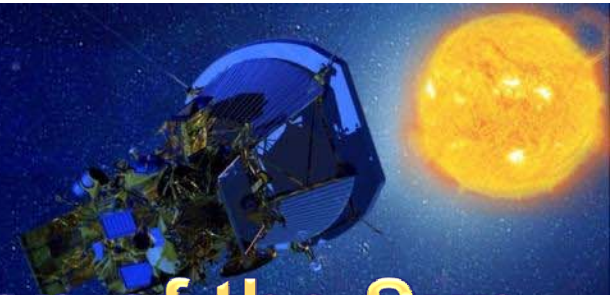
Solar Probe Plus

A NASA Mission to Touch the Sun



Integrated Science Investigation of the Sun
Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

ISIS Structural

Nick Alexander

ISIS Mechanical Engineer (SwRI)

Outline

- EPI-Hi Structural Analysis*
  - Requirements
  - FEM/Boundary Conditions
  - Modal Results
  - Stress Results

- ISIS Bracket Structural Analysis
  - Mechanical design/structural requirements
  - ISIS overall mechanical configuration
  - FEM/Boundary Conditions
  - Modal Results
  - Stress Results
  - Structural design margins and plans for strength verification

* EPI-Lo structural analysis shown in EPI-Lo mechanical presentation

EPI-Hi Structural Analysis Requirements

- Design Requirements taken from SPP Environmental Design and Test Requirements Document (EDTRD), Document 7434-9039 Revision –
  - A structural analysis shall be completed to verify the component structural integrity.
  - Instrument minimum resonant frequency shall be greater than 80 Hz.
  - PWAs shall be designed to have a first structural resonance frequency above 150 Hz.
  - All bus-mounted components and subsystems shall be designed to the quasi-static accelerations derived from the MAC (Mass Acceleration Curve).

EPI-Hi Environments

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Random Vibration ASD Specifications

Table 4-8. Side Panels Mounted Components & Subsystems Normal To Panel

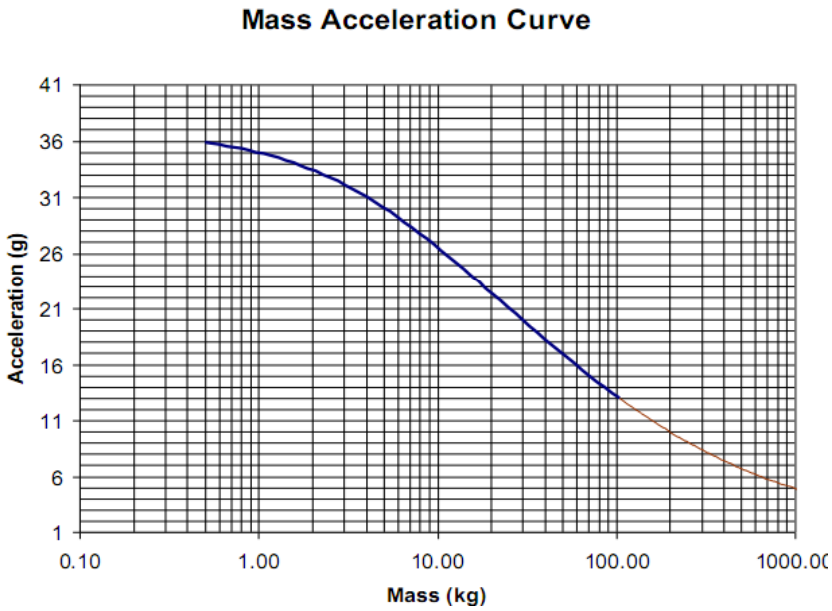
Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
60	1.25	1.25	0.63
200	1.25	1.25	0.63
350	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	16.4	16.4	12.6
Duration (mins)	2	1	1

Table 4-9. Side Panels Mounted Components & Subsystems Lateral To Panel

Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
35	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	6.8	6.8	6.8
Duration (mins)	2	1	1

EPI-HI: Y-direction is Normal to Panel;
X & Z-directions are Lateral to Panel

Analysis Employs Qualification Level Loads



EPI-HI: Mass with uncertainty=4.0 kg
MAC: for 4.0 kg, Acceleration=31 g

EPI-Hi Factors of Safety

- The tabulated factors of safety are applied to the limit loads for quasi-static and sine vibration loads.
- For random vibration, an additional factor of 1.28 is added to the factors of safety for ultimate and yield.
- For random vibration analysis, the 3-sigma RMS response from the finite element analysis is employed to calculate margins.
- Margins of safety calculated using equation on right:

