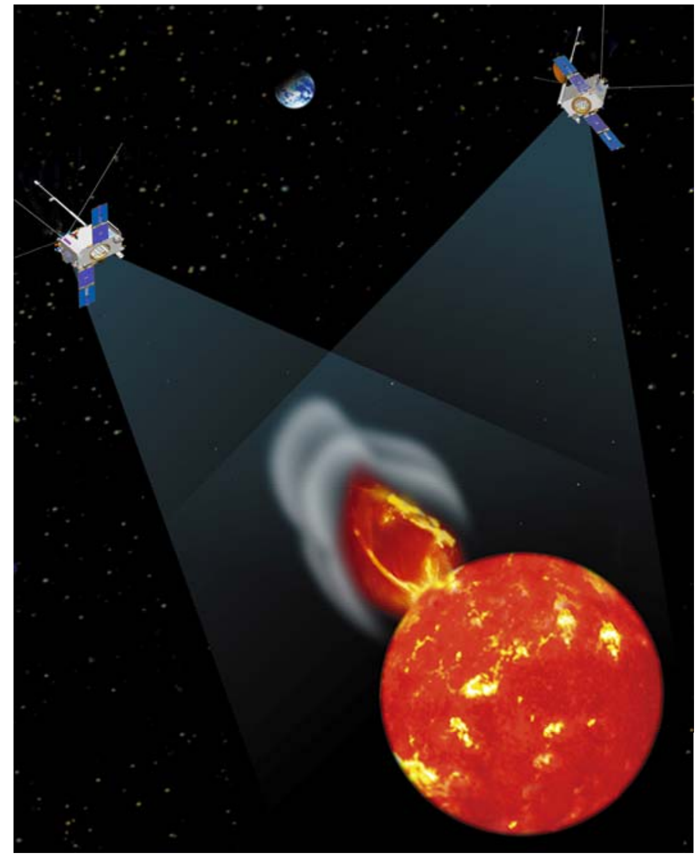
Acoustic Test and Analysis

Heliospheric Imager on STEREO



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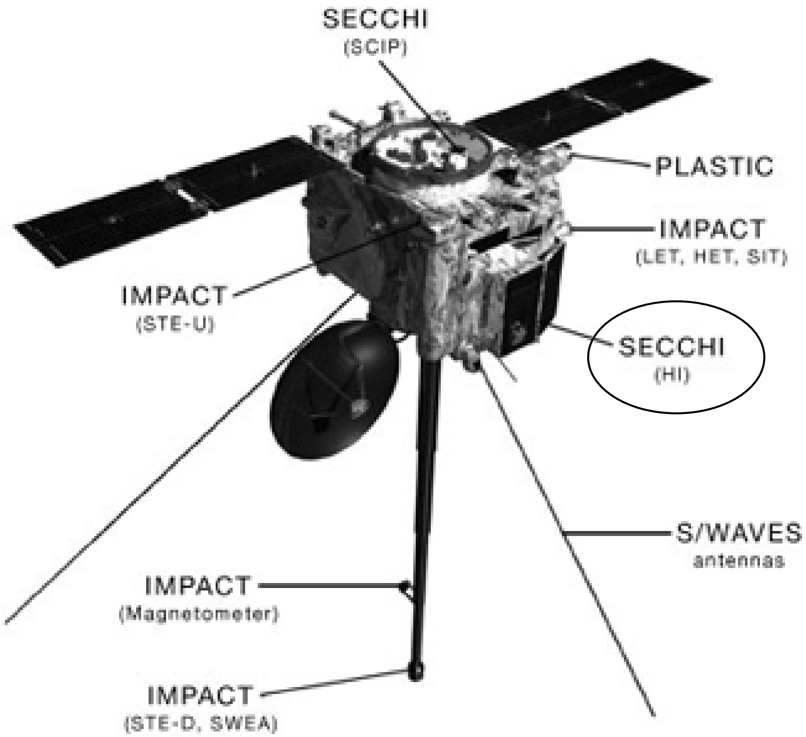
Outline

- STEREO Mission
- Description of HI instrument
- Test Flow
  - Qualifying HI-A and HI-B
    - Random vibration
    - Acoustic
- Acoustic Prediction
  - Matlab implementation of low frequency acoustic reverberant field

STEREO Mission

- STEREO (Solar TErrestrial RElations Observatory)
- Mission will employ two nearly identical space-based observatories to provide stereoscopic measurements to study the Sun and the nature of its coronal mass ejections.
- Launched October 25, 2006 on a Delta II 7925 rocket.
- Johns Hopkins University Applied Physics Lab (JHUAPL) responsible for STEREO spacecraft design and fabrication, observatory integration, testing, and mission operations
- Naval Research Lab (NRL) responsible for SECCHI instrument suite
- University of Birmingham (UB) in England responsible for Heliospheric Imager (HI) instrument with Centre Spatial de Liege, Belgium

Spacecraft Configuration

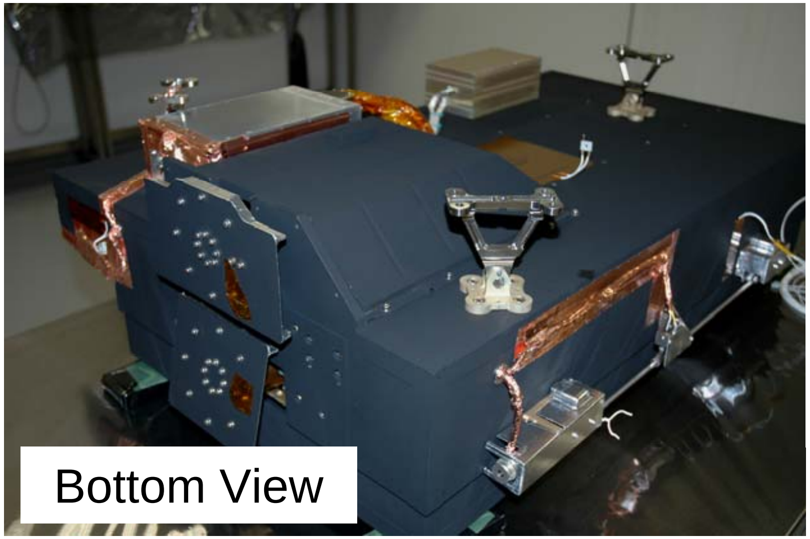


- Four instrument suites on each spacecraft
  - SECCHI (includes HI)
  - IMPACT
  - PLASTIC
  - SWAVES
- Composite high gain antenna dish
- Two sets of solar arrays on each spacecraft

Heliospheric Imager

- The HI is a wide-angle imaging system for the detection of coronal mass ejection (CME) events in space between the Sun and the Earth.
- HI consists of two small telescope systems mounted on the side of each STEREO spacecraft, sheltered from the glare of the Sun by a series of baffles.

