National Aeronautics and Space Administration

JPL

# INITIAL VIBRATION ANALYSIS OF THE ADVANCED STIRLING RADIOISOTOPE GENERATOR'S (ASRG'S) AFFECT ON SPACECRAFT INSTRUMENTS

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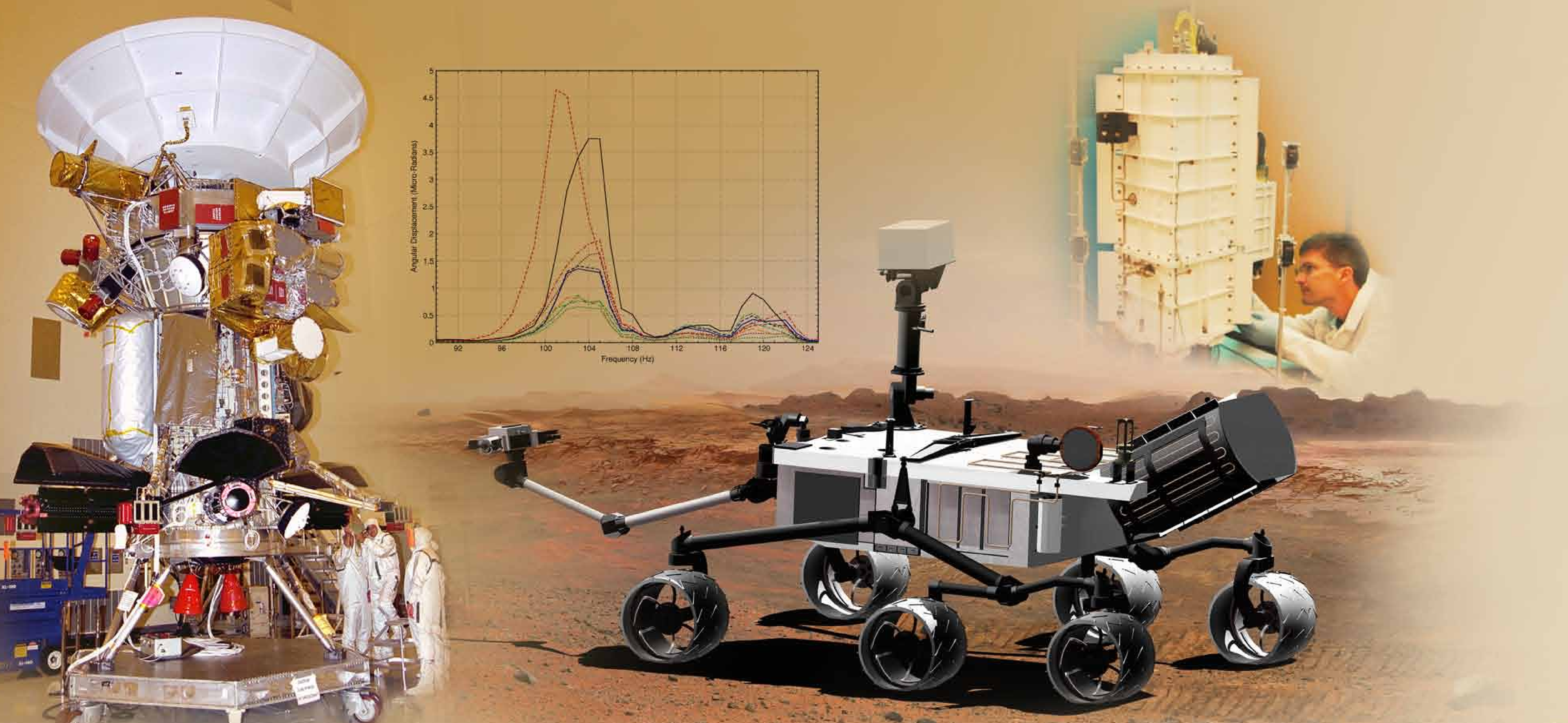


## OVERVIEW

### Problem Statement

Assess if nominal Advanced Stirling Radioisotope Generator (ASRG) vibration levels are sufficiently benign for unimpeded spacecraft instrument operation

