

The U.S. Department of Energy (DOE), Lockheed Martin (LM), and NASA Glenn Research Center (GRC) have been developing the Stirling Radioisotope Generator (SRG110) for use as a power system for space science missions. The launch environment enveloping potential missions results in a random input spectrum that is significantly higher than historical RPS launch levels and is a challenge for designers. Analysis presented in prior work predicted that tailoring the compliance at the generator-spacecraft interface reduced the dynamic response of the system thereby allowing higher launch load input levels and expanding the range of potential generator missions. To confirm analytical predictions, a dynamic simulator representing the generator structure, Stirling convertors and heat sources was designed and built for testing with and without a compliant interface. Finite element analysis was performed to guide the generator simulator and compliant interface design so that test modes and frequencies were representative of the SRG110 generator. This paper presents the dynamic simulator design, the test setup and methodology, test article modes and frequencies and dynamic responses, and post-test analysis results. With the compliant interface, component responses to an input environment exceeding the SRG110 qualification level spectrum were all within design allowables. Post-test analysis included finite element model tuning to match test frequencies and random response analysis using the test input spectrum. Analytical results were in good overall agreement with the test results and confirmed previous predictions that the SRG110 power system may be considered for a broad range of potential missions, including those with demanding launch environments.

SRG110 Stirling Generator Dynamic Simulator Vibration Test Results and Analysis Correlation

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Outline



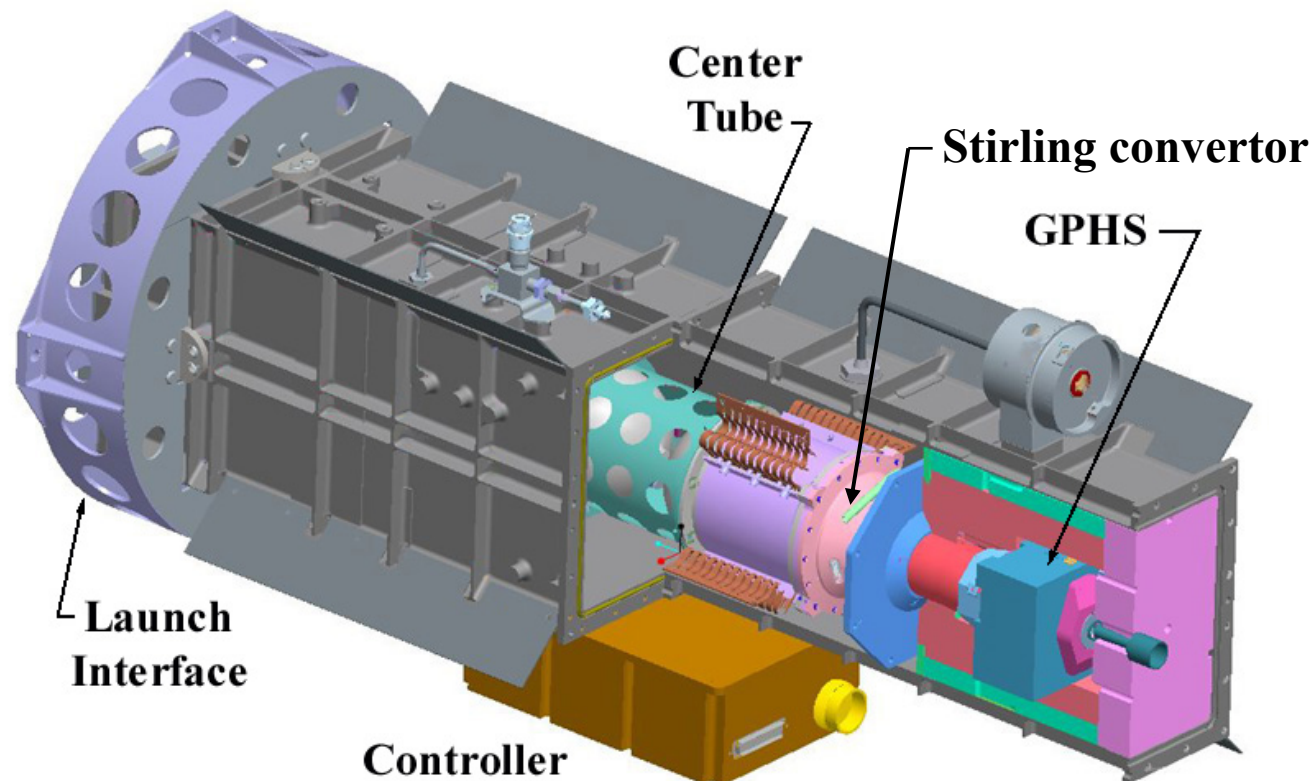
- Objectives of Stirling generator dynamic simulator testing and analysis
- Development of SRG110 Stirling generator dynamic simulator
- Vibration testing
 - » Modal results
 - » Random vibration test results
- Dynamic finite element analysis of the Stirling generator dynamic simulator
 - » Test results vs. analytical results
- Summary
- Conclusions

