# Tracker Prototype Module Testing Overview

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# Outline

- Objectives of the Prototype Module and Test Program.
- Description of the Module Under Test.
- Environmental Testing of Single Trays.
- Tower Module Level Testing.
  - First vibration test.
  - Modifications to address problems with the sidewall attachment.
  - Second vibration test.
  - Problems with structural failure around the corner flexure mounts.
- Possible Design Modifications.
- Conclusions.

See LAT-TD-00793 for a more complete report.

# Objectives

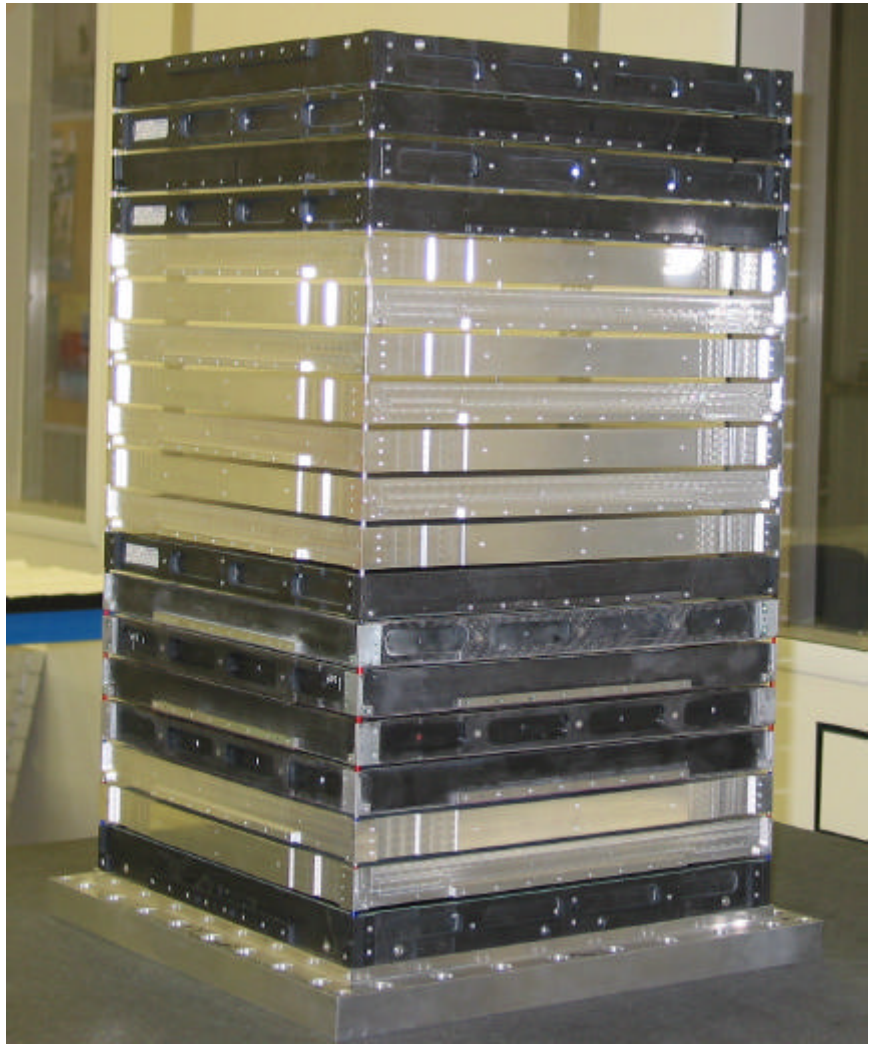
- We built prototype trays and a tower-module prior to the engineering model to
  - Test manufacturing of components, such as composite panels.
  - Test tooling and methods for tray assembly, especially for dimensional tolerances.
  - Test procedures and tooling for tower module assembly (two very different methods were tried and evaluated).
  - Early validation of the FEA used in the mechanical design process.
  - Environmental testing (thermal cycle, vacuum, and random vibration).
- The objective of the environmental tests was to reduce risk of structural failures during engineering-model testing by finding and correcting problem areas in the design early.
  - There is no allowance in the schedule to fix significant design problems post-CDR.
  - We still have some time now to fix design problems before committing to the engineering model fabrication.

# Test Objectives

- The environmental test program included
  - Thermal cycling of individual trays.
    - Check mechanical integrity of their construction.
    - Verify acceptable stress levels in the silicon ☆
  - Vacuum cycling of individual trays to check venting.
  - Vibration of individual trays to test their mechanical integrity, validate the FEA, and verify that the lowest frequency is >500 Hz.
  - Thermal cycling of the interface between tracker and grid:
    - Verify proper functioning of the flexures.
    - Check that no damaging stresses are applied to the bottom tray.
  - Vibration of the entire module
    - Validate the FEA.
    - Verify that the lowest frequencies are not too low and that the Q is low enough to avoid collisions between towers.
    - Check for any weakness or damage up to full qualification levels.
- This program arguably has been successful. Although significant problems have been found in the last point, there still is time to correct them in the engineering model.