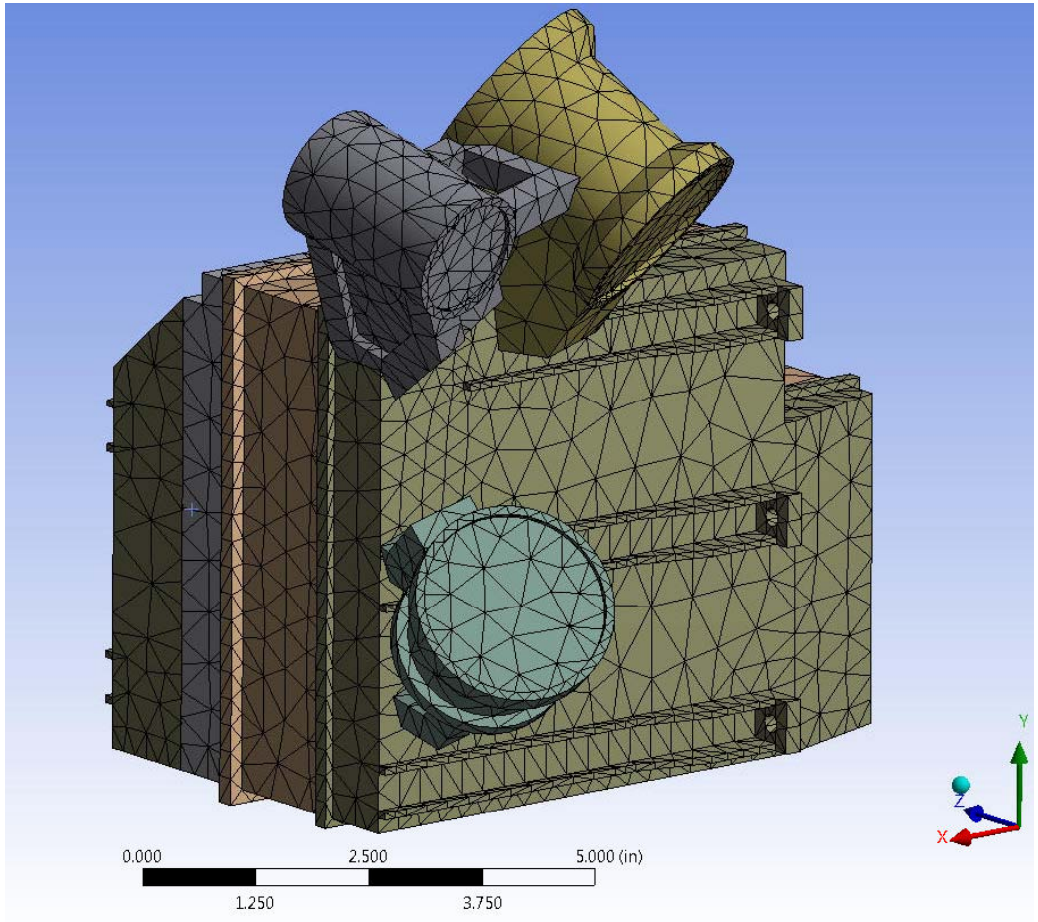
	Ultimate	Yield
Metallic Structures		
Tested	1.40	1.25
No Test	2.60	2.00
Beryllium	1.60	1.40
Composite & bonded structures (1)		
C-C laminate	2.0	NA
Others	1.50	NA
Carbon Foam	4.0	NA
Ceramic, glass		
Pressurized	3.0	NA
Nonpressurized	3.0	NA
Preloaded fastener joint		
External load	1.40	NA
Gapping	1.25	NA
Fitting factor (no test only)	1.15	NA
GSE	5.00	3.00

Includes bonded metallic and/or non-metallic sandwich structure.

$$Margin\ of\ Safety = \frac{Allowable\ Strength}{FS\ \times Applied\ Stress} - 1.0$$

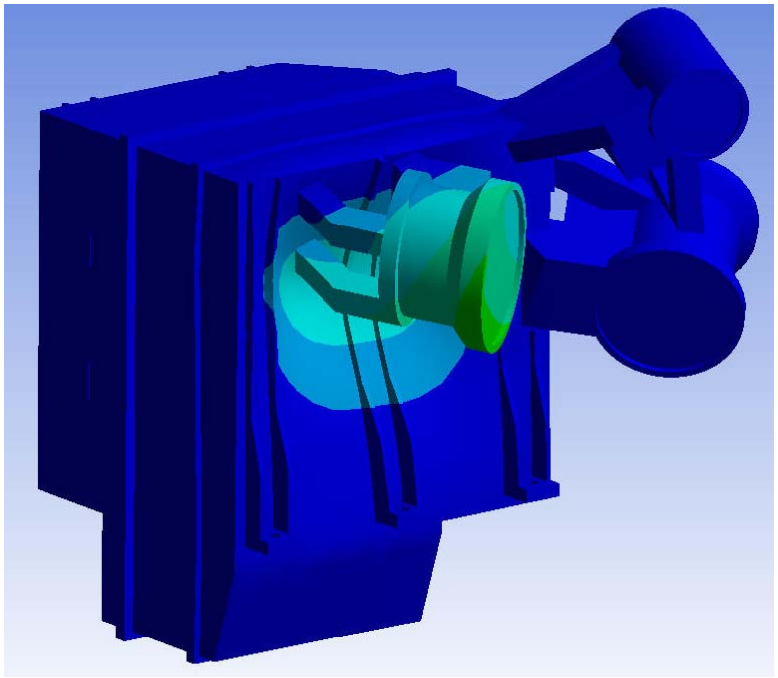
EPI-Hi FEM/Boundary Conditions

- FE Model Mass = 4.026 kg (CBE mass plus uncertainty)
- Fixed at mounting holes on feet (5 places)