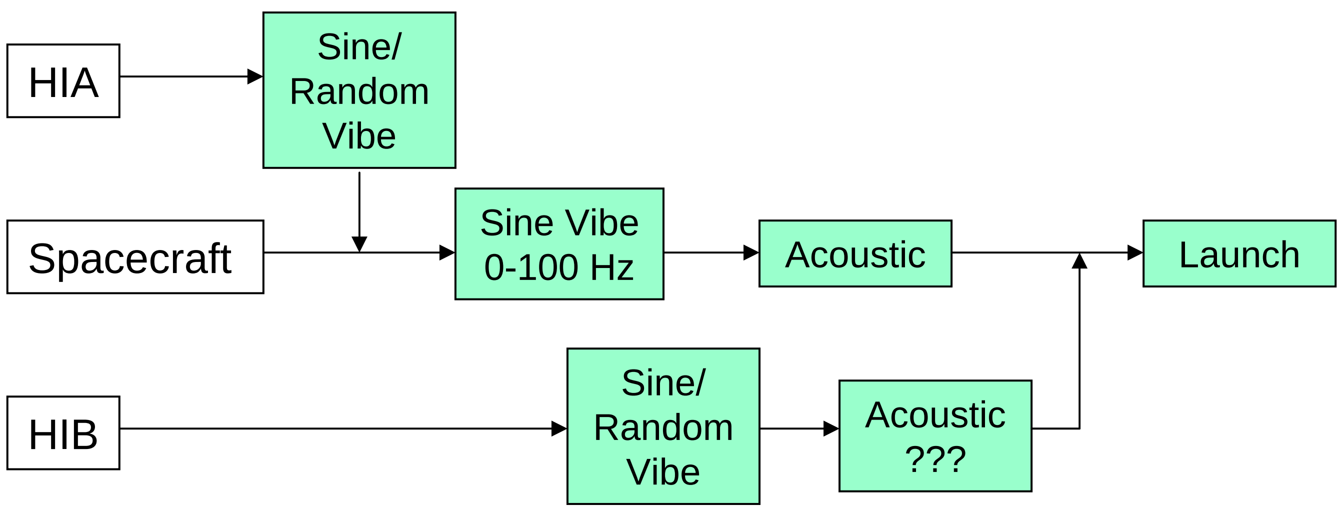
Top View



Bottom View

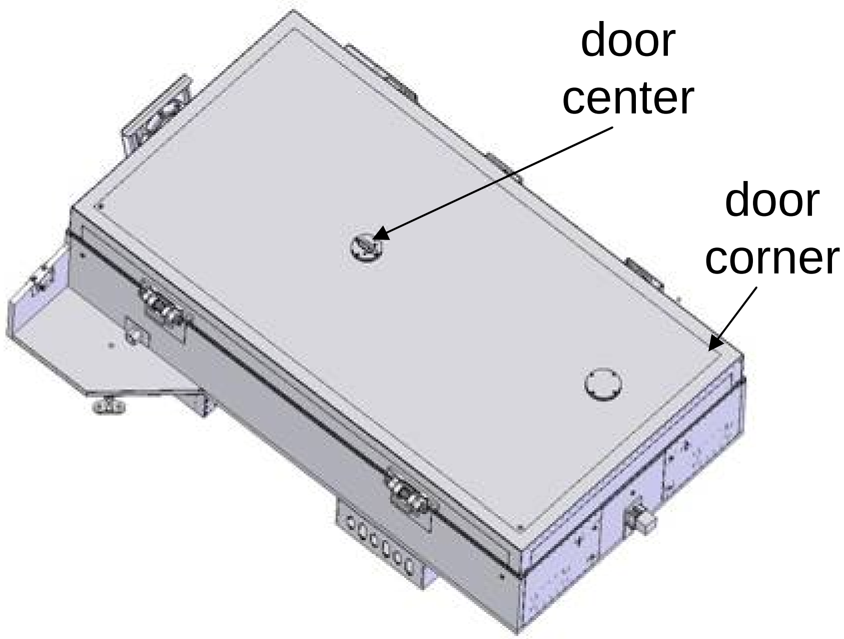
Test Flow

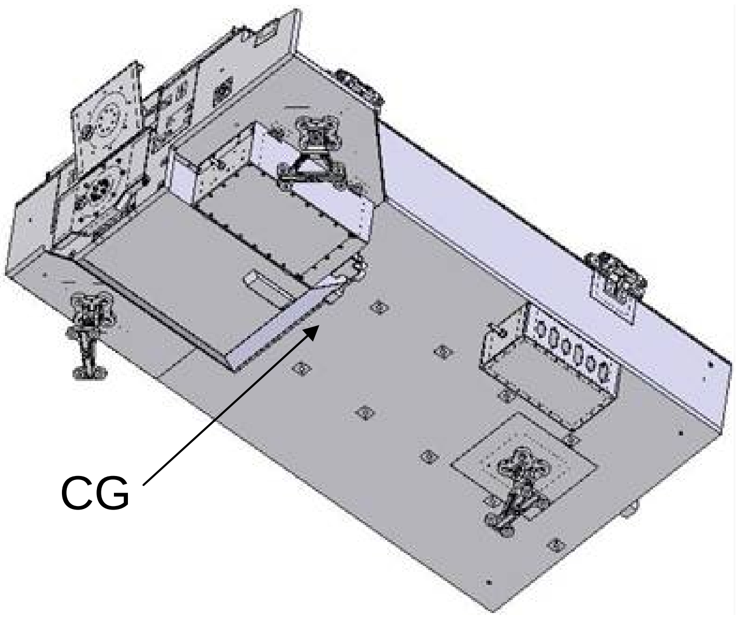
- Qualifying HI Units
  - Sine/Random at the instrument level
  - Acoustic at the spacecraft level
- HIB integration delayed
  - Does HI-B require a standalone acoustic test?
  - Compare test data from the HI-A unit



