch Test
- Conclusion

Introduction

- ASRG being developed as radioisotope power system for deep space missions
  - 4 times more efficient than current RTG's



- Testing utilized ASC-E2 convertors manufactured by Sunpower for ASRG project.
  - Higher hot-end temperatures than previous development units.
  - Similar to planned flight units.
- Eight ASC-E2 convertors delivered to GRC for extended operations and durability testing for the ASRG project.

Purpose of Tests

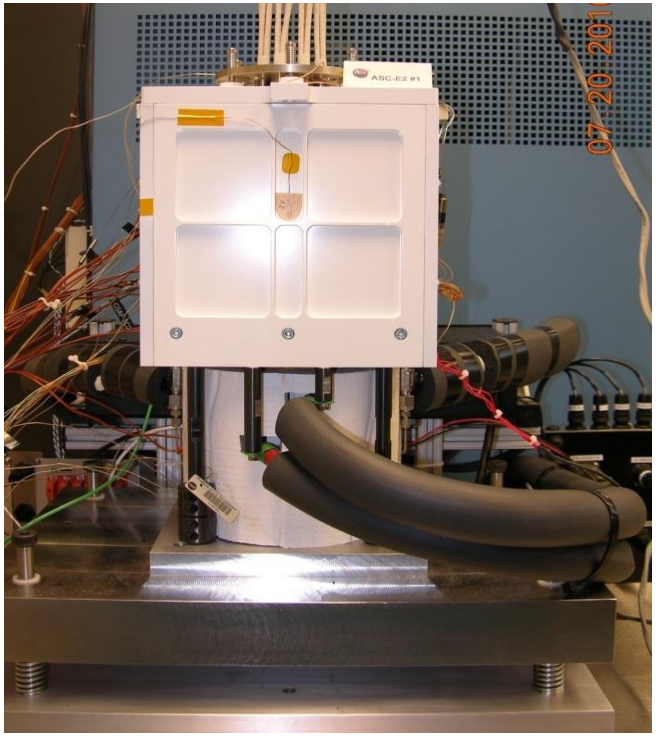
- Support Controller Development
  - Modeling and analysis alone are insufficient to finalize control strategies; need to quantify with test data.
- Simulate Variety of Conditions Convertor Experiences During a Mission for ConOps Development.
  - AC bus variation test helps understand sensitivity of amplitude and hot-end temperature relative to changes in AC bus voltage.
  - Argon venting test helps understand how convertor will operate during a launch scenario.

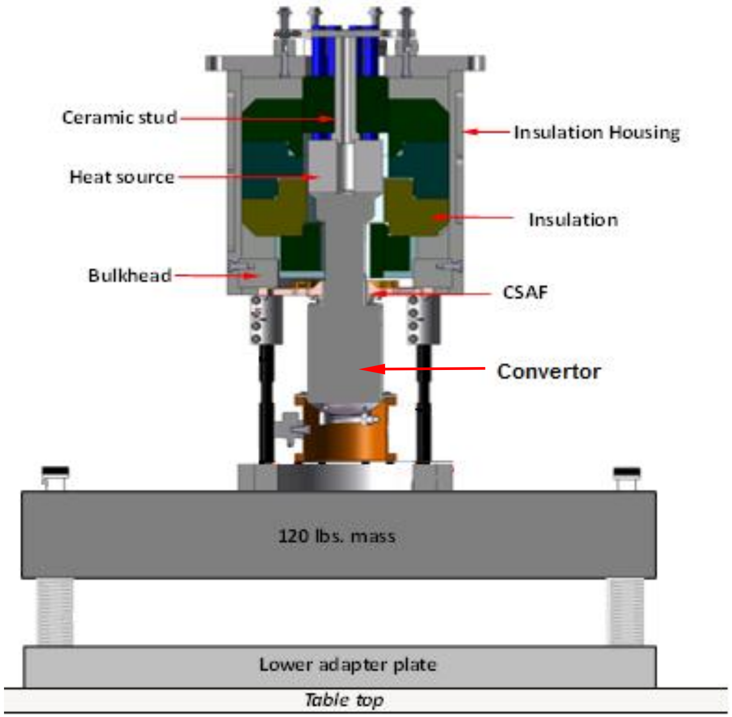
Why Test with ASC-E2 Convertors?