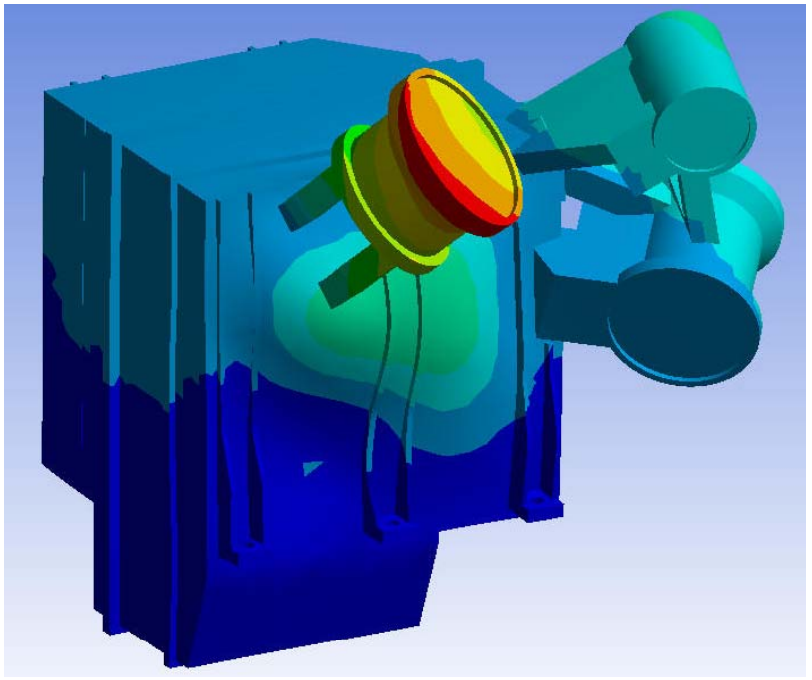


EPI-Hi Modal Frequencies (1/2)

- Instrument Fundamental Frequencies



471 Hz
(side panel diaphragm mode coupled with internal boards)



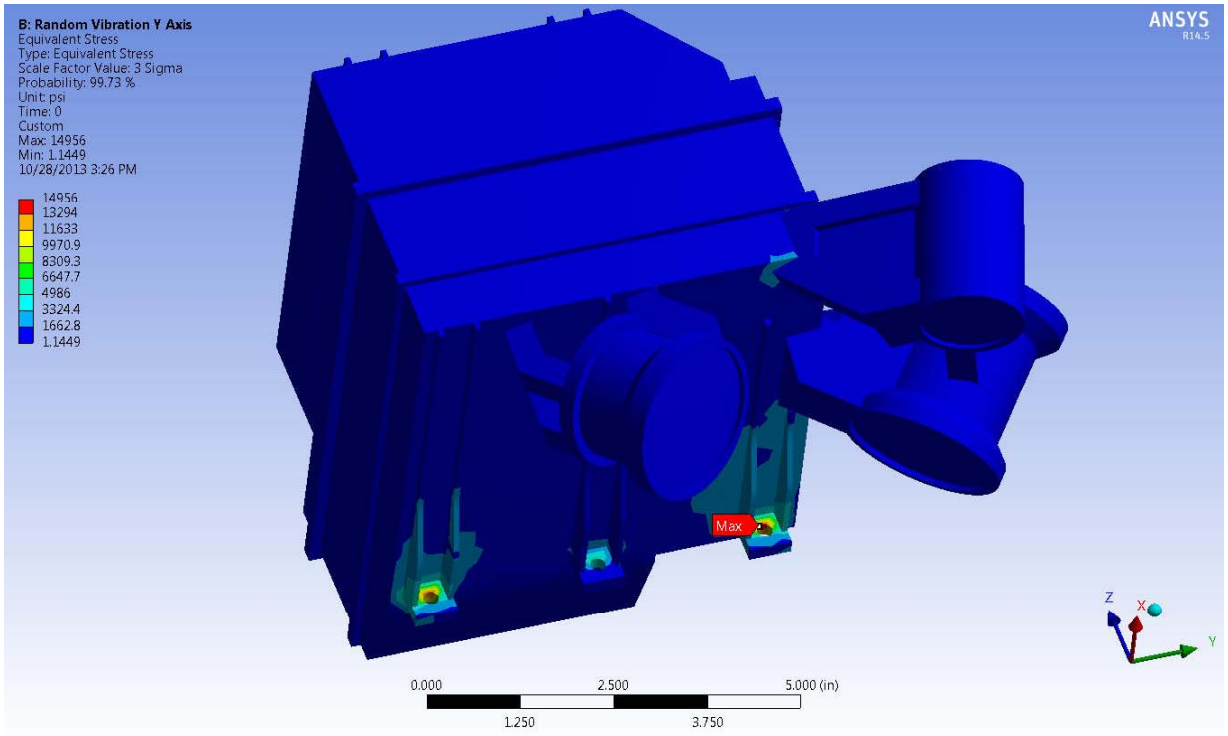
639 Hz
(instrument rocking mode)