- ASRG Vibration Spec review (Jet Propulsion Laboratory (JPL); Mar 09)—Concerns with existing criteria
- ASRG Vibration Review (JPL; May 10)—Concerns with off-nominals; hardware test proposed

### Approach

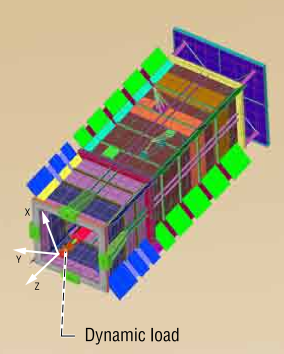
- Analysis performed using existing, dissimilar spacecraft with validated finite element models (FEM)
  - Cassini Orbiter (by Glenn Research Center (GRC)/QinetiQ)
  - Mars Science Laboratory (MSL) (by JPL)
- Analytically mounted ASRGs (no modification of interface or instruments to accommodate ASRG)
- ASRG forcing functions based on GRC measured data
- Performed NASTRAN Modal Frequency Response analysis
- Compared results with established spacecraft instrument vibration limits

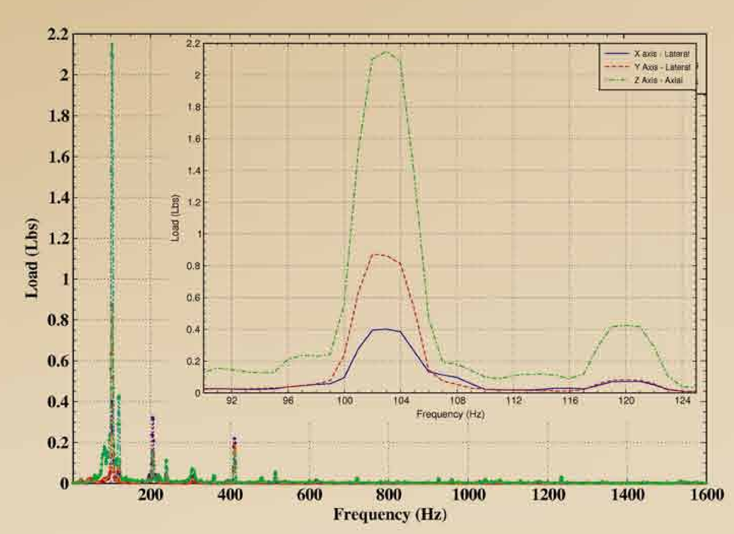
## LIMITATIONS AND ASSUMPTIONS

- Initial results only, with engineering judgment applied to analysis ground rules
- Spacecraft, ASRG (Qualification Unit), and ASRG Adapter (Engineering Unit (EU)) FEMs
  - ASRG FEMs chosen for expediency (Lockheed Martin) and of varying maturities
  - Past accuracy testing exceed vibration analysis range (Cassini: 70 Hz; MSL 60 Hz)
  - Existing spacecraft adapters minimally modified (Cassini) or unmodified (MSL)
  - ASRG EU adapter
    - Not designed for Cassini or MSL
    - Not analyzed for launch environments
- Science instrument limiting criteria: Angular Displacement
  - Cassini (at Remote Sensing Pallet)
    - 4 µrad for NAC, WAC, and VIMS (Cassini Orbiter Functional Requirements Book—CAS–3–170)
    - 5 µrad for remaining instruments (ASRG Disturbance Specification—K. Lohman; JPL; Mar 09)
  - MSL (at top of Remote Sensing Mast; static)
    - 80 µrad (ASRG–MSL Vibration Analysis—K. Lohman; JPL; Feb 11)
- 1:1 RTG replacement with ASRG at existing hard points
  - Cassini—analysis done at ½ power level
  - MSL—analysis done at full power level
- ASRG component angular displacements summed (worst case) rather than RSS'd for Cassini
- ASRG forcing functions based on measured vibration on rigid table (may not represent load on compliant structure)
- Material properties may be inconsistent with mission environments