- ASC-E convertors have 650 ˚C maximum hot-end operating temperature vs. 850 ˚C for flight
- ASRG EU uses ASC-E convertors
- Flight-like ASC-E3 convertors not available

➢ Currently, ASC-E2 convertors are closest to flight design

ASC-E2 Test Setup

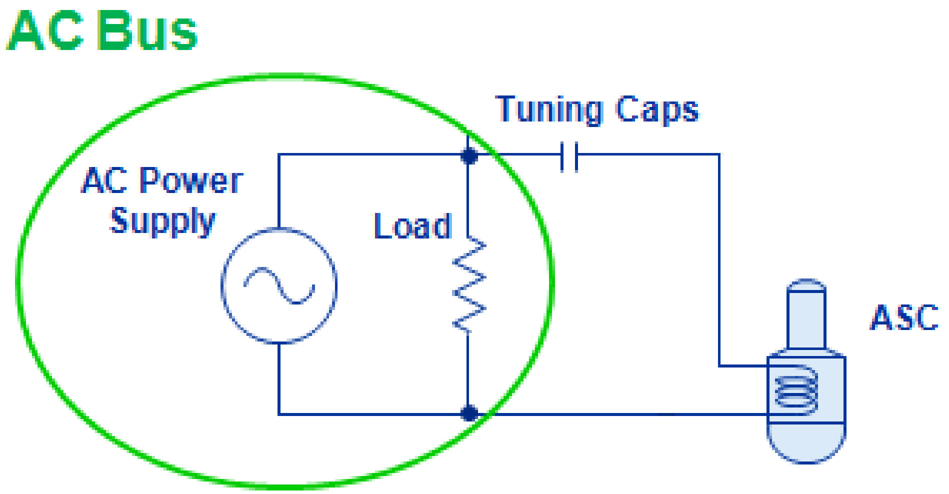




Completed ASC-E2 #1 assembly ready for operation (left) and mechanical hardware section view (right).

AC Bus Electrical Setup

- AC bus created with AC power supply and load resistors
- AC bus controlled with Programmable AC Power Supply
- Setting AC bus voltage sets the convertor piston amplitude
  - Increasing AC bus voltage increases piston amplitude