Objectives of generator simulator testing and analysis



- Main objective: characterize transmissibility and modal frequencies of the SRG110 generator simulator
- Reduce Stirling generator development risk by
 - » Evaluate isolation adapter approach
 - » Evaluate interconnect tube joining Stirling convertors
 - » Providing data to validate analytical models
- Not necessary to have exact replica of SRG110
 - » Dynamic similarity is sufficient
 - » Focus is system response to external excitation → Stirling convertors need not be operating during test

Introduction - SRG110 generator and launch interface



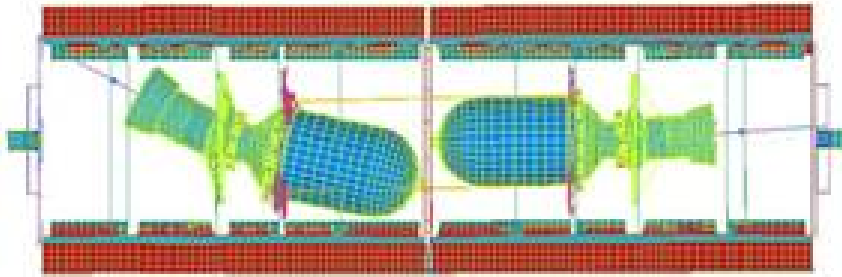
- Nominal 110 We Stirling radioisotope generator; 22 – 25% efficiency @ 34 kg
- Launch interface designed to achieve fundamental generator lateral and axial modes between 35 Hz and 50 Hz
 - » Above spacecraft primary structure / below convertor operation

Stirling generator dynamic simulator

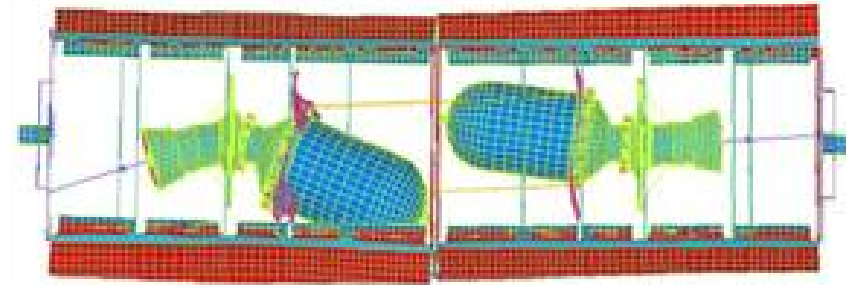
- Stirling convertor mass simulators
- Interconnect tube
 - » simplify load path and eliminate individual convertor modes
- Pressurized for structural and dynamic reasons



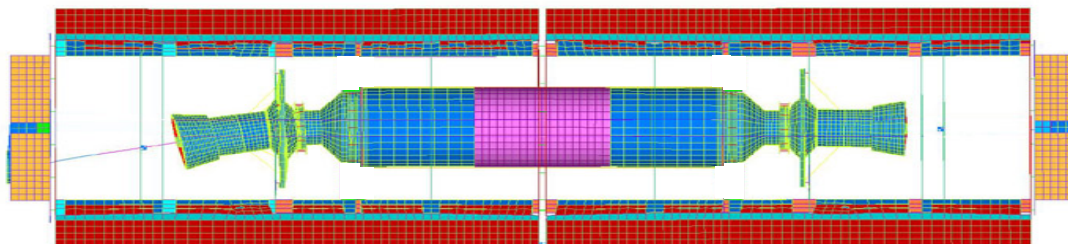
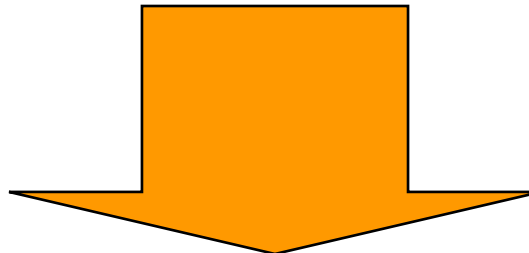
Interconnect tube eliminates individual convertor modes