Accelerometer Locations

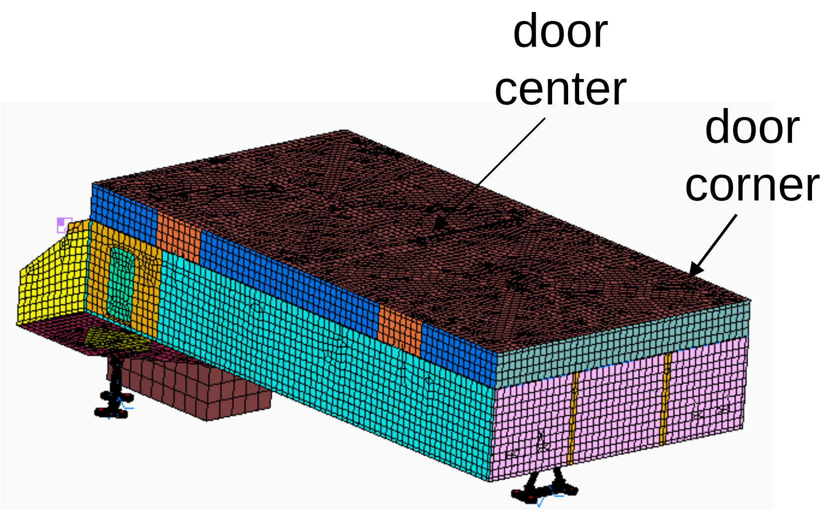
- Key locations discussed
  - CG, door

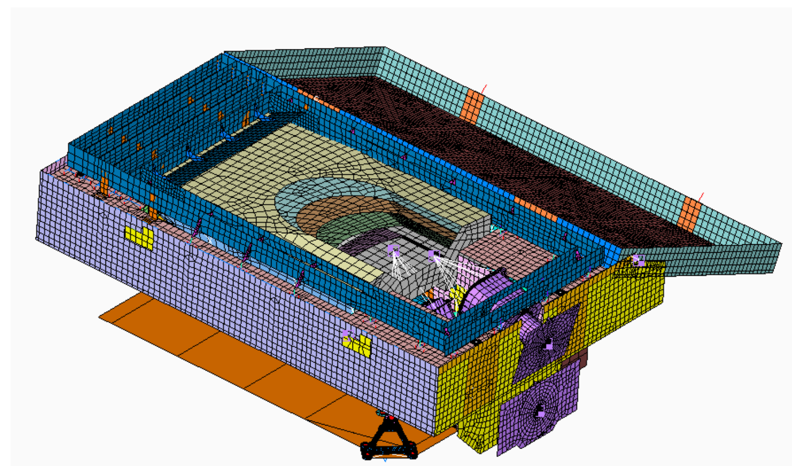




Finite Element Model

- Finite Element Model
  - 58,000 nodes, 107,000 elements
  - Facesheets (M55J and T300 Fabric)
  - Honeycomb panels
  - Bonded panel connections



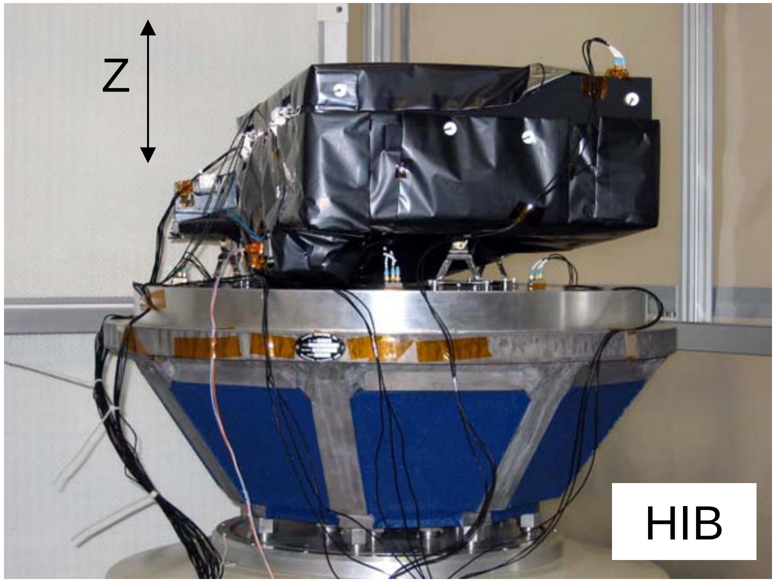


Vibration Test Setup

- Cleanroom shaker environment at CSL in Liege, Belgium
- Minor differences (thermal blanket)