# Description of the DUT

- Complete, full-sized Tracker module with 19 trays:
  - Top & bottom carbon-composite from PCI
  - 4 light carbon-composite mid panels from PCI
  - 4 heavy carbon-composite mid panels from Plyform in Italy (note aluminum closeout features)
  - 9 Al mass models
- Panels are loaded with bias circuits, tungsten, silicon (mass models include mass of those items)
- Aluminum base simulates Grid mount.



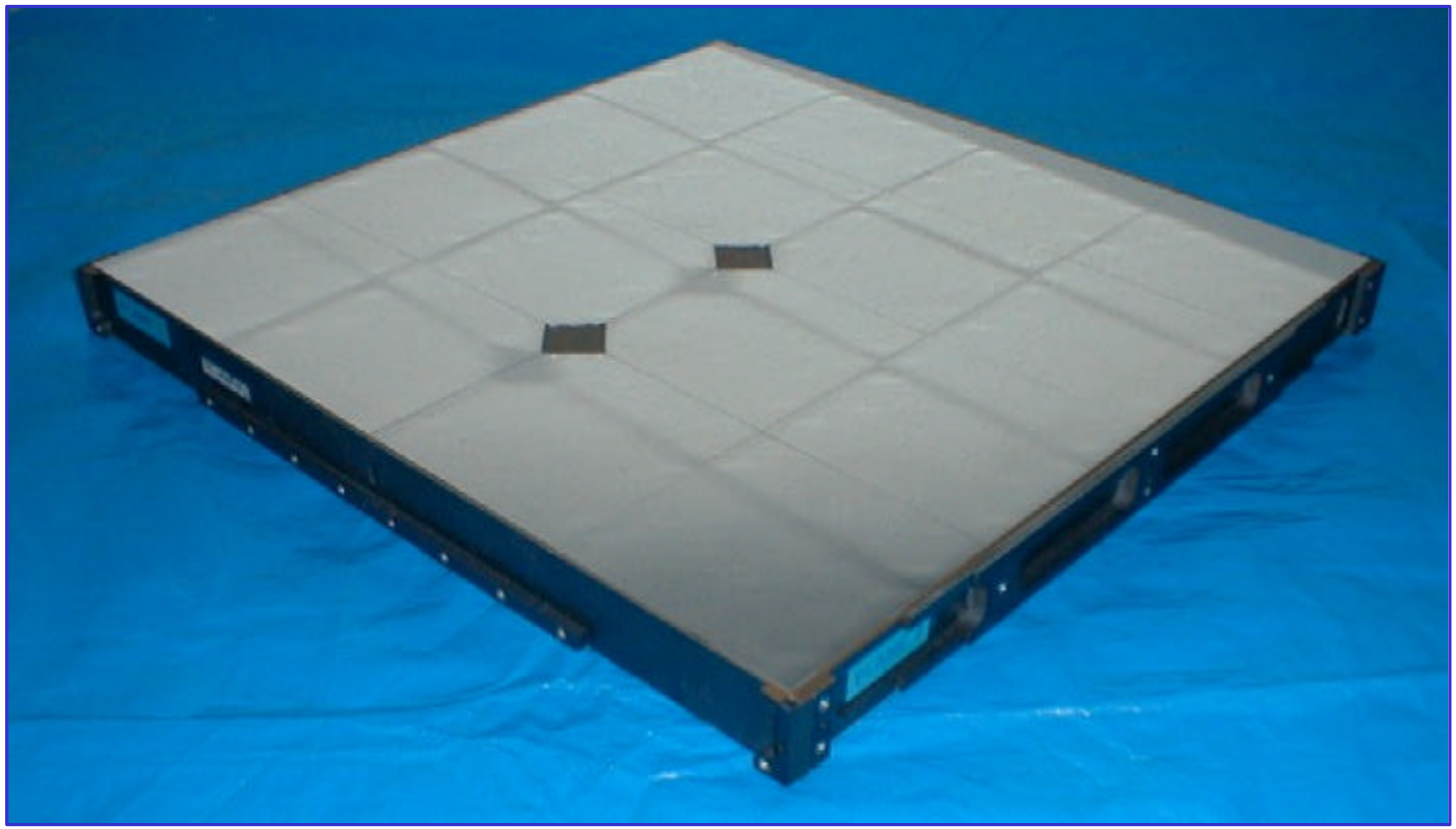
# Std. Composite Panels

- Standard tray panels and top/bottom tray panels assembled at PCI in California.
- 4 carbon-carbon closeout pieces machined at GMSI.
- Aluminum inserts
- 4-ply YSH-50 Gr/CE facesheets from PCI.
- 1 lb/ft$^3$ 5056 aluminum honeycomb cores
- Thin 3% rad. length tungsten foils (or none)



