Global Support Frame

April 10, 2000

Lawrence Berkeley National Laboratory

E. Anderssen, LBNL

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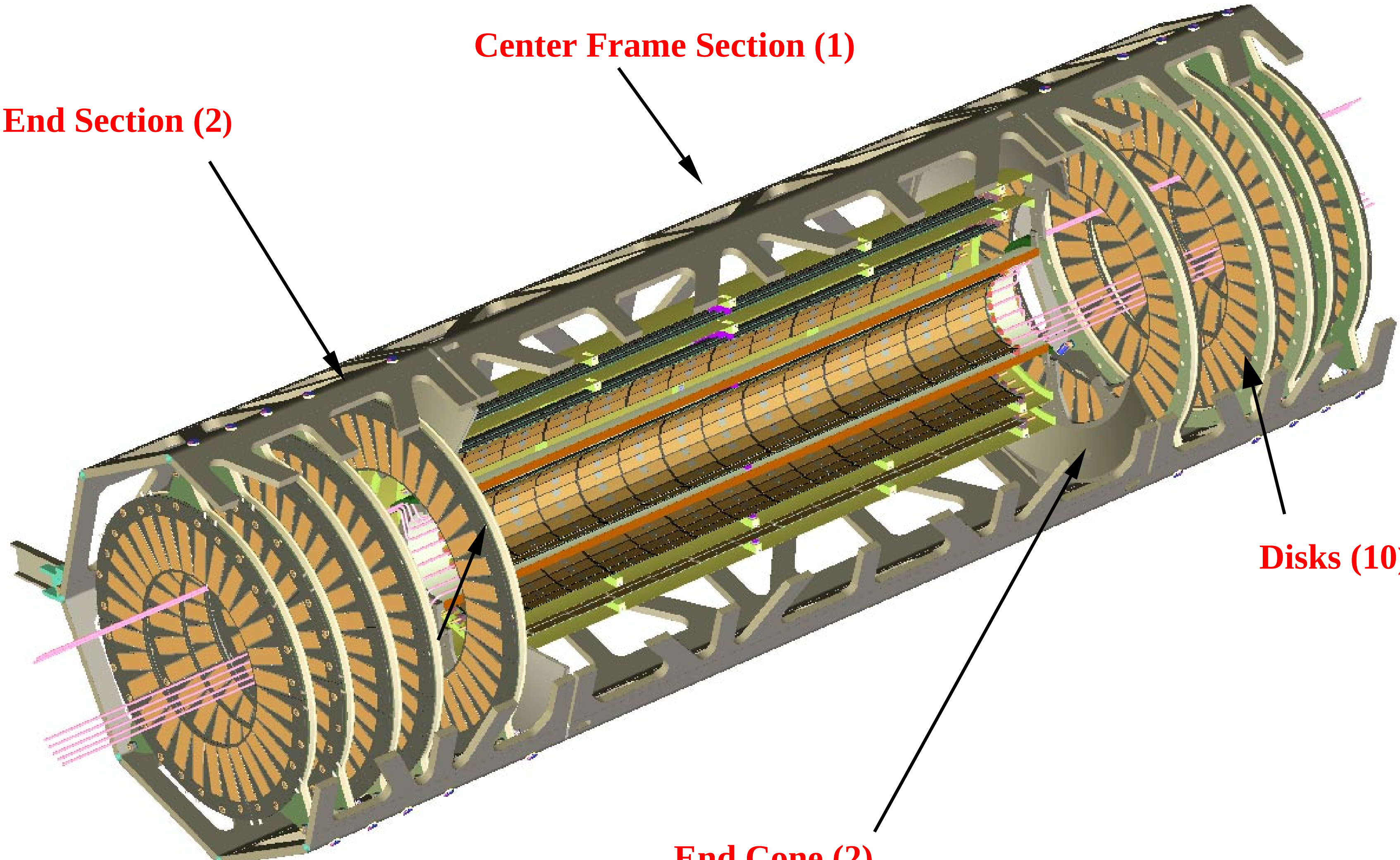
Overview

- **Discussion of What comprise Global Supports**
  - What are the parts
  - What is required of the design
  - Where are the interfaces
  - What has changed since the last review
- **What solutions are proposed**
  - Material Considerations
  - Prototype Fabrication and testing
  - How well does the testing support our conclusions
- **What are the remaining issues**

Pixel Detector

Global Support Frame



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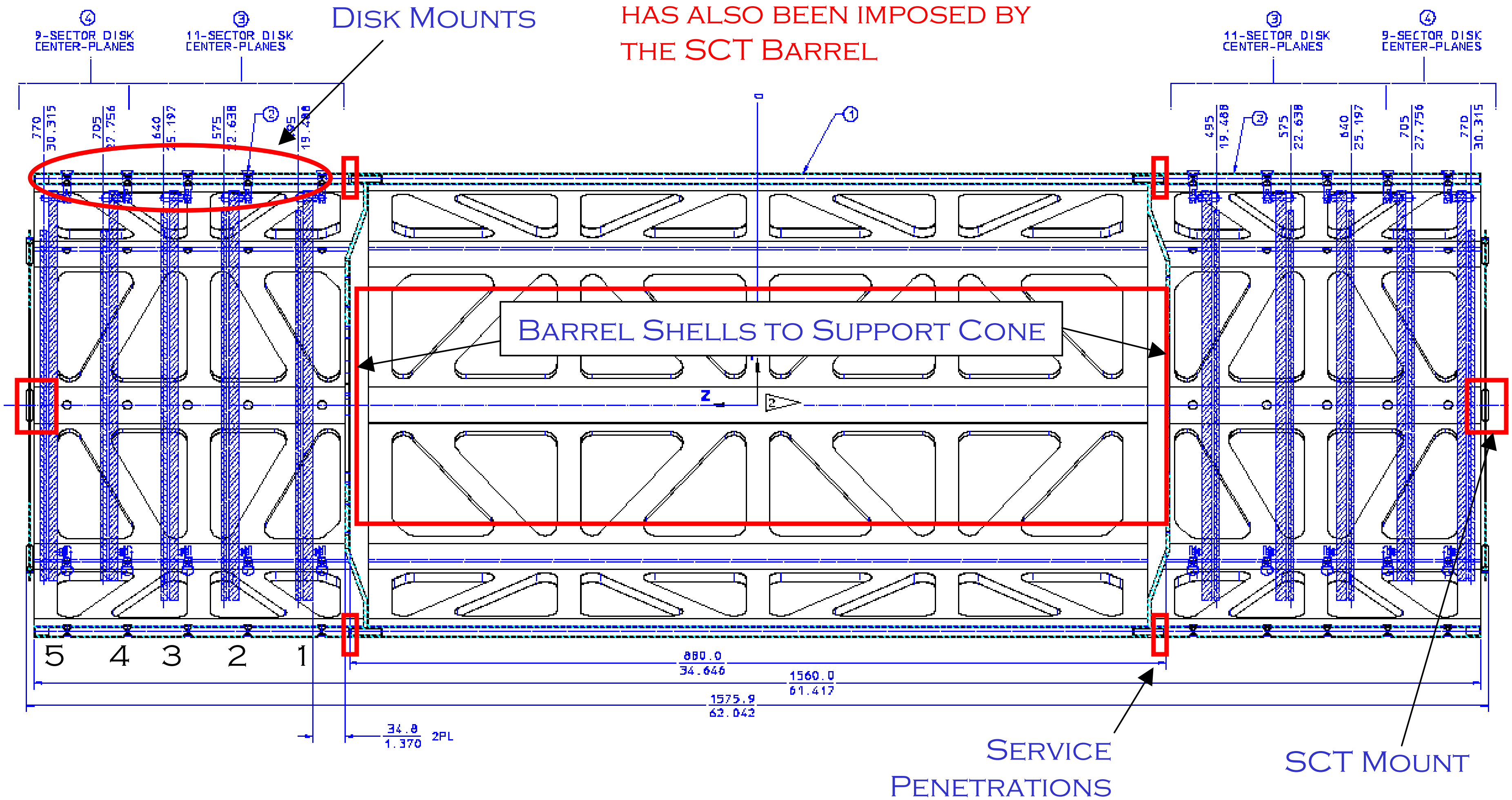
ATLAS

Pixel Detector

Interfaces and Geometry

Radial envelope of R-254 has also been imposed by the SCT Barrel



Note: this and the previous slide show the ring of Disk one on the wrong side. The position of the sectors are correct. This will be updated

April 2000
US Pixel Mechanics

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Pixel Detector

Requirements

- **Pixel Module is most sensitive in Phi direction**
  - 50μ X 400μ Pixel yields resolution of 15μ X 115μ (worst Case)
  - 10μ X 100μ is expected/hoped for
  - All geometric requirements tie back to these numbers
  - How these numbers map to the detector is frequently complex due to the kinematics of various deflections
- **Radiation Hardness**
  - Radiation Fluence of 10^{15} N/cm^2 and up to 25Mrad (1MGray)
  - Requires materials with RI>6 for all components
- **Material Minimization**
  -).35% X_O (Soft Limit) Normal Incidence
  - Material in forward and at low radius more stringently controlled
- **Geometry (fits)**
  - Fits in envelope, allows service access, is assemble-able, etc.
  - Subject of current configuration control efforts

Pixel Detector

Requirements

- **Detector Accuracy Requirements split into three levels**
  - Assembly
    - Accuracy of Survey ~ resolution
    - Build tolerance in Z tighter than pixel (physical constraints), Phi ~Pixel
  - Cool-down
    - Unambiguously identify surveyed pixels after placed in operating environment
    - Approximately equal in magnitude to 1/2 a pixel
  - Stability
    - 15μ inherent resolution will be increased to no more than 18μ by mechanical uncertainties (neglecting track alignment which may reduce the 18μ)
    - Stated another way: errors added in quadrature with the inherent resolution will not exceed that resolution by more than 20% (total budget)

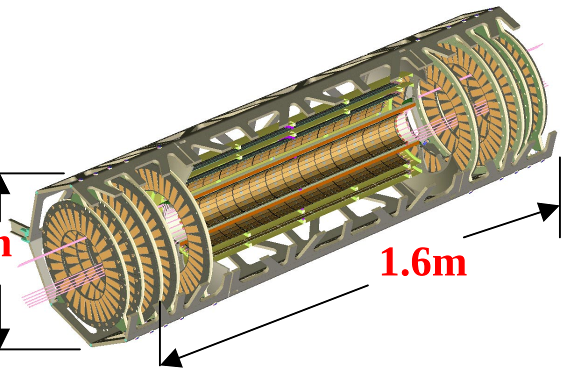
Tolerance	Module Coordinate		
	R	ϕ	Z
Assembly			
Barrel to Frame	10	10	25
Disk to Frame	10	5	10
Disk to Barrel	10	5	50
Frame to SCT	50	50	100
Cool-Down			
Barrel	50	25	50
Disk	50		80
Stability			
Barrel	10	5	10
Disk	10	5	20
Frame to SCT	10	5	10

STABILITY EXCURSIONS

XN80 Bryte EX1515 (Cyanate Ester)

CTE=coefficient of thermal expansion

CTE-near zero for quasi-isotropic



Conditions:

40°C temperature change

-0.5 <α<-1.0 ppm/°C

Result

18 to 36 μm's for 0.9m length

CME=coefficient of moisture expansion

CME is a function of Relative Humidity (RH)

Quasi-isotopic laminate data

105 ppm/%moisture exchange

Conditions:

assume moisture pick-up @ 55% RH (0.18%)

Frame members reject moisture to dry gas

Resulting contraction

~17 μm for 0.9m length

Comparable magnitudes

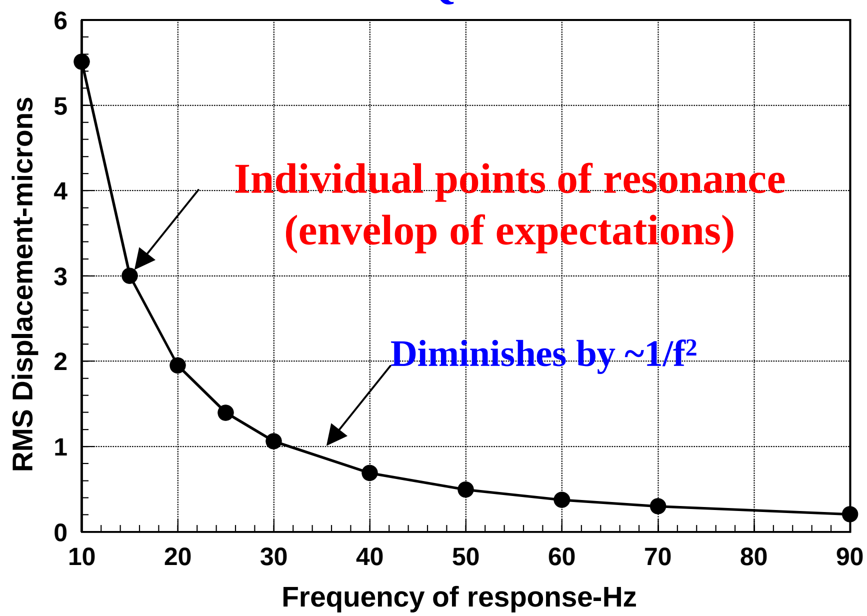
Strains induced are within the realm of construction tolerances