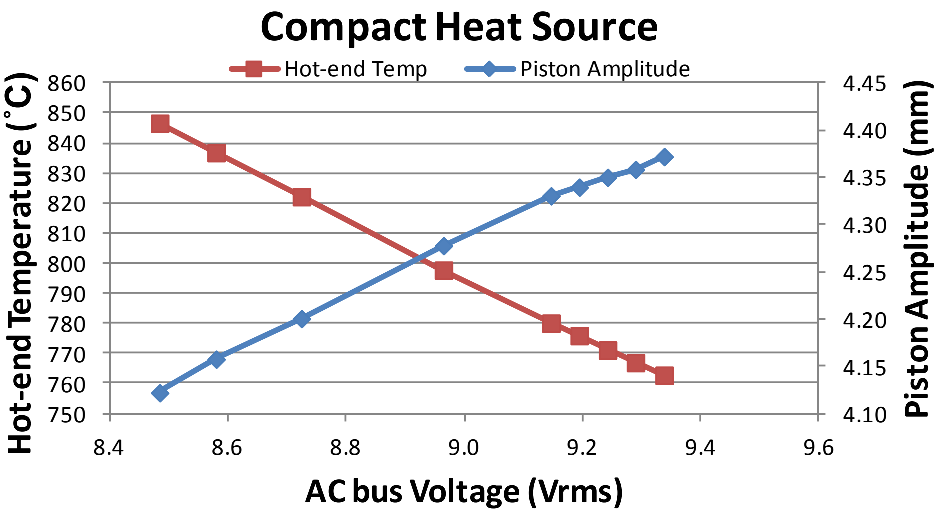


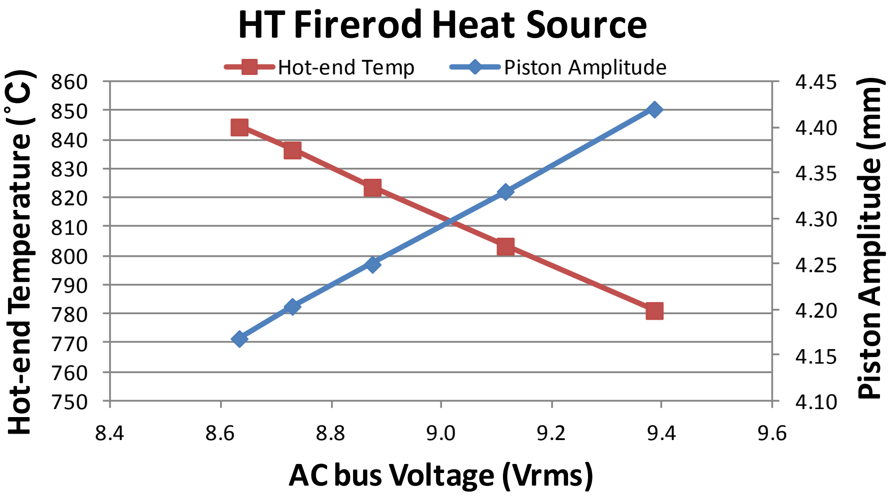
- Flight controller is analogous to AC bus control

Test Operating Parameters

- Beginning of test convertor operating conditions:
  - ASC-E2 Beginning of Mission Low Reject (842.5˚C hot-end/ 48.5˚C Cold-end/ 61˚C Alternator Housing)
  - Constant Gross Heat Input
- Increase AC bus voltage incrementally
  - Increase in AC bus voltage results in increase in piston amplitude and decrease in hot-end temperature.
- Data recorded using LabVIEW data acquisition system
- System allowed at least 8 hours to reach steady state
- Test conducted with two different heat sources (HS), compact and HT Firerod, because of failure of first heat source.

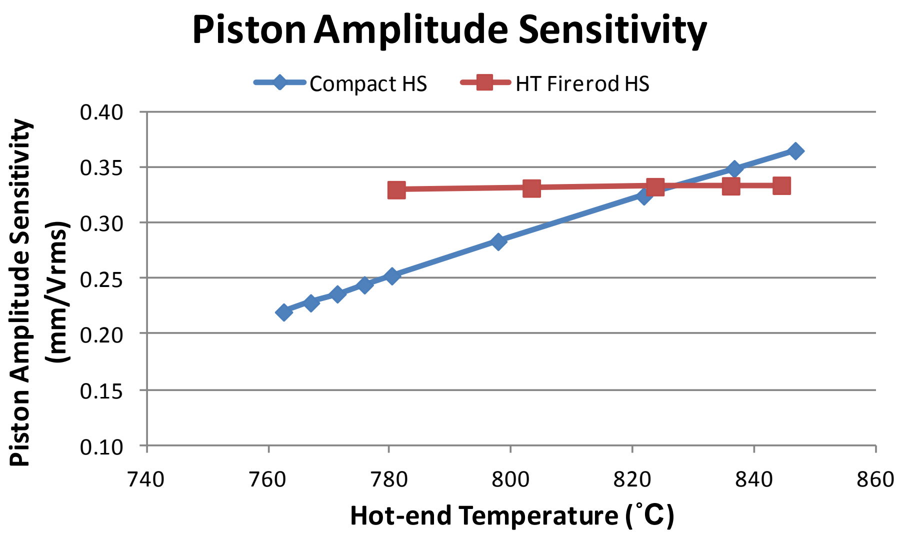
Test Results

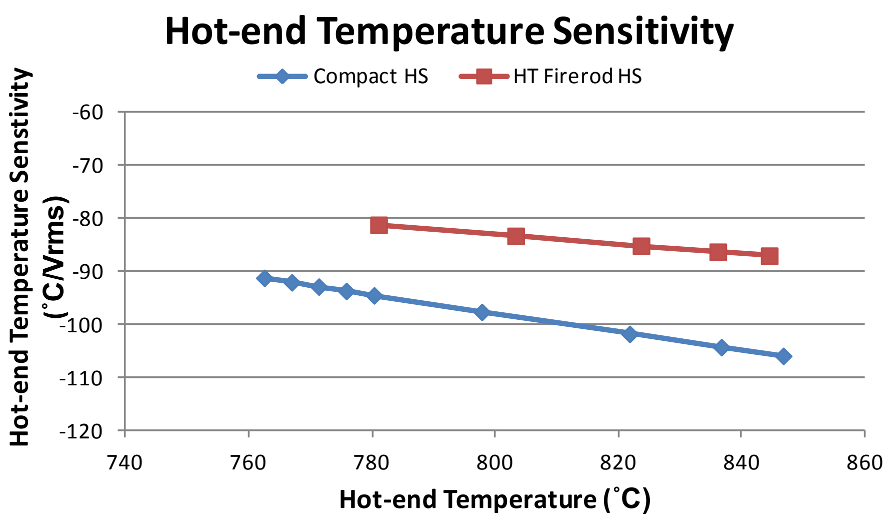




- Test data supports anticipated trends for piston amplitude and hot-end temperature.
- Different HS effects insulation losses and cause different results and sensitivities.
    - Desire to understand these sensitivities for controller development