- Heater head modes at 180 Hz



- Convertor bending modes at 265 Hz



Heater Head Bending Mode

- Heater head modes stiffened to 200 Hz
- Convertor assembly bending mode increased to 540 Hz
 - » Above peak part of input spectrum

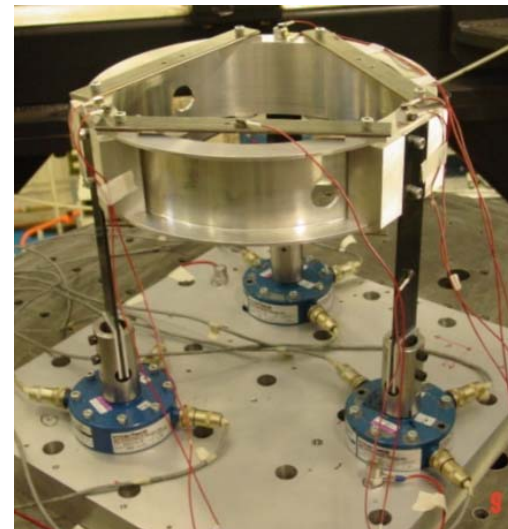
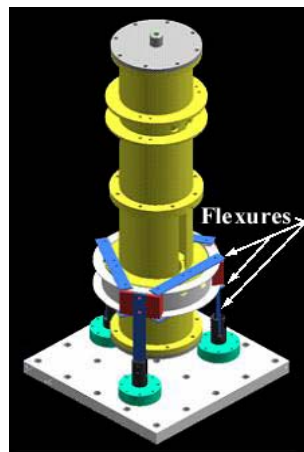
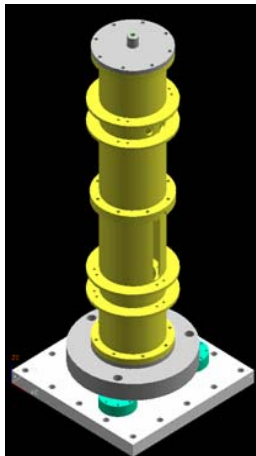
Stirling generator dynamic simulator

- Step 2 GPHS mass simulators
- Preload stud and washer assembly apply compressive preload to GPHS against Stirling convertor heat collector



Stirling generator dynamic simulator

- Two-piece cylindrical generator housing with bending stiffness similar to SRG110 housing.
- Two mounting configurations:
 - » Hard-mounted
 - » Isolation-mounted