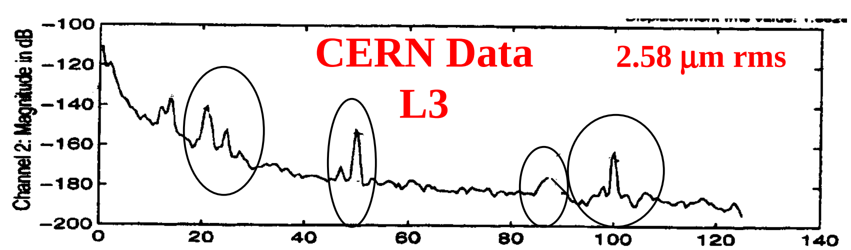
Frequency Requirement Discussion

- **Gravity Sag requirement sets the approximate order of F_1**
  - $F_1 \sim 1/2\pi\,(g/\delta)^{1/2}$ when deflection is due to gravity
- **Environment is not well characterized**
- **De-coupling from environment is conservative approach**
  - Random acceleration: PSD-estimated from CERN report
    4.85 10^{-9} g^2/Hz
  - A fundamental mode at 75 Hz would have a relative response of ~0.3µm rms, 1 sigma
  - Indicates that F_1 is not a hard requirment
- **However, Discrete spikes at 50Hz and its harmonics could yield motions in excess of 10µ**
  - *F_1 still desired ~100Hz*

Estimate based 1DOF Oscillator

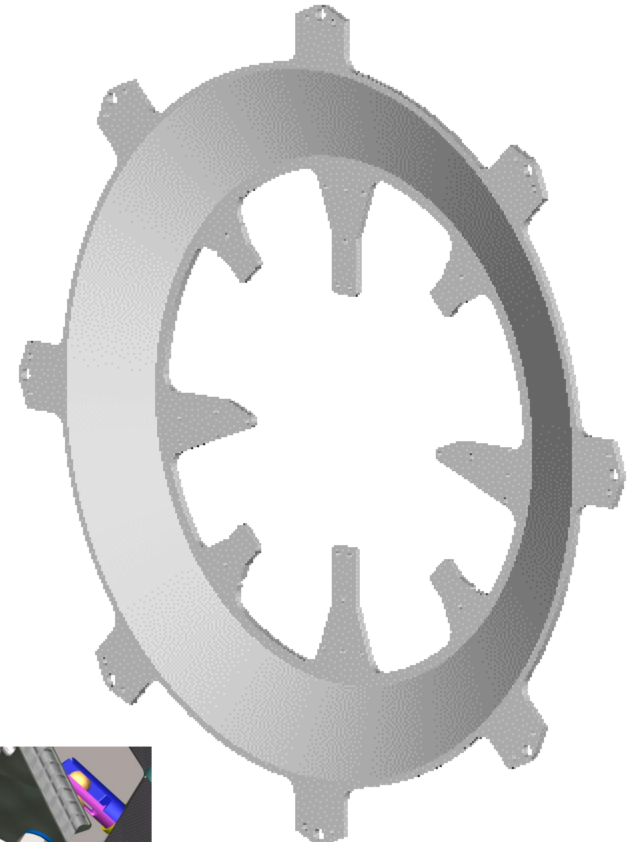
Q=40

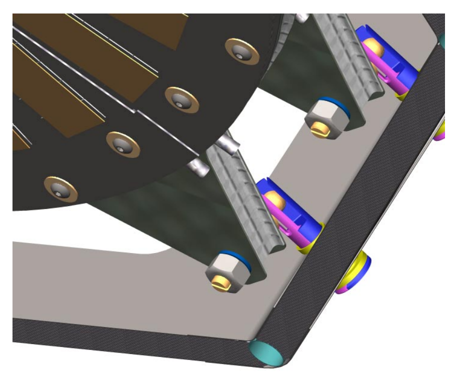




Intermediate Support Interfaces

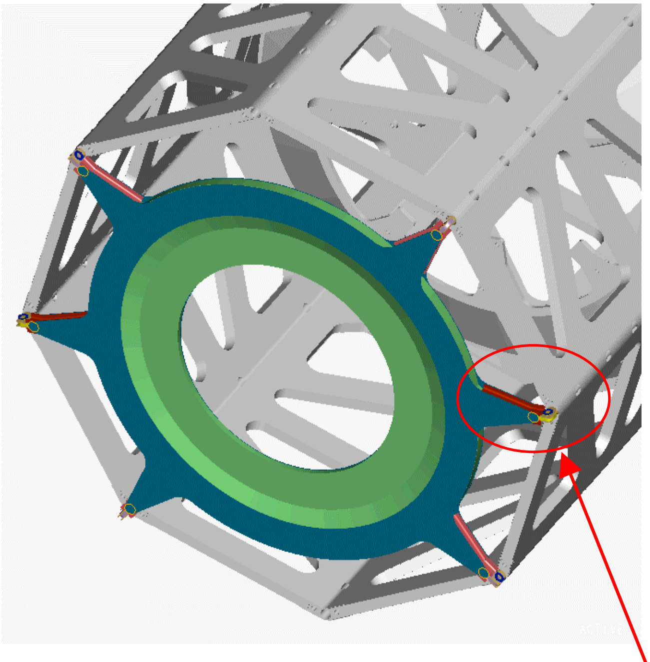
- **End Cones-*Barrel support***
  - Support Cone is integral part of frame
  - Core thickness 4 mm--being revised
  - Finger mounts to Barrel Shells are being re-investigated in response to new Barrel Shell designs.
  - Inner and outer fingers allow for Service routing
- **Disk Ring Mounts**
  - Require Frame Penetrations to be prototyped
  - Will BE prototyped this summer



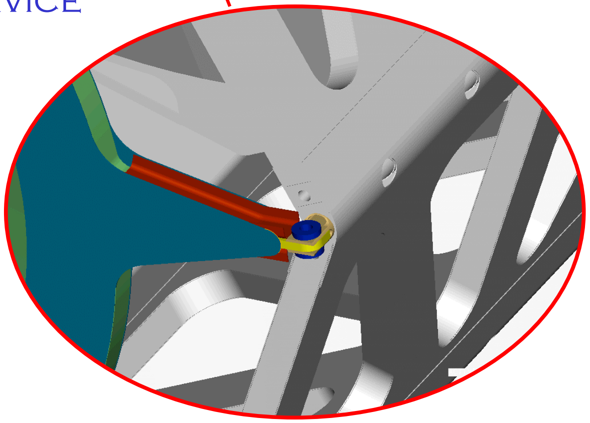


End Plate Stiffener/Thermal Barrier

- **End Plate Stiffener increases the radial stiffness of the Octagonal Frame**
  - Inserts in Global Support Frame and End Plate are Pinned together--helps to hold End Frame 'round'
- **Thermal Barrier flange attaches flexibly to End-Plate Stiffener**
  - (not shown)



(Shown without service integration details)



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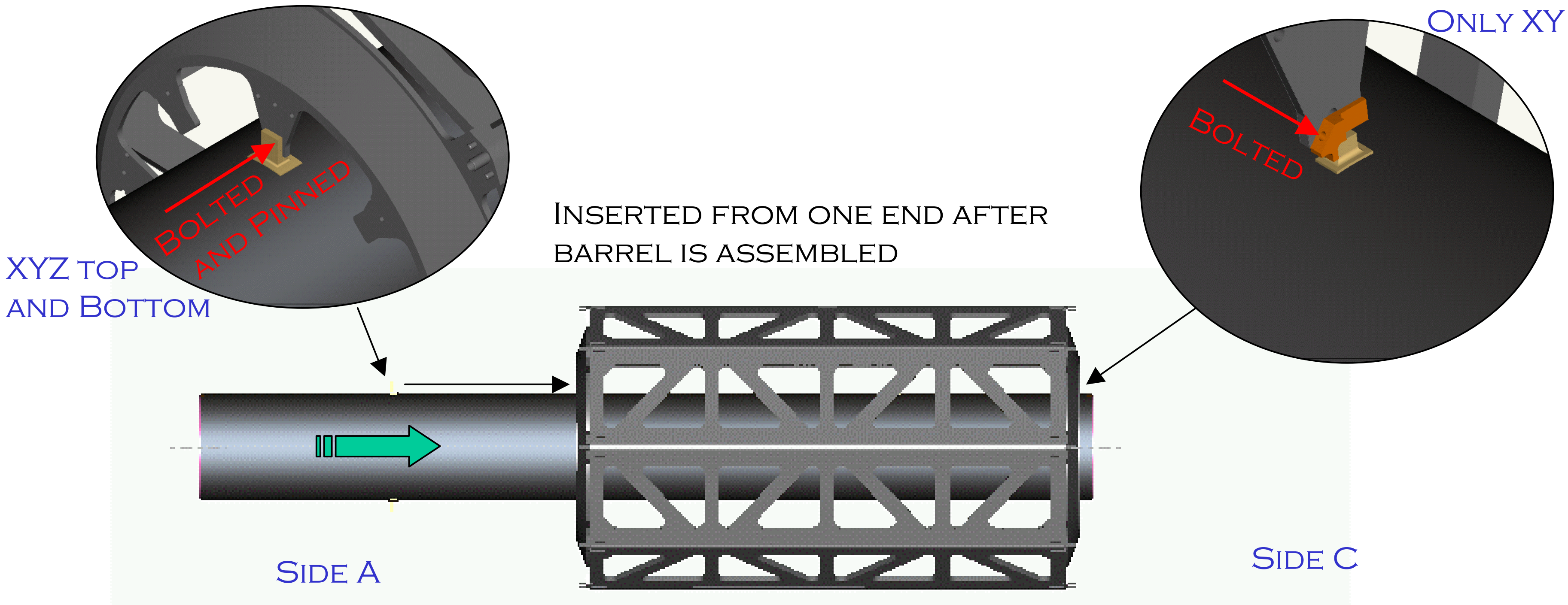
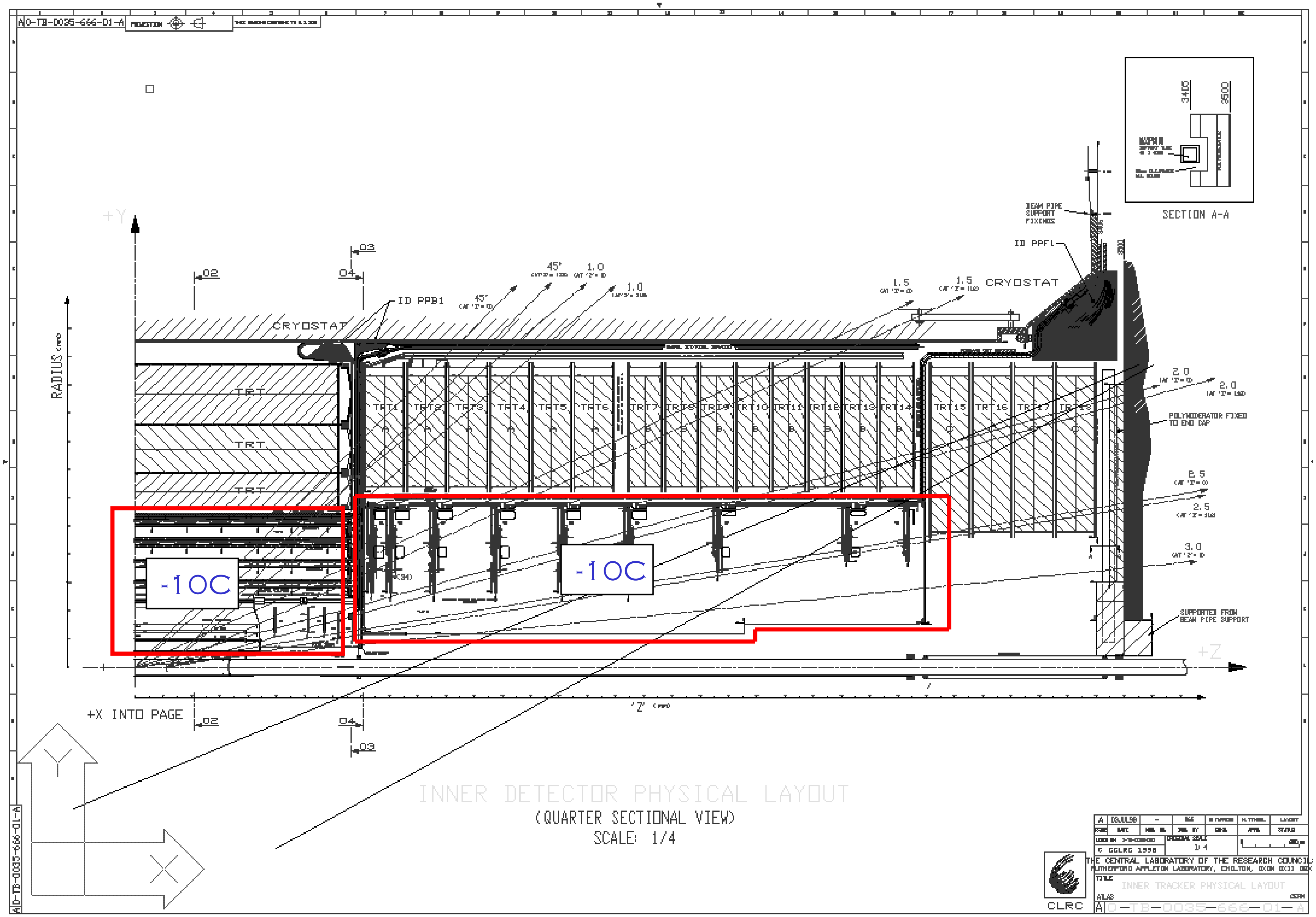
Thermal Barrier is B-Layer Support