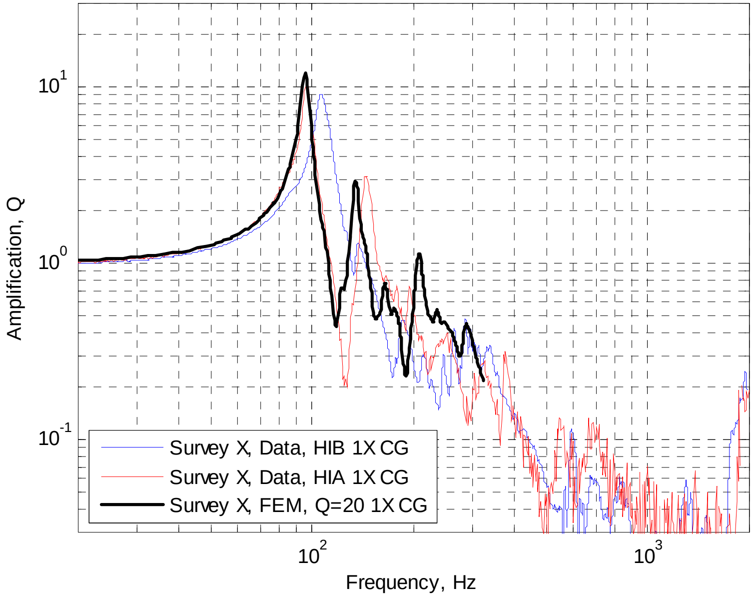
X Direction Shake

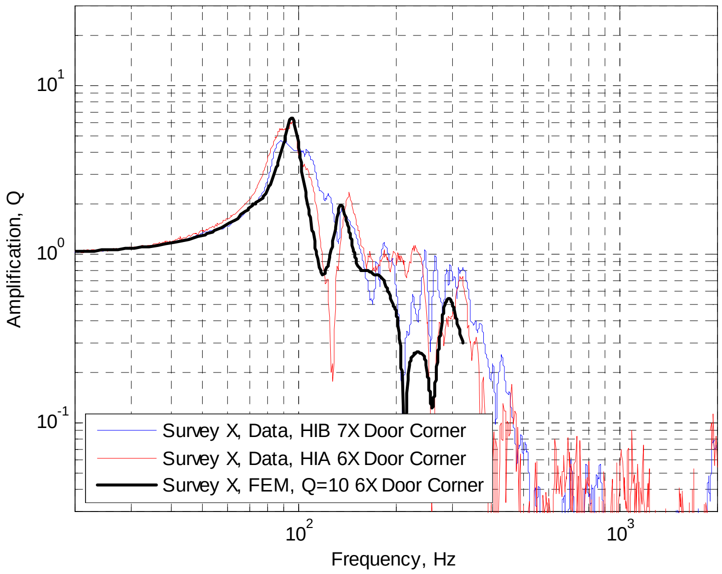
Z Direction Shake



Sine Survey Comparisons

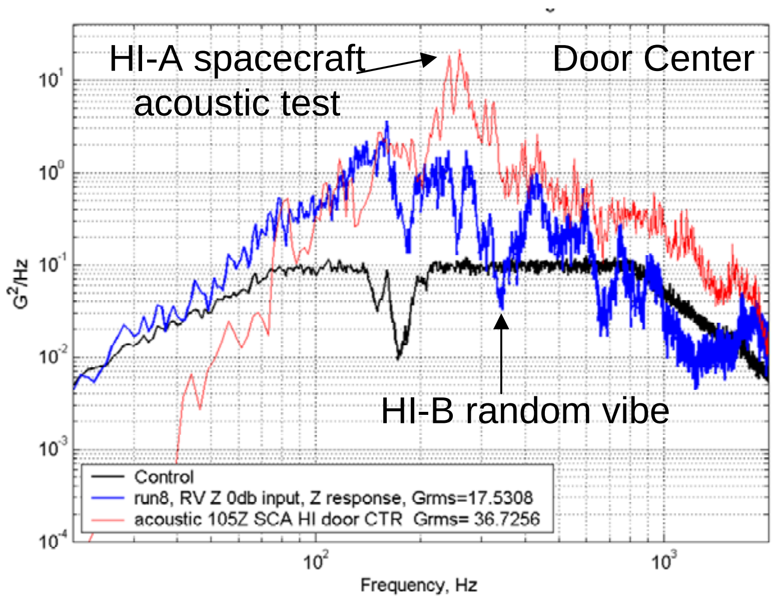
- HIA and HIB have similar responses
- Good match to FEM
- Determine damping





HI-B RV and HI-A Acoustic

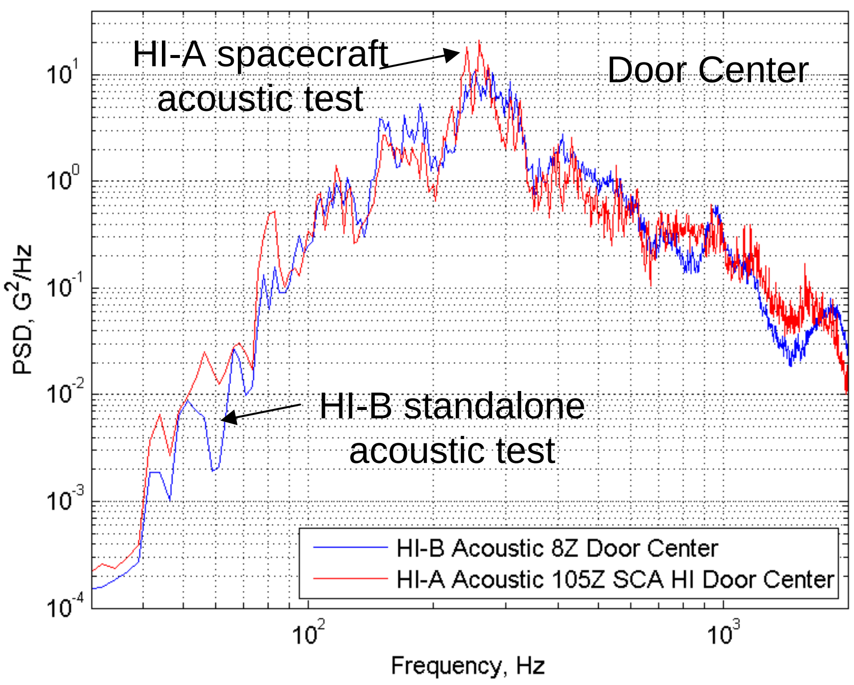
- All HI responses are enveloped by random response
  - Except the door
- Increasing random vibe level would overtest the instrument



HI-B standalone acoustic test needed to see expected flight loads

HI-B Acoustic Test

- HI-B successfully qualified with standalone acoustic test
  - HI-B door responses almost perfectly match HI-A on S/C
  - Free-free and mounted instrument door responses identical