EPI-Hi Modal Frequencies (2/2)

- PWA Modes
  - All PWA Fundamental Frequencies > 150 Hz (EDTRD_0307)

PWA	CBE Mass with Uncertainty [kg]	Frequency [Hz]
LVPS	0.350	>700
Bias supply	0.203	361
LET1	0.308	525
LET2	0.282	555
HET	0.282	471
DPU	0.335	361

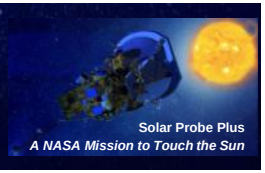
EPI-Hi Stress Results



Worst Case Stress: 14956 psi; occurs at housing foot in the Y-axis Random Vibration load case

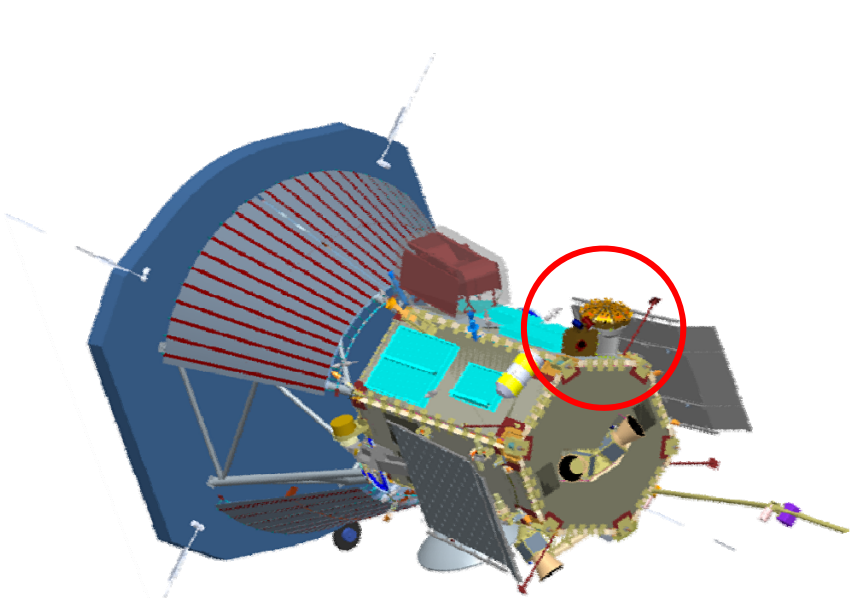
Analysis	Direction	Maximum VM Stress	Location	Material	Yield Strength	Ultimate Strength	Factors of Safety		Margins of Safety	
		[psi]			[ksi]	[ksi]	Yield	Ultimate	Yield	Ultimate
Random	X	14918	Standoff/Housing	Al 6061-T6	36	42	1.6	1.8	0.5	0.6
Vibration	Y	14956	Housing Foot	Al 6061-T6	36	42	1.6	1.8	0.5	0.6
	Z	4841	Standoff/Housing	Al 6061-T6	36	42	1.6	1.8	3.6	3.8
Static	X	3071	Standoff	Al 6061-T6	36	42	1.25	1.4	8.4	8.8
(MAC)	Y	4052	Housing	Al 6061-T6	36	42	1.25	1.4	6.1	6.4
	Z	3375	Standoff	Al 6061-T6	36	42	1.25	1.4	7.5	7.9