- Change from old design which was not rigidly attached (i.e. "floated")
- Directly mounted to barrel support cone
- Thermal Expansion on order of assembly/build tolerances

Pixel Detector



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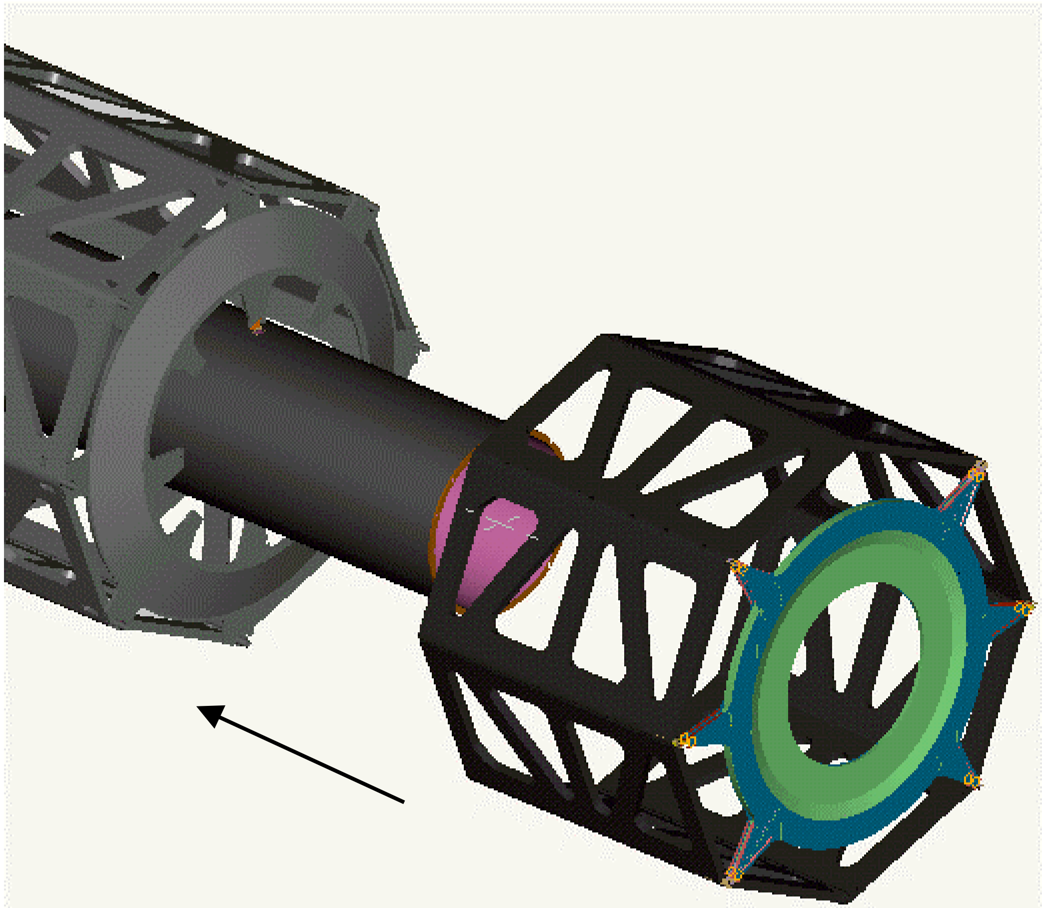
Pixel Detector

Assembly of Support Frame



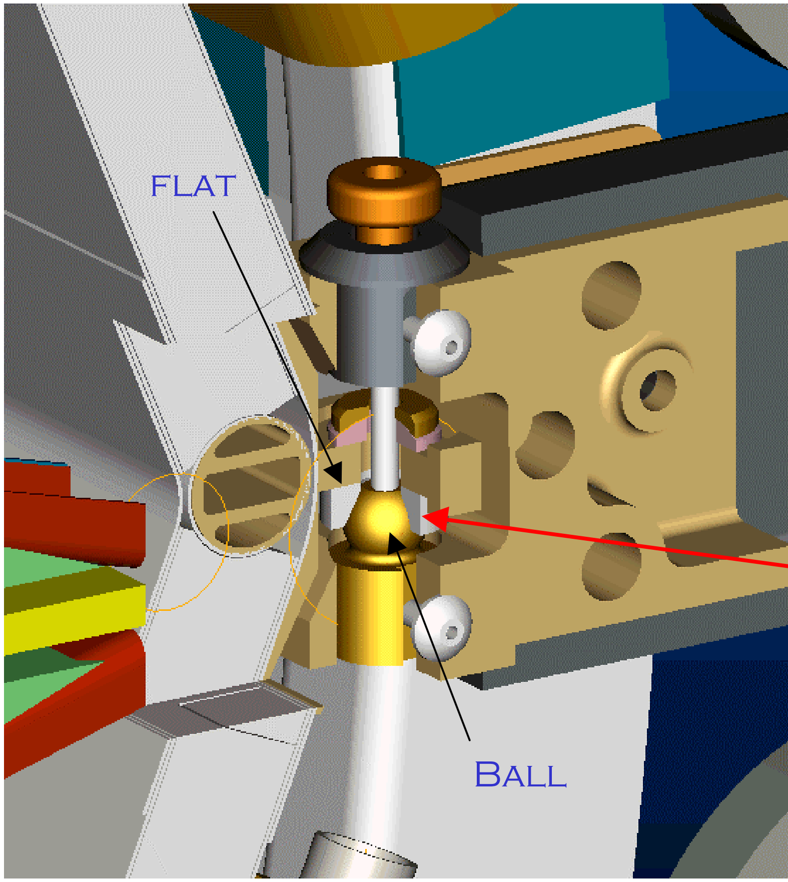
- Barrier is integrated with Barrel Region
- Takes all location from Support fingers
- End Frame is brought up and bolted into place
- Services (not shown) need support during all operations

End Plate stiffener is a useful part of end frame as it both supports the services as well as helps to make the end frame self supporting for installation

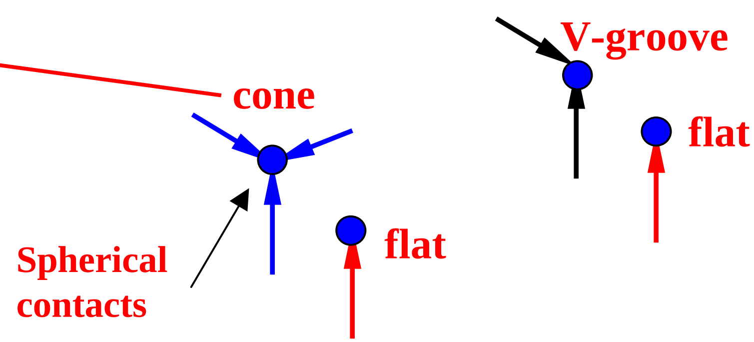
Detector Assembly Sequence

http://www-atlas.lbl.gov/~goozen/assdetset.html

PIXEL MOUNT POINTS



- VERY SMALL VOLUME IS ALLOWED FOR MOUNT POINTS, LEADING TO HIGH STRESSES
- PSEUDO-KINEMATIC MOUNTING
  - LEADS TO OVER-CONSTRAINT IN VERTICAL DIRECTION LEADING TO FRAME TWIST
- SMALL PROTOTYPE EFFORT NECESSARY
  - STABILITY BETTER THAN 5μ DESIRED
  - VALIDATE MATERIALS AND ACCURACY AS WELL AS STABILITY AND REPEATABILITY
- RESULTS ALSO USEFUL FOR DISK MOUNTS



ALL MOUNTS ARE CONE-SPHERE CONTACT BUT ONE- WHICH IS VEE-GROOVE. THE GROOVE AND ONE OF THE CONES ARE GLUED TO THE FRAME-THE OTHERS SLIDE ON THE FLAT, AFFECTING A "FLAT" INTERFACE. SPHERICAL CONTACTS ALLOW FOR NO LOCAL MOMENT TRANSFER FROM SCT TO PIXEL FRAME.

4-POINT SUPPORT CAN STILL TWIST FRAME

Masses used in FEA

Item	Frame mass-kg	Added Structural mass-kg	Non-structural kg	Total mass-kg
Outer Frame				
Center Section	1.219			1.219
End Section	1.986			1.986
Disks/cabling/cooling			23.24	23.24
End Reinforcement	0.085			0.085
Corner Tubes	0.20			0.20
Barrel Region				
End Cones	0.30			0.30
Inner Shell(s) Support	0.12			0.12
Outer barrel shell	0.46		4.43	4.89
Mid-shell		0.52	3.15	3.67
B-Layer Shell		0.47	1.35	1.82
Total	4.37	0.99	32.17	37.53

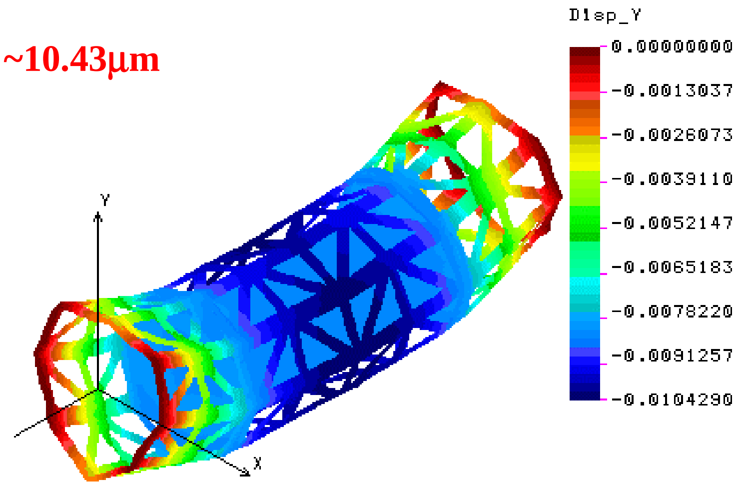
Total structural mass ~5.36 kg

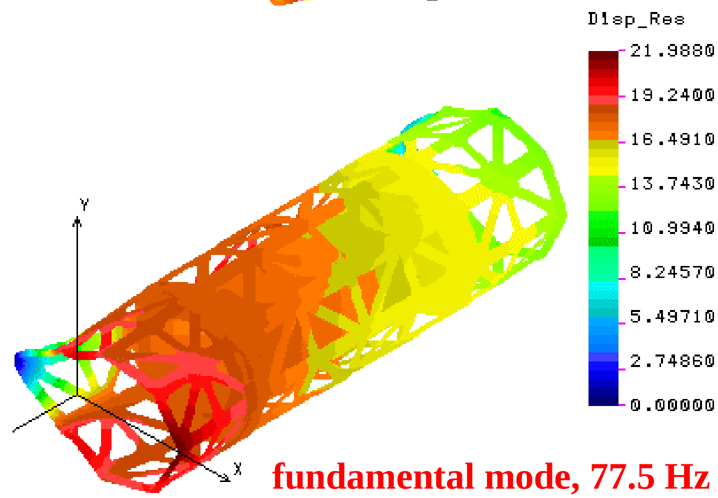
These are the masses used in the original FEM. The service mass changed ~ -0.5kg per side in the new model