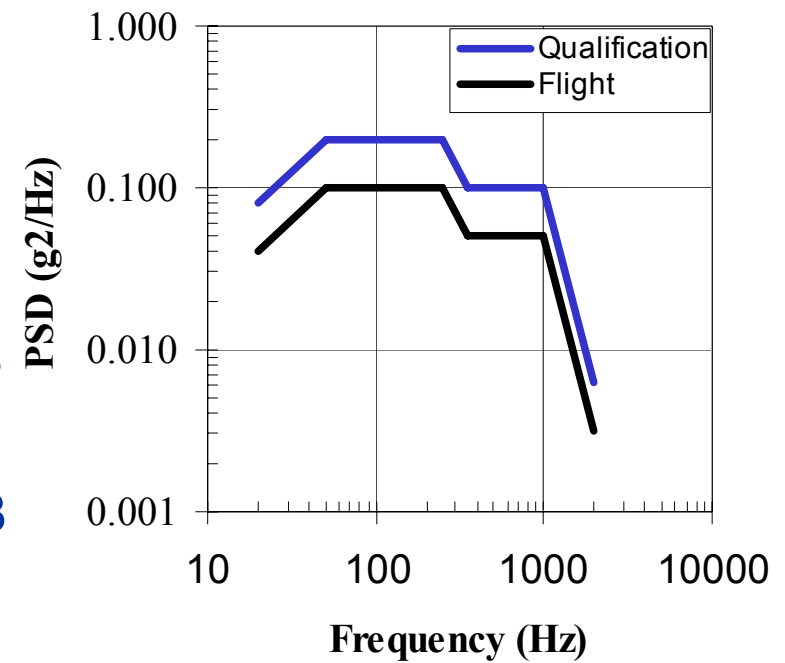


Vibration testing



- Data recorded:
 - » 93 accelerometers
 - » 3 force measurements
 - » 1 pressure measurement

- RPS flight acceptance test profile
- Flight level -> 8.7 grms
- Qualification level -> 12.5 grms (=flight+3 dB)
- Highest testing level was flight level + 4.8 dB = 15.1 grms (peak input of 0.3 g²/Hz)
- Force limiting

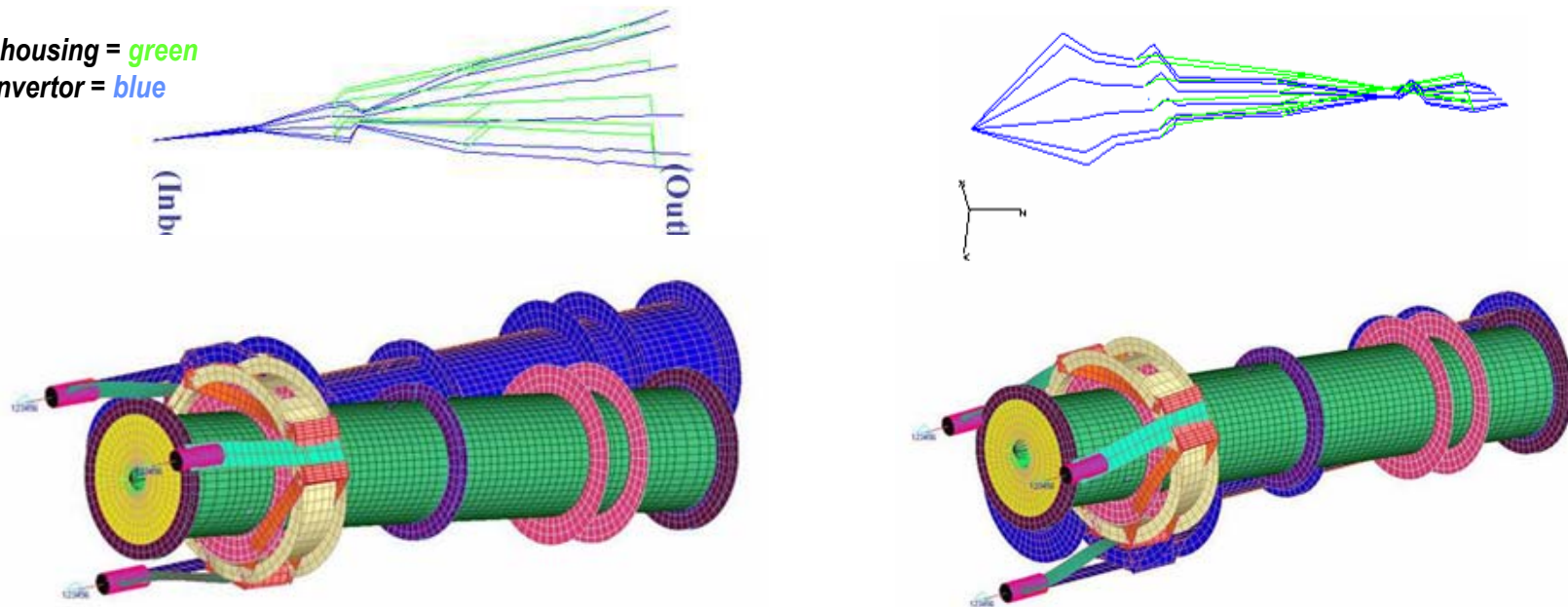


Modal results

- Modes extracted from low level random vibration input (flight-12 dB)