*Two views of the bottom tray panel*

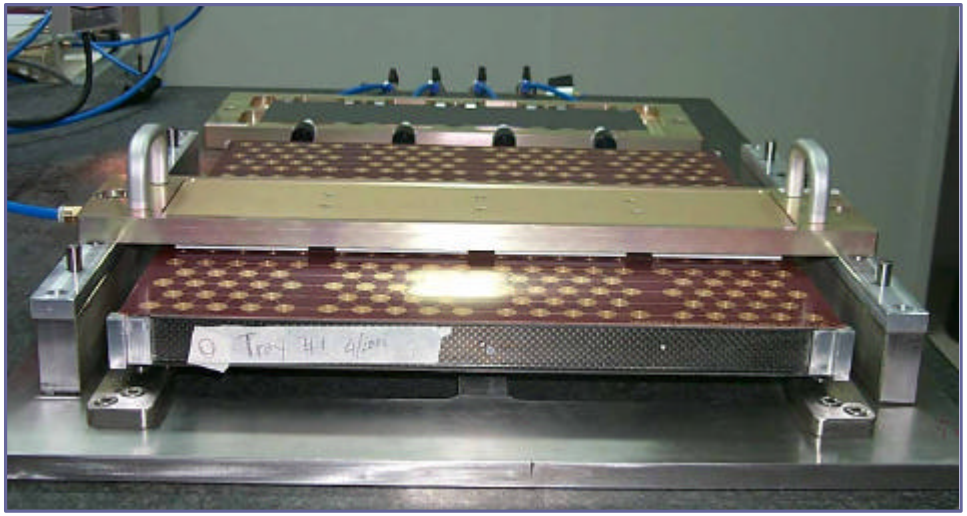
# Dummy Silicon Detectors



*Example of a standard mid-tray with a PCI built panel. It is loaded with bias circuits, thin tungsten foils, and aluminized silicon. Two holes are cut in the silicon for attachment of accelerometers to the panel.*

# Heavy Composite Panels

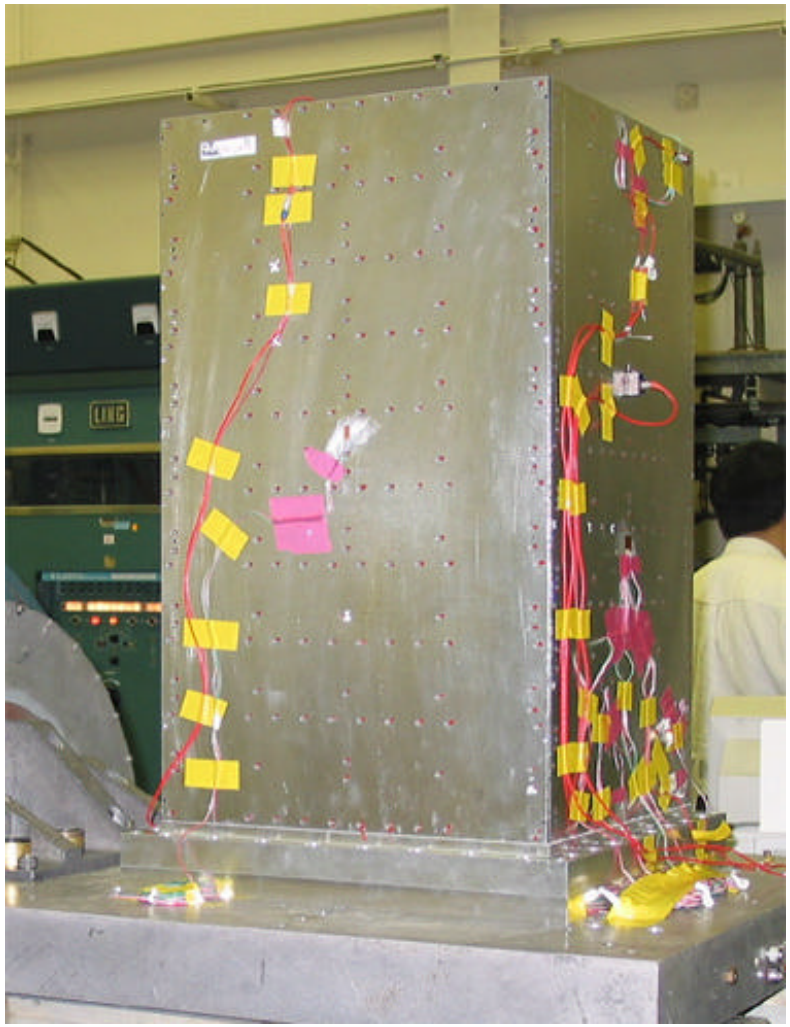
- Assembled at Plyform, near Milan, Italy.
- Closeouts do not conform to the current design but are similar:
  - Some carbon-carbon, some Gr/CE
  - Corner and thermal bosses are aluminum pieces that are bonded to the carbon-fiber.
  - These aluminum pieces are drilled and tapped to replace the inserts.
- 3 lb/ft$^3$ 5056 aluminum honeycomb cores
- 6-ply YSH-50 Gr/CE face sheets
- Thick 18% rad. length tungsten foils