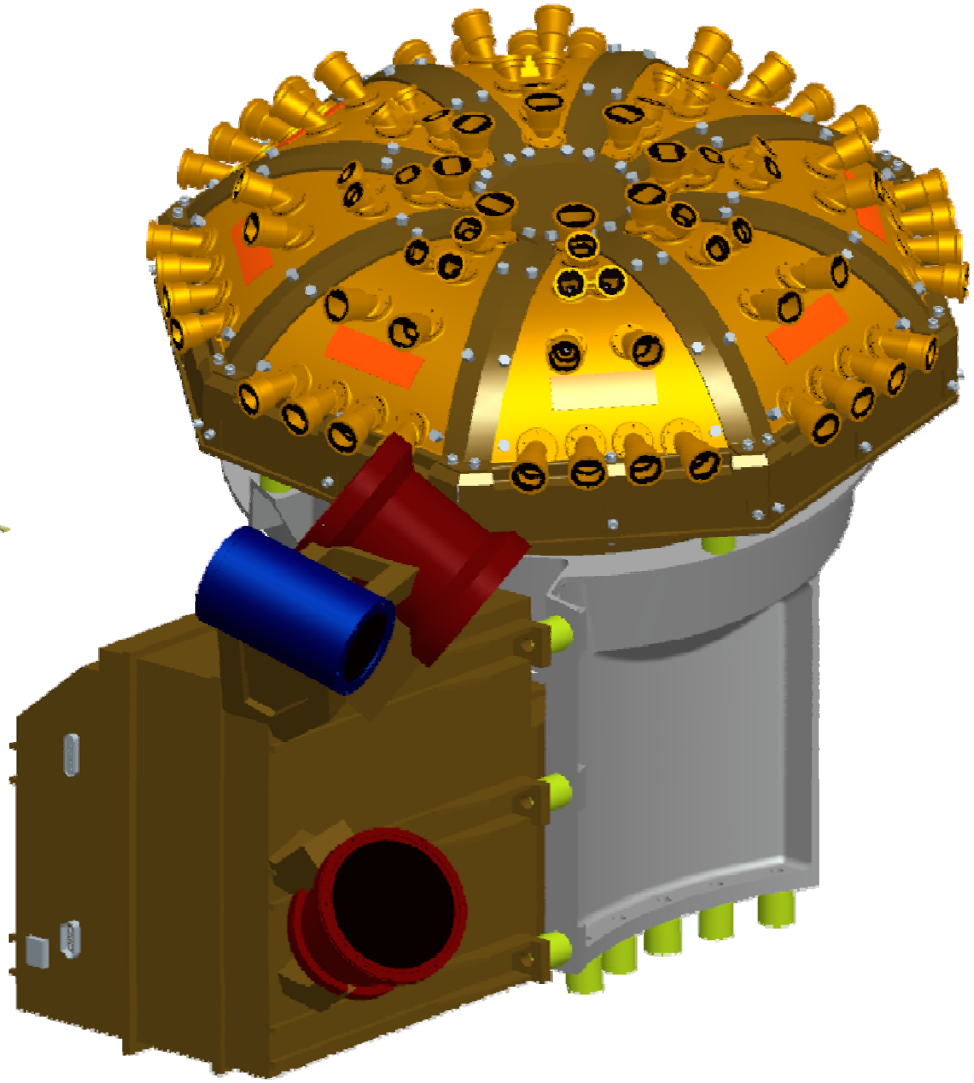
ISIS Bracket Mechanical Design Requirements



- ISIS bracket must hold EPI-Hi and EPI-Lo in position on the SPP deck
- ISIS bracket must be capable of independently removing EPI-Hi and EPI-Lo, in either order
- ISIS bracket must survive all environments for deck mounted components
  - Random vibration
  - Sine vibration
  - Shock
- All ISIS suite testing shall be performed on the bracket, with instruments or instrument analogs as appropriate

ISIS Mechanical Design Overview





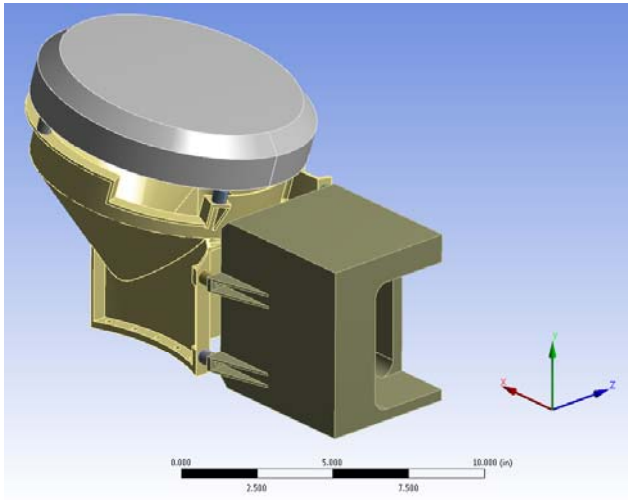
ISIS Bracket Design Overview

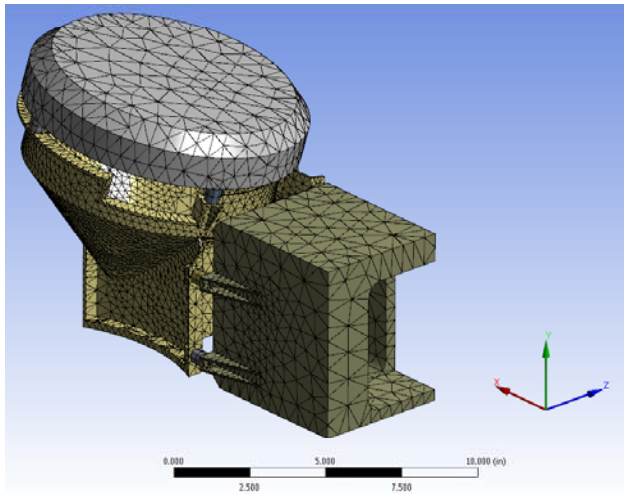
ISIS Bracket Fabrication

- The ISIS bracket can be machined using conventional machining processes
  - Monolithic design, will be machined from a single block
  - All operations can be performed on conventional machines (i.e. lathe, mill, etc.)
- Thermal isolators and mass models will also be fabricated to be used during structural testing
  - G10 isolators will be machined to flight-like quality
  - Mass models to reflect instrument mass properties with flight-like mounting interfaces
- Bracket height increase due to TPS shift can easily be accommodated as needed
  - Working with S/C mechanical team; any shift in the TPS only requires translation normal to the deck to remain adjacent to the umbra