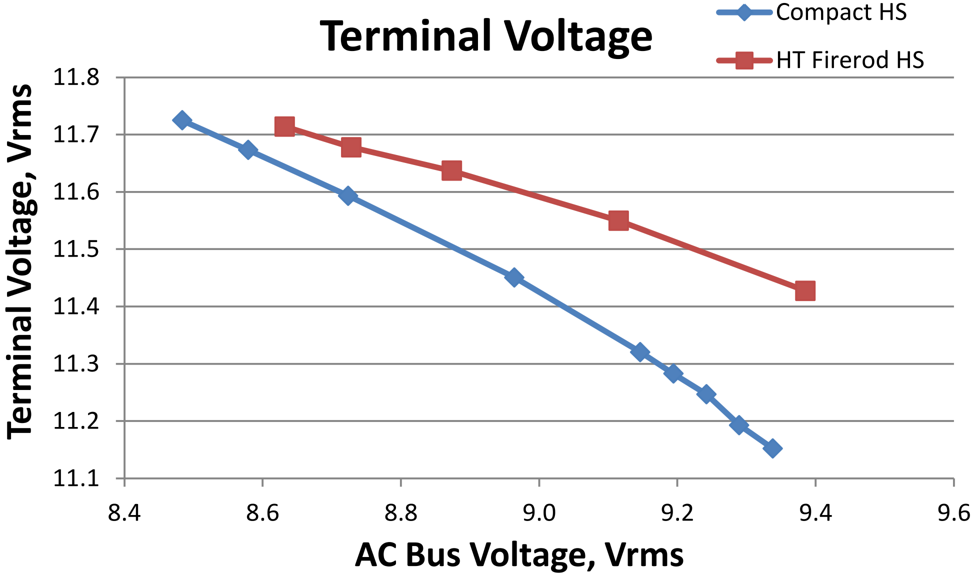
Sensitivity Analysis

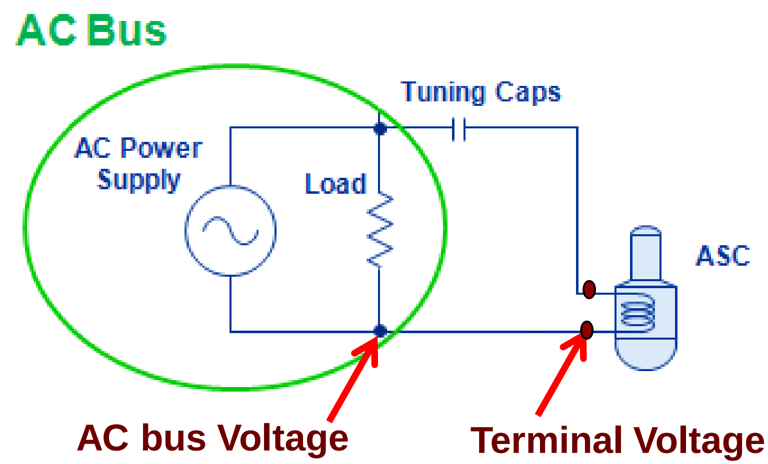




ASRG EU Sensitivities (650˚C hot-end in argon)
Piston Amplitude: 0.23 to 0.30 mm/V
Hot-end: -73 to -81 ˚C/V

Effect on Alternator Terminal Voltage





- For this particular test, as AC bus voltage increased, terminal voltage decreased. . . Why?
- As AC bus voltage increased, piston amplitude increased, and hot-end temperature decreased
- Decreasing hot-end temperature decreased the convertor's mean pressure, which changed the convertor's natural frequency
- This led to an increase in the alternator power factor required to maintain the operating frequency. As a result, the alternator terminal voltage decreased slightly for this particular test

Argon Venting During Launch Test

- Argon gas is vented from generator housing during launch of ASRG.
- Concurrently, ASRG rejection temperature decreases as spacecraft goes from warm fairing environment to space environment
- Uses ASC-E2 #5 convertor

  (Similar setup as ASC-E2 #1)
- 3 phases of test

  Phase 1: Baseline data for acceptor temperature sensitivity to gross heat input changes.