*One of the heavy-converter prototype trays, in the fixture for mounting SSD ladders in Pisa. Note the aluminum corner features and the fabric weave of the closeout, both of which differ from the current design.*

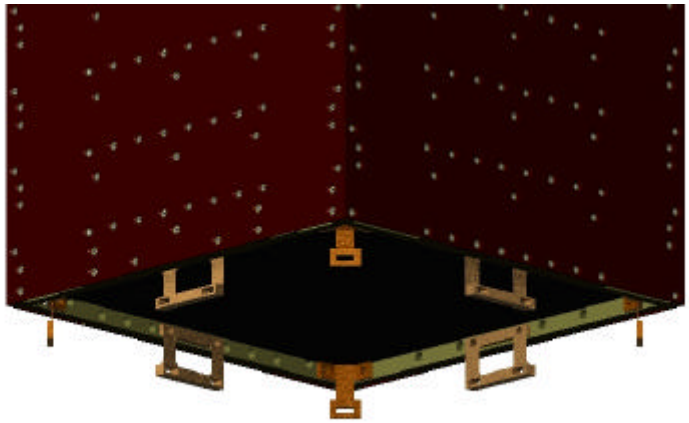
# Sidewalls

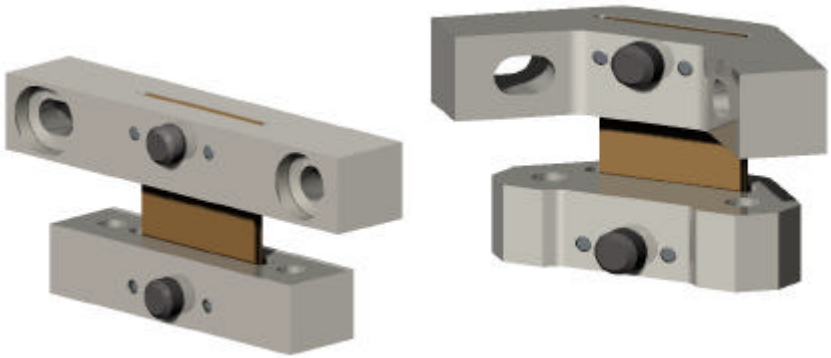
- Fabricated at PCI
- 1.5 mm thick Gr/CE
- 50 microns of aluminum post-bonded outer skin
- Countersunk 100° flat head screws (M2.5×0.45) attach into the closeout inserts. No inserts are in the sidewall themselves.



# Flexure Mounts & Gasket

- Their primary purpose is to allow differential thermal expansion between Tracker and Grid.
- Titanium blades and steel mounts.
- Attach to aluminum inserts in the closeout of the bottom tray.
- A thermal gasket compresses between the carbon-carbon closeout and the aluminum Grid.
- The gasket can also stiffen the interface relative to using the flexures alone.