Results from Last Review

- **Design status**
  - Met static design goals
  - Dynamic Goal Close
  - Solutions based on expensive high modulus fiber systems
    - cost impact being evaluated
  - Heavier Walled End Frame
  - Reinforcement at detector ends required
    - now question is how best to achieve desired stiffness with minimum material
- **FE model limited to just outer barrel, since European collaborators are now designing inner shells**
  - Clarification: results still included mass and stiffness of inner shells but performance was not investigated

gravity sag, ~10.43µm





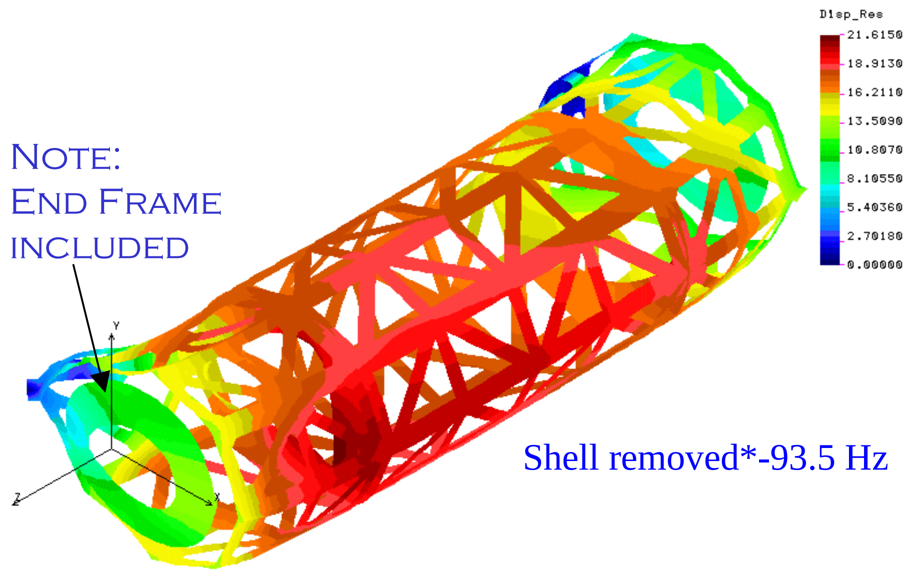
fundamental mode, 77.5 Hz

Support Frame Performance

- **Design Status**
  - Meets Static and Dynamic goals
- **What has changed**
  - End Plate Stiffener
  - End Frame material thickness same as central Frame
  - Barrel Shell support condition no longer "built-in"
- **Studies done looking at contribution of stiffness from Barrel Shells**
  - Static
    - 16.7µ without*, 16.6µ with
  - Dynamic
    - 93.5Hz without* 94.6Hz with
  - Barrels contribution to stiffness of Global Support frame is Negligible

16.7 µm's with shell removed*

Note: End Frame included



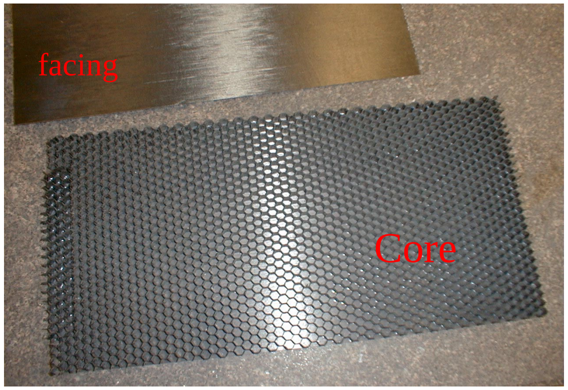
Shell removed*-93.5 Hz

*Barrel shells' mass is still included

Prototype Program

- Started with Single Panel, progress to Bi-panel Assembly, then to Full Frame
- Single panel Specimens Honeycomb and Foam Cores
  - facing material, XN80 90 g/m^2 prepreg with cyanate ester, 6 layers ~400-430 microns
  - core material, 6.35 mm cell (1/4”) XN50 fiber honeycomb 0.46 kg/m^3 (2.9 lb/ft^3)
  - Carbon foam 1.79 kg/m^3, 3X normal density, (requested 2X)
- evaluate differences in fabrication details for both sandwich cores--honeycomb versus carbon foam--select one to proceed
- Two panel evaluation
  - Light weighted panels joined with proposed corner reinforcement
    - Demonstrates tooling before proceeding to full frame assembly
- Disk region octagonal frame assembly
  - Use prototype of frame to investigate load transfer
    - within frame sections
    - between panel sections in a frame section

Prototype Panels



Item	Wt.-g	%
facings	93.9	61.8
core	30.1	19.8
Al blocks	14.4	9.5
total	151.9	

Adhesive average between two facings 106 g/m^2—***8.9%***
HYSOL- EA 9396, room temperature cure

Item	Wt.-g	%
facings	92.7	38.02
core	114	46.75
Al blocks	14.4	5.91
total	243.8	

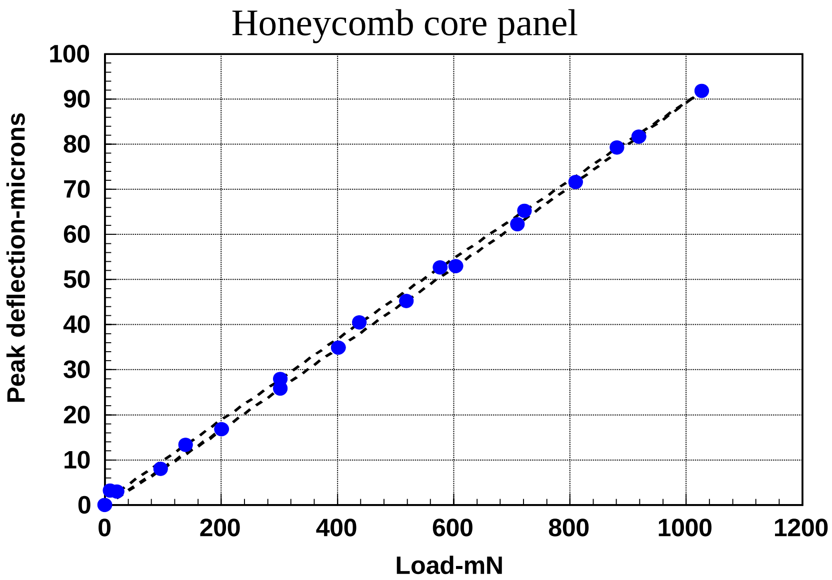
Adhesive average between two facings 196.4 g/m^2—***10.25%***
HYSOL- EA9396, room temperature cure

Foam density after CVD=0.179 g/cm^3
Panel as received 41 g

~2.78 mass gain factor from CVD

Pixel Detector

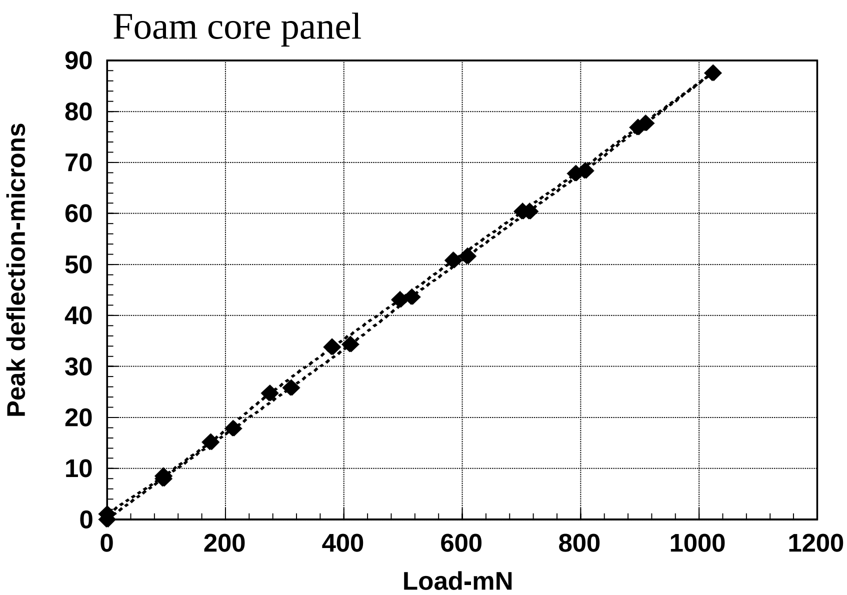
Initial results for simple bending



89 µm /N slope

•Varied from test to to test due to rigidity of support

•84 to 97 µm/N



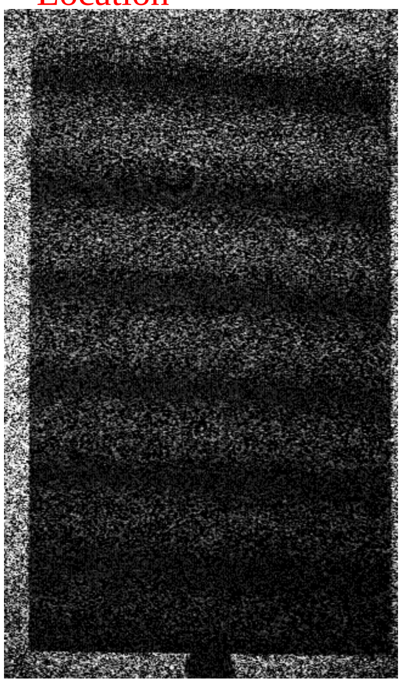
85.5 µm /N slope

•Varied less from test to to test

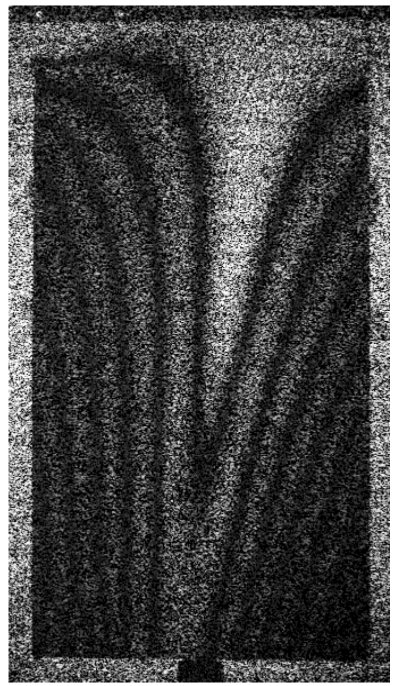
Honeycomb Panel Vibration Test

Support Location

91 Hz



437 Hz



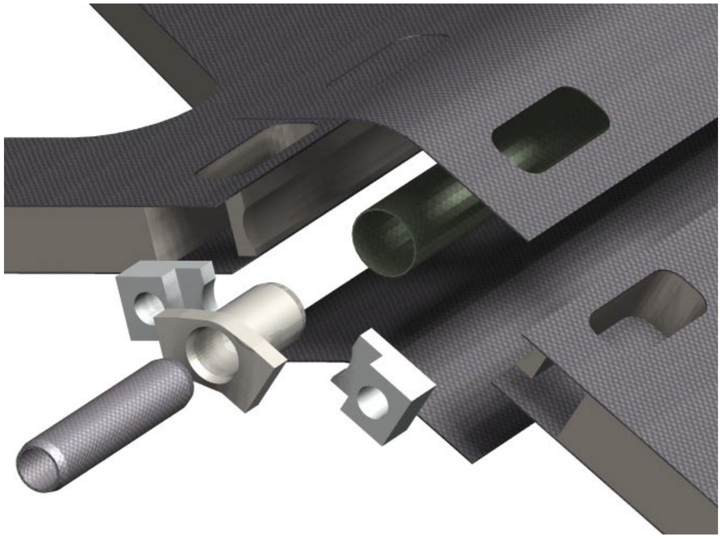
First two modes. The cantilever fundamental mode agrees well with the static test result, i.e., a Calculation based on the derived stiffness from the bend test predicts a value close to the 91 Hz

The FEA model predicts 118 Hz. The earlier remarks about BC's applies equally here.

The asymmetry in the torsional mode Is most likely caused by imperfections In the corner blocks and their location

Bi-Panel Assemblies

- **Static Test Objectives**
  - Determine static stiffness under loading similar to application
    - In particular evaluate joint behavior
  - Compare results to finite element model
    - Confirm technique used to model panels and corner/joint design
    - Try to isolate effects of loading condition and effects of base mounting



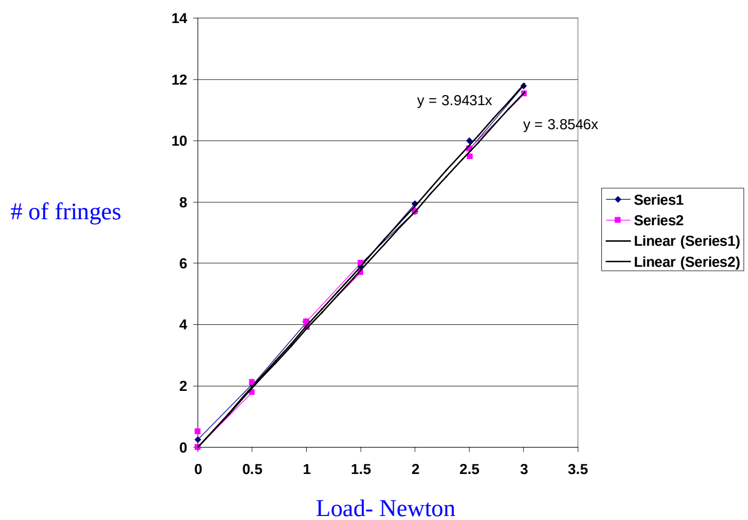
How well are the individual pieces bonded and integrated to into a stiff joint?