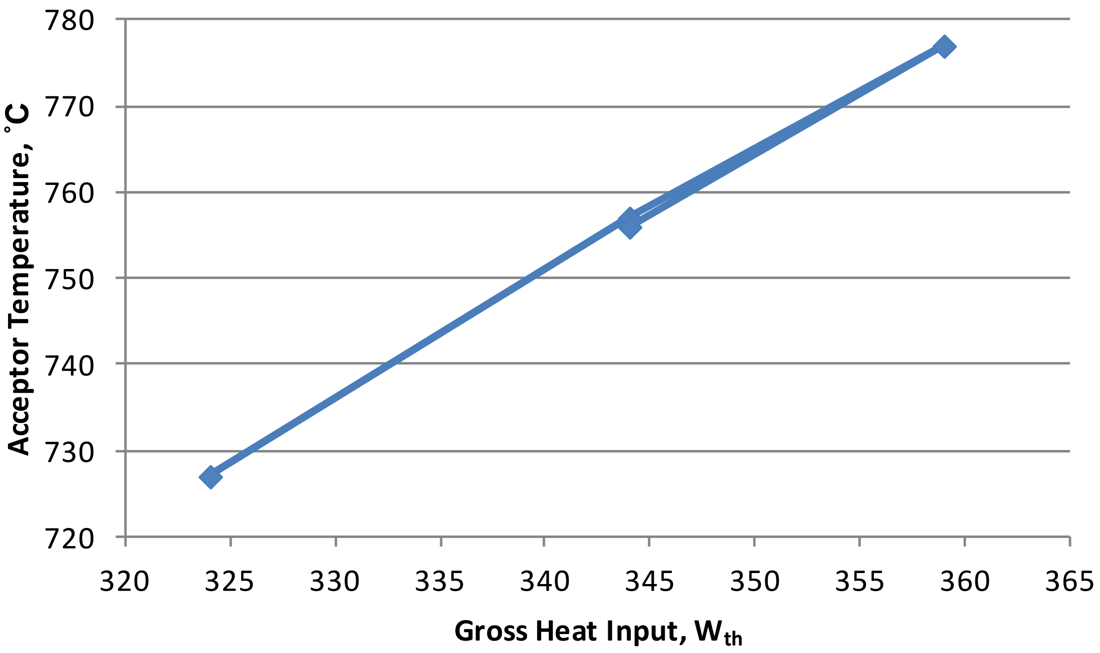
  Phase 2: Simulate argon venting.

  Phase 3: Simulate temperature sink change as the generator ascends from storage in the fairing to space.

Test Operating Parameters

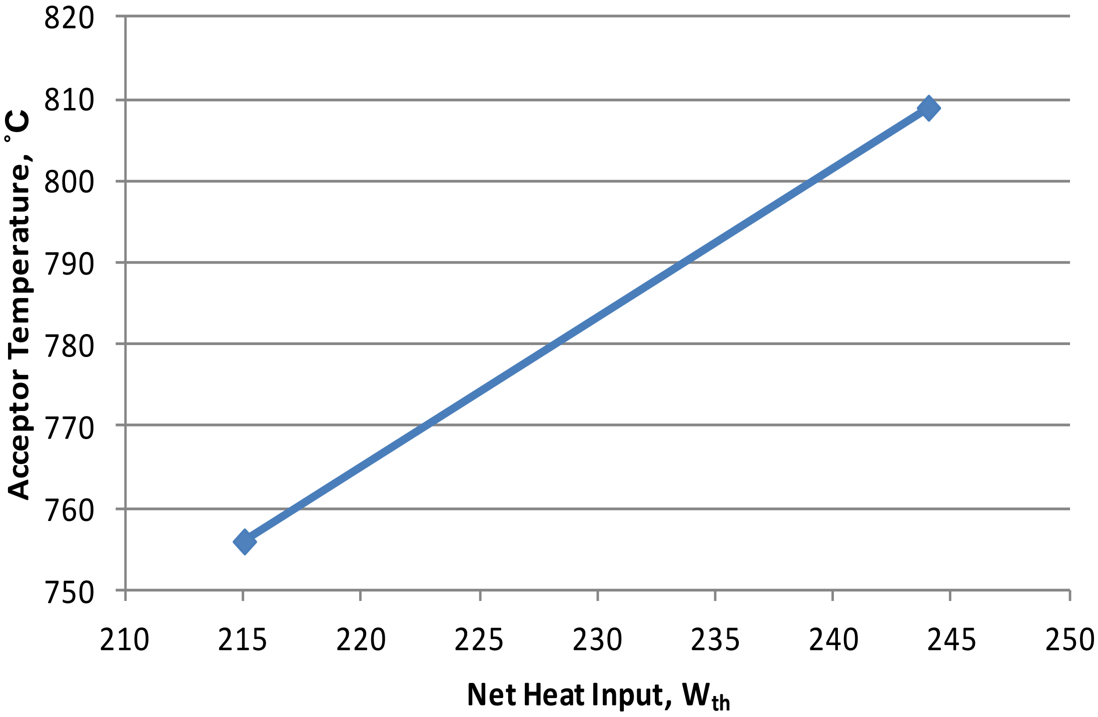
- Beginning of test convertor operating conditions:
  - ASC-E3/ASC-F Beginning of Mission High Reject (760˚C Hot-end/ 90˚C Cold-end/ 98˚C Alternator Housing)
- Data recorded using LabVIEW data acquisition system
- System allowed at least 8 hours to reach steady state
- Test conducted with HT Firerod heat source.

