Global Supports CDR

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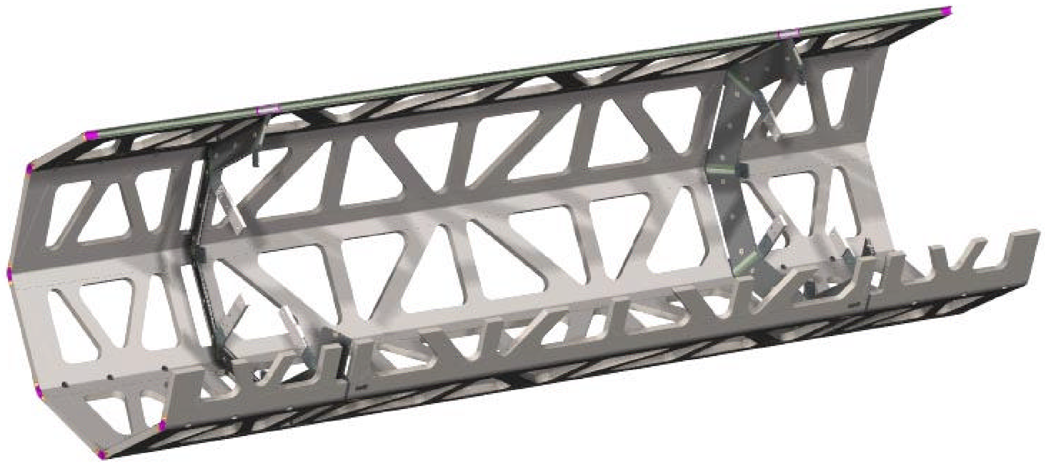
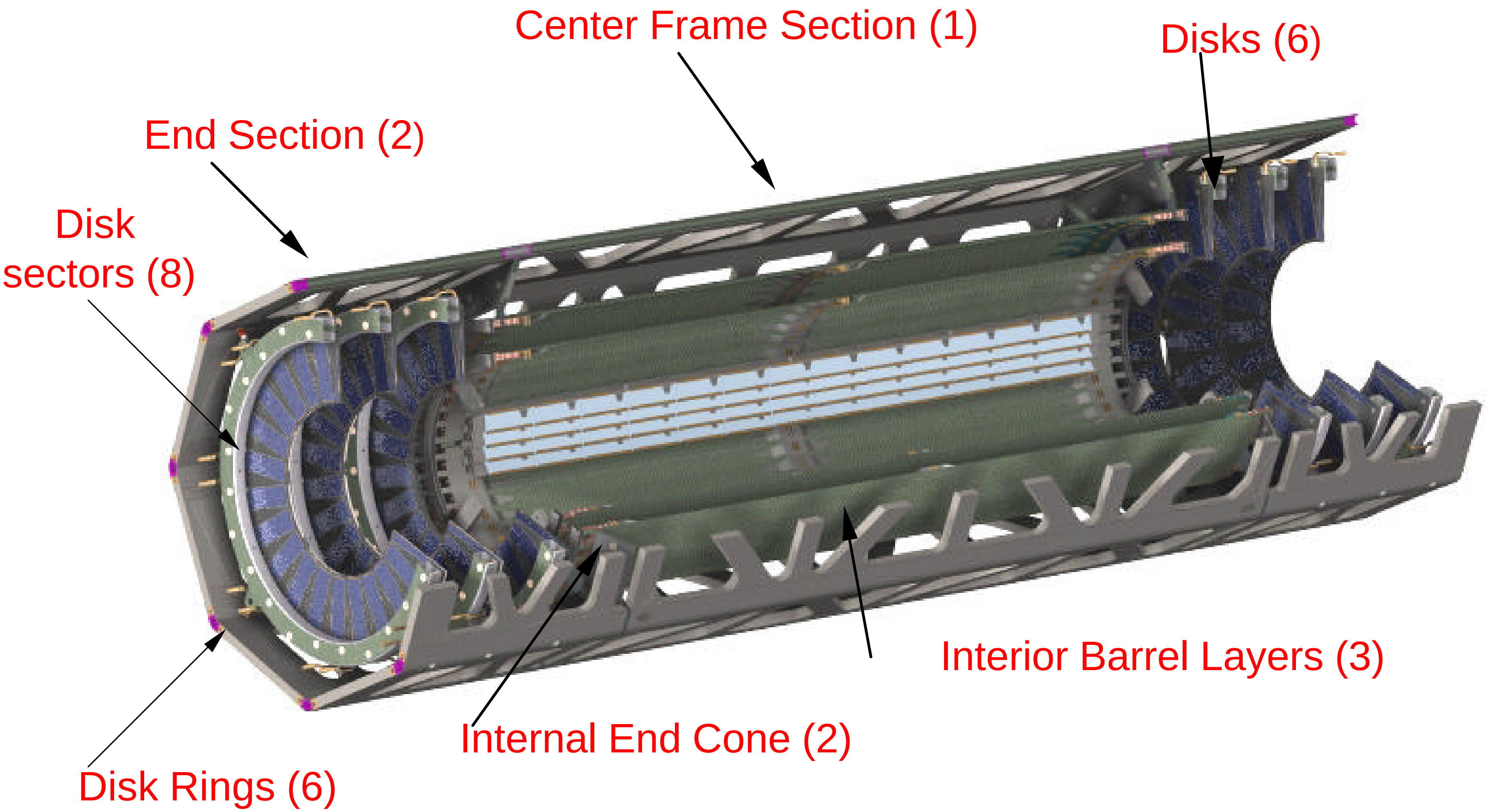
LBNL



Outer Frame and End Cone

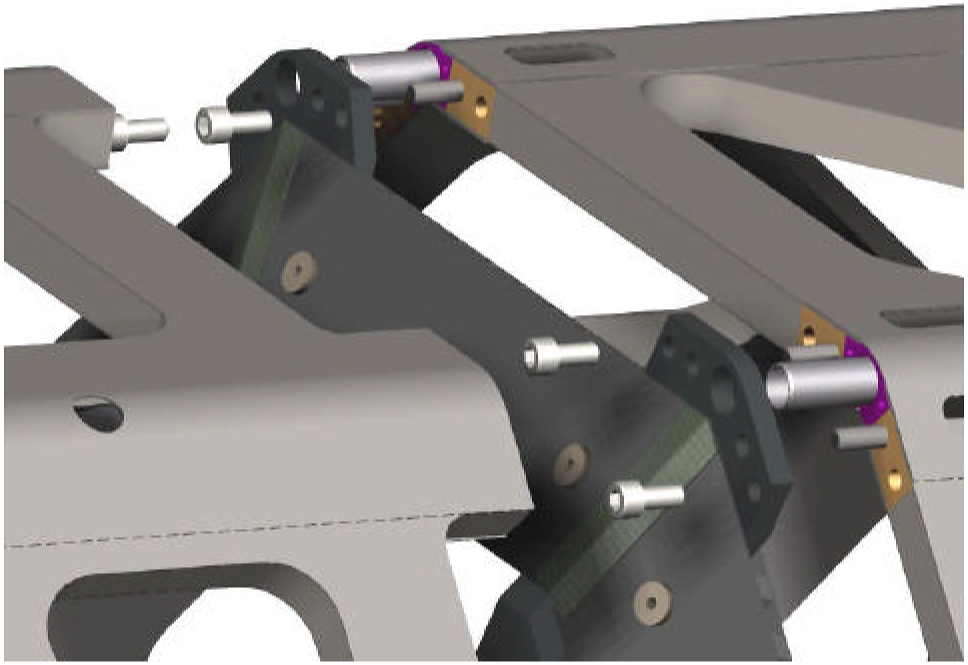
Global Support Concept



(B-Layer and Services not shown)

Frame Connections

- Exploded View of Outer Frame Connections
  - Alignment tube between sections
  - Fasteners retain End Cone to Barrel Section
  - Fasteners reside in recessed slots, which fix center section to Disk Frame sections



Fundamental Constraints

Design Constraints

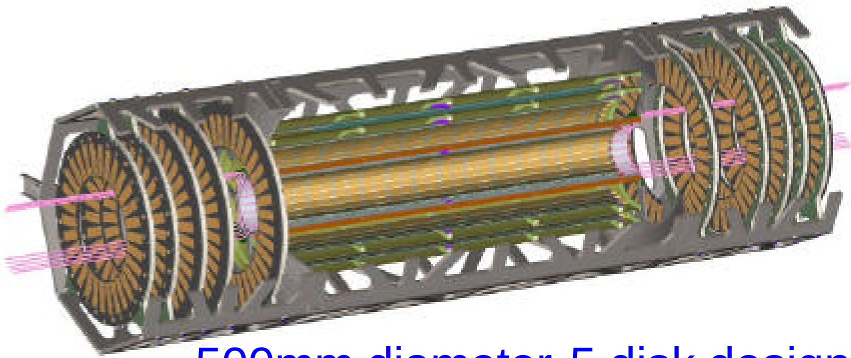
- Low mass
  - Composites, high stiffness to weight ratio
- Highly stable
  - Low CTE composites, insensitive to moisture
- Low percentage radiation length
  - Ultra-thin, predominately carbon material
- Materials compatible with high radiation environment
  - Low activation materials, radiation insensitive composites
- Composed of subsections to facilitate assembly
  - End sections for planar pixel disk assemblies
  - Barrel section for multi-layer of circumferential array of staves
- Insertable and removable in the ATLAS Detector
  - Registration and alignment to SCT requires indexing feature
- Mounting
  - To SCT barrel supports, possibly without regard for kinematic features

Global Supports Effort

- Development Steps
  - Assessed construction options at the onset
    - Chose flat panel concept over tubular frame primarily based on cost, but also construction simplicity, which equated to improved dimensional accuracy
    - Simple, low cost tooling for assembly
  - Frame sizing exercise-*via detailed FEA*
    - Selected sandwich construction parameters
    - Selected sandwich facing and core materials
  - Constructed full size prototype of outer frame section
    - Conducted extensive testing using precision measuring tool to confirm design and to validate Global Support Frame FE model
  - Constructing full size prototype of end cone---*1st unit complete*
    - Prototype testing of bi-panel is complete
- Design Status
  - Resized frame to 432mm outer envelope dimension (compatible with insertion requirement)
    - Design confirmation planned through FEA studies—*largely complete*
    - *Mounting aspects still under study*

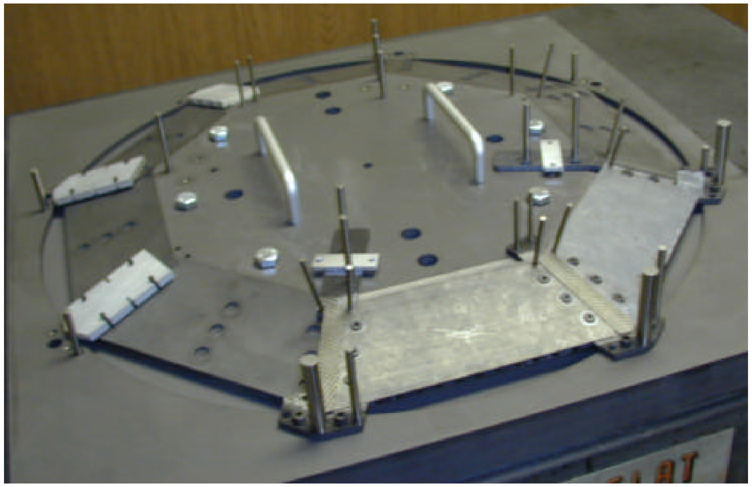
Design Steps

- Analysis
  - FEA design studies
    - Key sandwich dimensions
      - Facing 0.43µm
      - Core -10mm
    - Materials
      - UHM composites

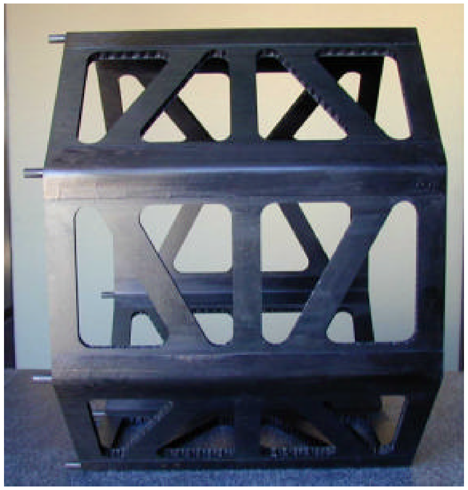


500mm diameter-5 disk design

- Prototyping Objectives
  - Manufacturability
  - Cost
  - Technical
    - Validate FEA
    - Static stiffness
    - Dynamic stiffness