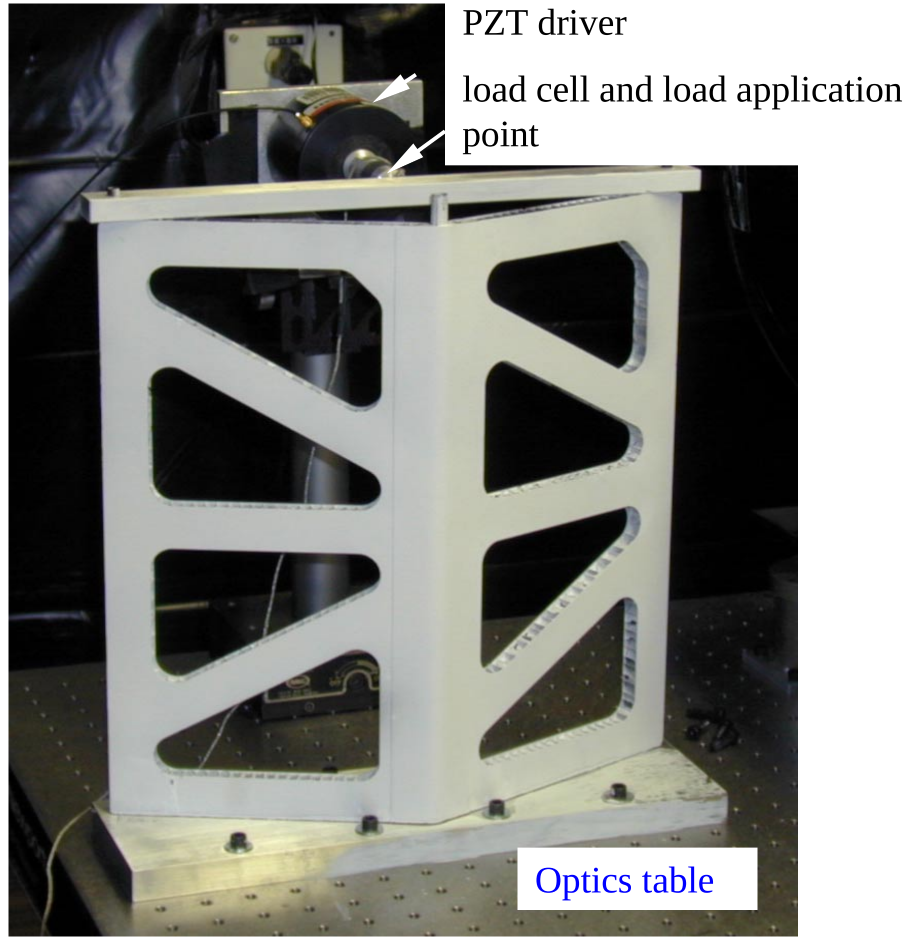
Pixel Detector

Bi-Panel Test Setup

Test arrangement

Applied static load in increments, while viewing deflection with TVH





Panel mounted directly to optics table

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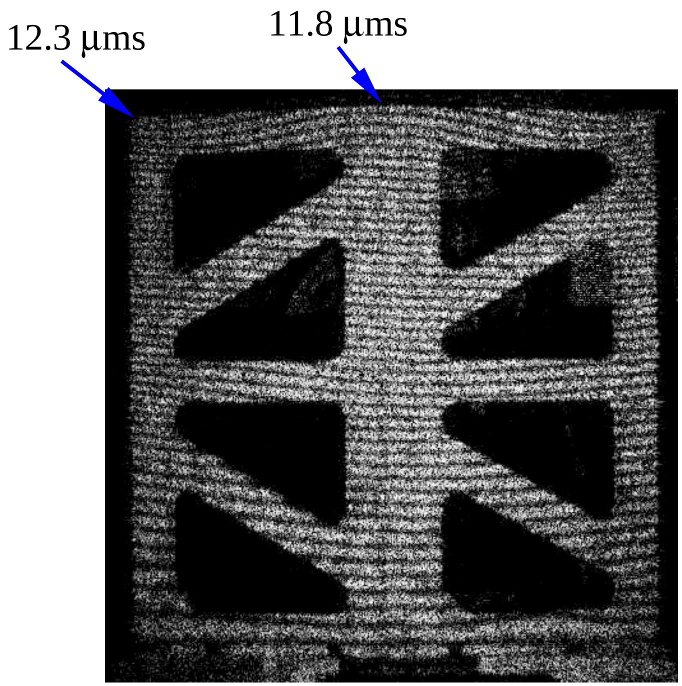
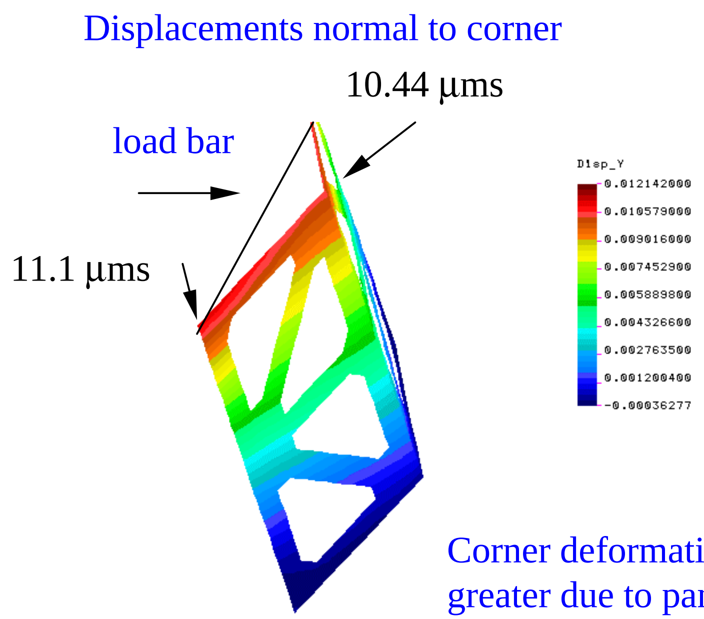
Pixel Detector

Bi-Panel Load Test



TVH fringe pattern



Corner deformation greater due to panel bending at point of load application

FEA using properties of prototype panel dimensions

Bend test-3 newton peak load

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Bi-Panel Test Summary

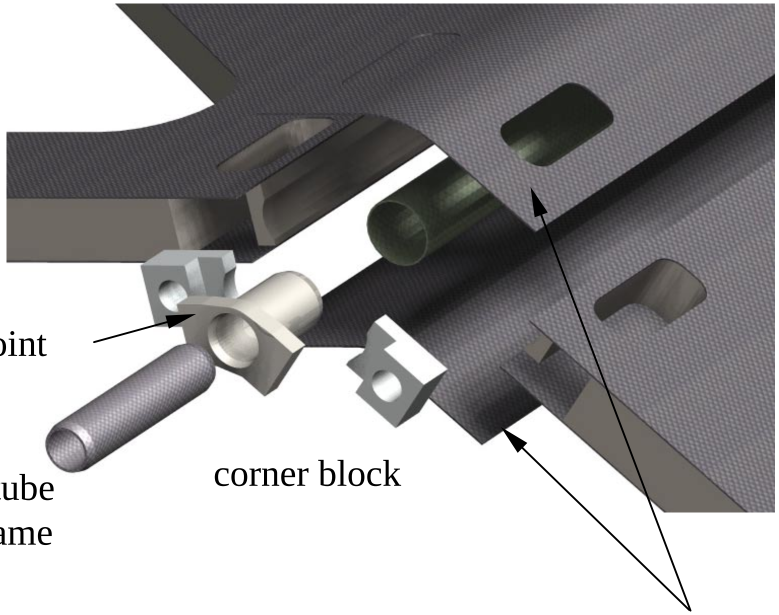
- **Initial test observations**
  - Bi-panel connected directly to optics table yielded test results that agreed exceedingly well with our predictions. The single panel comparison, however, still does not correlate well, possibly partly due to a load cell range problem. Full range on the load cell is 12 N.
    - Agreement within 5.2% (12.1 versus 11.5 μm's) for the bi-panel in bending and shear at 3 N applied load
    - Agreement within 39% (74 versus 103 μm's per N) for the single-panel in pure bending at 0.15 N applied load.
- **Frame prototype program progress**
- **Results thus far on the bi-panel have been highly encouraging**

It is believed that the global structural model remains an adequate representation of the frame behavior

Octagonal Frame Construction

Eight Flat panels are assembled into an Octagonal Frame

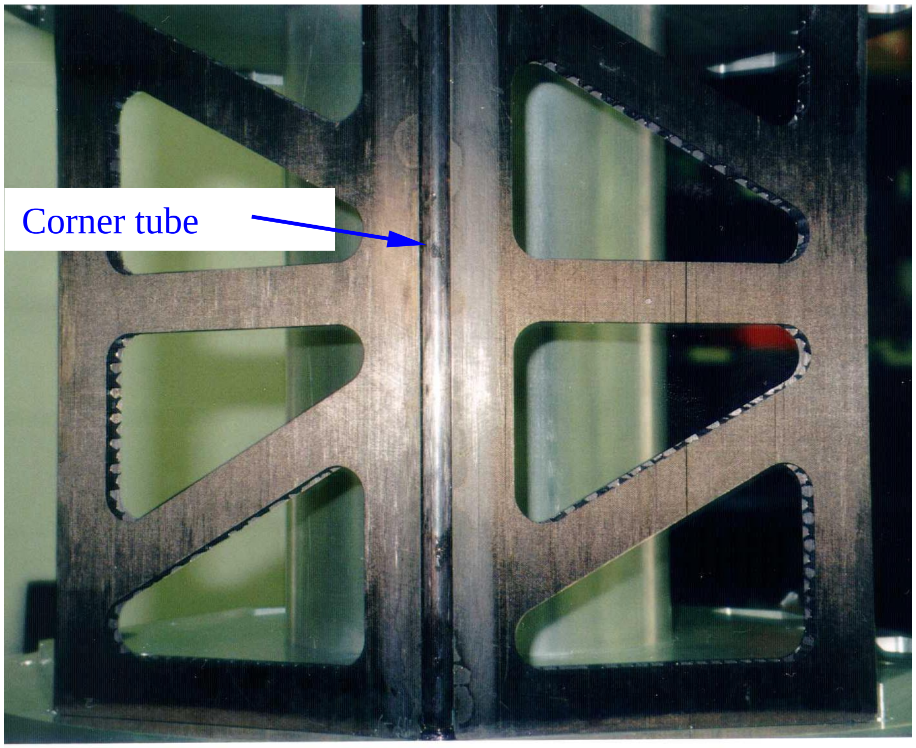
flat panel sandwich with XN80 facings and YLA Cellular honeycomb

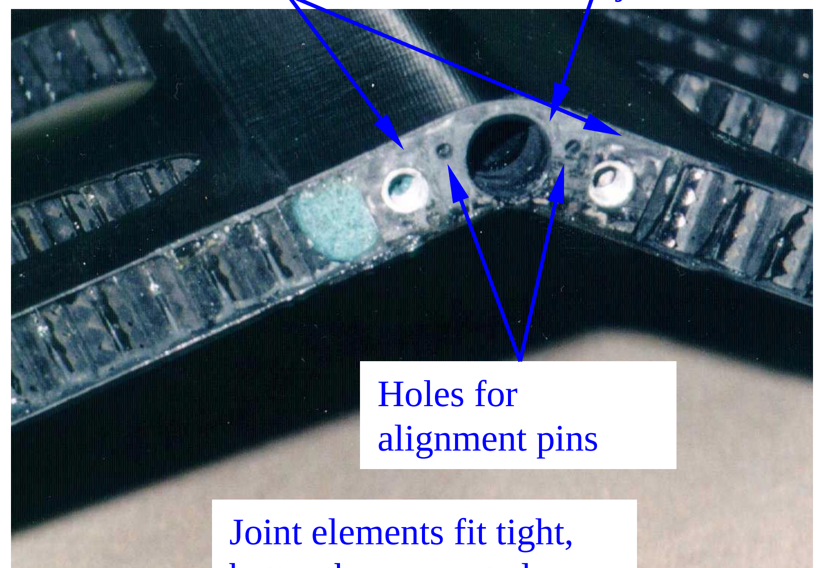


Frame Assembly Fixture

- **Fixture function**
  - Holds panel parts in place during bonding, utilizing self-jigging features of the corner parts
  - Index pins machined into top and bottom fixture plates hold circumferential alignment
- **Assembly steps**
  - Assemble sandwich panels with corner blocks
  - Place inner corner splice in fixture recess
  - Place two adjacent panels onto inner corner splice
  - Insert corner tube and vertex alignment joint
  - Install outer splice
  - Repeat process 4 times