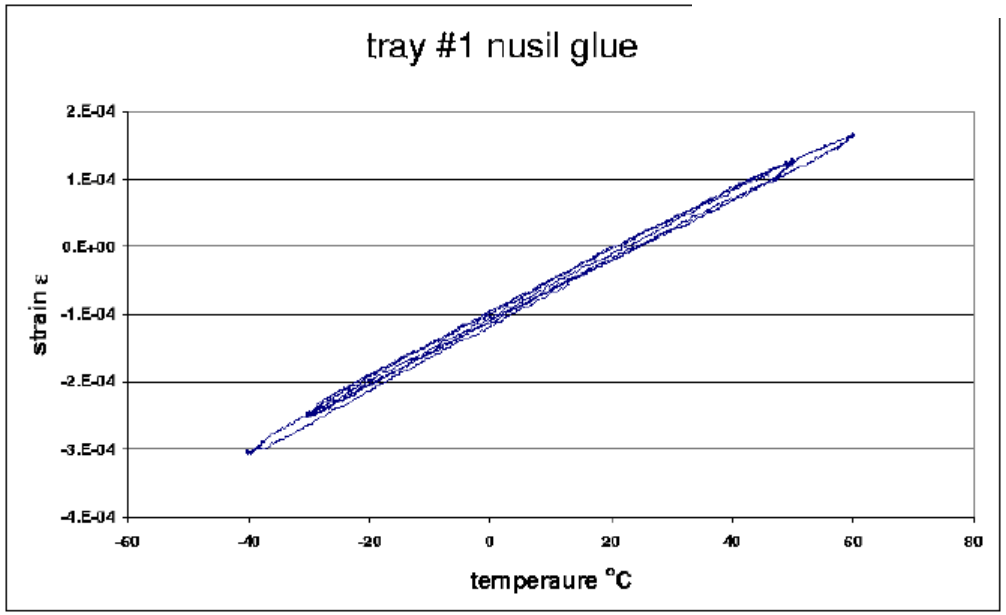


# Single-Tray Thermal Cycles

- PCI trays with thin converters were cycled 10 times –30°C to +50°C by Hytec.
- Plyform trays with thick converters were cycled –40°C to +60°C at Pisa.
- No damage to the structures or the silicon wafers.
- Maximum stress of 2100 psi (Hytec) and 3100 psi (Pisa) is far below the 30,000±6000 psi breaking stress.

See LAT-TD-00759

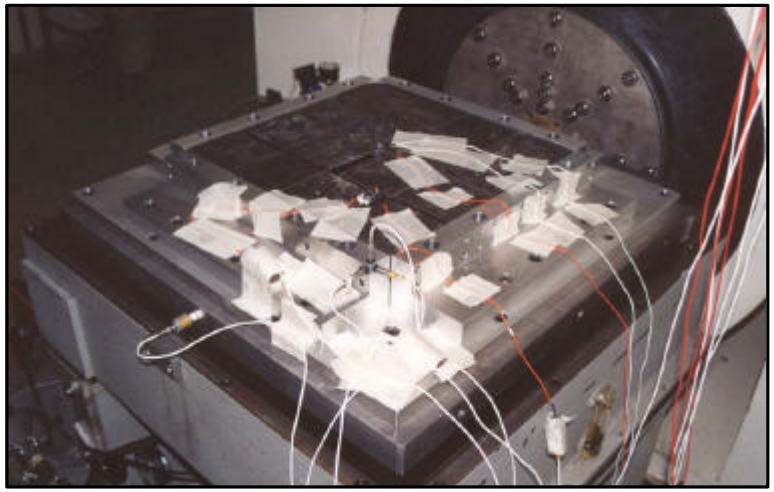
*Strain versus temperature for several cycles of a Plyform heavy-converter tray, with silicon fastened by an RTV-type adhesive.*



# Single-Tray Vibration

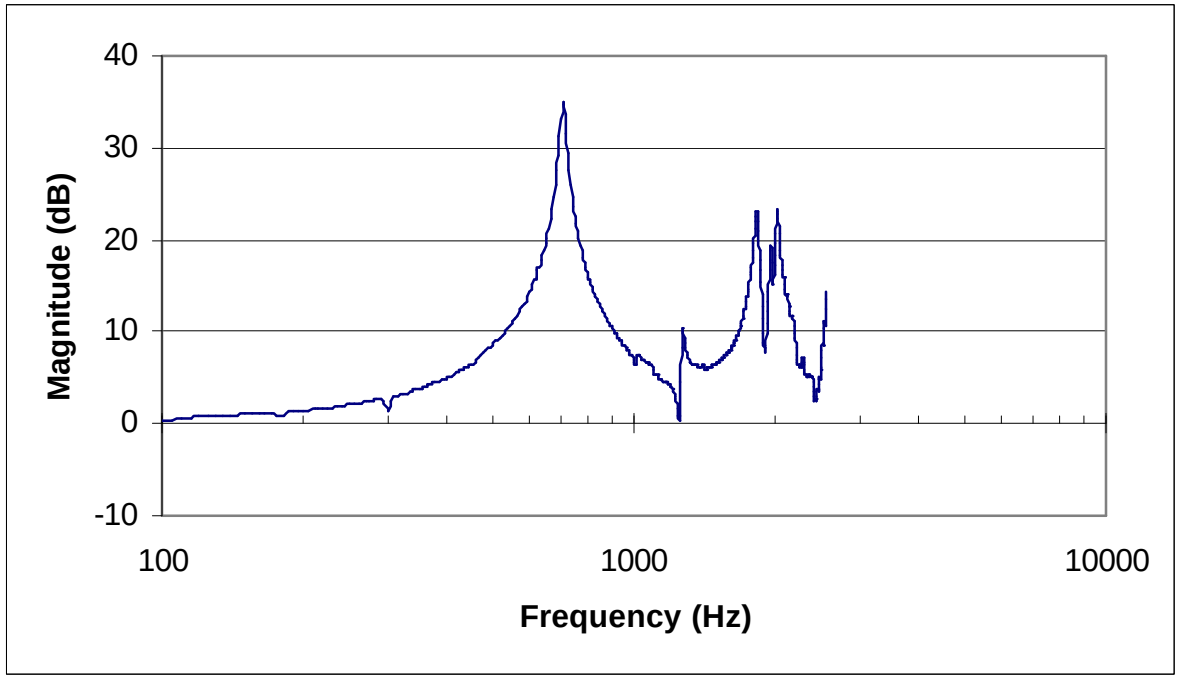
- Fundamental frequency agrees well with the FEA and is well above the 500 Hz requirement for all tray types.
- No damage to the silicon wafers during random vibration to full GEVS qualification levels (with notching at the resonances).
- For the PCI trays, there was no damage to the composite panel structure, including no evidence of production of carbon dust or loose fibers (the Plyform closeouts did not conform to the current design, so this point is not relevant in that case).