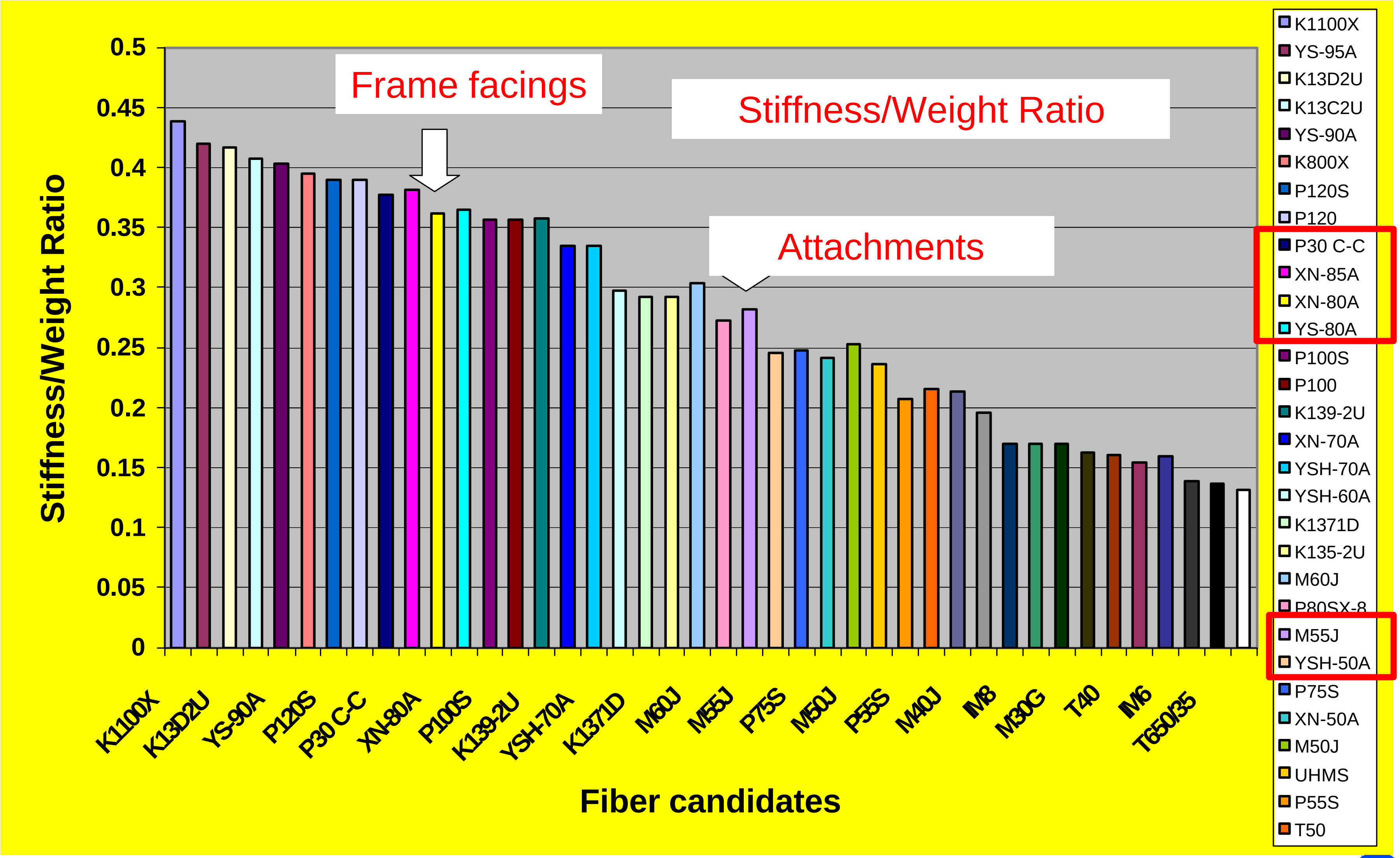


End cone and tooling

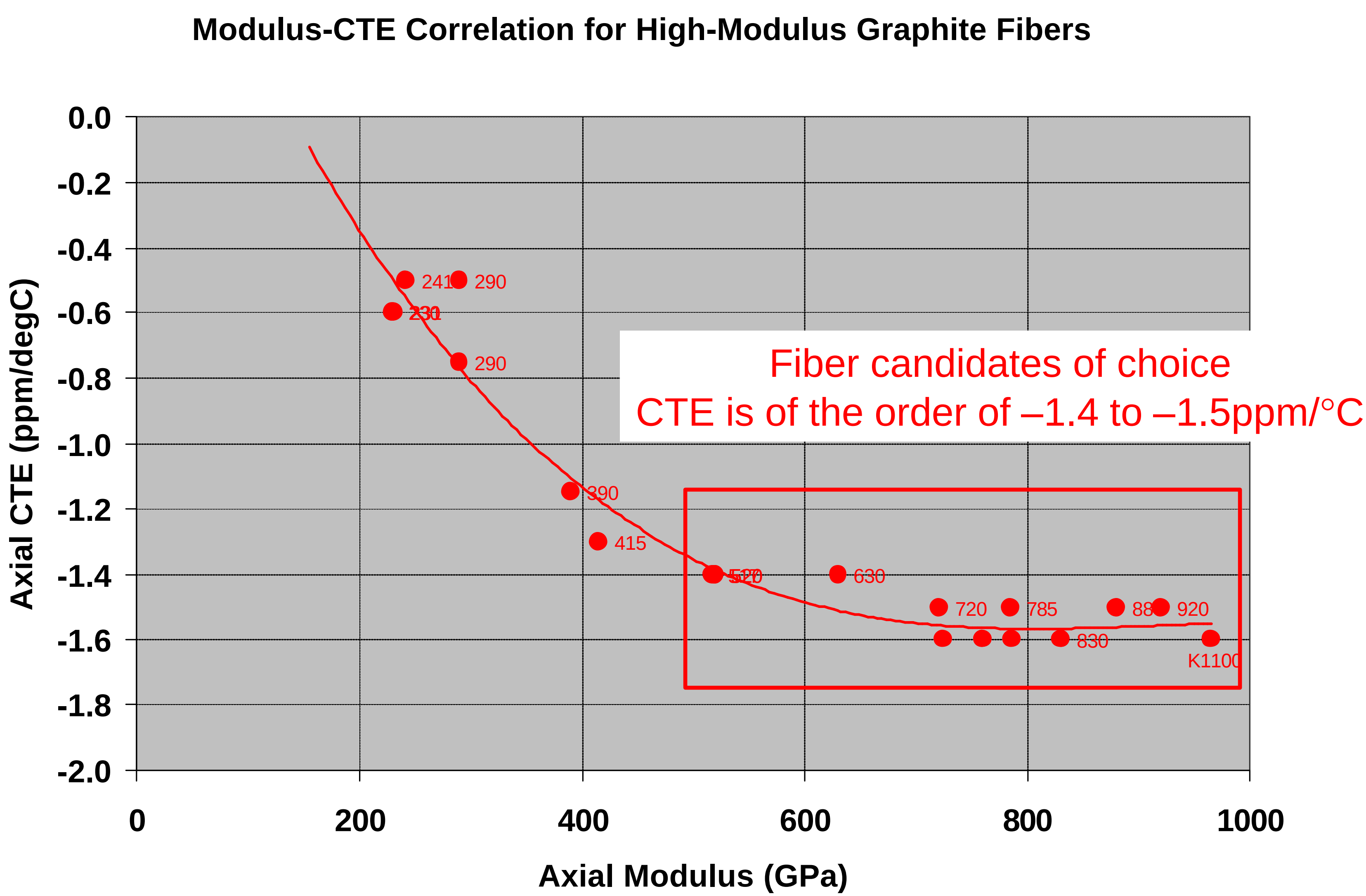


End section

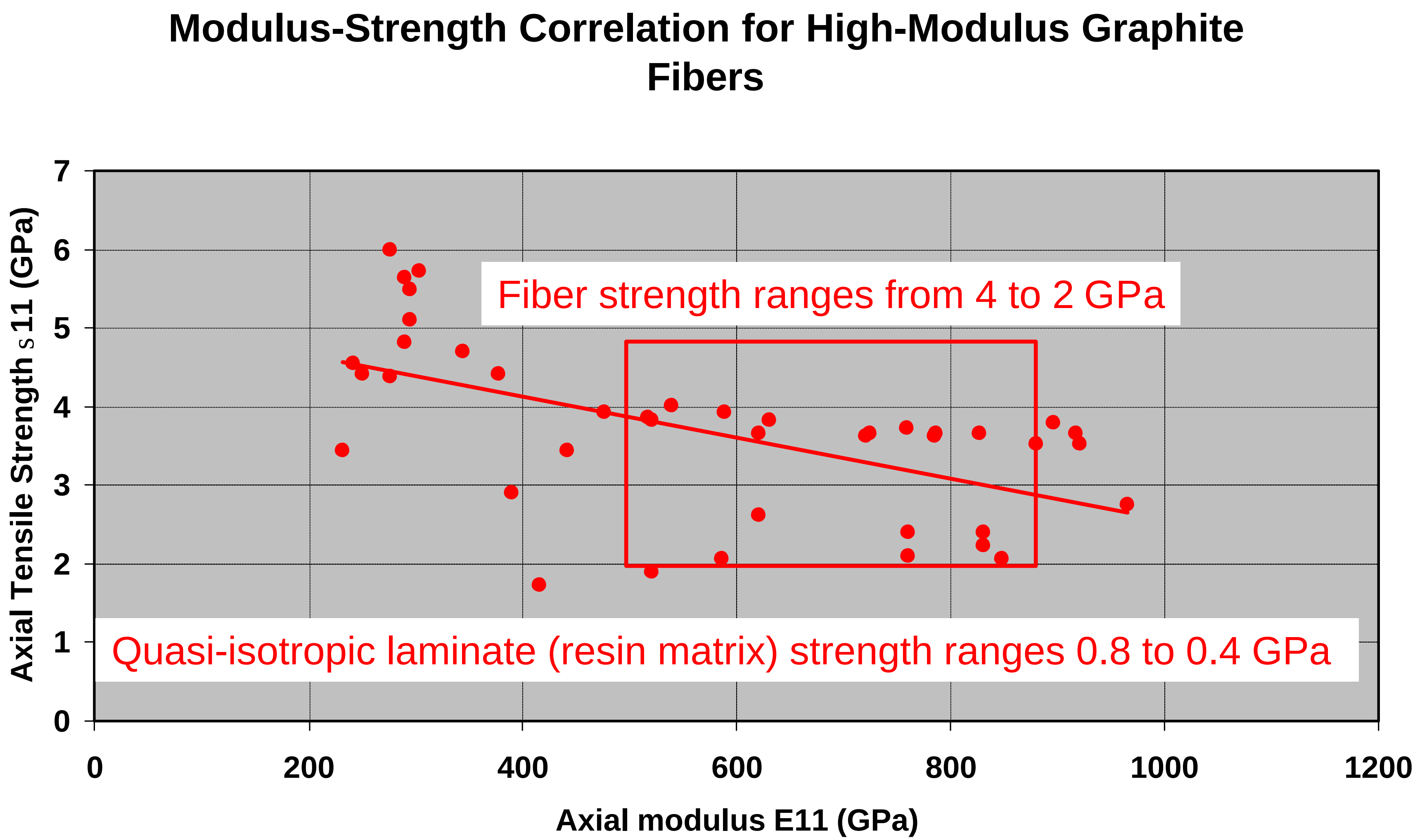
Materials Options



Materials Options



Materials Options

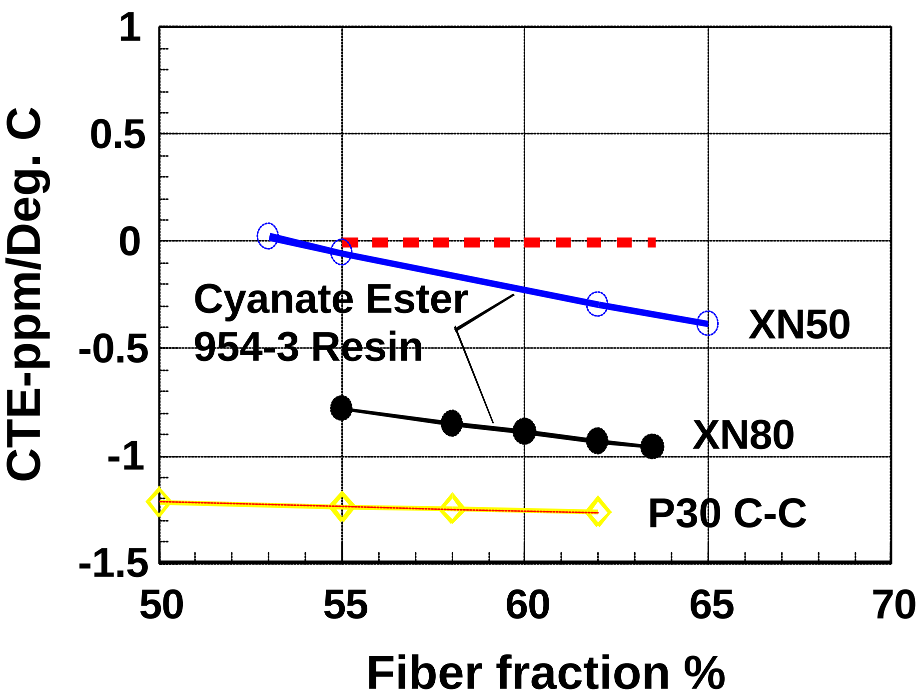


0.4GPa=58,021psi

Laminate CTE

- Structure Thermal Stability
  - High modulus fibers result in negative CTE laminates
    - In a sandwich configuration this is mitigated to some extent, and the CTE tends toward zero for a low expansion GF/CE honeycomb
    - Frame attachment pieces are YSH50 fabric, very similar in CTE as XN50
      - CTE is near zero for 58% fiber fraction, typical of the prototypes
  - *We estimate that the support structure and mounting interfaces will be near zero CTE*
    - *Thermal stability should not be an issue*