BI-PANELS ARE FABRICATED IN TOOLING

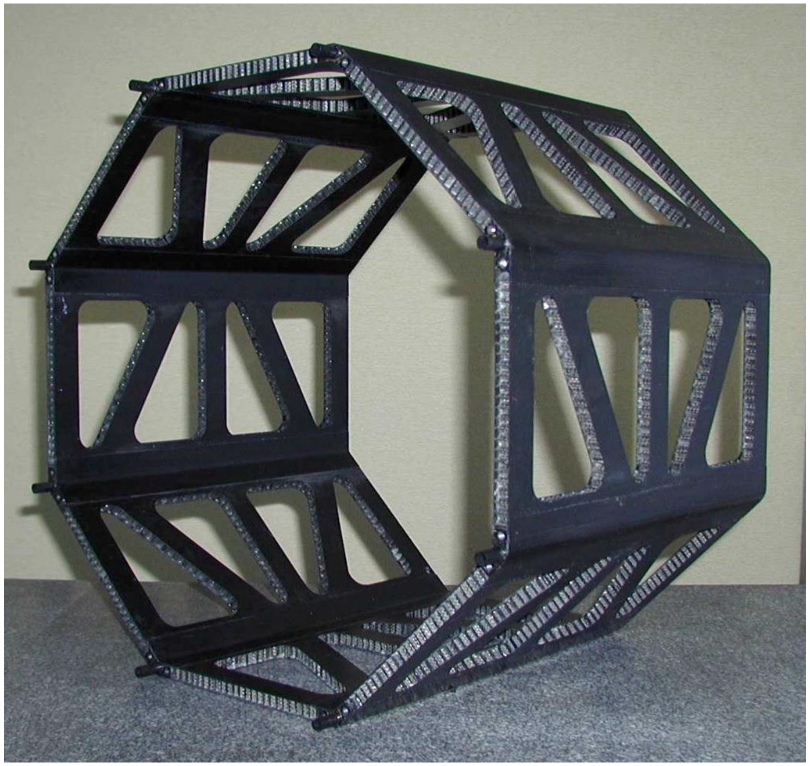




BI PANEL ASSEMBLIES ARE MADE IN THE SAME TOOL USED TO MAKE THE OVERALL FRAME

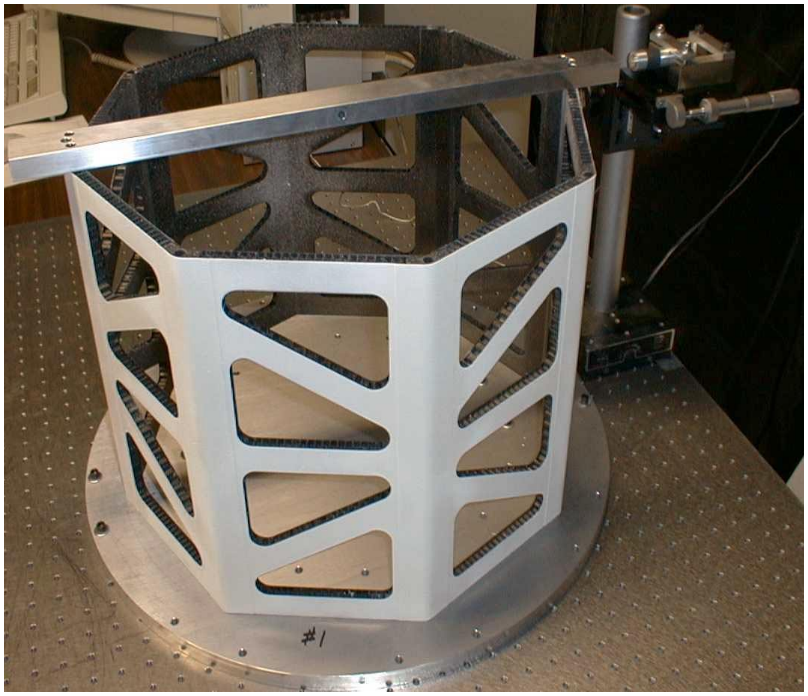
Frame Prototype Testing

- **Testing Issues**
  - Measurements to be made at low strain levels, at level simulating the application
    - Composite properties measured at higher strains, yet used to design at low strains
  - Effect of bonded joints
  - Load Application
    - Difficult to applied load without influencing end result
  - Boundary conditions
    - Frame is attached to central region through connections at 8-corners, using thin tubes for alignment
    - To test, frame is mounted to base support structure
      - Any compliance at base will affect frame stiffness result



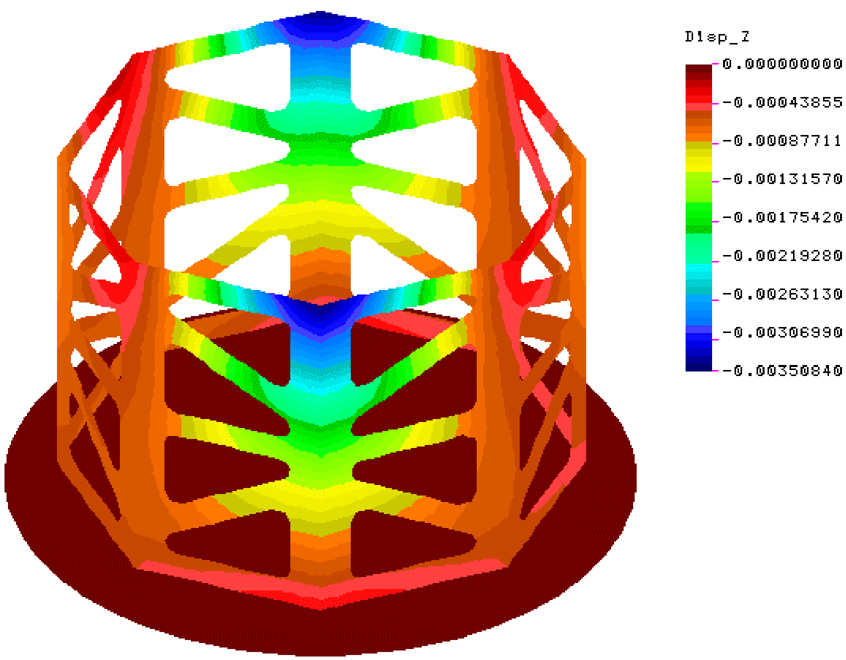
Frame Static Testing

- **Frame test-setup (case A)**
  - Octagonal frame is attached by #8-32 screws to 1.9cm (0.75in.) Al plate
  - Attachment plate is mounted to optics table
  - Cross bar attached to top of frame using #8-32 screws, at the corner joint
  - Load applied at center of bar axis
    - Axis alignment is achieved by adjustment of line of action. Slight residual misalignment is evident in fringe pattern



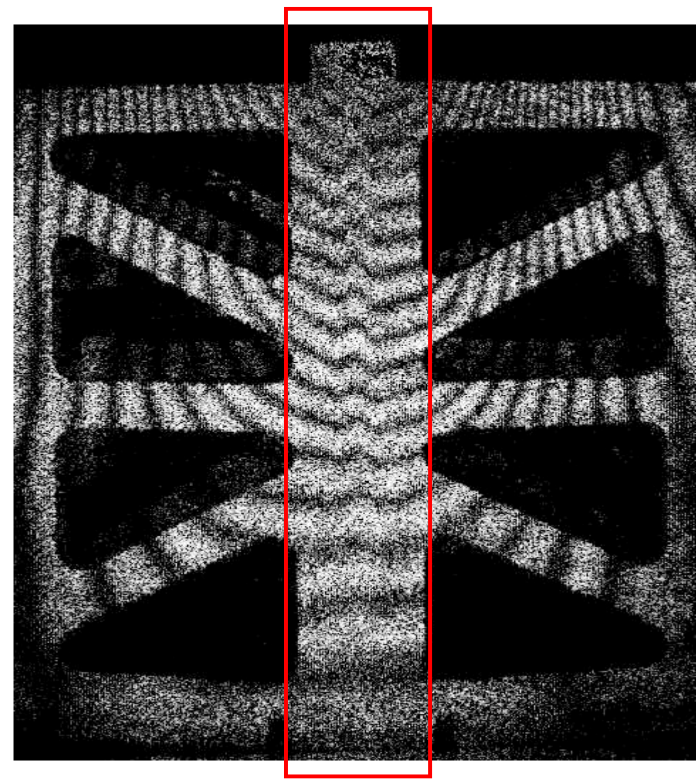
TVH RESULTS FOR LOAD CASE A

0.53 µm/N



Finite element model result

0.69 µm/N



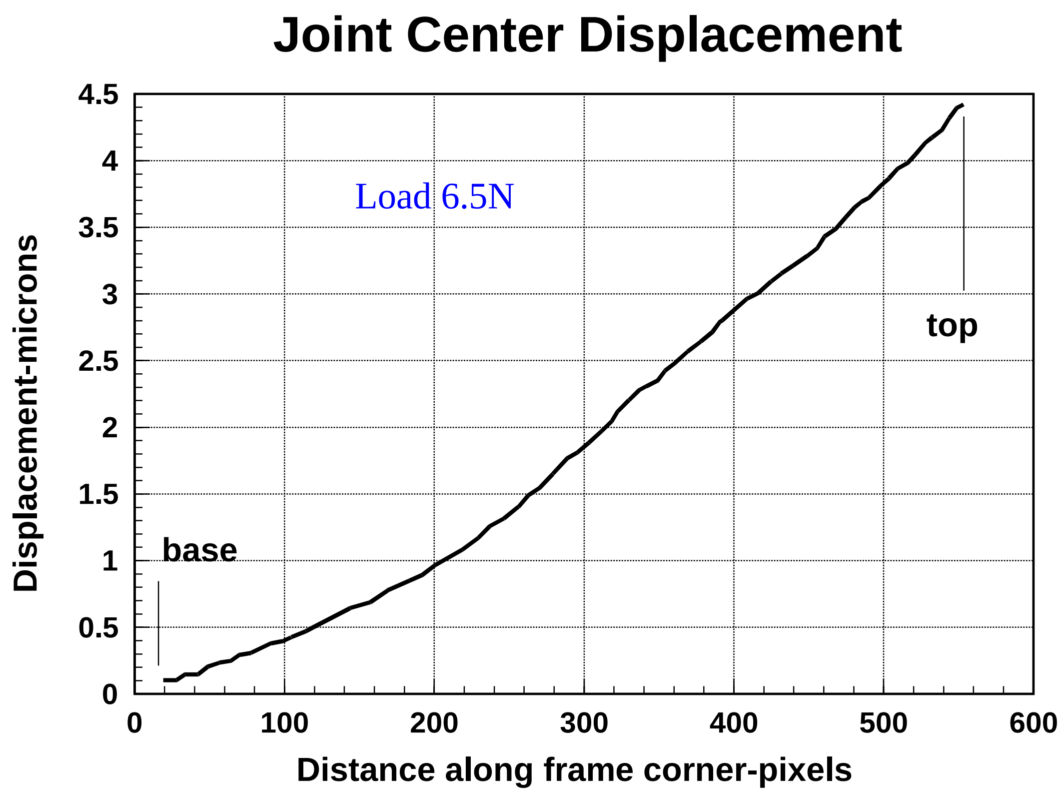
REGION OF UNWRAPPED PHASE PLOT

TVH Measurement of Joint Behavior

Top

Unwrapped image

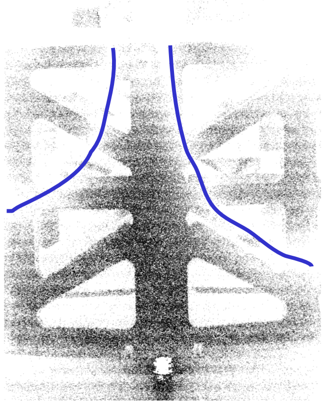
Base



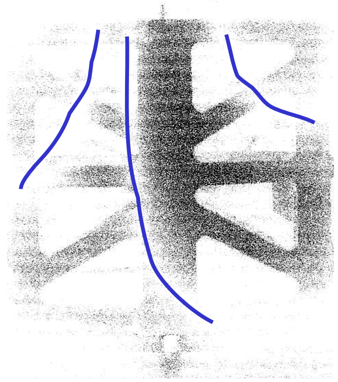
Frame Prototype Vibration Testing

- **Test setup**
  - Mounted to an aluminum plate, same as for static tests (w/out bar)
  - Used small PZT crystal to excite the frame
    - Frequency generator swept frequency range, 30 to 730 Hz, at constant displacement amplitude, not constant force (makes interpretation a little more difficult)
    - Test procedure amounted to watching for occurrence of fringes, indicating response in the structure
- **Magnitude of response tied to number of fringes produced, a large number of fringes corresponding to a resonance peak**
    - Response to excitation in the vicinity of actual mode is characterized by fewer fringes on either side of peak response
      - Lightly damped structure number of fringes increases quite rapidly as the mode is approached and conversely falls off quite rapidly as the modal frequency is passed
      - Structure with higher damping, the response is broader and fringes (fewer) are observed on either side of the peak response, over a significant frequency range
- **Test time**
  - Very short, further testing would be beneficial to improving our understanding of the FEA model for the global supports