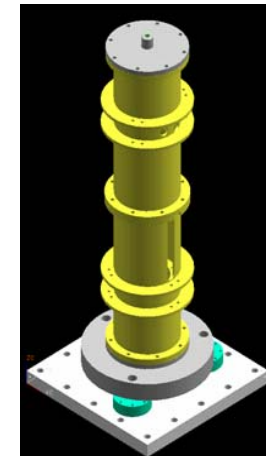
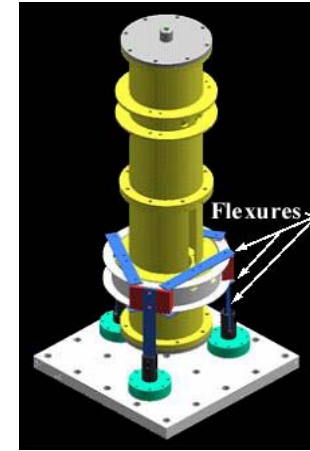
Mode	Natural Frequency (Hz)			
	Isolation-Mounted Configuration		Hard-Mounted Configuration	
	Test	Tuned Model	Test	Tuned Model
Lateral 1st Bending	31.6	31.6	89.4	89.4
Lateral 2nd Bending	81.2	70.0	-	
Longitudinal Translation	43.5	43.0		

Generator housing = green
Stirling convertor = blue



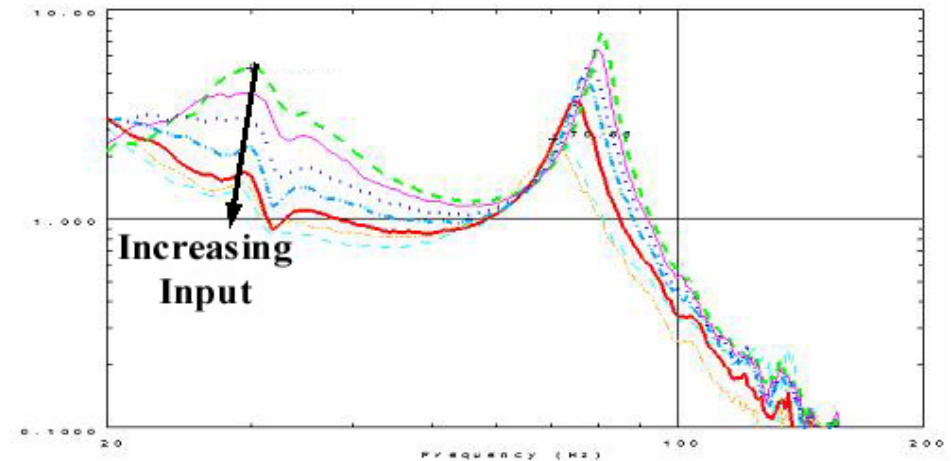
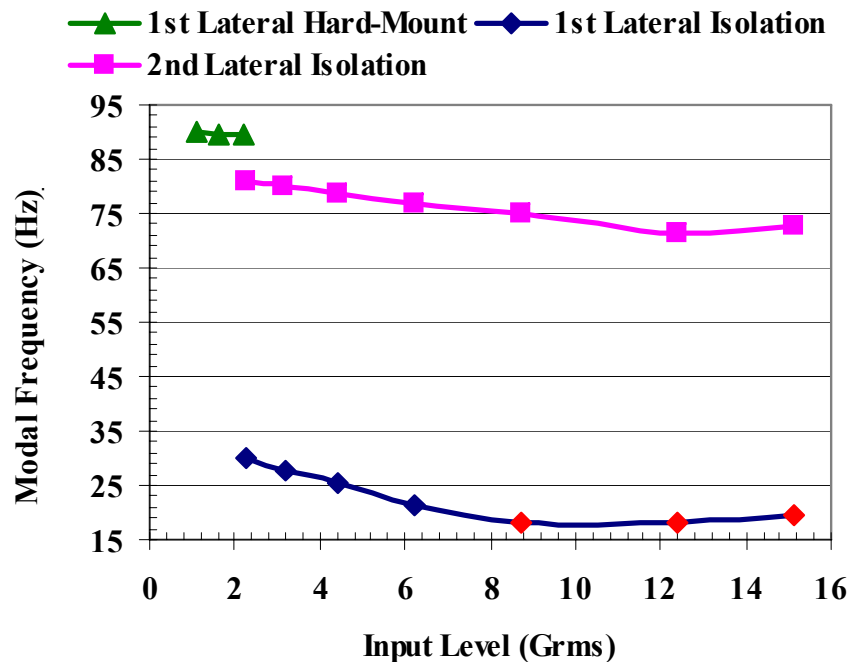
Random vibration testing