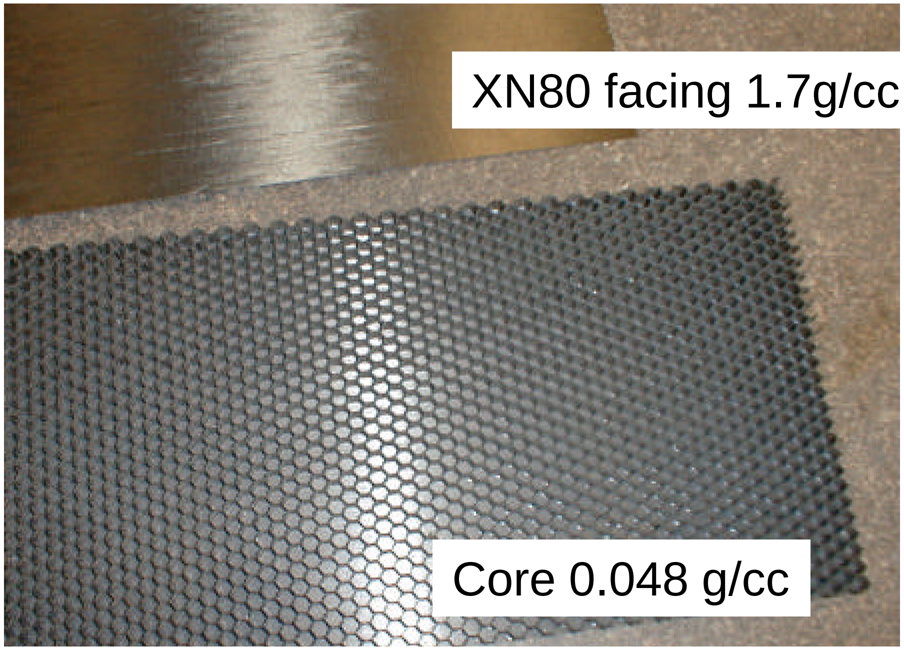
Quasi-isotropic Laminates



Flat Panel Elements

Materials: low CTE and low CME

XN80 Graphite fibers/cyanate ester resin-8 layers quasi-isotropic~0.42 mm



XN50 graphite fiber/CE Core 10 mm thick

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

XN80 Laminate

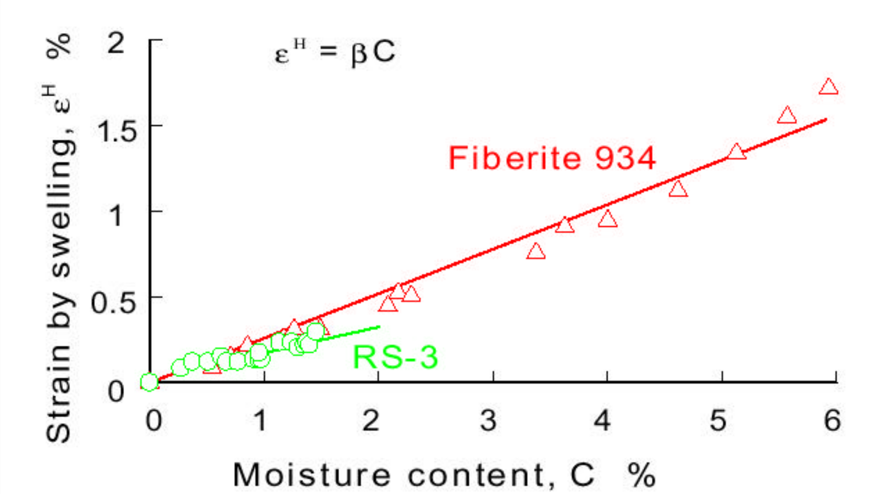
Calculation for quasi-isotropic
Layup, 0/60/-60/s, 60% FV

E	**162.6/(23.58)**	**GPa/(Msi)**
s_u	**463.3/(67.2)**	**MPa/(Ksi)**
e	**0.285**	**%**
r	**1.774**	**g/cc**
a	**-0.9**	**ppm/°K**
b	**0.001488**	**(DL/L) per %weight gain**

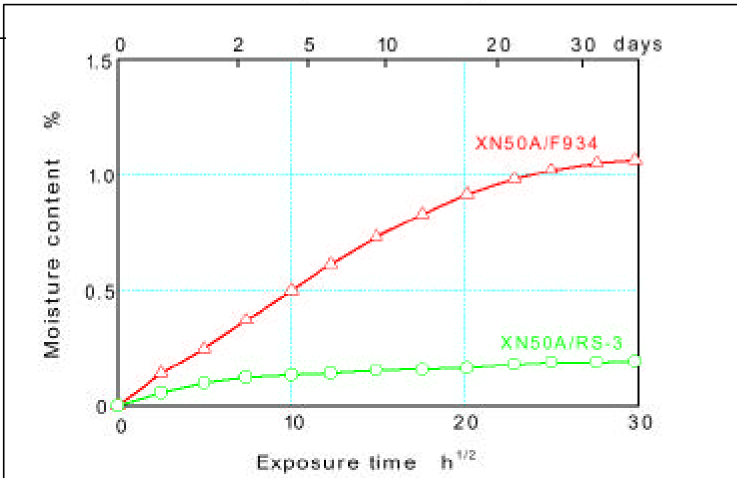
Tensile Modulus Msi	Tensile Strength Ksi	Strain to Failure %
0° Direction		
21.8	55.1	0.25
22.8	88.8	
23.3	71.6	0.31
23.9	72.8	0.31
23.4	79.8	0.33
Avg=23.5	***Avg=74.7***	***0.32***
90° direction		
21.0	61.3	
21.4	60.9	
20.7	60.3	
21.4	62.9	
21.6	61.1	
Avg=21.2	***Avg=61.4***	

Moisture Sensitivity

- Composite Matrix Selection
  - Selected cyanate ester resin because of low moisture absorption and low volumetric swelling
    - EX1515 resin by Byrte Technology, 0.4% *neat* resin moisture absorption, low temperature curing, very stable, resistant to microcracking
    - RS-3 resin supplied by YLA, similar characteristics
  - XN80 prepreg material
    - Estimated CME, 0.0015 per % weight gain
      - .005 (0.5% max gain, or release)
      - $7.5\mathrm{x}10^{-6}$ $\Delta L/L$ change or roughly *10.4 microns* for the *1.4m frame length*
- *Moisture effects-minor initial inconvenience*



Swelling Behavior of Matrix Resins at Room Temperature, 100%RH



Moisture Absorption of CFRP Unidirectional Laminates (80°C,80%RH)

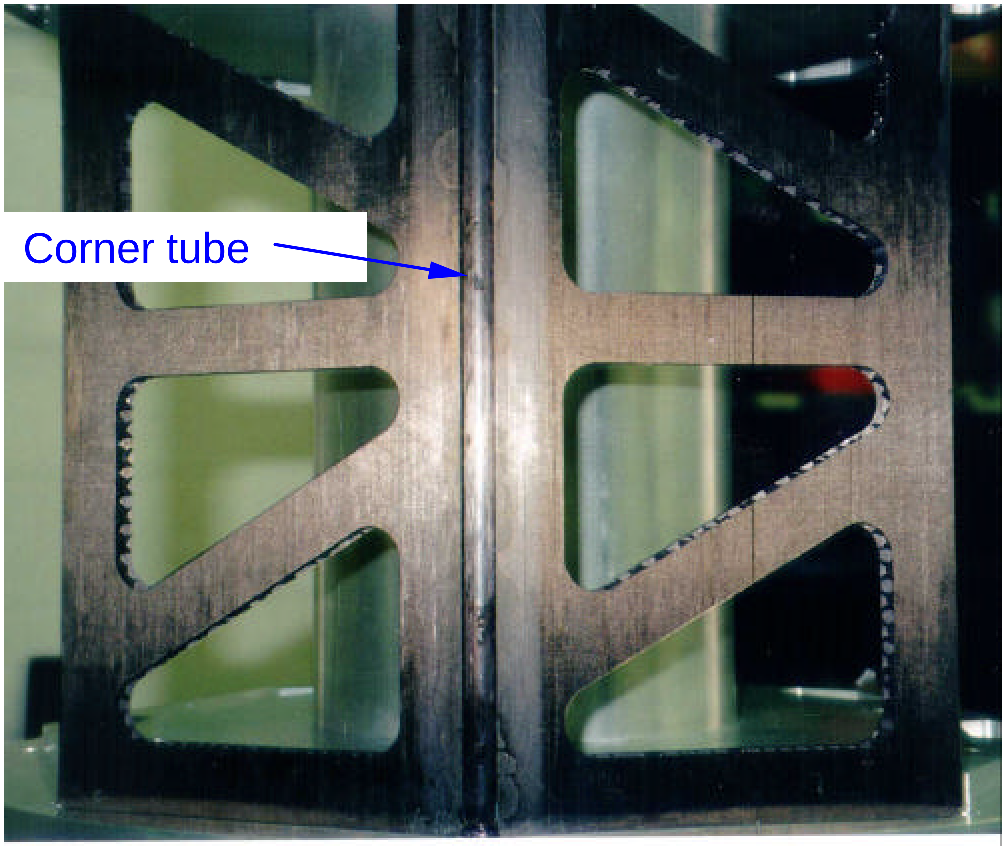
Frame Prototyping

355 mm long Frame Section---*Disk Section*

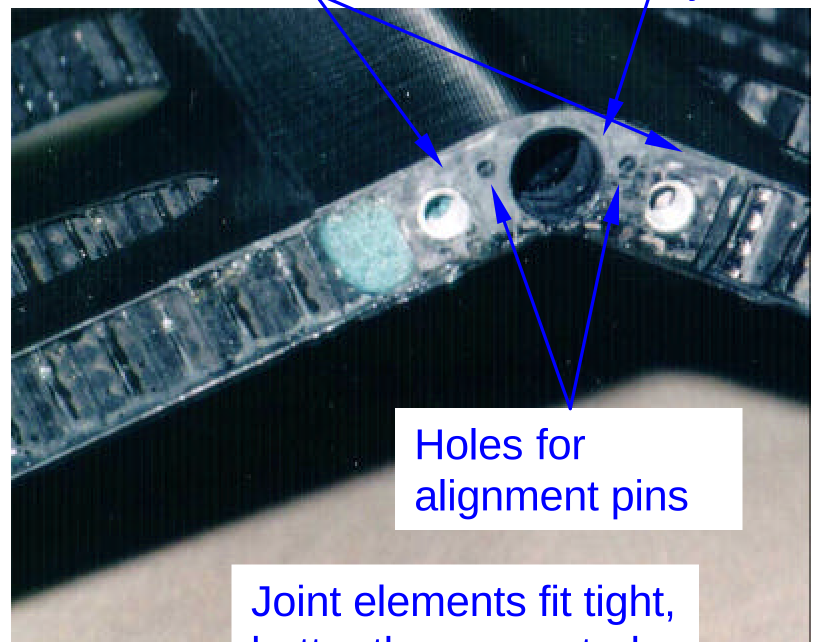
- Fixture function
  - Holds panel parts in place during bonding, utilizing self-jigging features of the corner parts
  - Index pins machined into top and bottom fixture plates hold circumferential alignment
  - One fixture for all three sections
- Assembly steps
  - Assemble sandwich panels with corner 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

Panel weight 84.3 g after removal of material (39.7% reduction)