## PROCESSED ASRG VIBRATION LOAD DATA

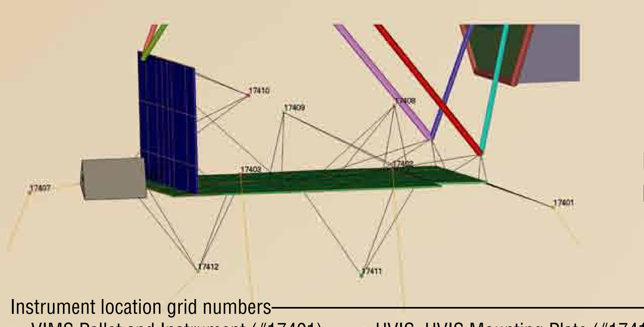
- Vibration load data from ASRG EU testing at GRC (force versus frequency from 0 to 1600 Hz)
- Forcing Function Application
  - ASRG force applied to center of RBE3 connect to four attach points
  - Forcing functions aligned with each ASRG
  - Dynamic load applied in the same manner as it was measured



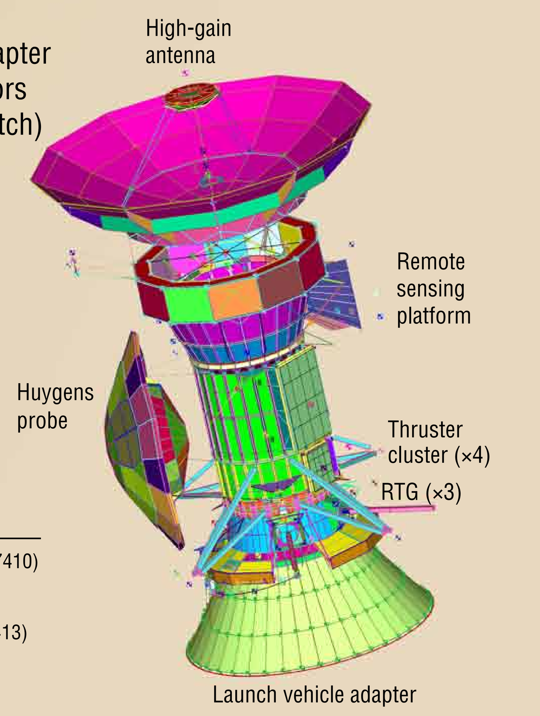

## CASSINI FINITE ELEMENT MODEL

- Modified launch FEM for verification of coupled loads (test verified by modal survey up to ~70 Hz) into a FEM for probe release configuration
  - Off-loaded propellant to probe release levels
  - Removed Huygens probe and launch vehicle adapter
  - Removed Radioisotope Thermoelectric Generators (RTGs), replaced with ASRGs 1:1 (no power match)
- Remote Sensing Pallet grid locations used for analysis



Instrument location grid numbers

- VIMS Pallet and Instrument (#17401)
- Star Trackers (#17402-17403)
- CIRs Instrument (#17407)
- VIMs Electronics (#17408)
- CIRs Electronics (#17409)
- UVIS, UVIS Mounting Plate (#17410)
- NAC (#17411)
- WAC (#17412)
- cg of Pallet + Instruments (#17413)