*Bare PCI tray in a vibration fixture in N.M.*



*Plyform tray in a vibration fixture in Italy.*

# Single Tray Vibration



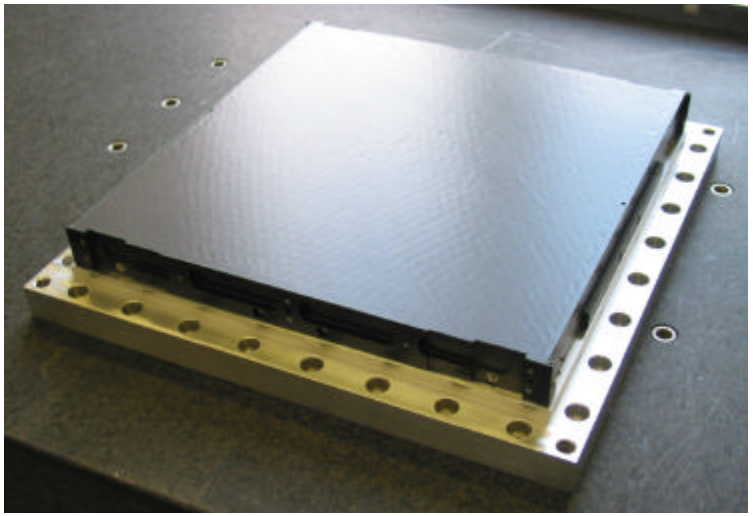

Fully Loaded PCI Tray (SN 808-002)

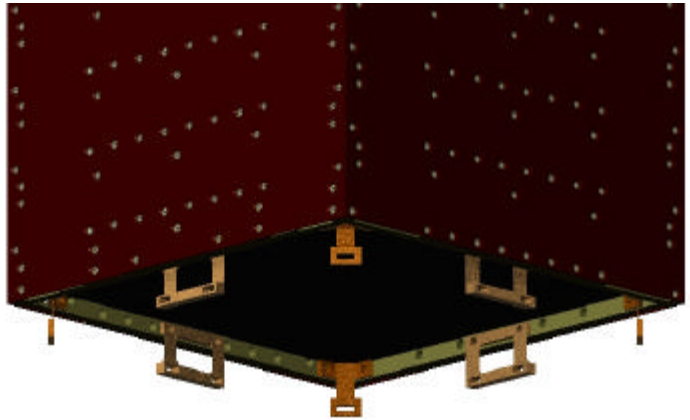
- $\nu_1$ =710 Hz
- Q = 28.4
- FEA Predicted 711 Hz

See LAT-TD-00759

# Thermal Cycling of the Grid Interface

- A bottom tray was mounted via the flexures to the aluminum "grid" and cycled at least 30 times from –30°C to +50°C.
- No damage to any structures.
- At first look, the strain data on the tray look consistent with expectations and well below any danger point.
- A report is in preparation.





# First Module Vibration Test

- Sine sweep and modal survey; Thrust axis and then transverse.
- Random vibration up to qualification level of 12.3 g rms for 2 minutes.
- Started at –12 dB, then –6 dB, -3 dB, and finally full qual level; no notching
- White noise after each test to look for changes in resonant frequencies.

Fastener problem:

The flat-head counter-sunk screws for sidewall attachment could not be tightened to more than about 60% of the design torque without rounding out the hex heads.

We decided to torque stripe them and proceed with the test while watching them carefully.