- Isolation-mounted configuration
 - » Tested to flight level + 4.8 dB (15.1 grms, 0.3 g^2/Hz maximum) because amplification was low
 - » Highest vibration level anticipated for RPS
 - » Lateral and axial testing
- Hard-mounted configuration
 - » Tested to flight level – 12 dB due to high amplification of test article
 - » Lateral testing only



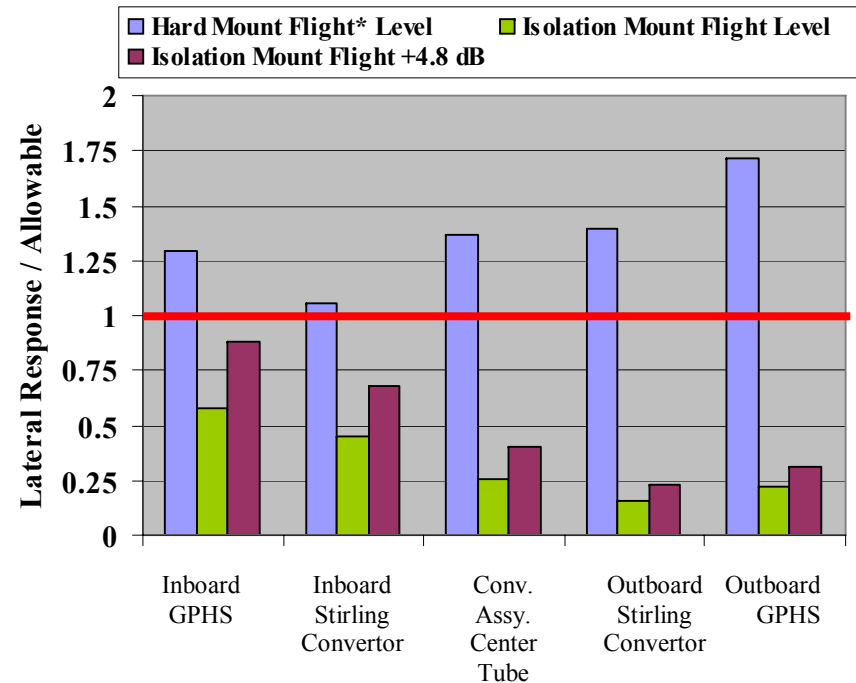
Linearity study

- No significant change in hard-mount 1st lateral frequency (small vibration range)
- Slight nonlinearities in 1st and 2nd bending modes for isolation-mount configuration
- Damping increased with input vibration level