## THREE ASRG-TO-CASSINI INTERFACE APPROACHES

**RTG adapter only**

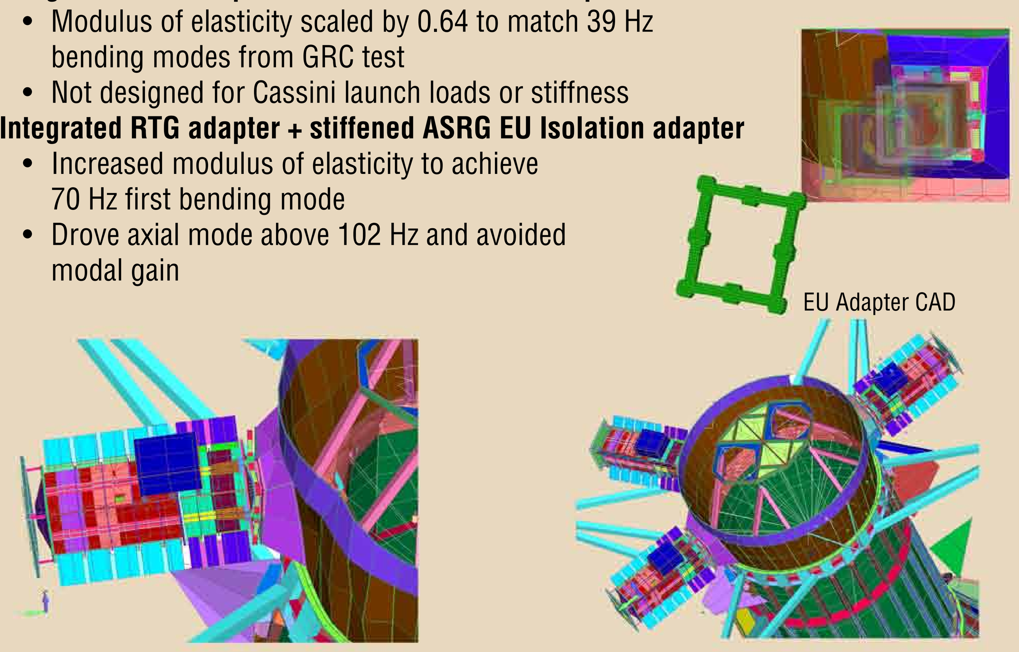
- ASRGs mounted on existing RTG adapters at four attach points
- RTG adapter moved to corner nodes to fit ASRG SVIF adapter

**Integrated RTG adapter + ASRG EU Isolation adapter**

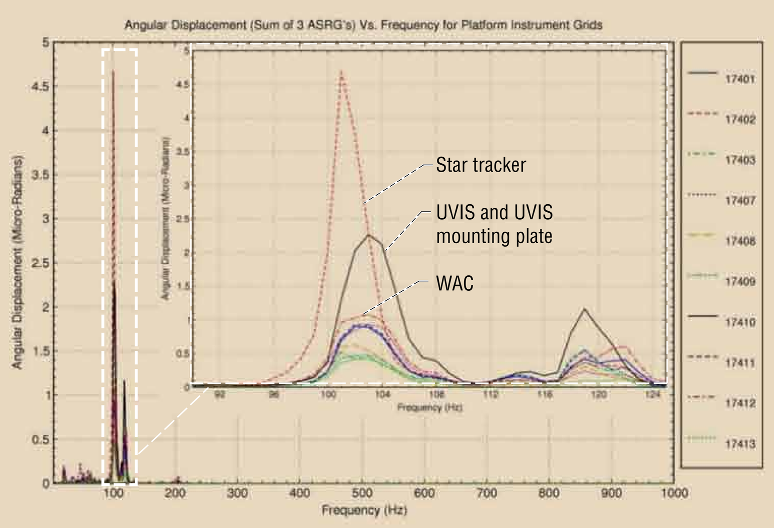
- Modulus of elasticity scaled by 0.64 to match 39 Hz bending modes from GRC test
- Not designed for Cassini launch loads or stiffness

**Integrated RTG adapter + stiffened ASRG EU Isolation adapter**

- Increased modulus of elasticity to achieve 70 Hz first bending mode
- Drove axial mode above 102 Hz and avoided modal gain