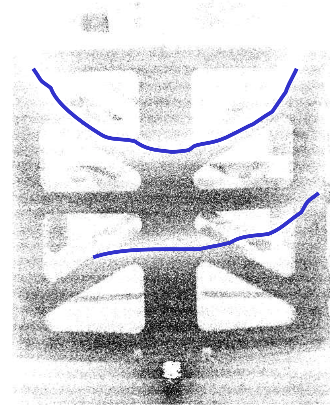
Fringe Plots at Significant Modes



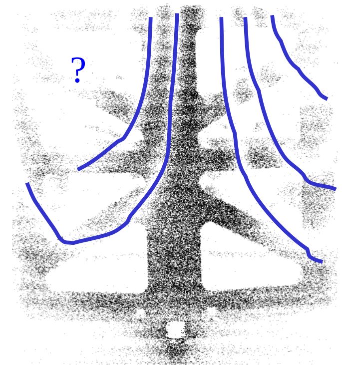
376 Hz
0.52 µm



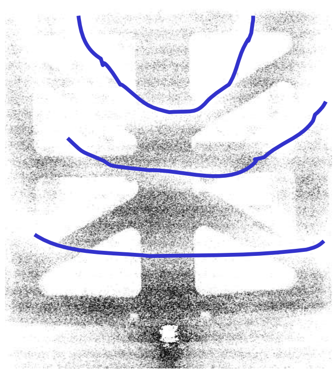
387 Hz
0.78 µm



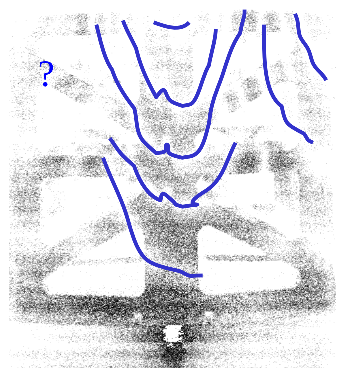
471 Hz
0.52 µm



546 Hz
1.04 µm



651 Hz
0.78 µm



721 Hz
1.3 µm

Negative of TVH fringe pattern, white paths through frame are taken to be fringes

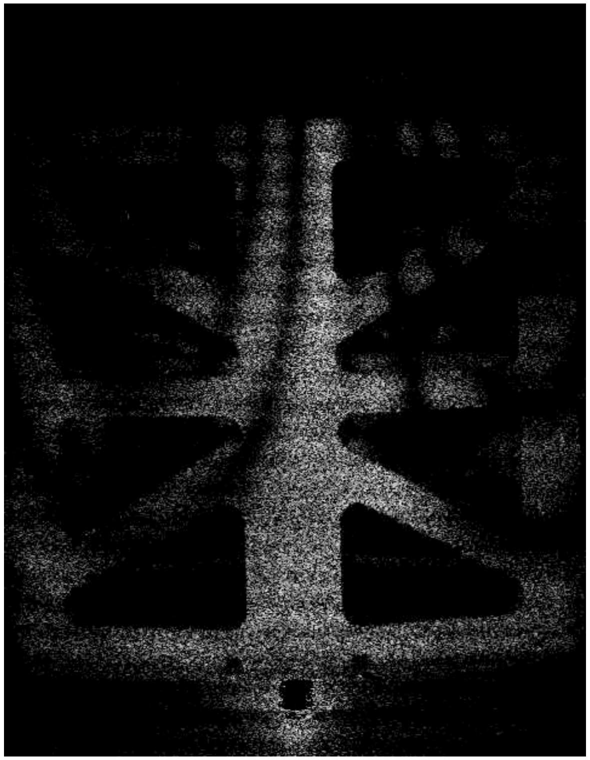
Looking for peak number of fringes along the corner of the frame where the PZT crystal is located

COMPARISON BETWEEN PREDICTED AND MEASURED FREQUENCIES

FEA Prediction- mode number/Hz		TVH results-Hz	Comments
1st	515.6	546	Fringe pattern agrees with FEA
2nd	520.8		No corresponding fringe pattern
3rd	705.8	721	Fringe pattern agrees with FEA
4th	705.8		*Duplicate predicted mode*
5th	748.8		Appears to be nearly pure cantilever motion
6th	748.8		*Duplicate predicted mode*
7th	986.3		TVH test did not span this point

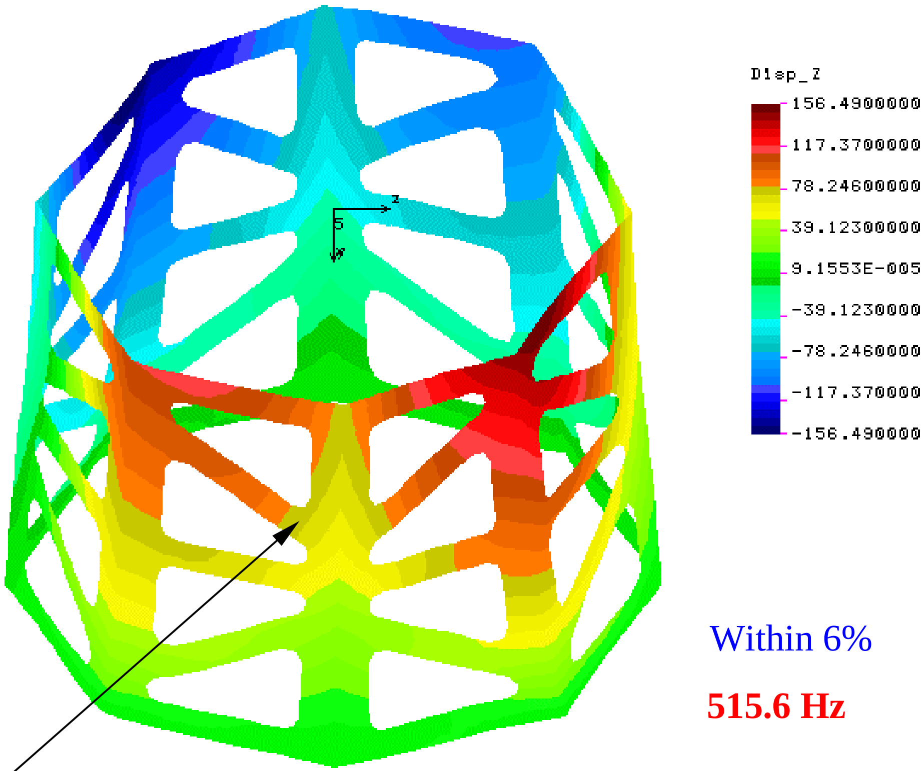
1st significant mode for the Frame Prototype

TV holography result



546 Hz

FEA prediction



Within 6%

515.6 Hz

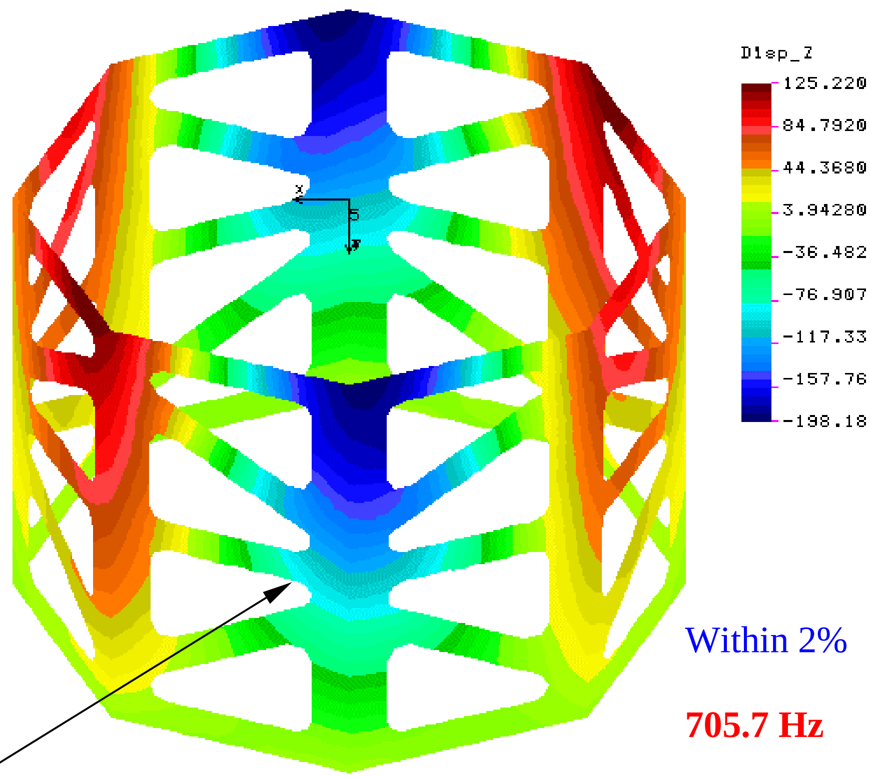
Shape of contours quite similar to fringe pattern

3rd Significant Mode of Prototype Frame Vibration

TV holography result

721 Hz

FEA Prediction



Within 2%

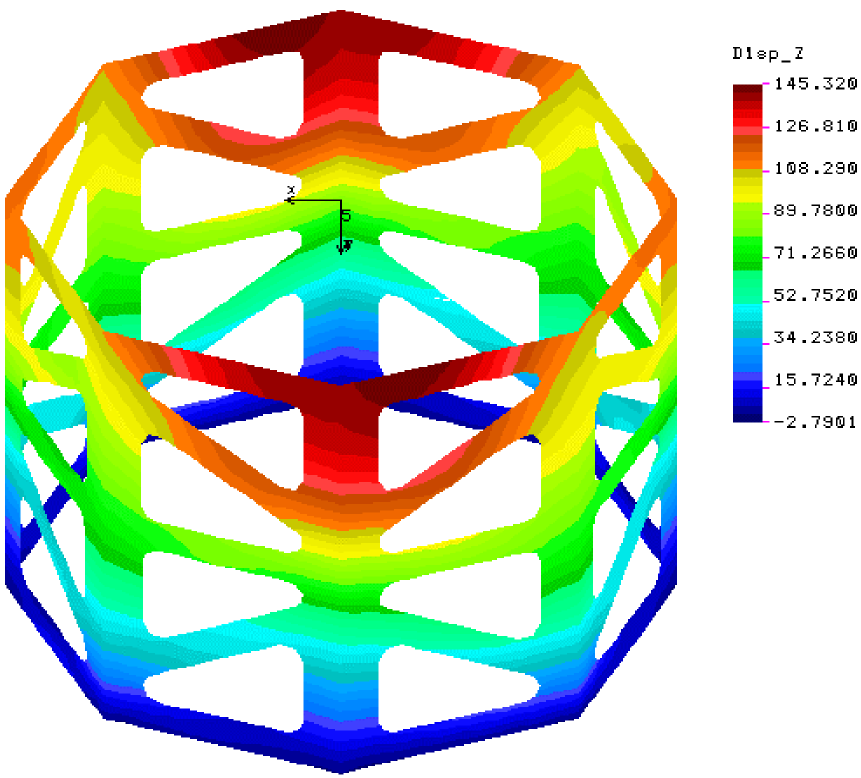
705.7 Hz

Again similarity with fringe pattern

5th mode Predicted by FEA

According to FEA the 5th mode mode shape is very nearly a pure cantilever motion.

The TVH testing stopped at 730 Hz, so quite possibly this important mode was missed.