ISIS Bracket FEM/Boundary Conditions

- Model includes bracket, EPI-Hi and EPI-Lo mass models (at max allocation) and thermal isolators
  - Bracket: Aluminum 7075-T6 properties
  - Mass models: Aluminum 6061-T6 properties
  - Thermal isolators: G10 material properties
- Mass models represent accurate mass and CG properties
  - Test results will be easy to compare to model
  - Mass models are stiff enough to not introduce modes
- Edge to surface connections for all mounting interfaces
- Fixed supports on 10 bracket mounting holes

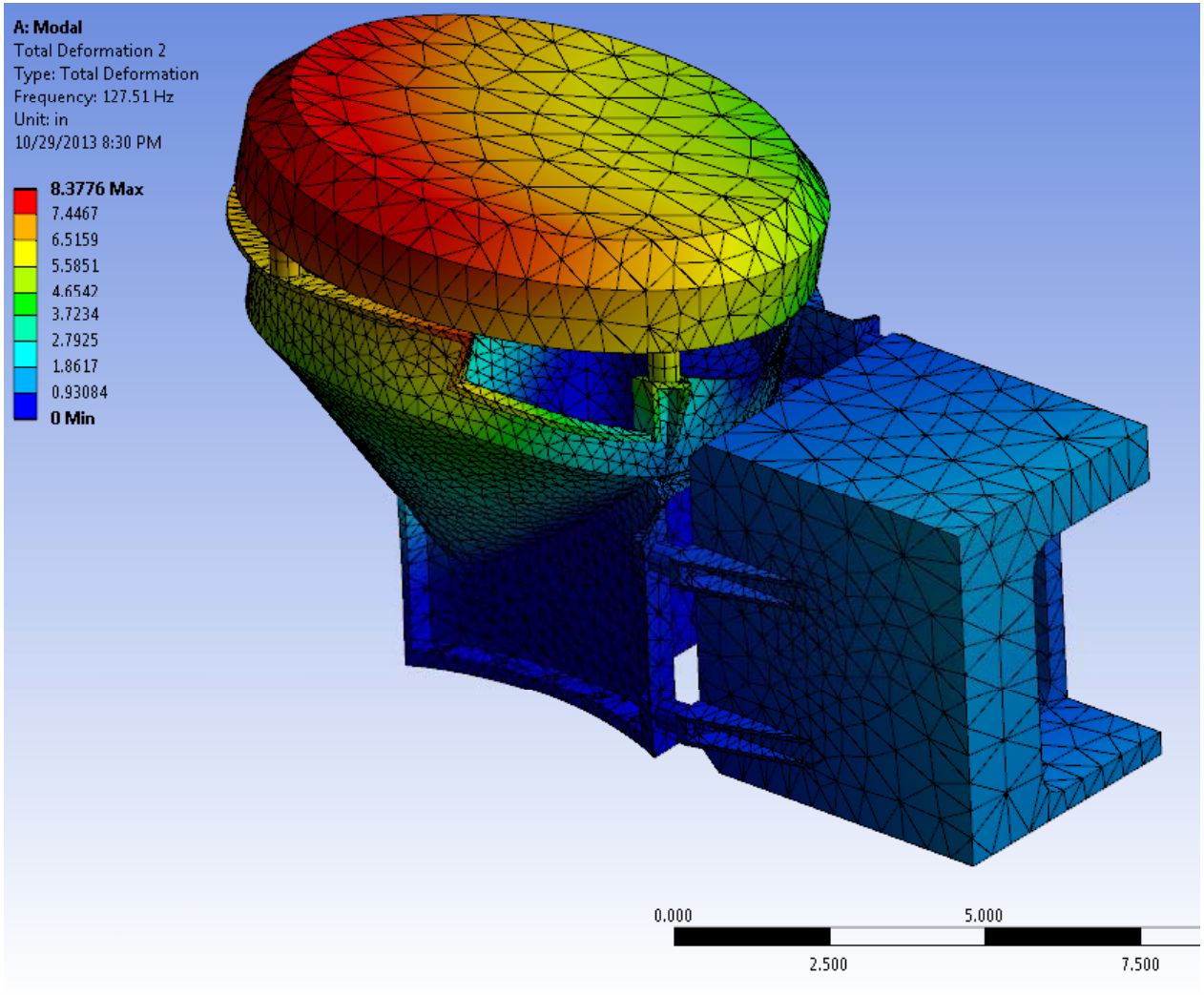




ISIS Bracket FEM - Modal Results

- Primary Mode:
  127.51 Hz
  (rocking mode)