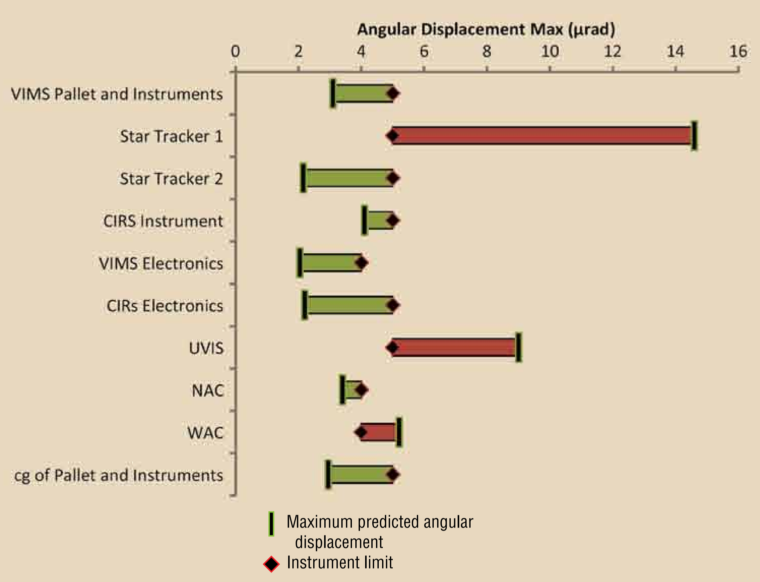



## SUM COMPONENT ANGULAR DISPLACEMENT WITH RTG ADAPTER ONLY




## CASSINI ANGULAR DISPLACEMENT WITH 39 HZ EU ISOLATION ADAPTER

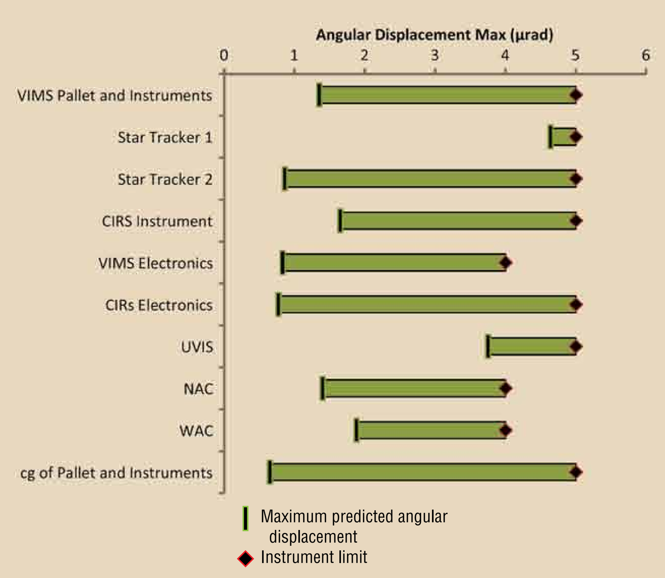
Instrument Limits Versus Predicted Angular Displacement