Probably a mistake, in hindsight…

# Thrust-Axis Vibration

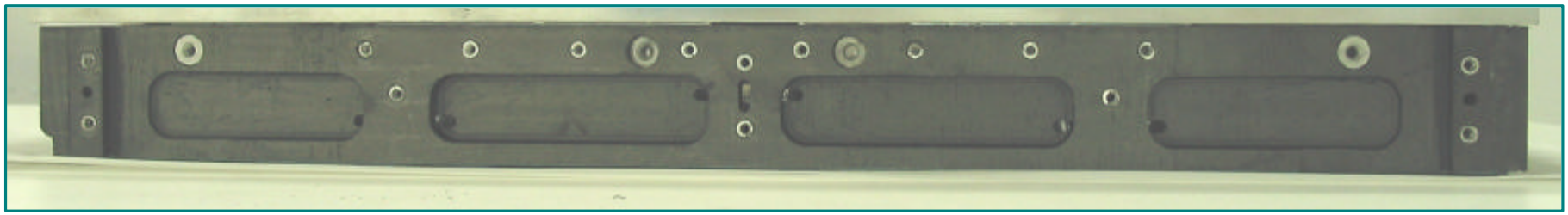
- Lowest mode is a plunging motion of the module on the flexures.
- Thermal gasket problem (FujiPoly SARCON 100G-N):
  - Random vibration caused the fundamental frequency to drop from 408 Hz before to 232 Hz after.
  - Large amplitudes cause plastic flow of the gasket.
  - After qualification-level vibration, there is essentially no remaining pressure exerted by the gasket.
  - This is a potential thermal problem but also confuses the mechanical testing by lowering the resonance frequency and changing loads throughout, especially in the flexures.
- FEA models well the response without the gasket.
- Trays move coherently in modes that FEA predicts well.
- No damage evident anywhere in the module.

*See LAT-TD-00788*

# Transverse Axis Vibration

- First mode is a rocking of the module on the flexures.
- Without any significant remaining support from the gasket, the lowest resonant frequency in the sine sweep was 88 Hz, lower than the desired lower limit of 100 Hz.
- Fastener problem:
  - After the –3 dB level some loosening of the sidewall screws was noticed in the lowest tray. They were retorqued to the degree possible.
  - During the 0 dB level the screws began backing out rapidly on the two sides of the lowest tray perpendicular to the MCM.
  - The test was terminated prematurely.
  - Before the test could be terminated, those two sides had essentially come loose from the bottom tray, resulting in some violent tower motion and wallowing out of the holes in the sidewalls where the loose screws were.
- After disassembly, no damage visible above the bottom tray.

# Design Revisions after the Test



- Purchased a new set of screws, this time with Torx-Plus heads.
- Doubled the number of screws holding the sidewalls to the lateral closeouts of the bottom tray (see above).
- Added aluminum inserts to the sidewalls for those fasteners that go into the bottom tray.

- We also refurbished the bottom tray (above), added the new inserts, and did some touch-up machining to improve its overall tolerances such that it matches the trays above better.

# Planning the Second Test

- Purpose:
  - Verify the new modifications of the attachment of sidewalls to the bottom tray. Do the fasteners back out during qual level transverse vibration?
  - Try a different gasket material. Can the gasket pressure be maintained? Can the transverse resonance frequency be kept above 100 Hz?
- New gasket material: Berquist "Gap-Pad VO-soft"
- Test plan: similar to the previous test, but start random vibration at –6 dB.

- While preparing the bottom tray for this test, a small crack in the closeout near a corner flexure mount insert was noticed by Hytec and called to our attention. We decided to proceed, anyway, which in retrospect was a mistake…

# Performance of the 2nd Gasket

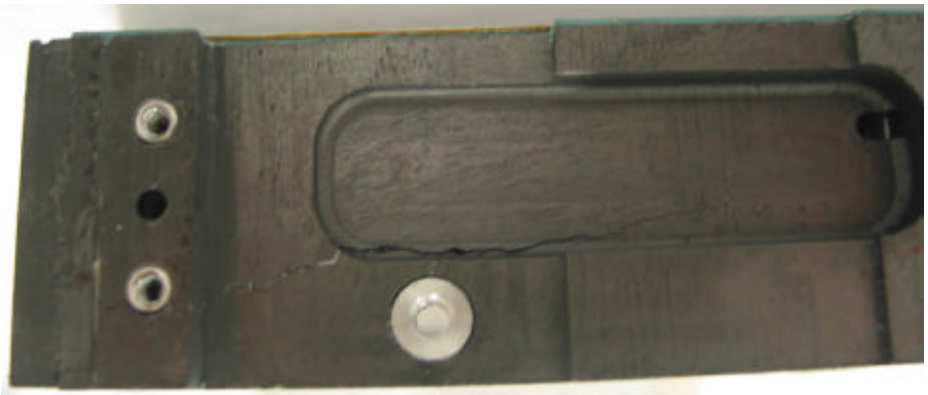
- Somewhat better than the first material, but still leaves a lot to be desired.
- Thrust-axis random vibration up to full qual levels:
  - The frequency dropped from 407 Hz to 292 Hz
  - The material showed some recovery after each 2-minute random vibration episode, with the resonance frequency increasing with respect to what was seen during the random vibration.
- Transverse-axis random vibration:
  - 110 Hz before hand (but after the thrust-axis vibe)
  - 90 Hz after the –6 dB vibe (launch level)
  - 85 Hz after the –3 dB vibe (acceptance level)