HI-B Responses
Random and Acoustic

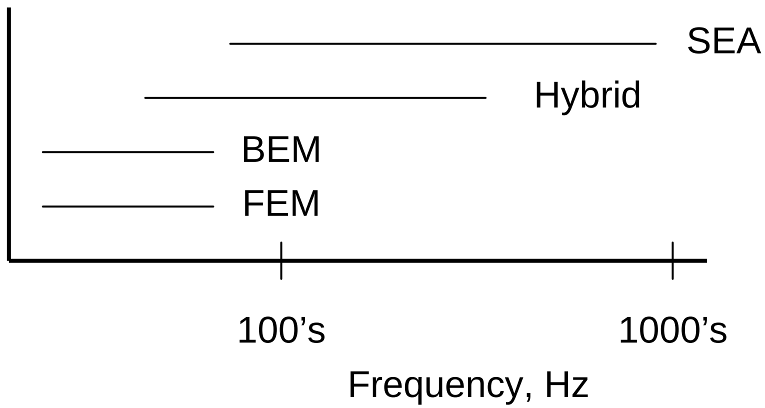
- HI-B qualification requires
  - Random vibe for telescopes and baffles
  - Acoustic for door
- Random vibe Grms on telescopes and baffles ~ 2x's acoustic Grms
- Acoustic Grms on door ~ 2x's random vibe Grms

Max Grms HI-B response

Channel No.	Accel No./Dir.	Accelerometer Description	HI-B Standalone Acoustic Test Response Grms	HI-B Random Vibe Highest Grms	HI-B Random Vibe Driven Axis
1	1x	CG	0.9	3.0	x
2	1y		1.4	3.6	y
3	1z		4.8	12.5	z
4	2x	CEB	1.3	3.8	z
5	2y		2.0	4.4	y
6	2z		2.5	10.9	z
7	3x	TC2	4.8	8.5	z
8	3y		4.7	9.3	z
9	3z		4.9	18.2	z
10	4x	Oval	3.5	7.9	z
11	4y		7.7	15.9	z
12	4z		7.2	16.0	z
13	5x	HI-1 FPA	2.1	5.1	z
14	5y		3.5	8.5	z
15	5z		2.5	9.5	z
16	6x	HI-2 FPA	2.8	5.2	x
17	6y		2.7	18.6	y
18	6z		2.8	11.5	z
19	7x	Door Fwd Corner	4.6	4.2	y
20	7y		4.7	4.6	y
21	7z		26.5	16.5	z
22	8x	Door Center	3.4	3.3	x
23	8y		4.5	4.6	y
24	8z		37.6	17.5	z
25	9x	Door Aft Latch	5.2	5.3	y
26	9y		18.9	11.4	y
27	9z		18.7	6.0	y

Acoustic Analysis Methods

- Use test data to compare to analysis
- Several different analysis methods available based on frequency range of interest



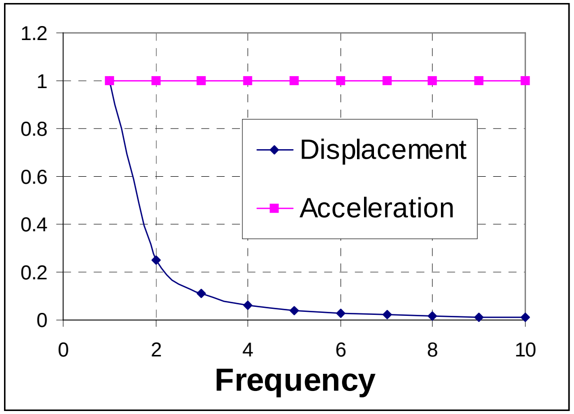
- Interested in Low Frequency FEM

Motivation for Low Frequency

- Structural damage occurs at low frequency
  - "Estimation of Payload Random Vibration Loads for Proper Structure Design", Chung et all
    - Frequency cutoff for Grms : Limit PSD integration under 300 Hz
    - Based off of strain gage data
  - Displacement (and stress) rolls off with acceleration/(freq)^2

$$x = e^{j\omega t} \qquad \ddot{x} = -\omega^2 e^{j\omega t}$$

$$x = -\frac{1}{\omega^2}\ddot{x}$$



FE Analysis outside of Nastran

- External programs can include functionality/insight beyond Nastran
  - "Solving Dynamic Problems Outside of Nastran", Scott Gordon, FEMCI Workshop, May 22, 2002
  - Typical solutions easily done in Matlab
    - Frequency response
    - Transient response, including jitter
    - Base Shake
    - Random Analysis
      - <u>Acoustic Analysis: include correlation coefficient matrices which are not easily incorporated in Nastran, such as for a reverberant acoustic field</u>
- Use Nastran as eigensolver only
  - Eigenvalues (natural frequencies)
  - Eigenvectors (mode shapes)

Acoustic Analysis Prediction

- Purpose of analysis
  - Use Stereo test data to compare to Matlab approach for low frequency acoustic response
- Low frequency acoustic analysis
  - FEM method only
  - Area of interest is hinge and latch stress
- Approach
  - Extract eigenvalues and eigenvectors from Nastran
  - Extract nodal forces from unit pressure from Nastran
  - Use Matlab to solve SDOF modal equation for each loaded node
  - Obtain transfer functions between each loaded node and response node
  - Solve random solution with specified PSD
  - Include sin(kx)/kx spatial correlation matrix for reverberant field
  - Include surface correction factor

Acoustic Analysis Prediction

Matlab Script

Nastran FEM

- Eigenvalues, $\{\omega_n\}$
- Eigenvectors, $[\phi]$
- Nodes #'s
- Node locations, (x,y,z)
- Node #'s with load
- Nodal forces from unit pressure, {F}

- Damping (modal)
- Driving frequency, $\{\omega_d\}$
- Response node

- Determine transfer function {H} between each loaded node {Fi} and the response point, for each driving frequency, Wd
  - Use SDOF solution in generalized coordinates to simplify calculations
- Solve random solution as transfer function squared
  - Multiply by input PSD to obtain response PSD
  - Include spatial correlation coefficient matrix, sin(kx)/kx
  - Include surface correlation correction factor, maximum of 3.0

Theory (1/2)

Dynamic equation

$$M\ddot{x} + C\dot{x} + Kx = F$$

Eigenvector transformation

$$x = \phi q, \quad \ddot{x} = \phi \ddot{q}$$

Dynamic equation in mass normalized modal coordinates

$$\ddot{q} + 2\zeta\omega\dot{q} + \omega^2 q = \phi^T F$$

SDOF system solution

$$\ddot{q} = h\phi^T F \qquad h = \frac{-\omega^2}{(1-\omega^2) + 2i\zeta\omega\omega_n}$$