Phase 1: Acceptor Temperature Sensitivity to Gross Heat Input



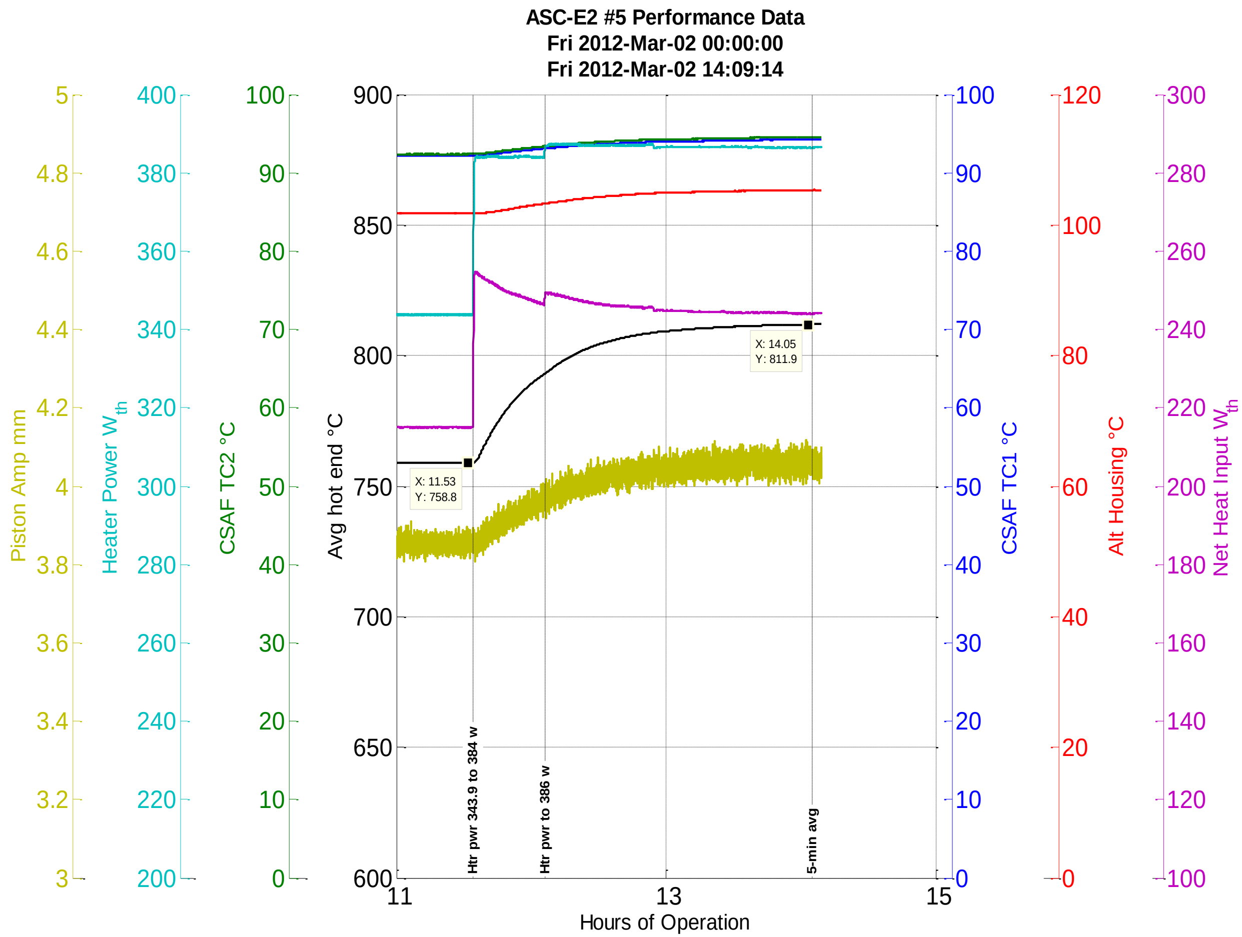
- **How much does acceptor (Hot end) temperature change as heat input increases?**
- **Baseline data for acceptor temperature sensitivity to gross heat input.**
- **Changed gross heat input by -20/+15 $W_{th.}$**
- **Sensitivity was found to be 1.4 °C/W_{th}.**