Verification of Bonding/Assembly Methods

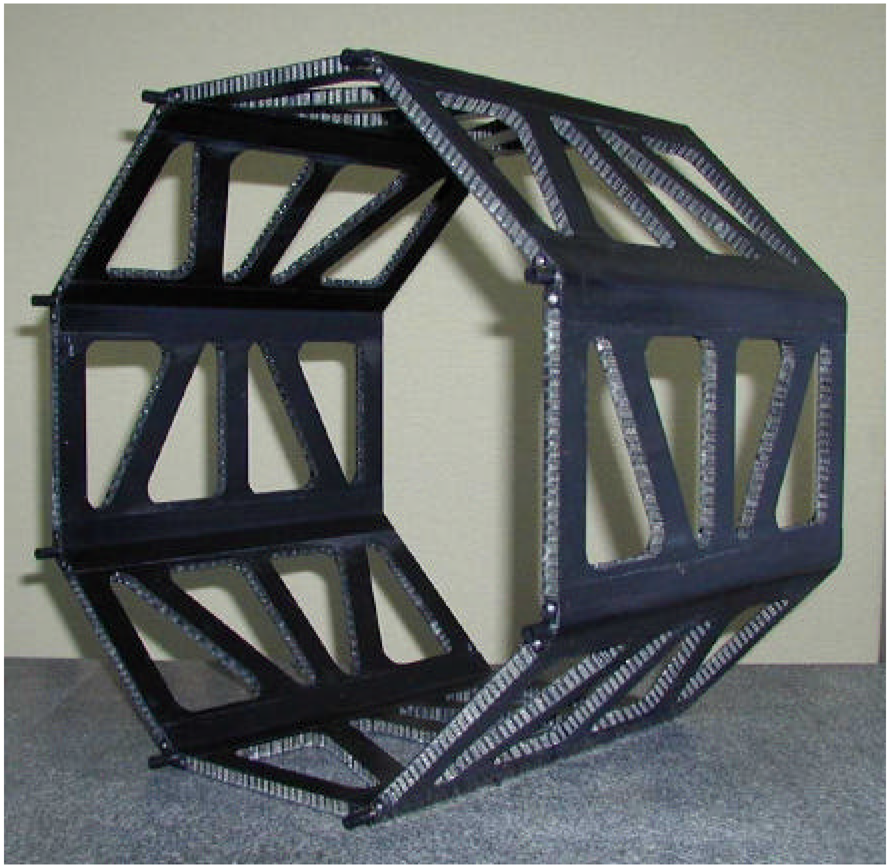


Tube fit-up in recessed cavity



Frame Section

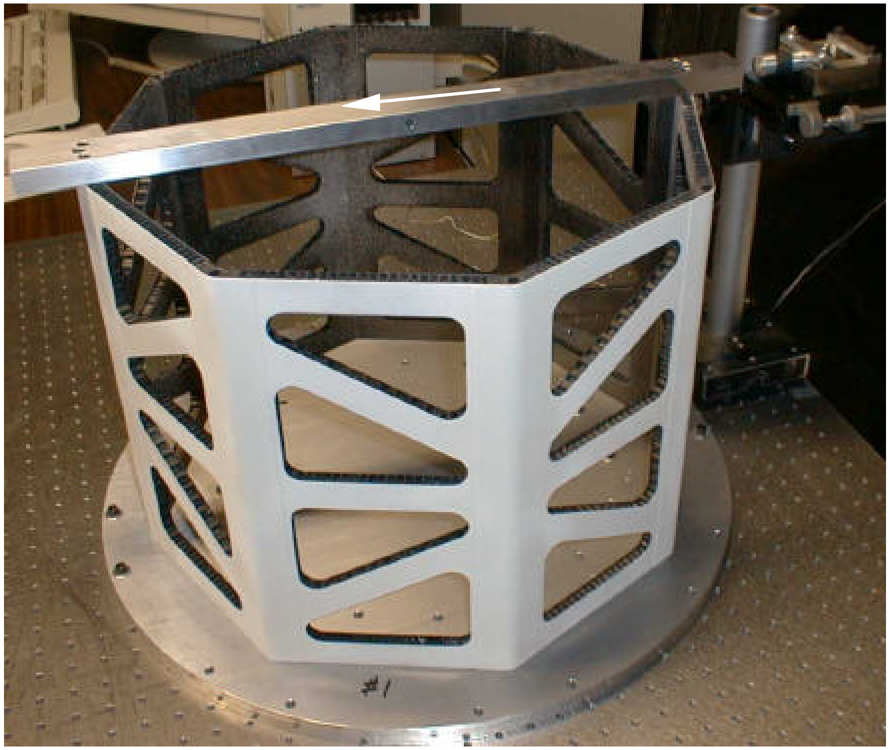
- Testing evaluated:
  - Stiffness at low strain levels, at level simulating the application
    - Composite properties measured at higher strains, yet properties were used to design at low strains
  - Effect of bonded joints
  - FEA modeling approach for Global Supports
- Testing issues
  - Load Application
    - Difficult to apply load without influencing measurement
  - Boundary conditions
    - To test, frame is mounted to a base support structure
      - Objective is to limit compliance at base



One of Many Tests
Transverse Loading-*In Line With Corners*

- Frame test-setup
  - 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
- TV holographic imaging of distortion
  - Load applied at center of bar axis
    - Axis alignment is achieved by adjustment of line of action
  - Symmetry noted in fringe pattern, suggesting good alignment

Load Case A



Test Evaluation

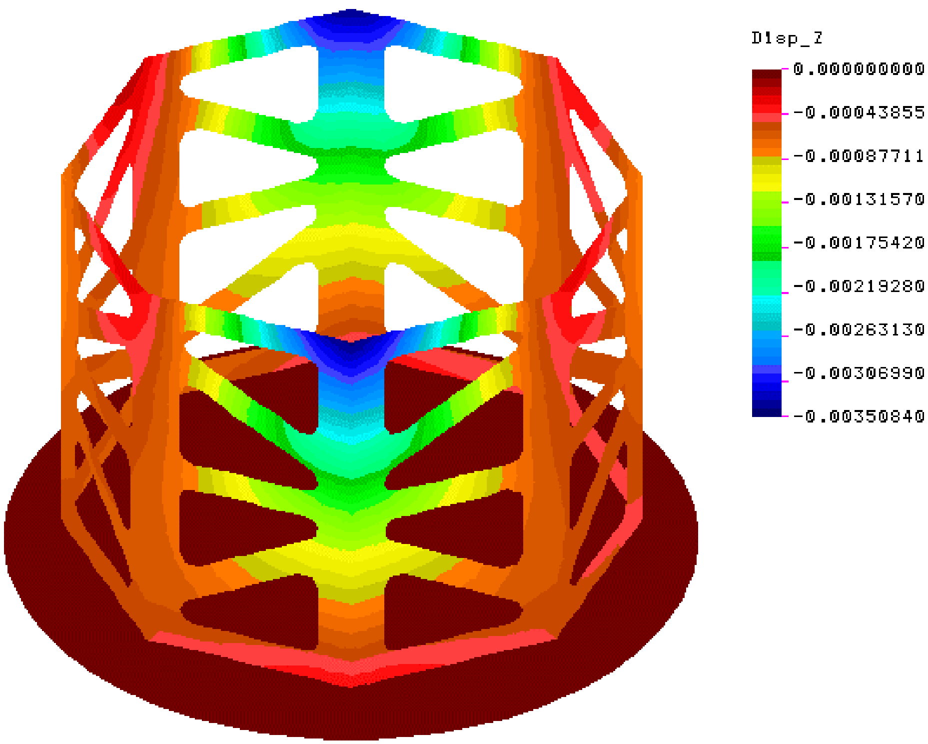
Transverse Loading-*Typical Load Case*

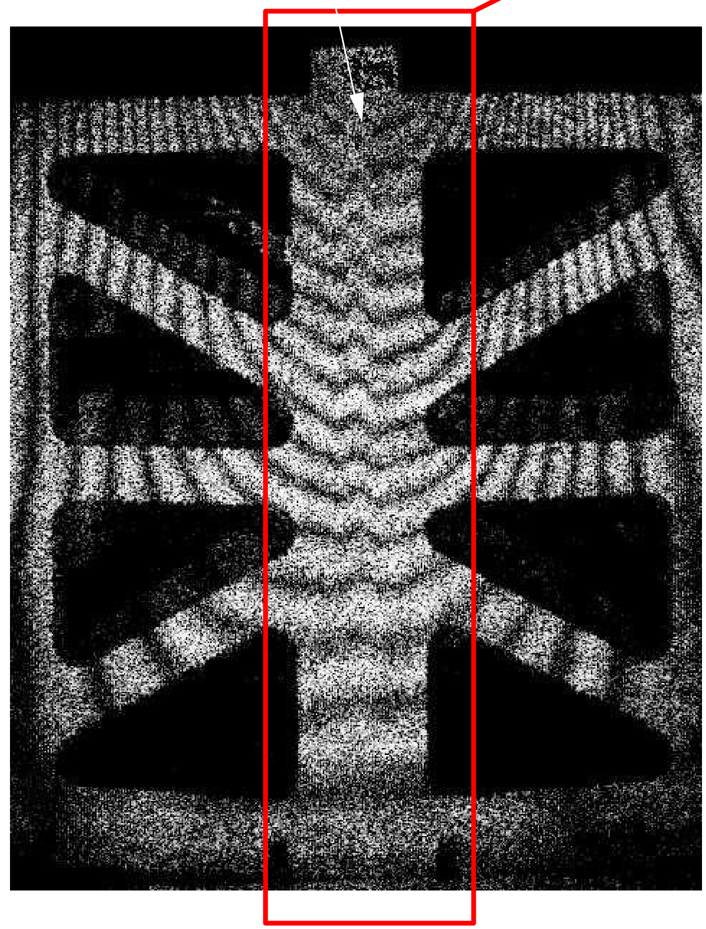
0.53 µm/N

Peak distortion in corner

0.69 µm/N

Corner region





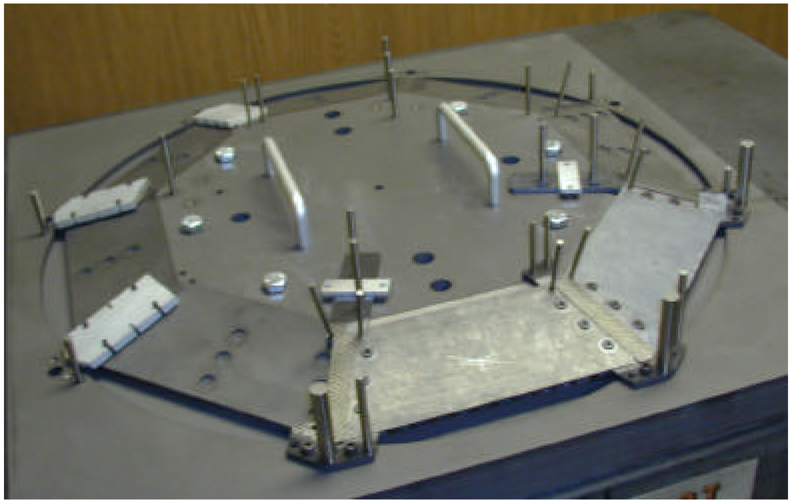
Finite element model result

Prototype Results

- Summary
  - Frame construction principles demonstrated
    - Dimensional accuracy quite good, but improvement is expected by using low thermal expansion tooling option
  - Material options are well understood
    - Stiffness
    - Strength
    - Radiation resistance
  - Current design process
    - Down sizing outer dimensions to achieve insertable feature

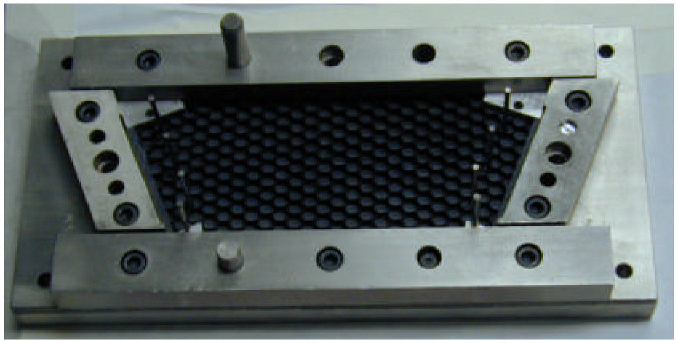
End Cone Design

- Prototype Construction for 500mm diameter frame
  - Objective-test out construction approach
  - Validate FEA approach
  - Evaluate use of P30 CC facings for the sandwich facings
- Salient points
  - P30Carbon-carbon facings
  - XN50 honeycomb, 4mm thick
  - YSH50 quasi-isotropic laminate for outer supports and inner tabs for mounting barrel shells