Physical coordinates Solve for each F (nodal force from unit pressure)

$$\ddot{x} = \phi\ddot{q} = H$$

Transfer function From unit pressure

Theory (2/2)

Random solution
<u>at each driving frequency</u>

$$\{PSD_{resp}\} = \{H\}[\rho]\{H\}^{T} * \{PSD_{in}\} * surfcorr$$

1xpg pgxpg pgx1

Vector size:
pg is # of loaded nodes

Correlation coefficient matrix, $[\rho]$, is symmetric matrix of sin(kx)/kx, where k is wavenumber and x is distance between any two loaded points

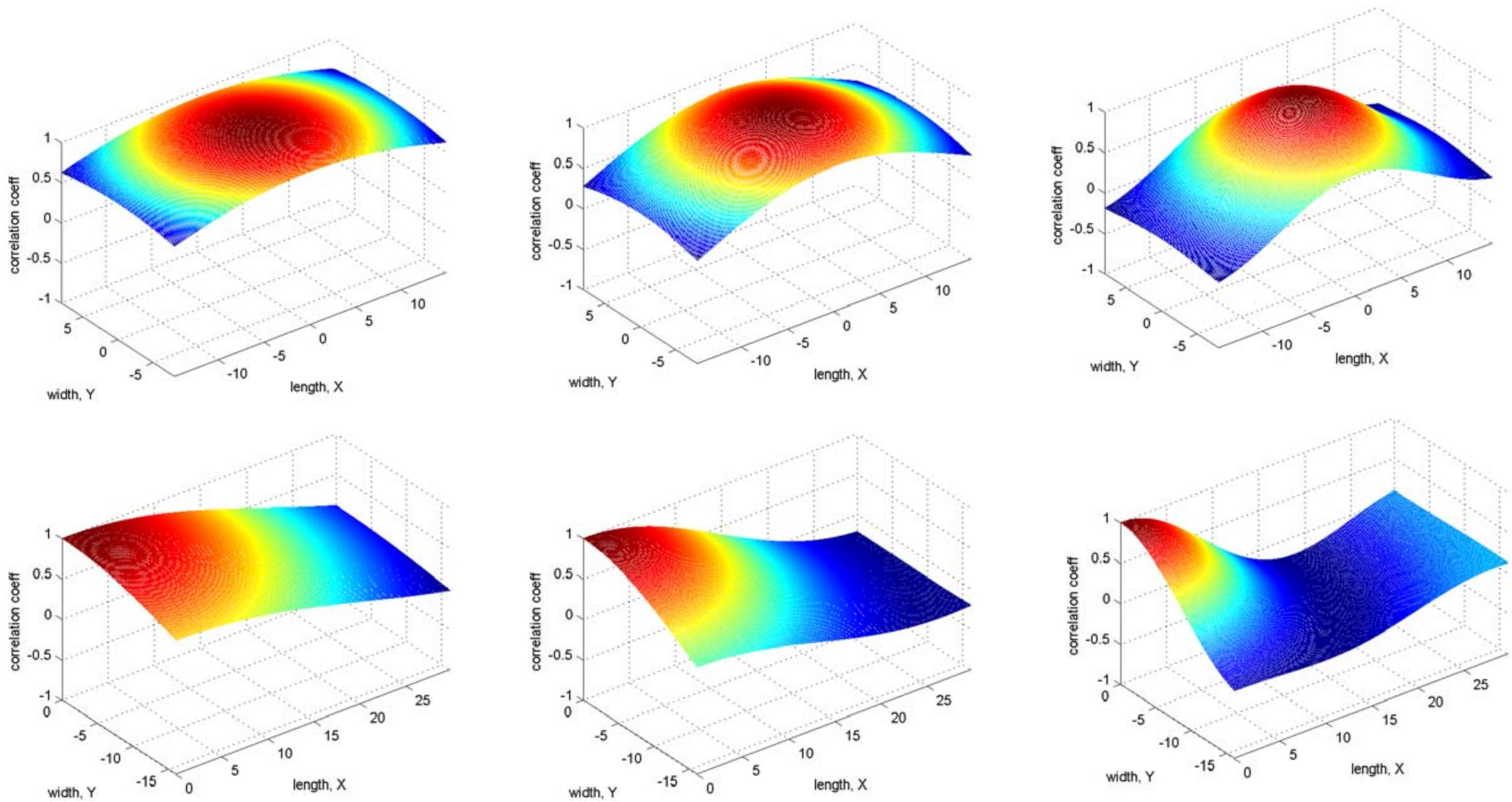
Including $[\rho]$ is difficult in Nastran – default is a matrix of ones for all frequencies (perfectly correlated pressure field)