Phase 2: Argon Venting

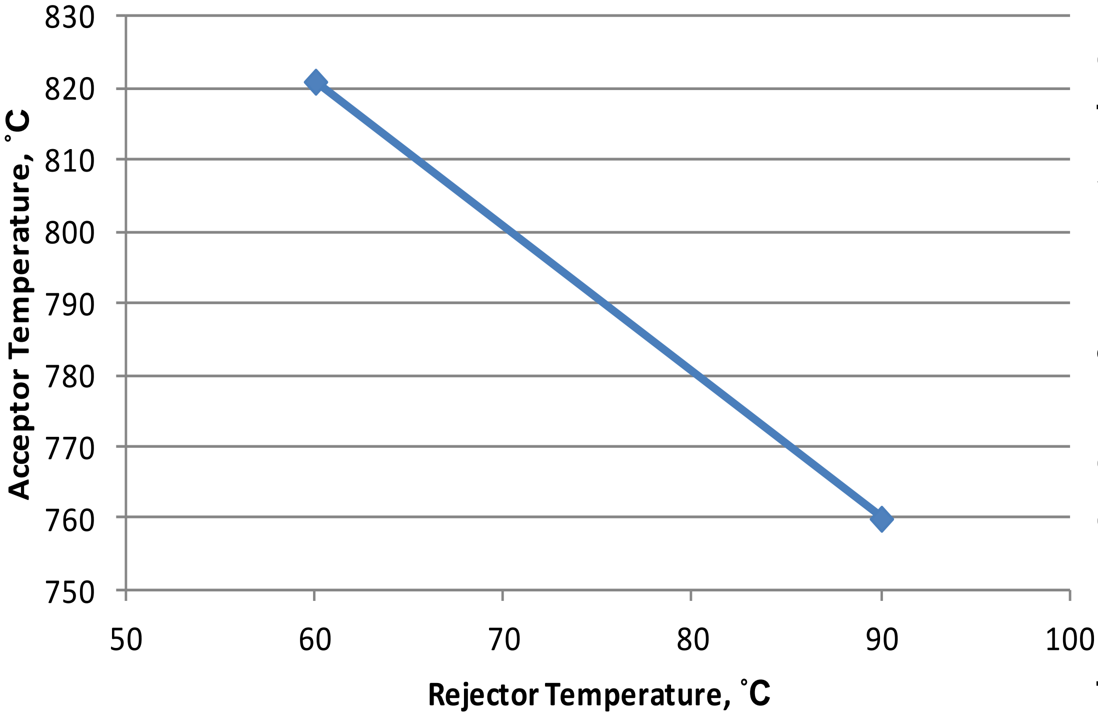


- Simulate venting of argon and increased effectiveness of thermal insulation.
- Increased Net heat input by 30 Wth
- This resulted in acceptor temperature increase of 53 °C.