**Three instrument limits violated**

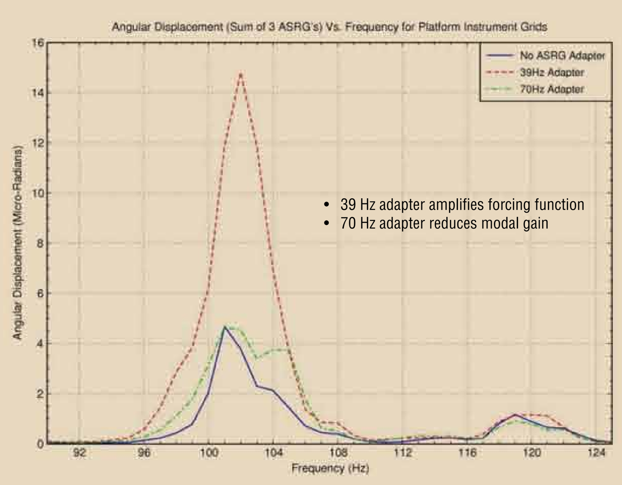
## CASSINI ANGULAR DISPLACEMENT WITH 70 HZ EU ISOLATION ADAPTER

Instrument Limits Versus Predicted Angular Displacement



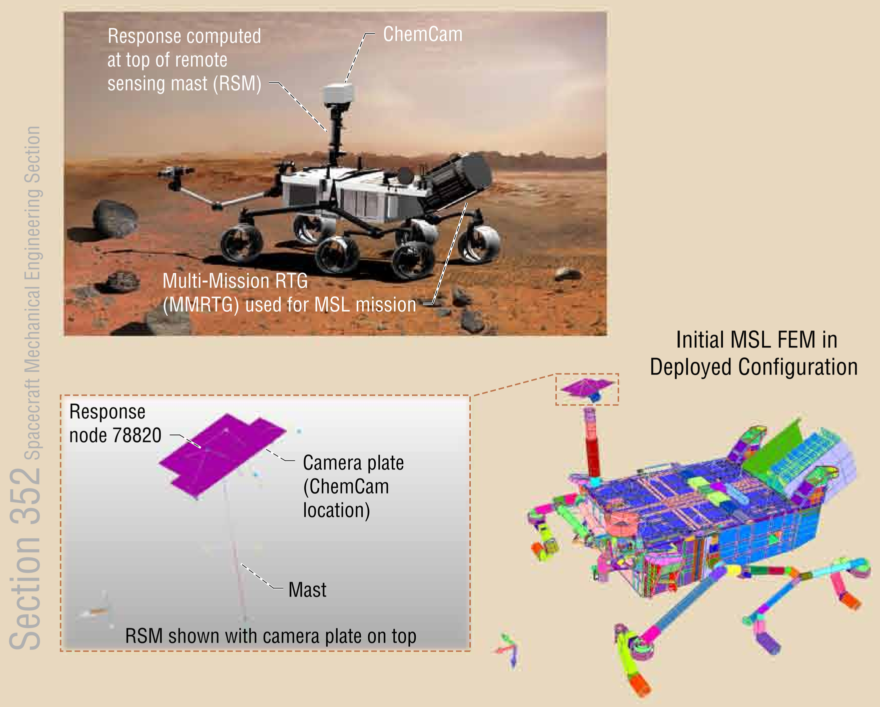

**No instrument limits violated**

## CASSINI MAXIMUM SUM COMPONENT ANGULAR DISPLACEMENT



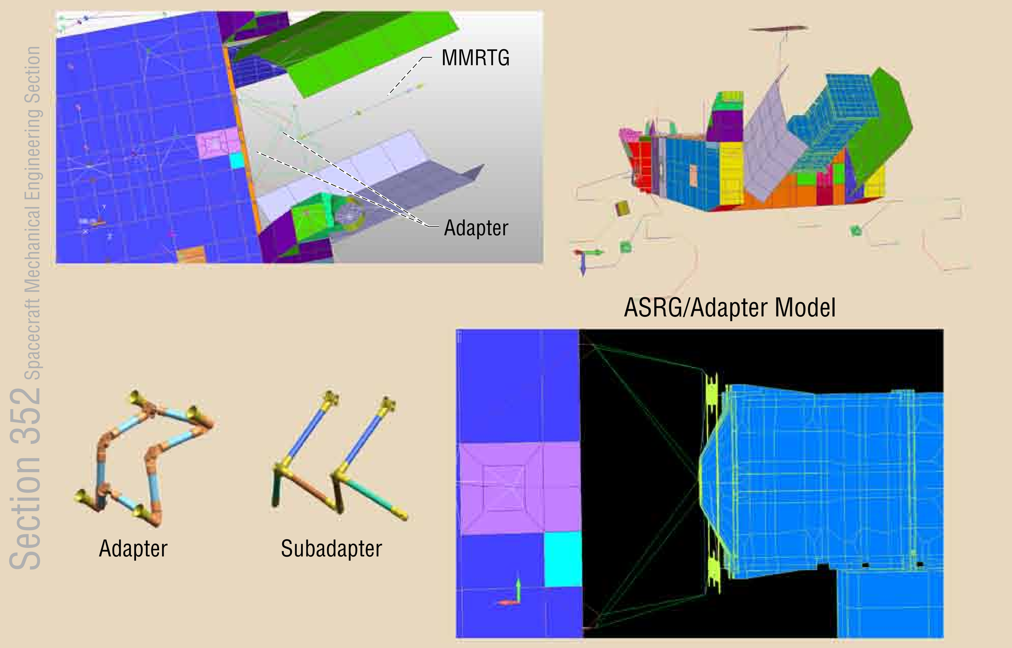

- Softness of adapter combined with Cassini structure—ASRG has significant modes in 100 to 105 Hz range
- Not the case with RTG adapter only or 70 Hz EU isolation adapter (can be seen when comparing mode shapes)