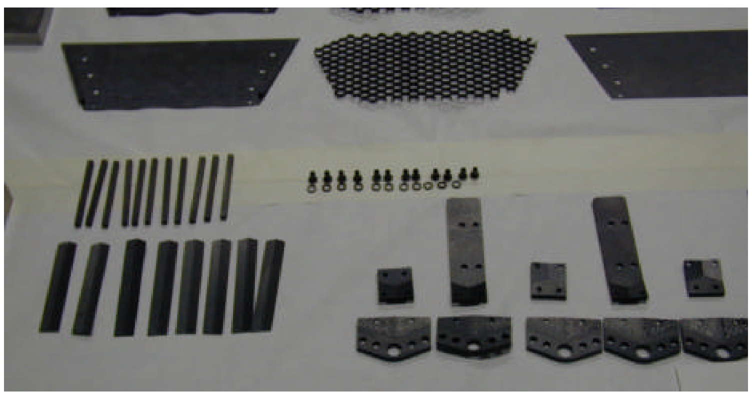


Graphite tooling with two test panels

End Cone Development

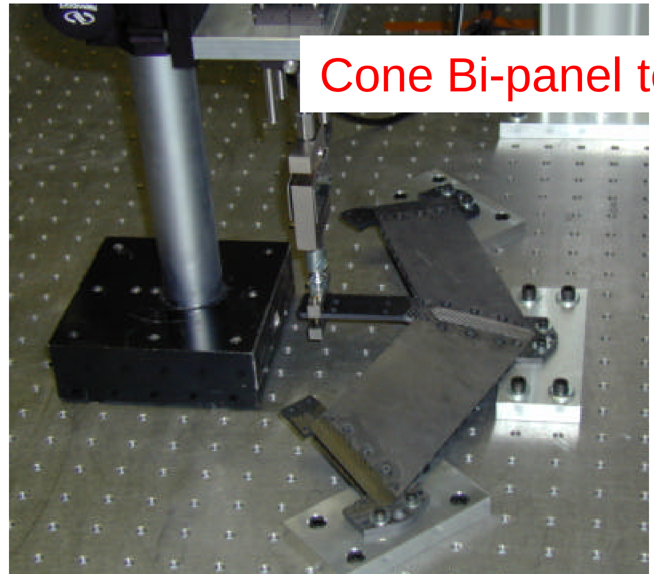


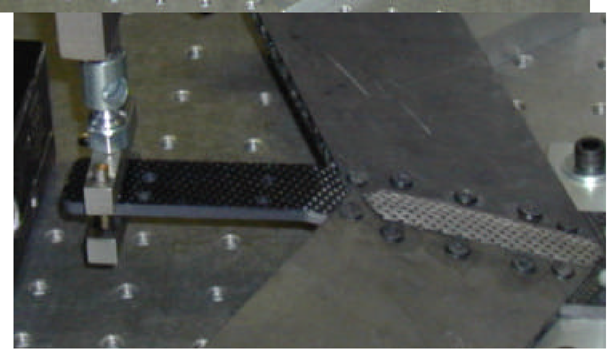
Panel bonding fixture



End cone components

Cone Bi-panel testing

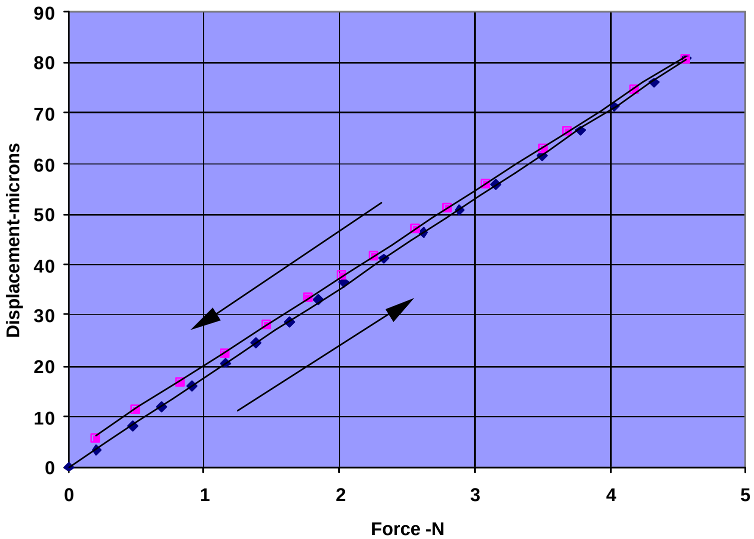


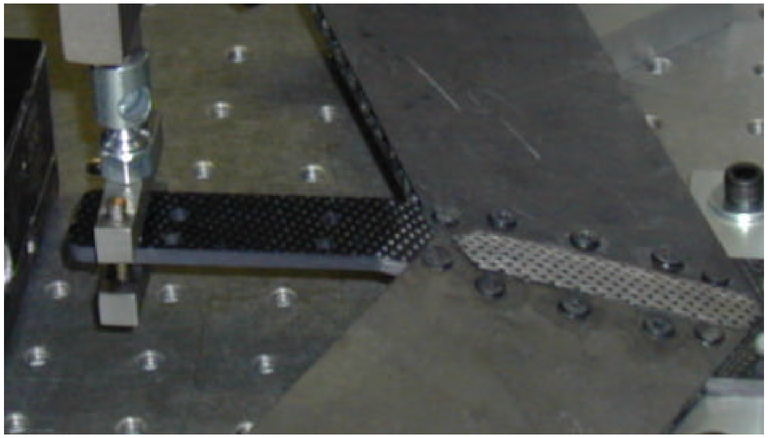


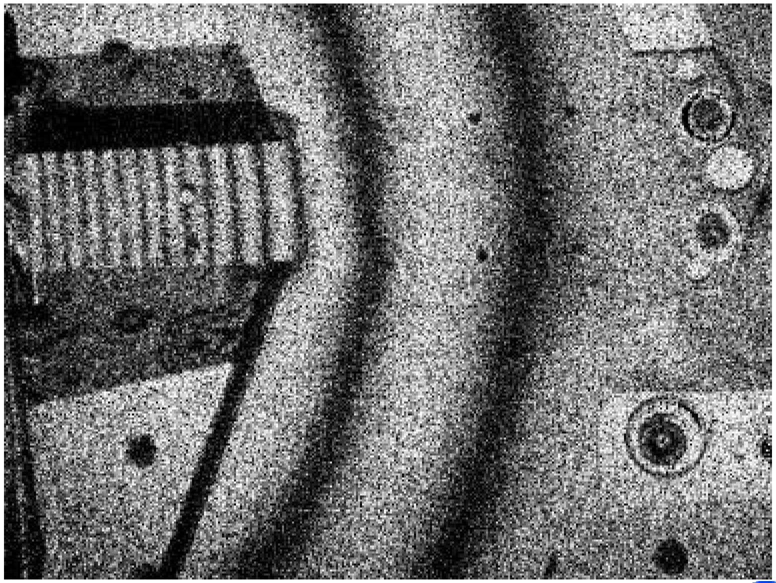
Emphasis on tab bending stiffness

Bi-Panel Static Test

- **Static Test**
  - Load application on inner mounting tabs
  - Stiffness recorded for mounting tab of 17.6µm/N
  - Slight error noted in fringe counting over large deflection range
  - Approximately 78µm's for 1lbf(4.448N) load



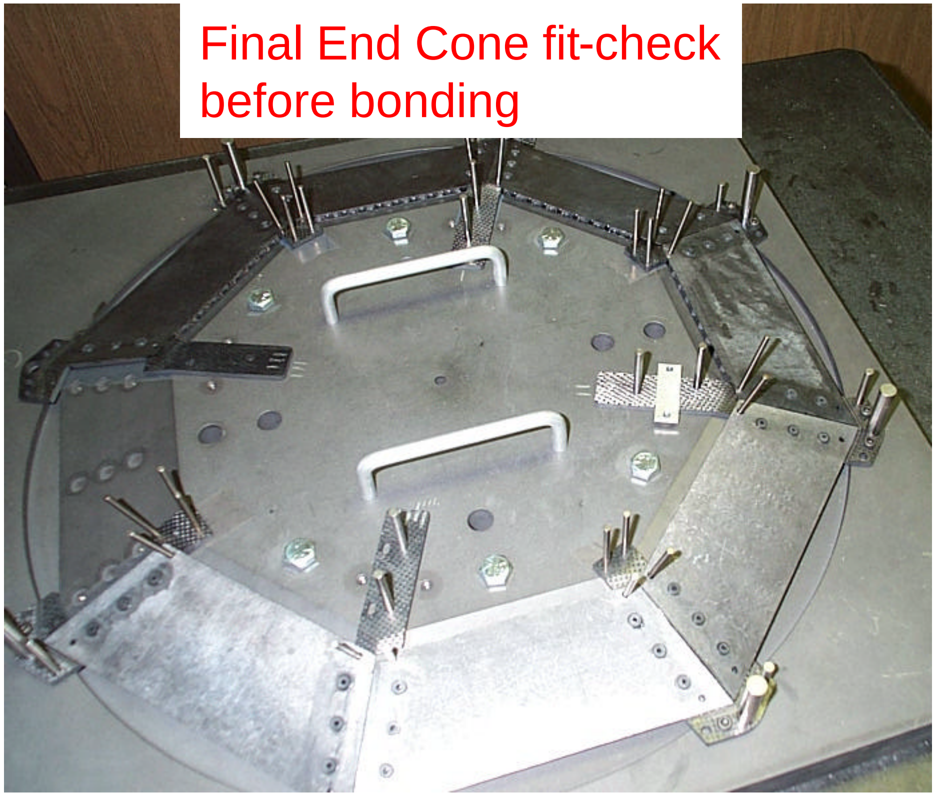




  - We note that the fringes are smooth and continuous over the Bi-panel joint

End Cone Assembly

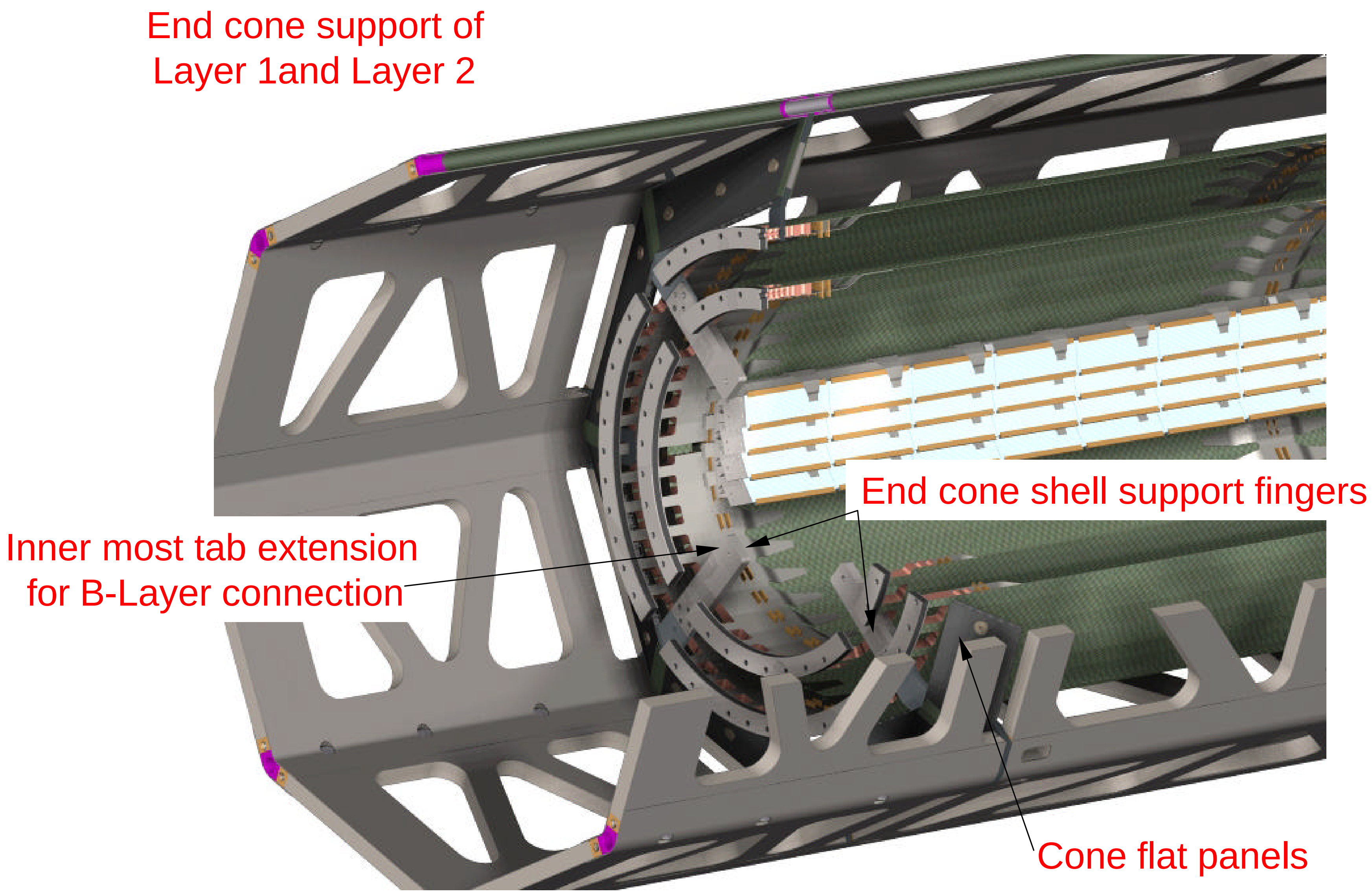
- Near Term Test Objectives
  - Static stiffness
    - Basic cone
    - Inner mounting tabs for barrel supports
  - Dynamic stiffness
    - Modes and frequencies