System response: hard-mount vs. Isolation-mount

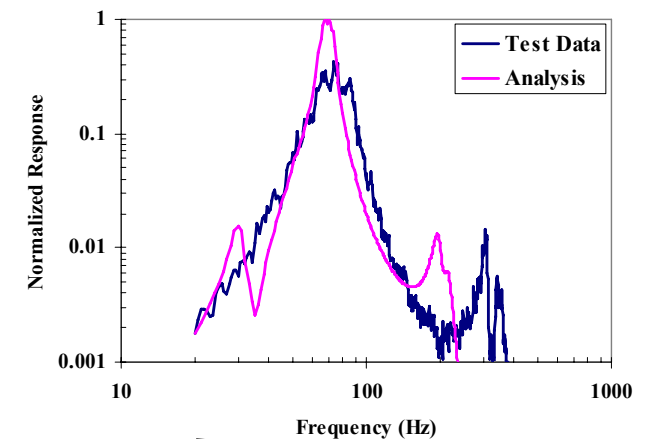
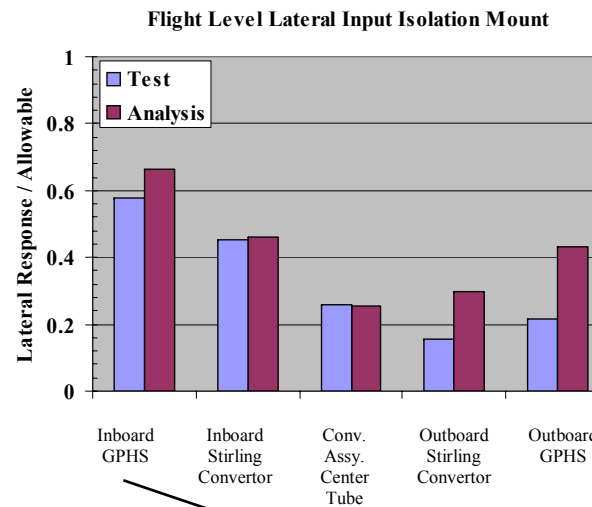
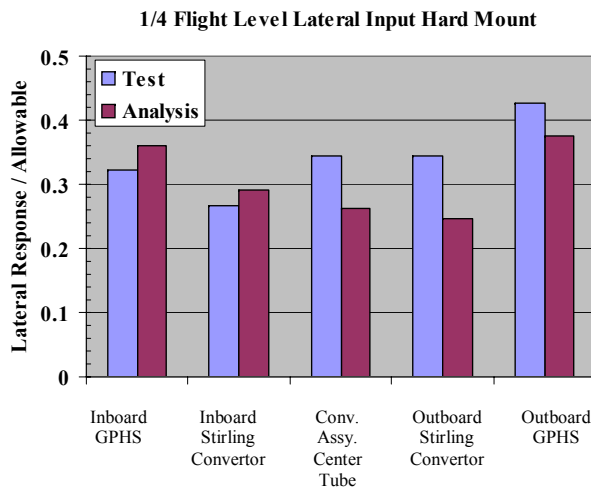
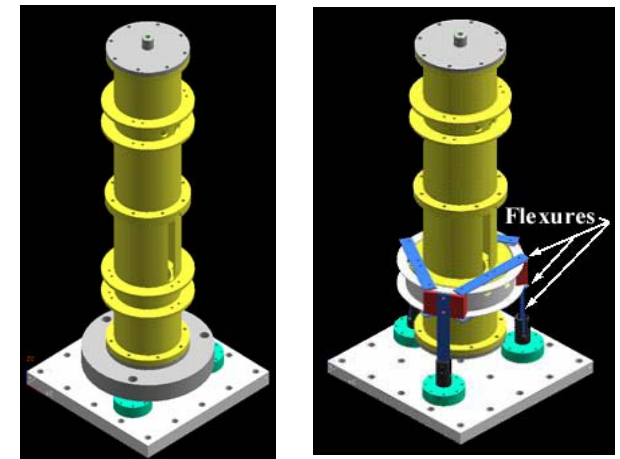
- Component response compared to allowable vibration level
- Ratios greater than 1 indicate component allowable exceeded
- Hard-mount: component allowable exceeded at flight level
- Isolation-mount: response within acceptable limits even for flight + 4.8 dB
- Isolation-mount response 2x to 9x lower than hard-mount response