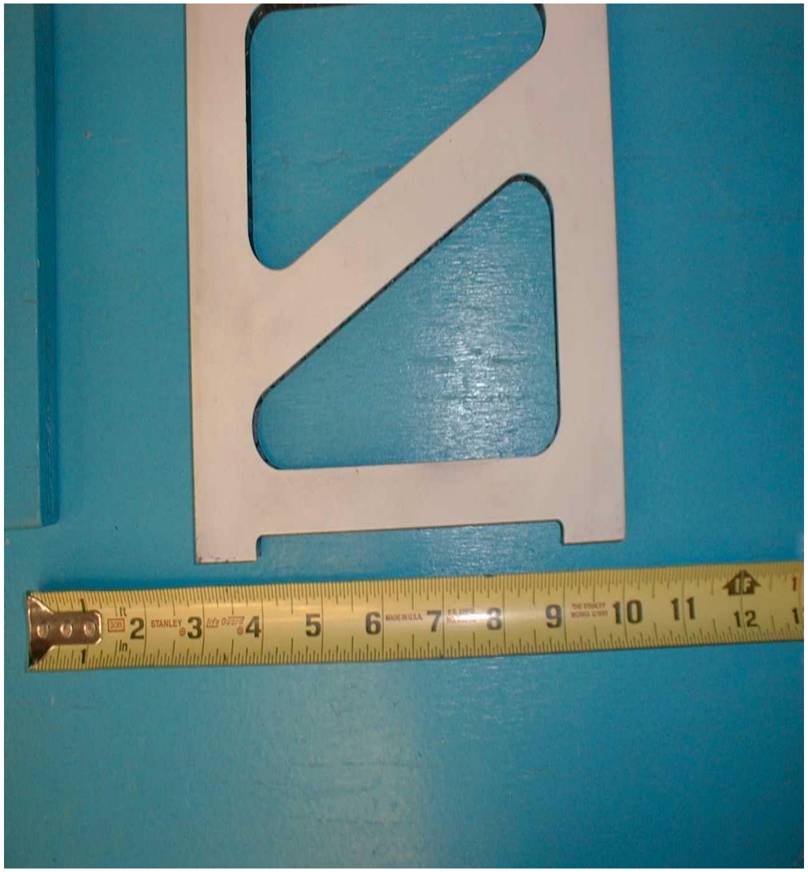
748.3 Hz

Comments on TVH Vibration Results

- **Vibration measurements made with TV holography**
  - The high resolution of the laser-based holography system enables the identification of vibration modes that might otherwise be missed with other methods
    - Interpretation of the results and making comparisons with finite element solutions can be difficult because of this extreme sensitivity
  - Case in point, the FEA did not predict any modes below 515 Hz, yet the TVH recorded evidence of 2-3 fringes of different forms, over the frequency range of 366 to 399 Hz, with no distinct peak
  - Conclusion of this preliminary interpretation (based on FEA solutions) is that the primary response is above the last excitation frequency (730 Hz)
    - Fair agreement obtained between TVH and FEA at two frequencies, 546 and 721 Hz where some consistency in mode shape between two methods existed
    - Response at 651 Hz may be the beginning of the peak response at 721 Hz
    - Response in cantilever mode shape to excitation at the top appears to be in vicinity of 748+ Hz

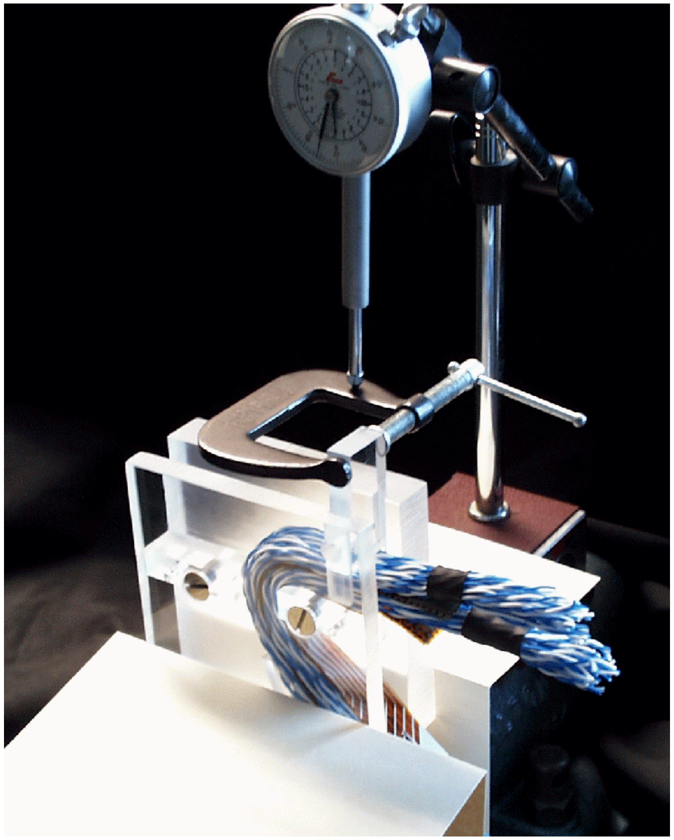
Services Require Frame Modifications

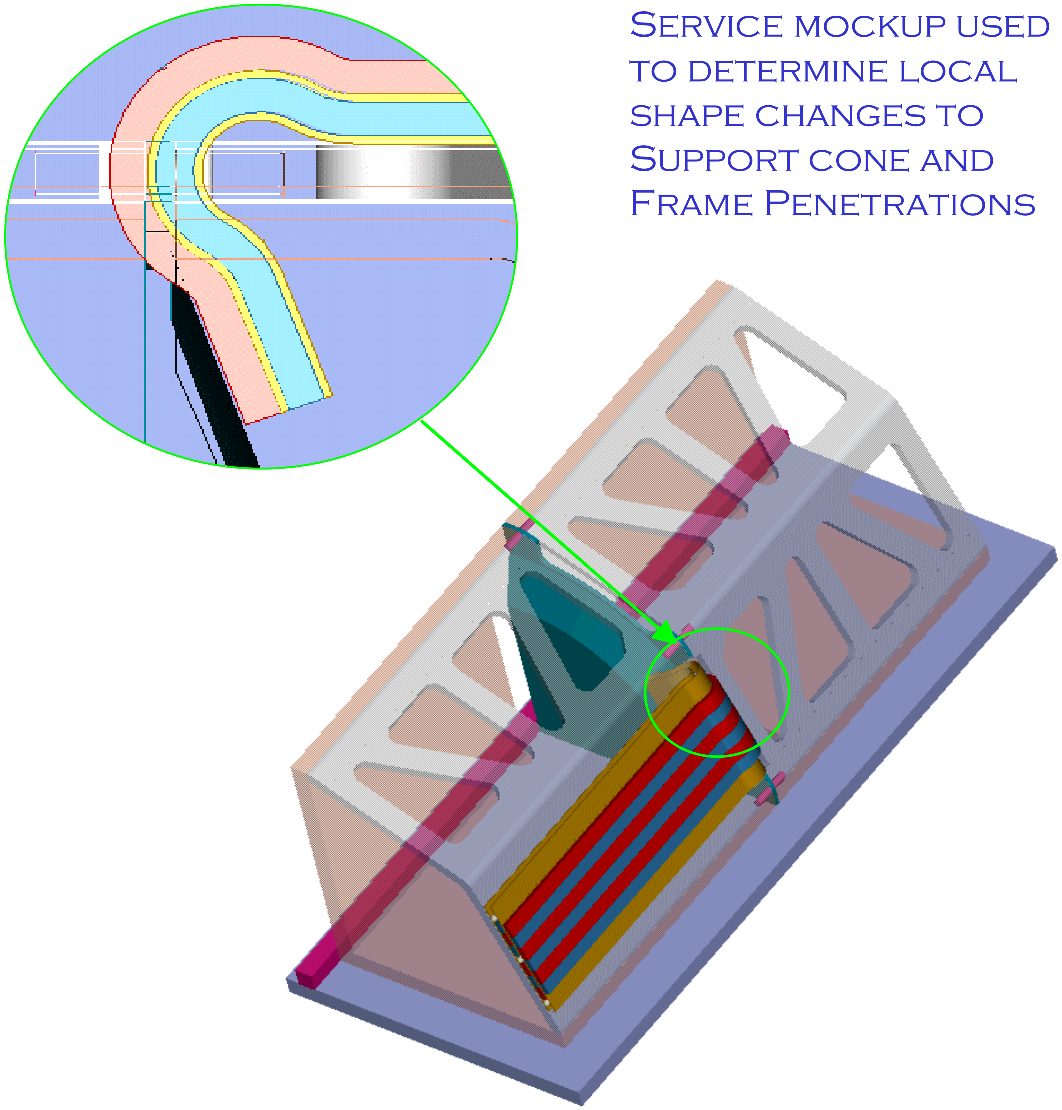
- **Exploratory testing with Single Panel Prototypes**
  - Both honeycomb and carbon foam foam core panels were modified
  - Honeycomb panel
    - Lower section of panel modified with 7.5 mm cutout
    - Provides additional space for service routing to outside
  - Carbon foam core panel
    - Lower cross member removed entirely
- **Test**
  - Simple bend test, measuring response holographically



Pixel Detector

Frame Penetration





Service mockup used to determine local shape changes to Support cone and Frame Penetrations

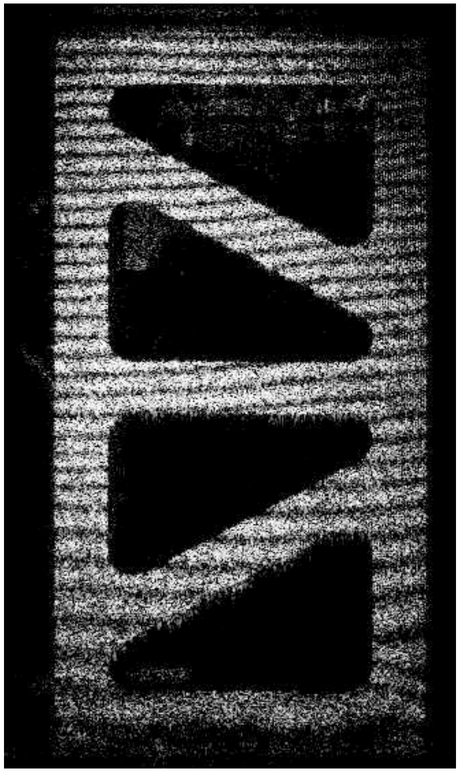
Model of Service Bundle Cross Section

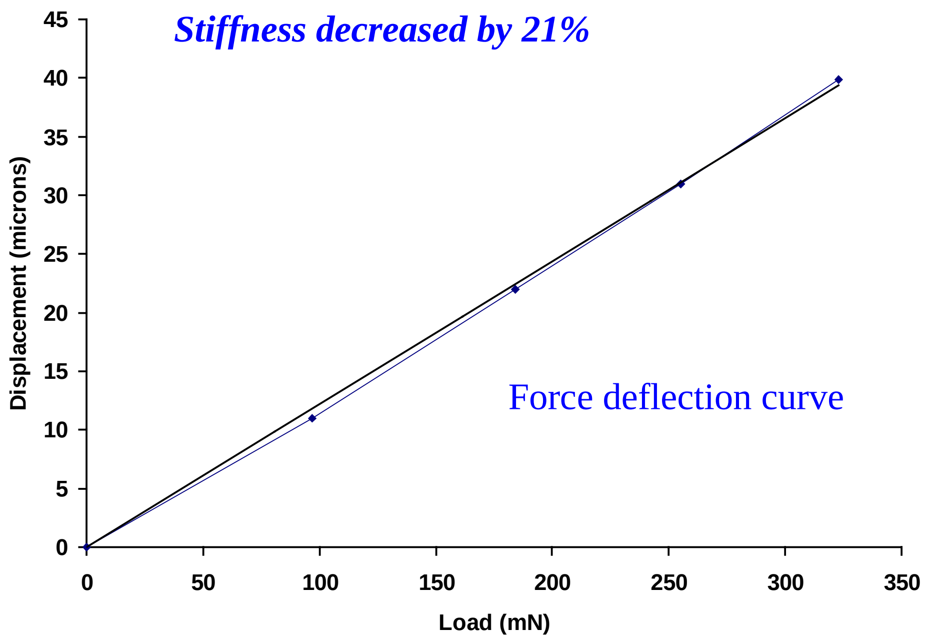
- Verified Packing Factor and Bend Radii Approximately 20% safety margin
- Measured Force-nominally 600gramF per penetration

LBNL Mechanical Engineering
E. Anderssen LBNL

Modified Honeycomb Panel

8.9 microns @ 68mN (131 microns/N)





Summary of Observations

- **Preliminary conclusions from testing**
  - Reasonable agreement exists between the static predictions and the measurements taken at very low strains
    - Remaining difference is tentatively attributed to method of representing the loading bar and its effect on the stiffness of the frame
      - Comparison of predictions with measurements suggest a stiffening from the bar that is not exactly modeled correctly-bar representation is too crude
    - No convincing evidence of non linearity in the panel response to static loading
      - Testing at higher strains will follow at a later date
  - Agreement with the dynamic response measurements appears improved over the static correlations
    - Further testing with improved fringe contrast and at higher frequencies would help in isolating the fundamental vibration modes and adding confidence to our global support FEA model

Issues Remaining

- **Impact of Services on Frame**
  - Service penetration
  - Strain Reliefs
    - Force from service bundles
    - Extra structural coupling
- **Disk Support Frame penetrations**
  - Study impact on Frame while at LBNL
- **Update 3D models and Finite Element Model to represent recent changes**
  - Inclusion of the Thermal Barrier into the overall FEA model
    - Integrated with End-plate and Services
  - Support Cones and End Plate Prototypes
    - Interface of Barrel Shells to Support Cone--Discussions this Week
    - Thermal Barrier Interface to Support-Cone and End-Plate
- **Produce Support-Cone, and End-Plate stiffener Prototypes**
  - Test structural connections to frame members
  - Lends to argument that Frame prototype is representative of Global support performance

Conclusion

- **Solid progress on prototyping**
- **Preliminary results of prototype testing very promising**
  - Indications are that FEA is predictive and understood
  - Prototypes have not severely underperformed--no showstoppers
  - Too early to claim all spec's are met
- **More testing and prototyping is necessary to verify the total Global support frame concept**
  - End frame and cone prototypes are necessary to fully qualify prototype frame performance
- **Integration and Configuration Control are coming up to speed**
  - Design and integration of services and barrel shells has progressed open loop
  - Need to fold recent geometry changes into FEA before proceeding too much farther