Final End Cone fit-check before bonding

Assembly completed
6/29/01

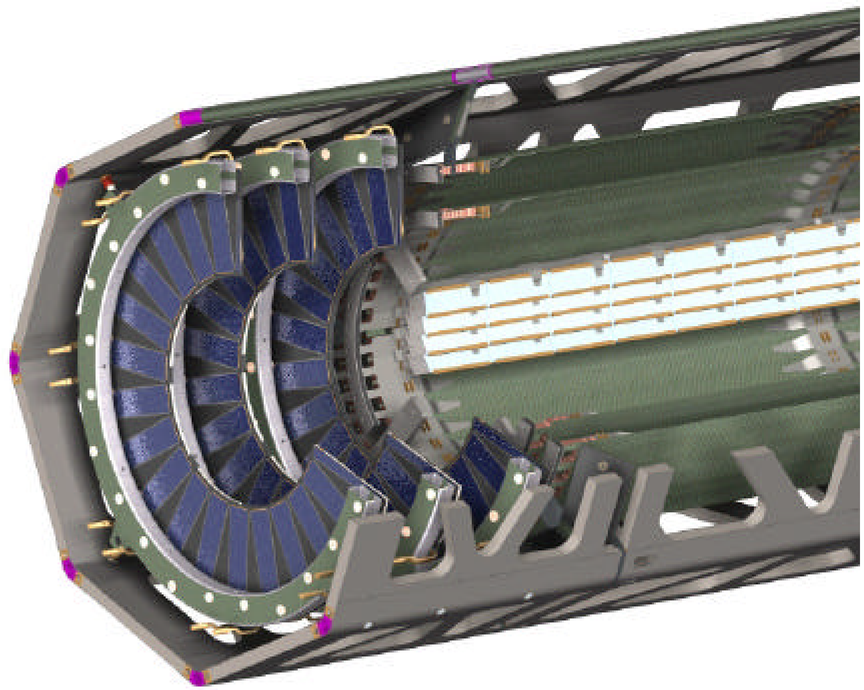
Nomenclature



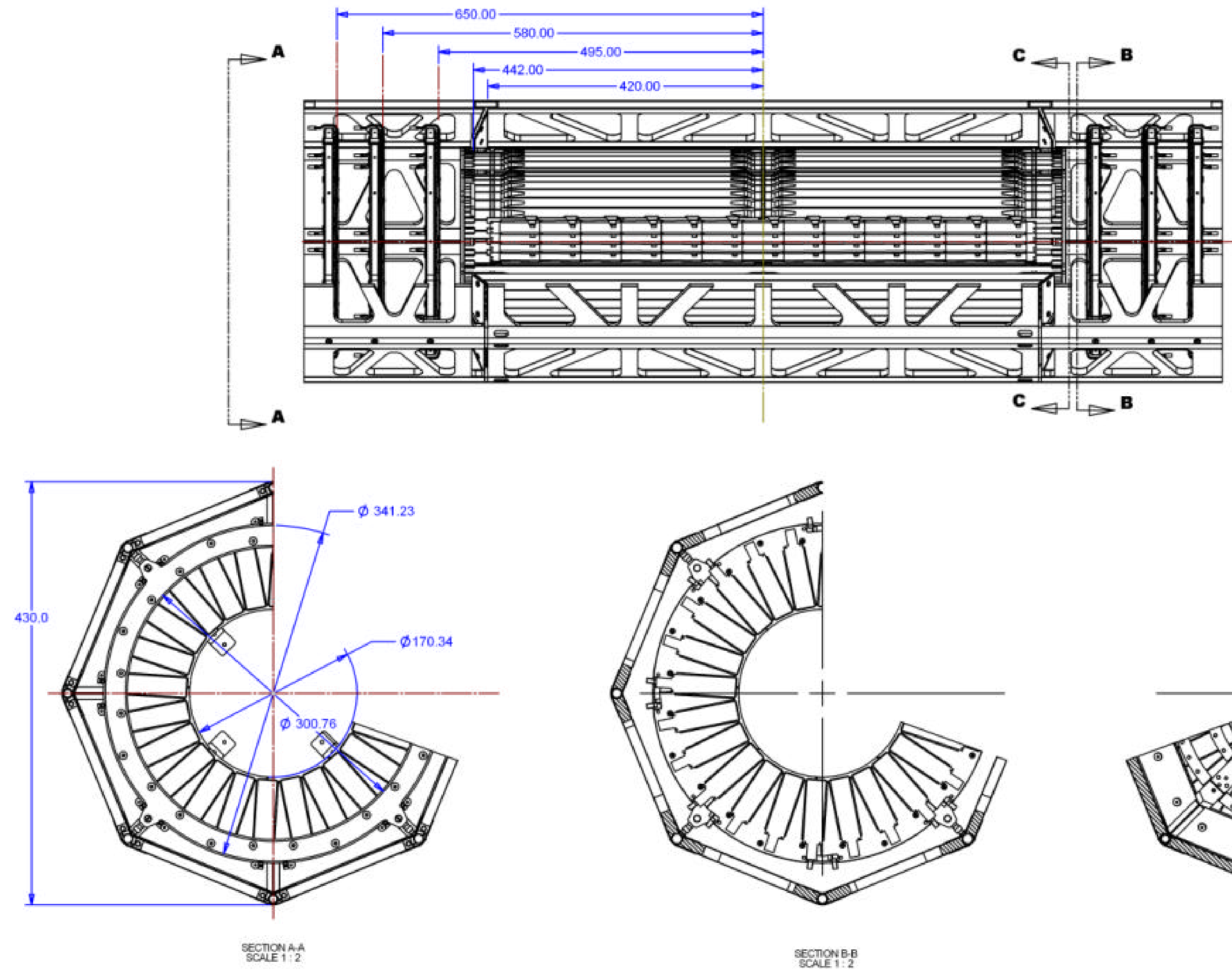
Final Frame Design

- Design configuration
  - Frame reduced from 500mm to 432mm diameter envelope
    - Length tentatively remains the same at 1400mm
  - Mass estimate for dynamic and static FEA
    - 2.85kg new frame structure, 21.04kg non-structure, total of 24.64kg
    - 3.79kg old structure, 33.74kg non-structure, total of 37.53kg
  - Mass of inner barrel structures
    - Layer 1 + Layer 2=1.55kg, counted as non-structural mass with respect to outer frame
    - Early FEA pointed to the coupling between the shells and the end cones being *soft,* thus the inner shells and outer frame do not act in conjunction as a family of concentric shells
  - *Structural mass of reduced frame concept does not include an end stiffener as used in the final design of the 500mm dia. frame.*