- Requirement:
  80 Hz minimum



ISIS Bracket FEM - Structural Setup

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Random Vibration ASD Specifications

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200	1.25	1.25	0.63
350	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	16.4	16.4	12.6
Duration (mins)	2	1	1

Table 4-9. Side Panels Mounted Components & Subsystems Lateral To Panel

Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
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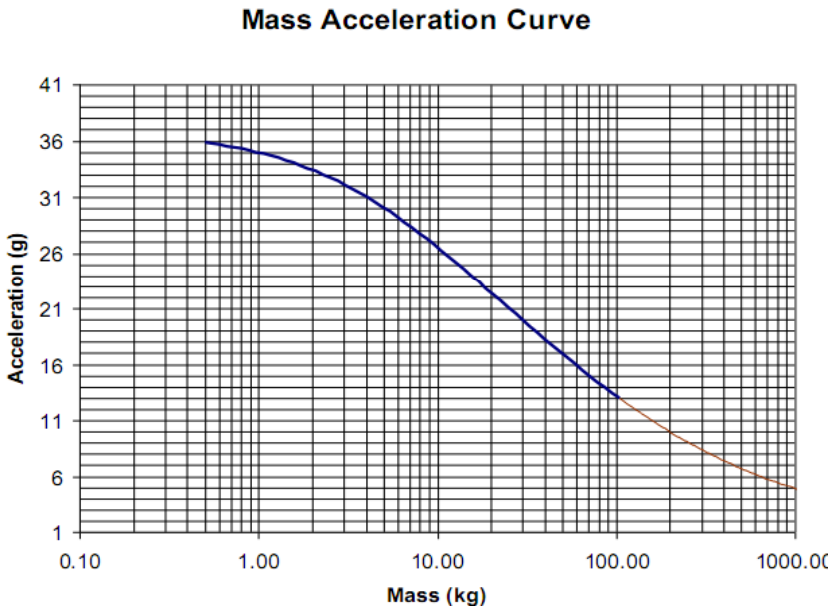
35	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	6.8	6.8	6.8
Duration (mins)	2	1	1

ISIS: Y-direction is Normal to Panel;
X & Z-directions are Lateral to Panel



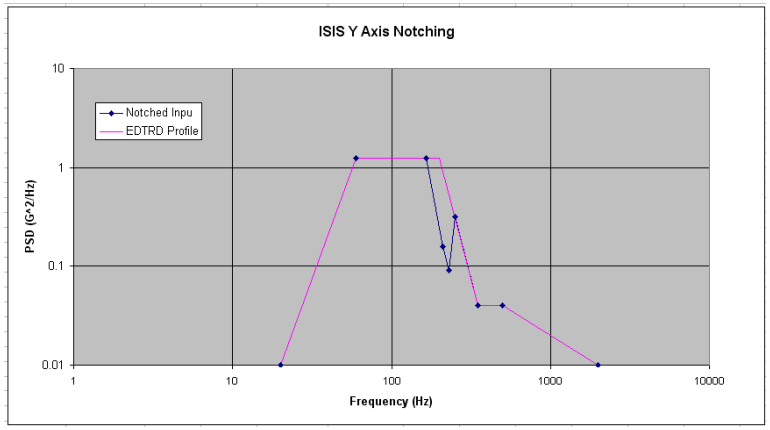
ISIS: NTE Mass=7.74 kg
MAC: for 7.74 kg, Acceleration=28 g

Analysis Employs Qualification Level Loads with Notching

ISIS Bracket FEM - Notching

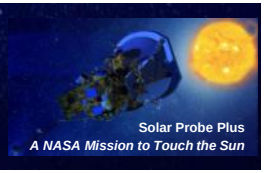
- Notching performed on the Y Axis in accordance with ETDRD Section 4.4.7.4
  - CBE Mass: 7.74 kg
  - MAC Acceleration: 28 G
  - MAC Limit Load: 1.25
  - Notching Limit Load: 2657.5 N (35 G)
  - Un-notched Reaction Load: 7498.8 N
  - Notch Depth: 7.65dB, Notch Width: 20 Hz, Ramp: +/-15 dB/Oct
  - Notched Frequency: 220 Hz
  - Resulting Profile

Y Axis Random Vibe	
Frequency	PSD
20	0.01
60	1.25
166	1.25
210	0.159
230	0.091
250	0.3168
350	0.04
500	0.04
2000	0.01