Reverberant field on HI Door
sin(kx)/kx

200 Hz | 300 Hz | 500 Hz

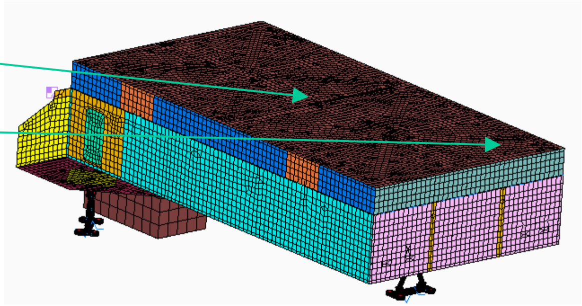
Door Center

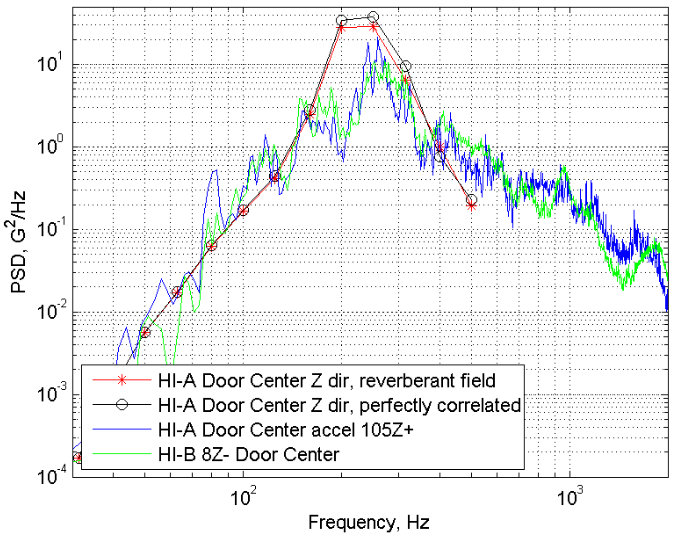
Door Corner

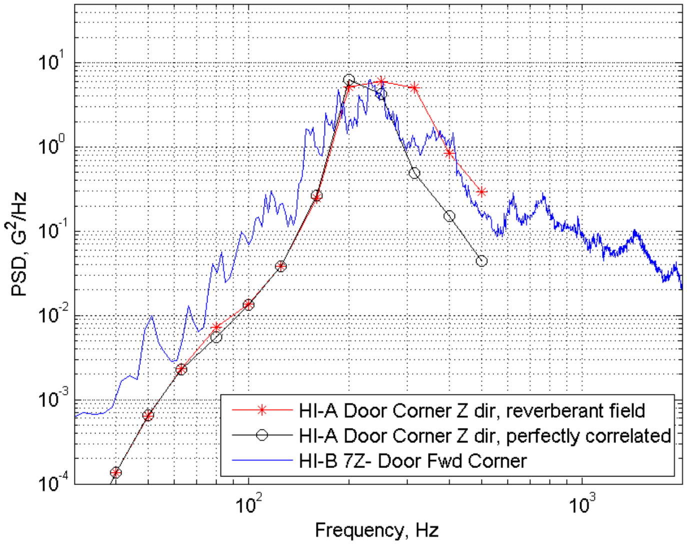


HI Door Results

- Door Center
- Door Corner

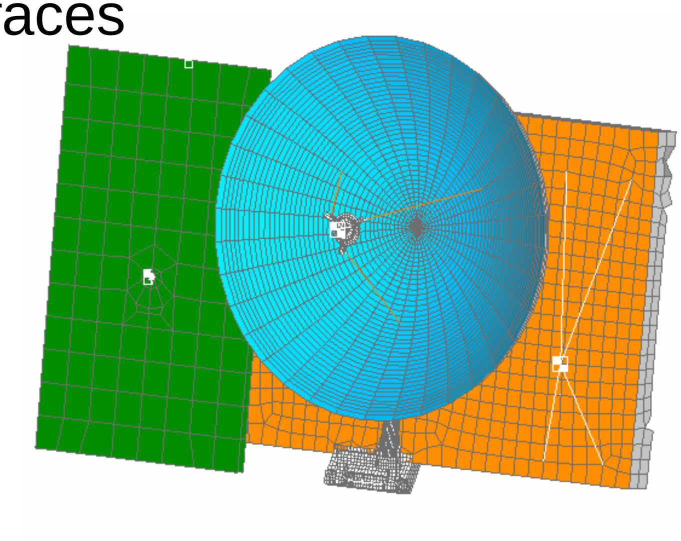






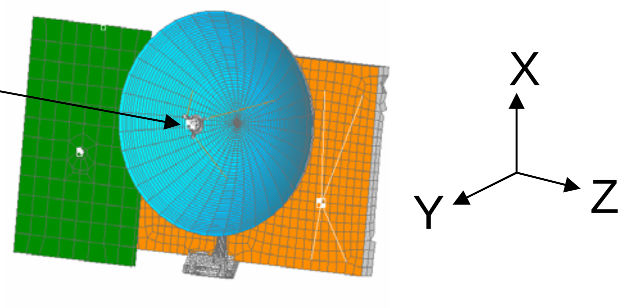
Additional Acoustic Results

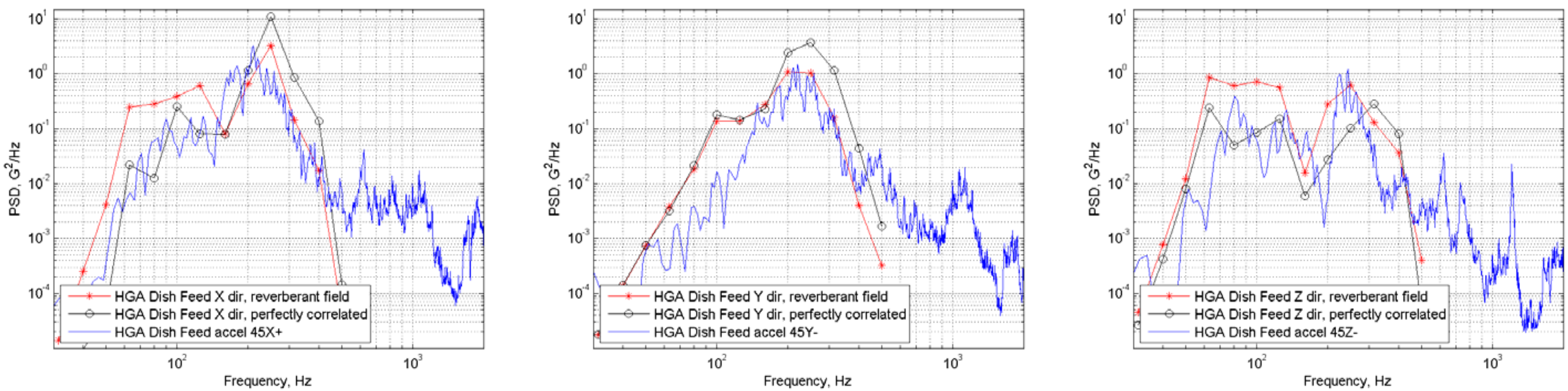
- Extract side panel of STEREO FEM
  - High Gain Antenna
  - Compare reverberant to perfectly correlated pressure field
- Apply normal pressure to colored surfaces