Design Studies



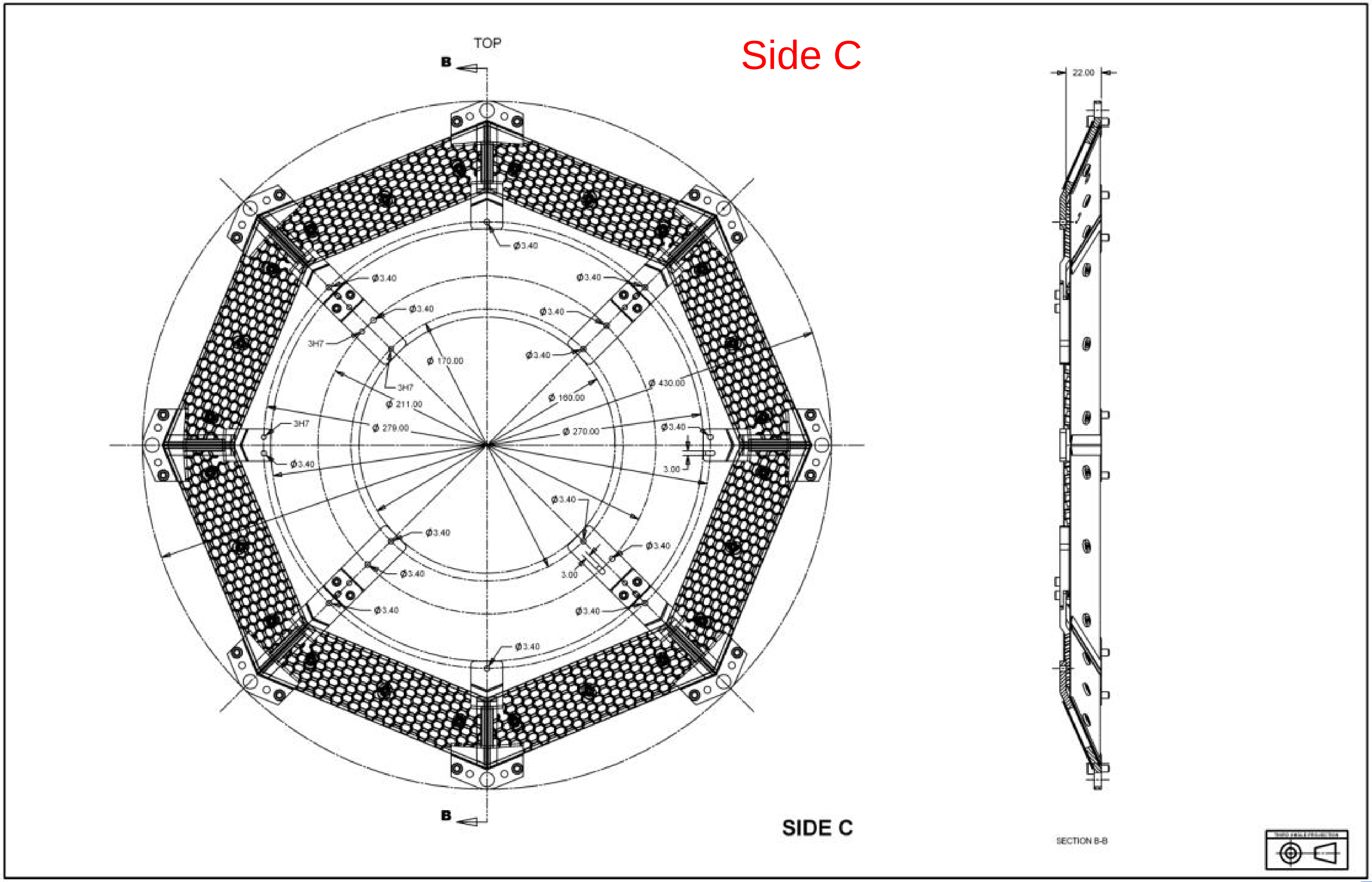
Frame Dimensions



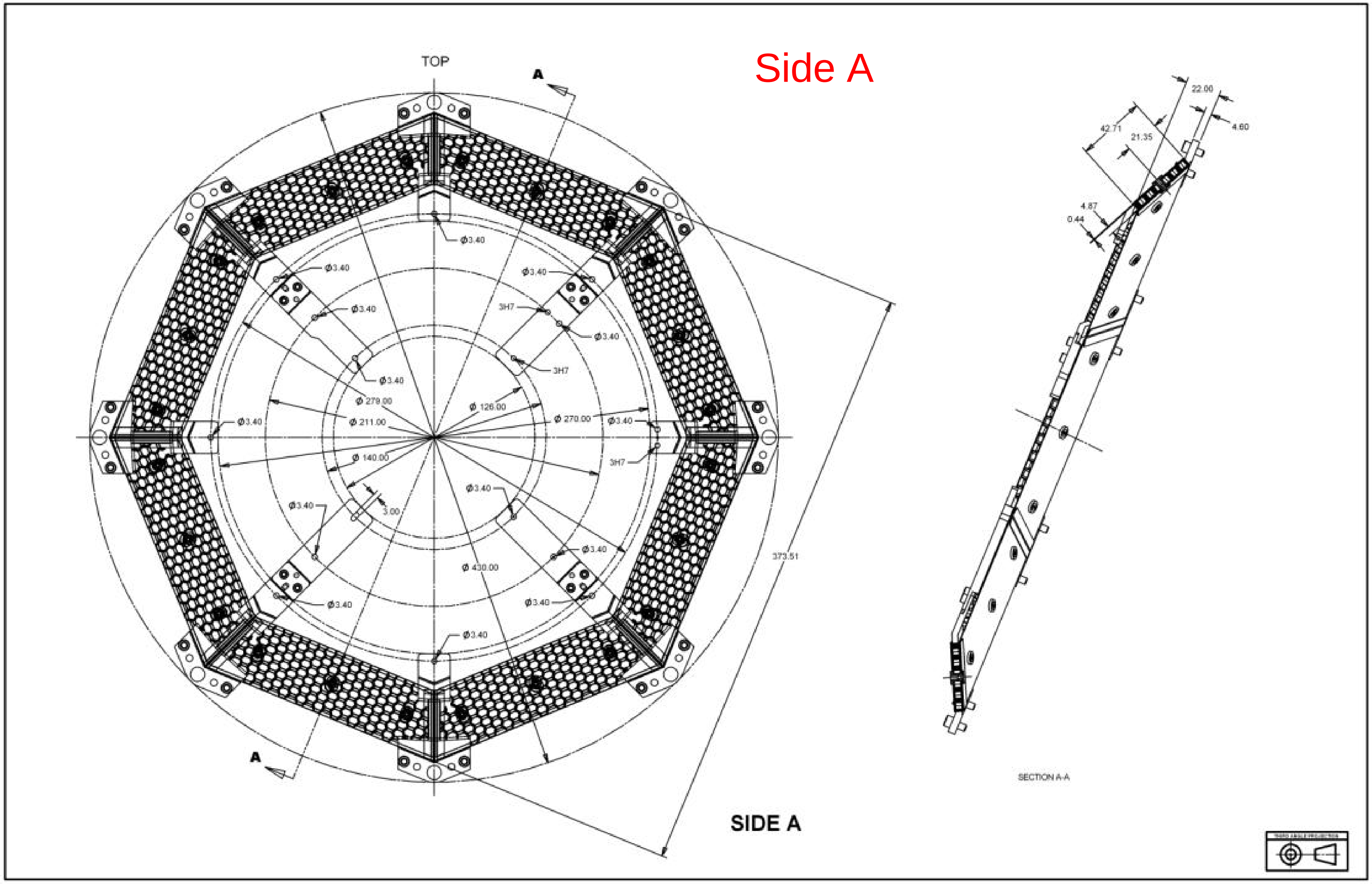
Outer envelope
432mm

Length
1400mm

End Cone Dimensions



End Cone Dimensions



W.O. Miller
July 2001

Frame Dynamic and Static Stiffness

- Dynamic
  - Evaluate structural response to random and harmonic vibration inputs
    - Random vibration level—used a conservative level, several orders of magnitude above various large scale experimental facility data
    - Harmonic-*similar approach*, estimated a fixed harmonic excitation level
  - Objective was to clarify the design strategy for the end reinforcement and the constraint conditions at the frame four support points.
- Static
  - Two fold
    - Evaluate gravitational sag of frame from non-structural mass
    - Assess static stiffness at points where extraneous forces may appear

FEA Model Mass

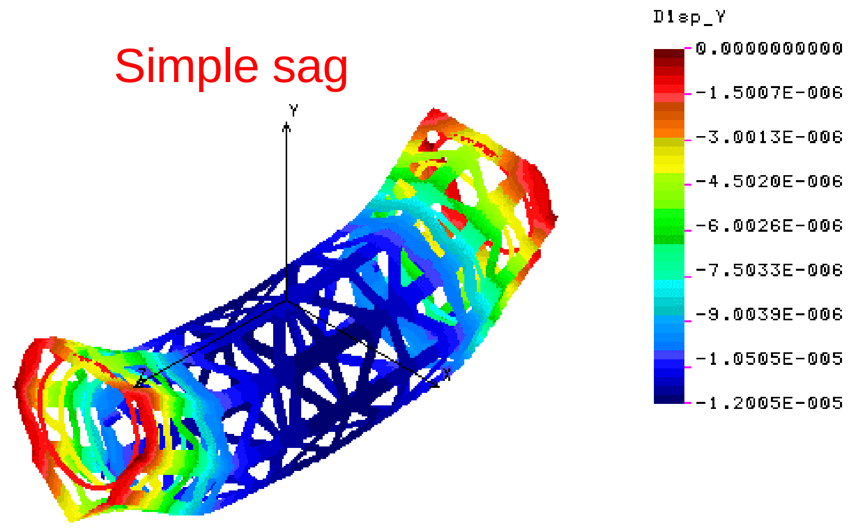
Global Support Structure

Item	Frame Structural Mass-kg	Non-Frame Structural Mass-kg	Added-non Structural Mass-kg	Total Mass-kg
Outer frame-3sections	2.55			2.55
End cones-2	0.3			0.3
Disk Support Rings-6		0.47		0.47
Support Ring Mounts-18		0.28		0.28
Sectors-48			2.16	2.16
Disk Services-(30%)			0.78	0.78
Barrel Layer 2 Shell			0.9	0.9
Barrel Layer 1 Shell			0.65	0.65
Staves Layer 1 & 2-(90)			9.90	9.90
Stave Services L1/L2 (30%)			2.85	2.85
B-Layer Shell			0.65	0.65
B-layer Staves-(22)			2.42	2.42
B-Layer Services-(30%)			0.73	0.73
Totals	2.85	0.75	21.04	24.64

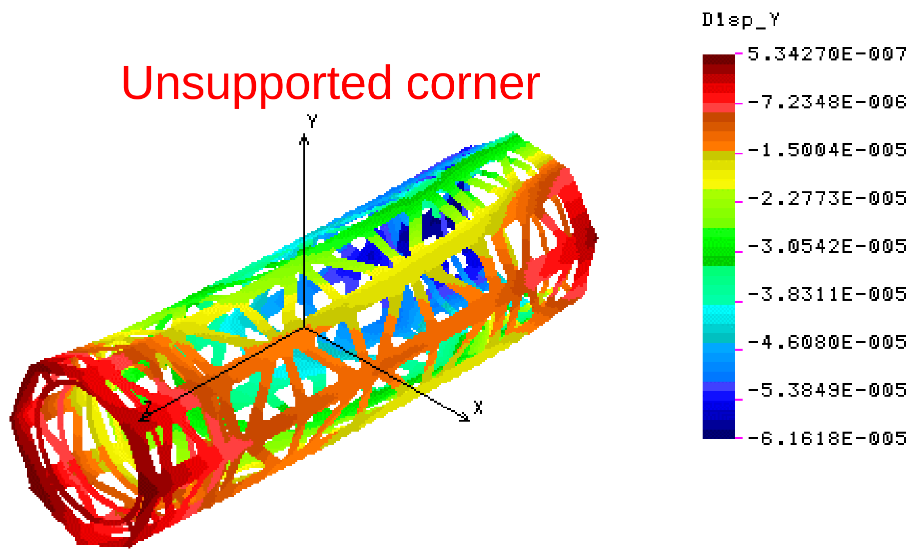
Gravity Loading

- Static load analysis
  - Gravity sag
  - Torsional stiffness
- Results (24.64kg system)
  - Gravity sag, 12µm peak, with most of the strain occurring between the supports and the barrel region
  - Torsion-
    - One corner unsupported, peak sag is 61.62 µm
    - Sensitivity, angular twist is 5.55µrad/N for corner load
- End reinforcement plate will not correct for either effect

Simple sag

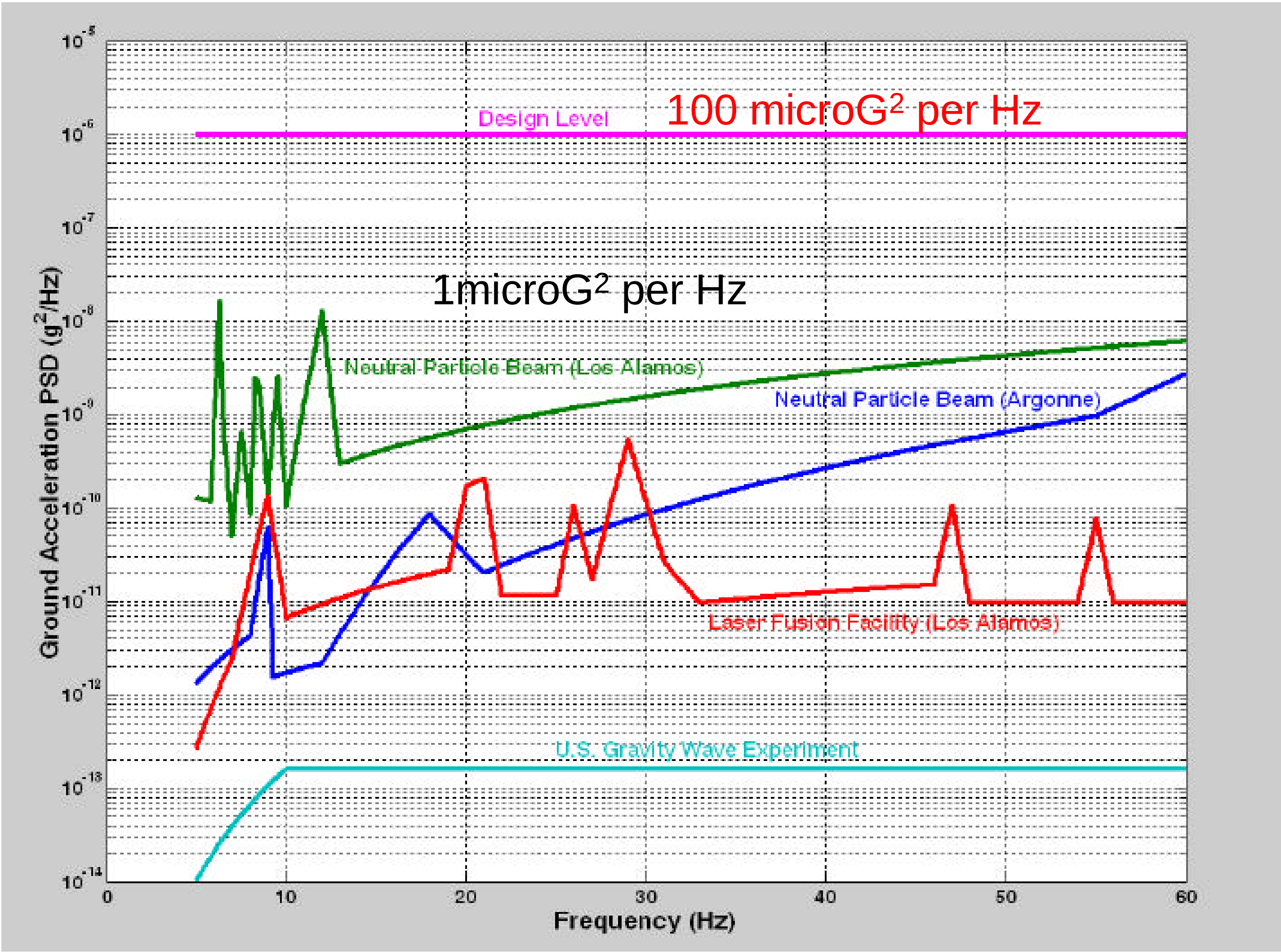


Unsupported corner



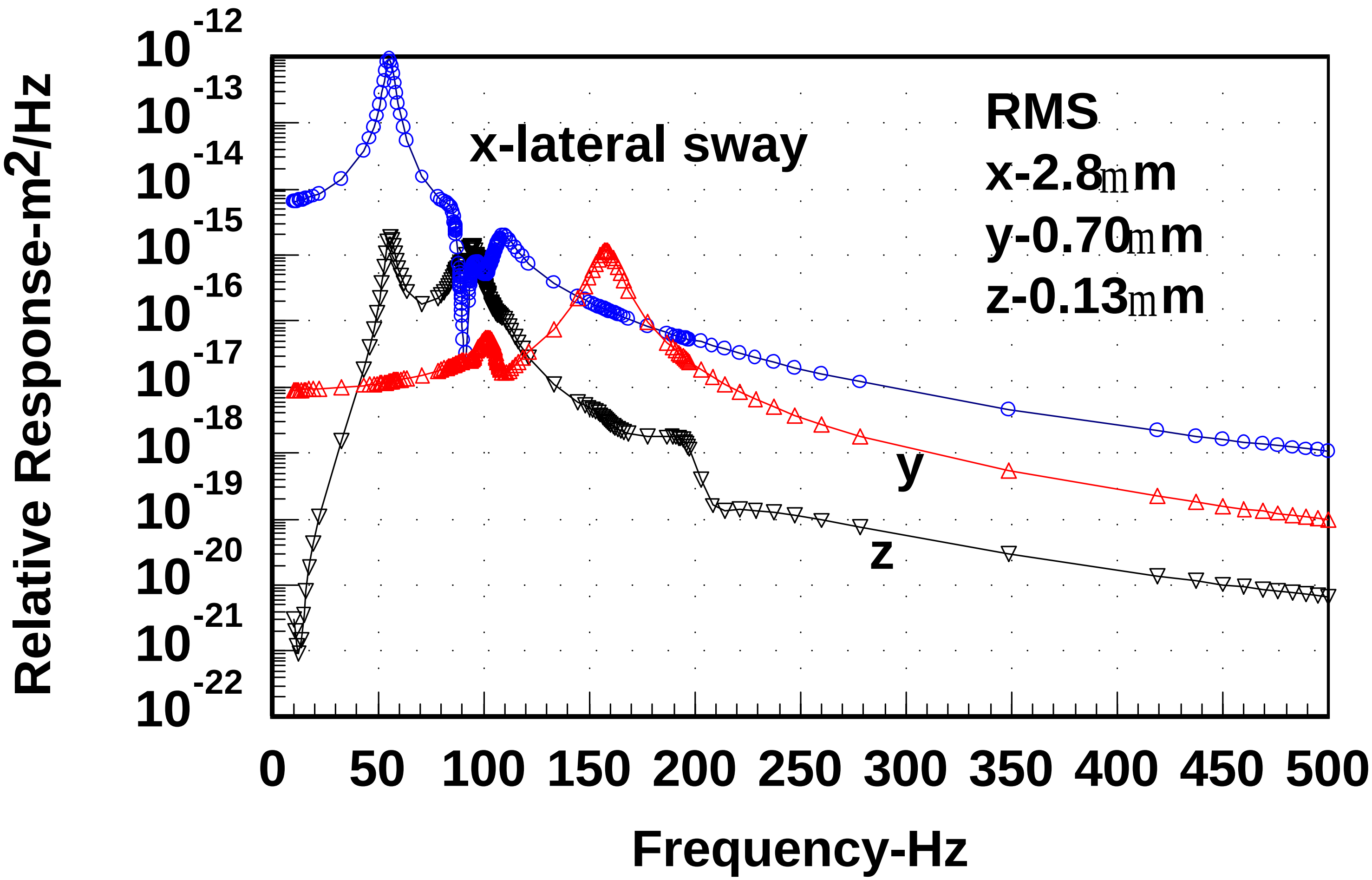
Vibration Analysis

Selection of a Random Vibration Spec (PSD)