Phase 2: Argon Venting



Phase 3: Sink Temperature Change



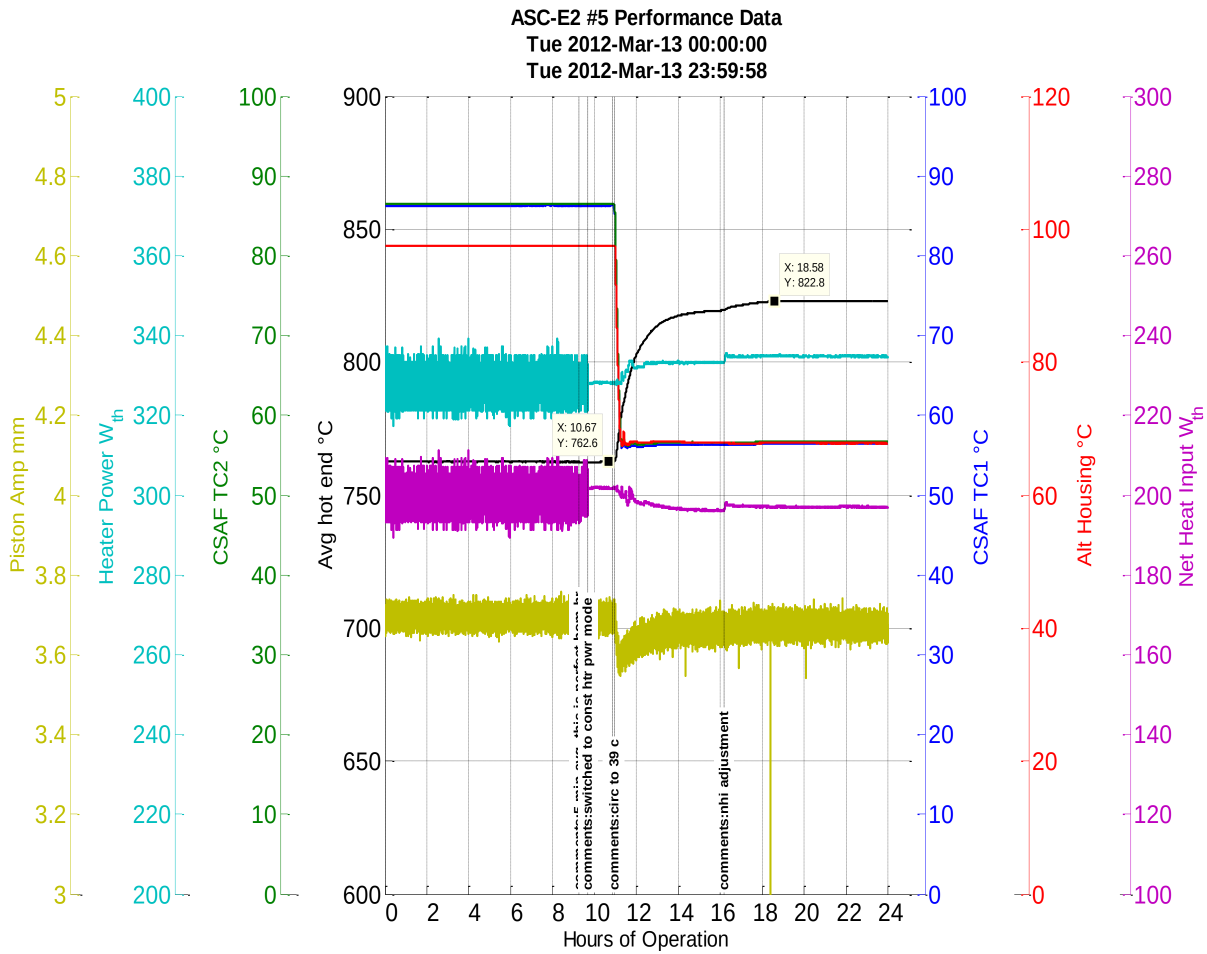
- **Simulate sink temperature change during mission, going from fairing environment to space environment.**

- **Reduced rejector and alternator housing temperature by 30 °C – corresponds to worst case 4 K deep space environment.**

- **This resulted in acceptor temperature increase of 61 °C**

- **Acceptor temperature to rejector/ alternator housing temperature change is -2.0 °C/ °C**

Phase 3: Sink Temperature Change



Conclusion

- Performance variation tests are an important part of understanding behavior and performance of convertors.
  - Information gathered in these tests can be used by system integrators for controlling the convertor during deep space missions.
- Testing showed sensitivity of AC bus voltage variation and performance changes due to argon venting during launch.
- Future tests need to be conducted on next generation of the Advanced Stirling Convertors with flight-like test hardware and flight-like environments.

NASA