High Gain Antenna Acoustic Response

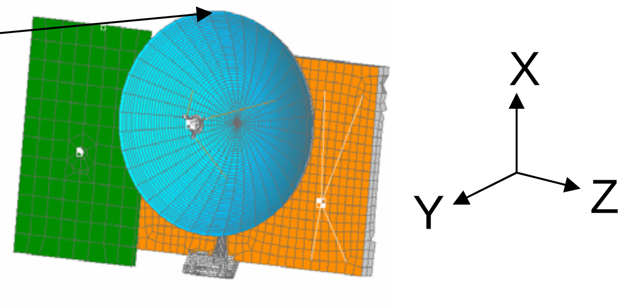
- High Gain Antenna – Feed
  - Reverberant field more accurate
  - Can give larger or smaller response to perfectly correlated pressure
  - Surprisingly accurate to 400 Hz

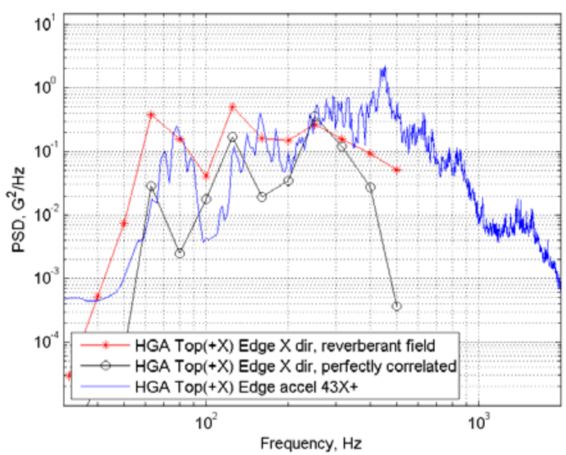


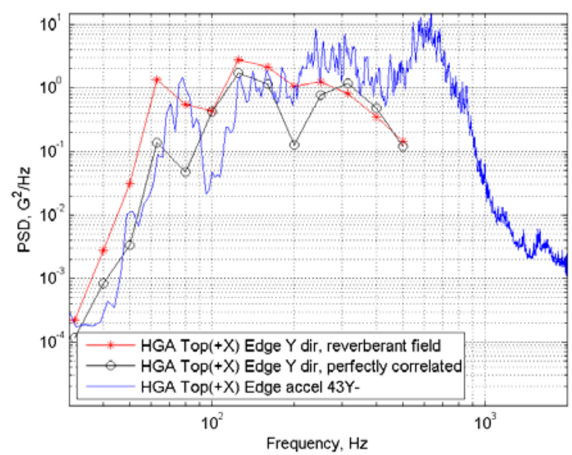


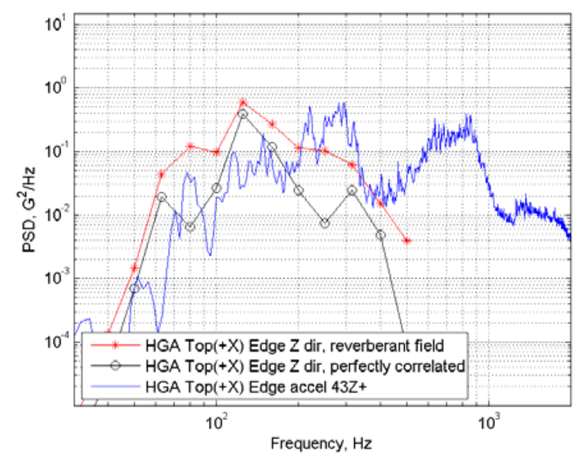
High Gain Antenna Acoustic Response

- High Gain Antenna – Top Edge
  - Reverberant field more accurate
  - Accurate to 200 Hz
  - Model frequencies slightly low







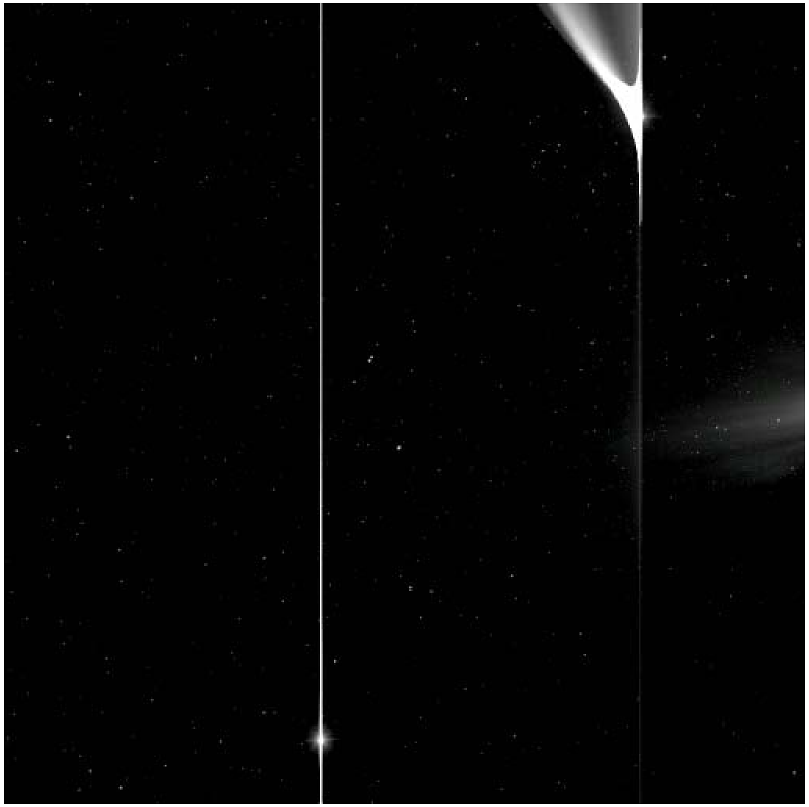


HI Door Opening Movie

- Movie of HI Door opening (conceptual)

HI1-B 1st Data Movie

- McNaught Comet, January 11- 18, 2007.
  http://stereo.gsfc.nasa.gov/gallery/highlight.shtml



Conclusions

- Successful test program
  - HI-B required both random and acoustic test for qualification
- Fully operational flight units
- Matlab acoustic analysis
  - Low frequency response
  - Include spatial correlation matrix
  - Compared well to test data
    - More accurate than perfectly correlated pressure field
  - Only as good as the FEM

Coronal Mass Ejection from HI
http://www.stereo.rl.ac.uk/STEREO_Gallery.html