*Scaled ¼ Flight Data

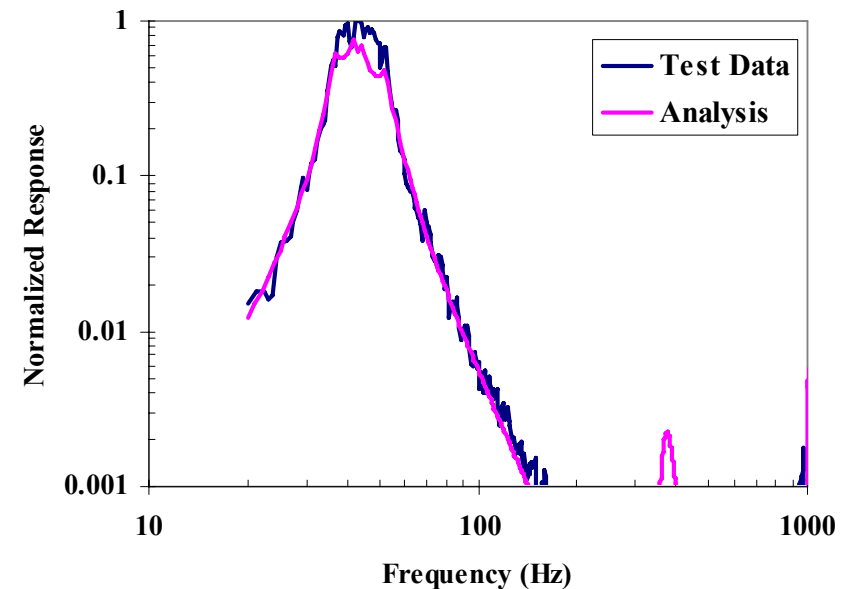
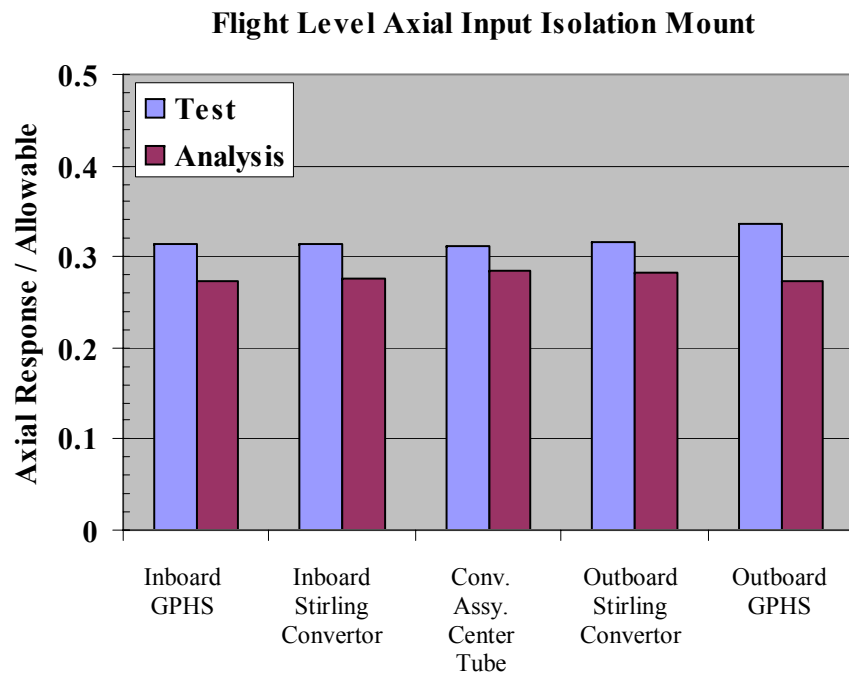
Random vibration: test and analysis comparison

- **Lateral response**
 - » 5% structural damping assumed for the dynamic FE model
 - » Analytical model included force limiting, as applied during test
 - » Good general agreement in magnitude of responses as well as trends in response levels from inboard to outboard end



Random vibration: test and analysis comparison

- Axial response
 - » Good agreement between test and analysis
 - » Response dominated by 1st mode at 44 Hz from flexures



Summary

- Stirling generator dynamic simulator was fabricated
 - » Isolation-mounted and hard-mounted configurations
 - » Interconnect tube connected Stirling convertors
- Hard-mounted configuration tested up to $\frac{1}{4}$ flight level
- Isolation-mounted configuration tested up to flight level + 4.8 dB
- Analytical model of the generator dynamic simulator was developed
- Test and analytical model mode shapes and response compared

Conclusions

- Connecting Stirling convertors together simplified the load path and eliminated individual convertor modes
- General agreement between test and analytical results
 - » Analytical model can be used to guide future generator designs
- Isolation mounting of the generator to the spacecraft is a viable method to reduce vibration response of the generator and its components
- With the isolation mounting tested, component response was limited to acceptable levels even when tested at the highest RPS qualification input levels (15.1 grms, 0.3 g²/Hz maximum)

Acknowledgments



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Contributions from:

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- **Jeffery Schreiber and Richard Shaltens - NASA GRC**

Questions?