  - Resulting Reaction Load: 5588.7N

ISIS Bracket Structural Design Margins



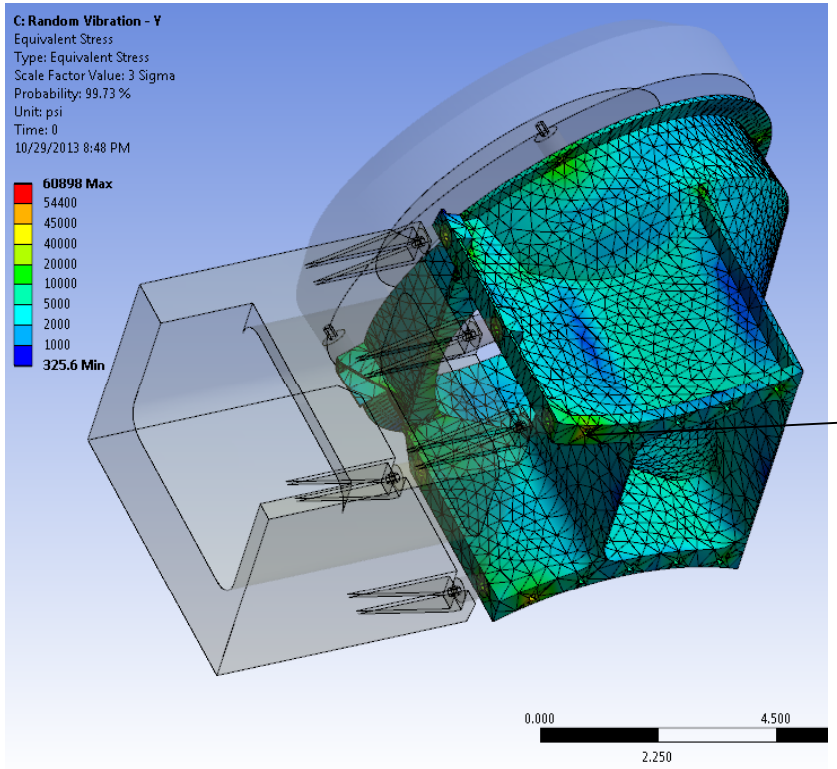
- The tabulated factors of safety are applied to the limit loads for quasi-static, random and sine vibration loads.
- For random vibration analysis, the 3-sigma RMS response from the finite element analysis is employed to calculate margins.
- Margins of safety calculated using equation on right:

	Ultimate	Yield
Metallic Structures		
Tested	1.40	1.25
No Test	2.60	2.00
Beryllium	1.60	1.40
Composite & bonded structures (1)		
C-C laminate	2.0	NA
Others	1.50	NA
Carbon Foam	4.0	NA
Ceramic, glass		
Pressurized	3.0	NA
Nonpressurized	3.0	NA
Preloaded fastener joint		
External load	1.40	NA
Gapping	1.25	NA
Fitting factor (no test only)	1.15	NA
GSE	5.00	3.00

Includes bonded metallic and/or non-metallic sandwich structure.

$$Margin\ of\ Safety = \frac{Allowable\ Strength}{FS\ \times Applied\ Stress} - 1.0$$

ISIS Bracket Stress Results (Preliminary)



Worst Case Stress: 49979 psi; occurs at S/C Interface Bolt in the Y-axis Random Vibration load case

Analysis	Direction	Maximum VM Stress [psi]	Location	Material	Yield Strength [ksi]	Ultimate Strength [ksi]	Factors of Safety		Margins of Safety	
							Yield	Ultimate	Yield	Ultimate
Random	X	35233	EPI-Lo Flange	Al 7075-T6	68	78	1.25	1.4	0.5	0.6
Vibration	Y	49979	S/C Interface Foot	Al 7075-T6	68	78	1.25	1.4	0.1	0.1
	Z	41057	Buttress	Al 7075-T6	68	78	1.25	1.4	0.3	0.4
Static	X	19389	EPI-Lo Flange	Al 7075-T6	68	78	1.25	1.4	1.8	1.9
(MAC)	Y	11467	EPI-Hi Flange	Al 7075-T6	68	78	1.25	1.4	3.7	3.9
	Z	27022	Buttress	Al 7075-T6	68	78	1.25	1.4	1.0	1.1

ISIS Bracket Structural Testing

- ISIS bracket will be tested at SwRI facilities with EPI-Hi and EPI-Lo mass models
  - G10 thermal isolators will be included
  - Mounted using flight quality mounting hardware
- Tests will check natural frequency, random vibe response, sine vibe response
  - Natural frequency must be >80 Hz (EDTRD_0095)
  - Must survive random vibration loads (EDTRD_0111) per tables in EDTRD 4.4.3
  - Must survive sine sweep loads (EDTRD_0114) per sine environment (TBD) given in EDTRD 4.4.4
  - Pre & post test low-level sine sweeps used to identify any change in fundamental frequency
- Once fabricated and tested at SwRI, ISIS bracket will be used in support of EPI-Hi and EPI-Lo environmental testing

Summary

- EPI-Hi, EPI-Lo, and ISIS Bracket modeling have been completed
  - Satisfies EDTRD requirements
  - Have required margins of safety
- Ready to begin EM Fabrication and move into Phase C