## MARS SCIENCE LAB DEPLOYED CONFIGURATION AND FINITE ELEMENT MODELS




## ONE ASRG-TO-MSL INTERFACE APPROACH

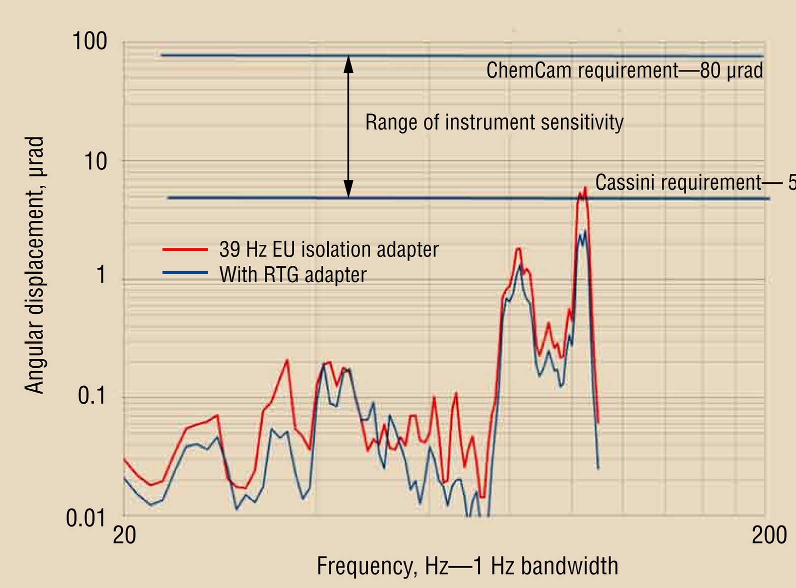
- MMRTG attached to MSL through adapter fitting
- Stick model representation of MMRTG
- No modification of MMRTG or ASRG adapters
- Attached with rigid elements




Section 352 Spacecraft Mechanical Engineering Section

## ANALYSIS RESULTS—ANGULAR DISPLACEMENT

MSL ChemCam Camera Plate Response—RSS Response




## CONCLUSIONS FROM INTERIM RESULTS

- Vibration source characteristics, spacecraft structure stiffness, instrument location, and instrument attachment have profound impact on vibration response
  - Cassini—generally flexible structure with vibration-sensitive instruments
  - MSL—generally rigid structure with vibration-tolerant instruments
- Angular displacement criteria generally satisfied
- ASRG-to-spacecraft adapter stiffness can greatly influence responses (~3× compared to no-ASRG adapter)
- Comparison of ASRG operation to traditional spacecraft vibration sources (i.e., reaction wheels, control rate gyros, cryocoolers, etc.) deserves more scrutiny

| | Cassini (Summed 3 ASRGs) | | | MSL (1 ASRG) | | |
|---|---|---|---|---|---|---|
| | Without adapter | With 39 Hz adapter | With 70 Hz adapter | Without adapter | With 39 Hz adapter | With 70 Hz adapter |
| Satisfied Instrument Criteria | 10 out of 10 | 7 out of 10 | 10 out of 10 | 1 out of 1 | 1 out of 1 | N/A |

## RECOMMENDATIONS FOR FUTURE ASRG USERS TO MITIGATE POTENTIAL VIBRATION ISSUES

1. Proceed with standard launch vibration analysis. Design and modify the FEMs of ELV-to-spacecraft adapter and the ASRG-to-spacecraft adapter until launch vehicle and spacecraft constraints are satisfied.
2. Review RPS Program-provided leading-edge analysis of frequency vs. response vs. spacecraft type for spacecraft reconfigured for ASRG. Compare to other spacecraft vibration sources, determine if they are within a range of concern.
3. Perform vibration analysis for in situ conditions due to other vibration sources on the spacecraft (i.e., reaction wheels, control rate gyros, cryocoolers, etc.). Assess whether structural response (angular displacement) is within ranges tolerable for each instrument
   - Without the ASRG vibration contribution
   - With the ASRG vibration contribution (forcing functions provided)
4. Identify whether ASRG or other vibration sources are major vibration contributors. If the major vibration contributor
   - Is **NOT** the ASRG (or ASRG is comparable to other vibration sources), then apply typical mitigation methods to other sources
   - **IS** the ASRG
     - And only a few sensors are of concern, isolate them individually with typical mitigation methods to avoid modal gain
     - Otherwise, if most/all sensors are of concern, apply typical mitigation techniques
       - Modify ASRG-to-spacecraft interface adapter design or materials
       - Redesign instrument pallet structure
       - Examine other integration orientations for the ASRGs, such as colinear to the spacecraft's major axis
   - Reanalyze and redesign adapter until instrument vibration criteria are satisfied
5. Reanalyze entire stack for Earth-to-orbit vibration environment

## FOR FURTHER INFORMATION

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