# Performance of the Sidewall Attachment

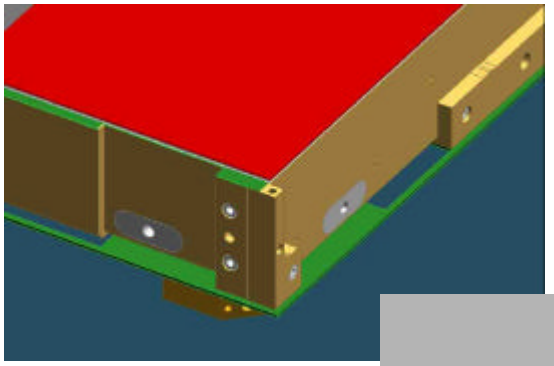
- No problems seen anywhere after the thrust-axis vibration
  - All sidewall fasteners still tight.
  - Torque still good in all the flexure mounts.
- One screw loosened about 1/8 turn during the –6 dB transverse vibration, but after retightening it, it did not move again in subsequent tests.
- A few other screws in the bottom tray took a tiny bit of tightening after each vibration episode, even though there was no noticeable breaking of the torque stripe. (Probably a relaxation of the materials rather than a turning of the screw.)
- No screws backed out even in the full qual-level vibration.
- At 0 dB one insert failed and came loose in the closeout (with the screw still torqued). However, this was caused by failure of material around the nearby failure of the flexure mount and does not reflect on the performance of the sidewall attachment.

# Failure of the Corner Flexure Mounts

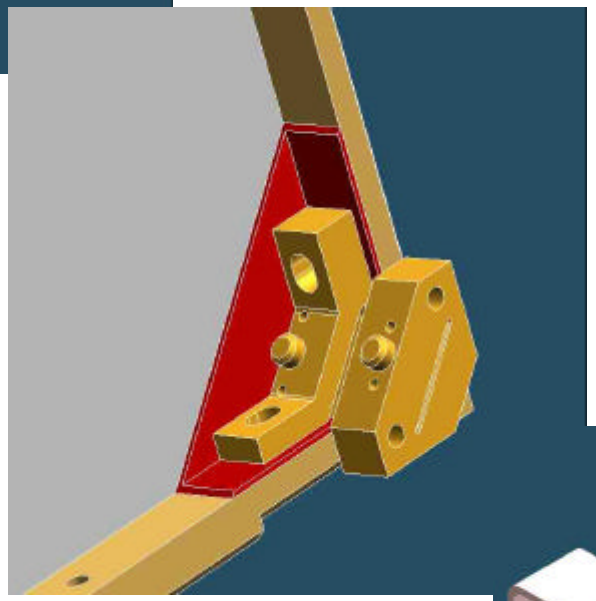
- After the full 2 minutes of transverse oscillation at 12.3 g rms, the module was removed from the jig and the flexures inspected.
  - All of the fasteners for the 4 corner flexures were loose from the tray closeout.
  - Some of the inserts were loose, such that the screws could not be retightened. The closeout material was cracked around those inserts.
  - All 4 mid-span flexures were completely secure, even though they evidently had taken on the full load of the module.



# Strengthening the Corner Mount

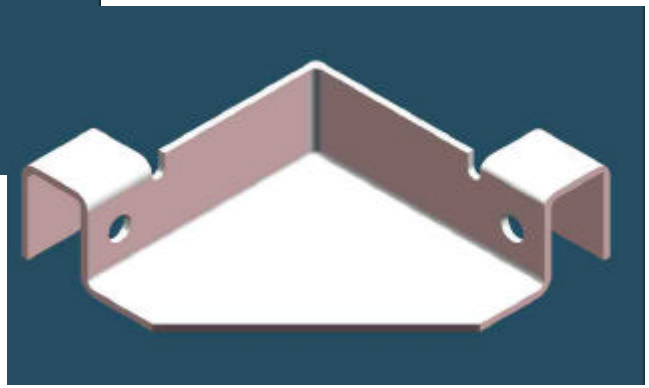


- Larger heads on the inserts, to distribute the load.
- Steel inserts, to allow more torque.



Metal corner gusset bonded to the carbon-carbon.

- Eliminate the pockets in the bottom tray.
- Increase the height of the bottom tray.
- Better gasket!



Or even make the gusset wrap around the closeout edge.

# Conclusion

- Poor judgement on our part led to tests with some ambiguous results and perhaps unnecessary failures.
- Nevertheless, the prototype module tests served their purpose of giving us advance notice of problem areas.
- Most of the tower module mechanical design is sound.
- The problem with the sidewall attachment to the bottom tray has been solved.
- Some work needs to be done to
  - Understand better the data from the tests and evaluate loads with FEA. Erik Swensen will talk about this next.
  - Improve the strength in the design of the corner flexure mounts and the bottom tray closeout. Erik's talk.
  - Plan to modify the design prior to engineering-model fabrication and test as much as possible. Tom Borden's talk.
- We do not see a need to change the tracker schedule at this point to resolve these issues!