Vibration Analysis

Figure provides an indication of the relative motion between the SCT and the Pixel Detector for random vibration



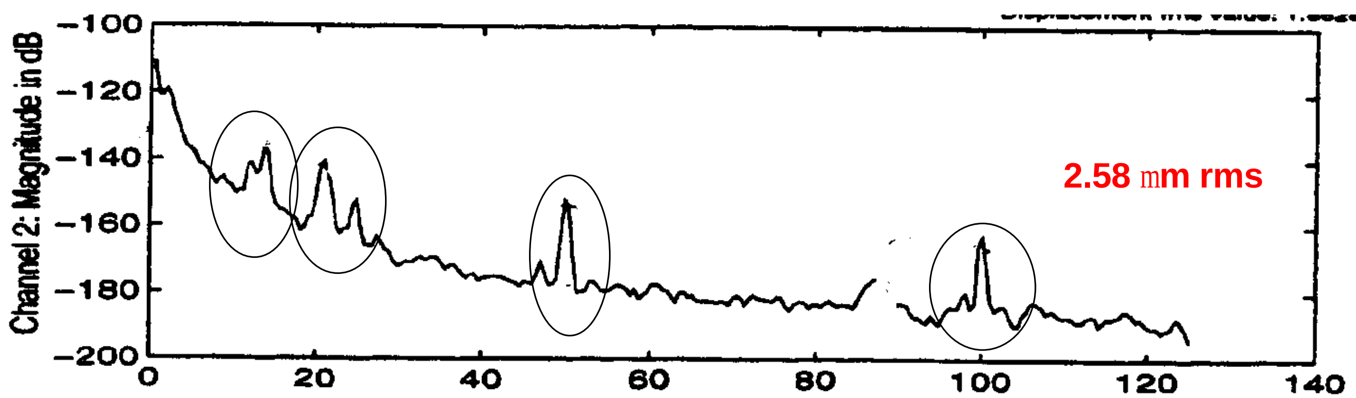
Random vibration input-100microG^2/Hz

Vibration Data

Estimation from L3

- Random and Harmonic Vibration Data
  - *Discrete vibration spikes at:*
    - *15, 22, 25, 50, 100+ Hz*
  - *Resulting random vibration measured on detector component*
    - *2.58 mm’s*
    - *Difficult to say what the ambient excitation PSD spectrum was---*

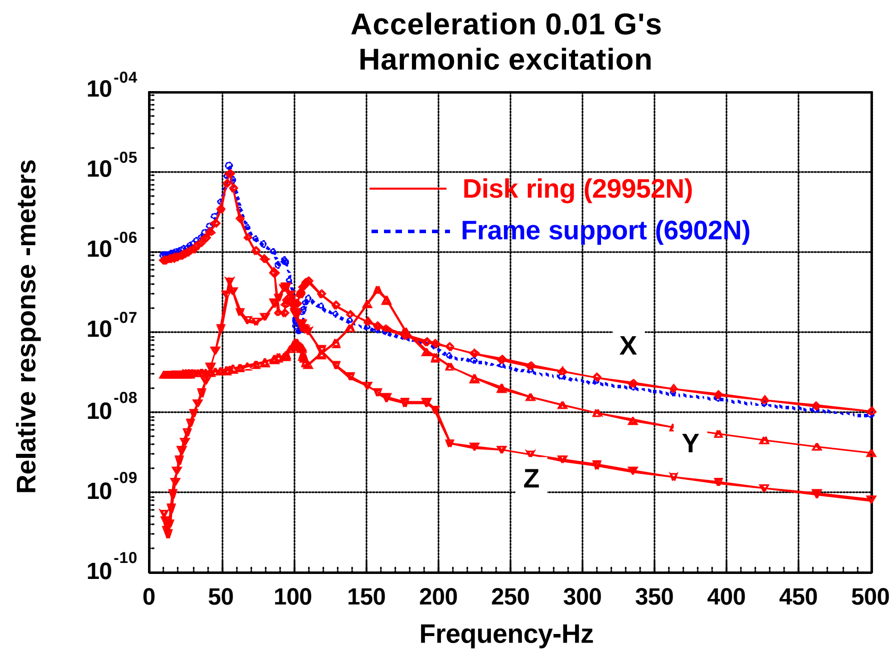
**CERN Data
L3**

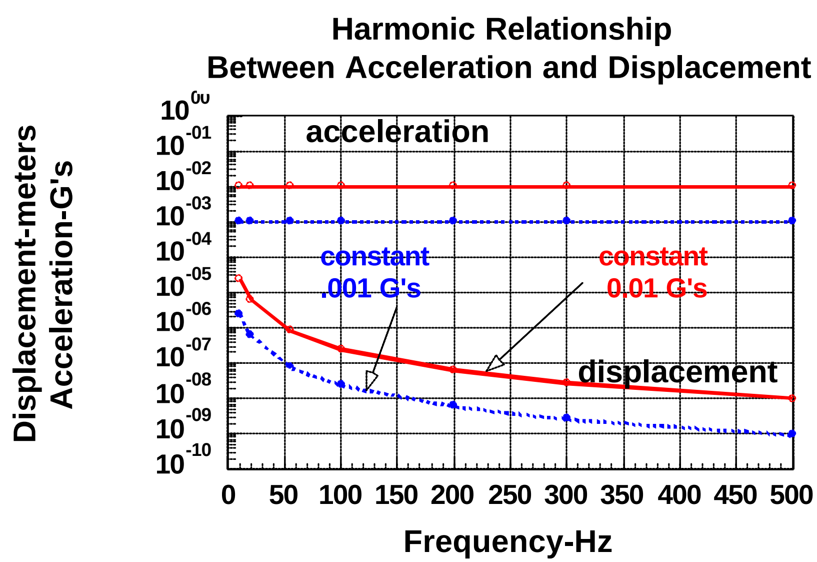


Vibration Analysis

Harmonic Inputs

- Excitation Level
  - Constant acceleration input as high as 0.01G's (by the SCT to the Pixel supports)
    - Then input displacement level to the Pixels supports at low frequency, e.g., 35Hz could be easily as high as 2 microns
    - The input displacement does decay as function of $1/f^2$, resulting in an input of 0.81microns at the Pixel 1st mode
  - Assuming modal damping of 4%, then the Pixel relative response would be 11.8 microns—undesirably high
    - The graph shows Pixels are only vulnerable to the low frequency excitation
    - Since we expect harmonic inputs at discrete frequencies like 30, 60, and 120Hz, it seems prudent that the Pixel frame 1st mode be raised





Mode Summary

- Response Characteristics
  - Modal characteristics of the frame are such that:
    - 1st mode defines the response- lateral X direction
    - Modal participation factors coupled with lower inputs at higher frequencies for higher modes do not produce significant response
      - Y, Z and shell modes
  - SCT/Pixel model-J. Cugnoni
    - Assumed Pixel Detector mass of 75kg
      - 2nd and 5th modes would possibly couple with 1st mode of Pixel Frame
      - *Revisions to Pixel Frame should concentrate on raising 1st mode above 75Hz*

Pixel Frame Modes

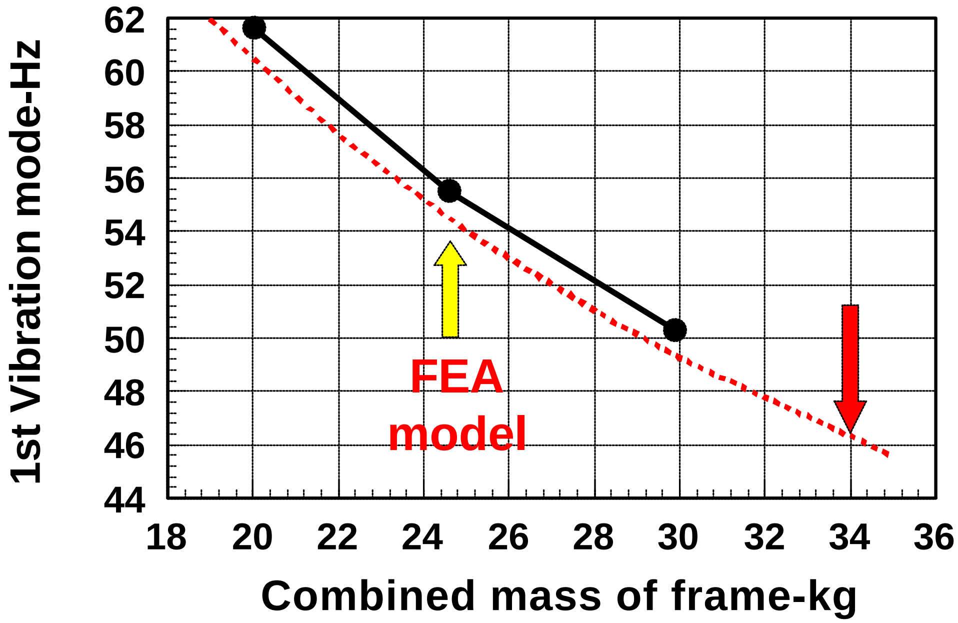
Mode	Hz	Mode	Hz
1	55.5	11	101.7
2	86.4	12	104.2
3	89.2	13	104.5
4	94.3	14	104.8
5	94.9	15	106.4
6	97.4	16	106.7
7	99.9	17	106.7
8	101.2	18	108.1
9	101.2	19	158.2
10	101.4	20	197.5

SCT+Pixels

Mode	Hz
1	21.5
2	54.4
3	59.1
4	60.1
5	61.9

Effect of Frame Mass

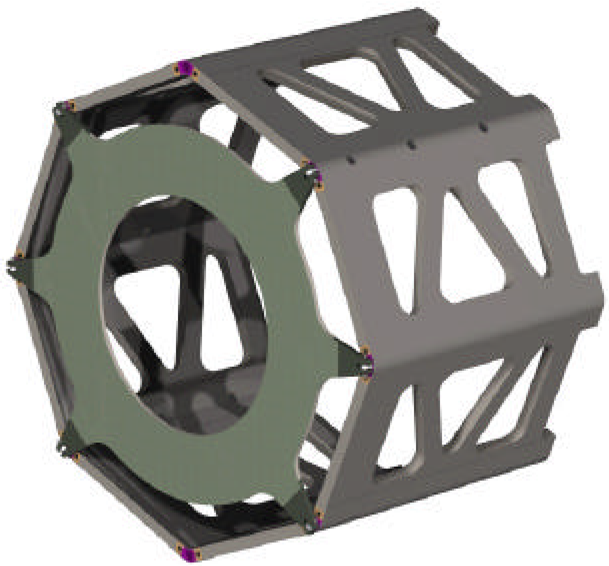
- Impact of increase in non-structural mass
  - 1st order approximation is given by adding mass to end cones
  - Decrease in frequency of 1st mode follows $1/M^2$, characteristic of a single degree of freedom spring-mass model
  - FEA model non-structural mass may be low; Pixel Detector fundamental mode maybe as low as 46Hz
- Recommendation
  - *Use reinforcement end plate to raise natural frequency*
  - Over constraining 4 support points is another, but less desirable option



Frame End Plate

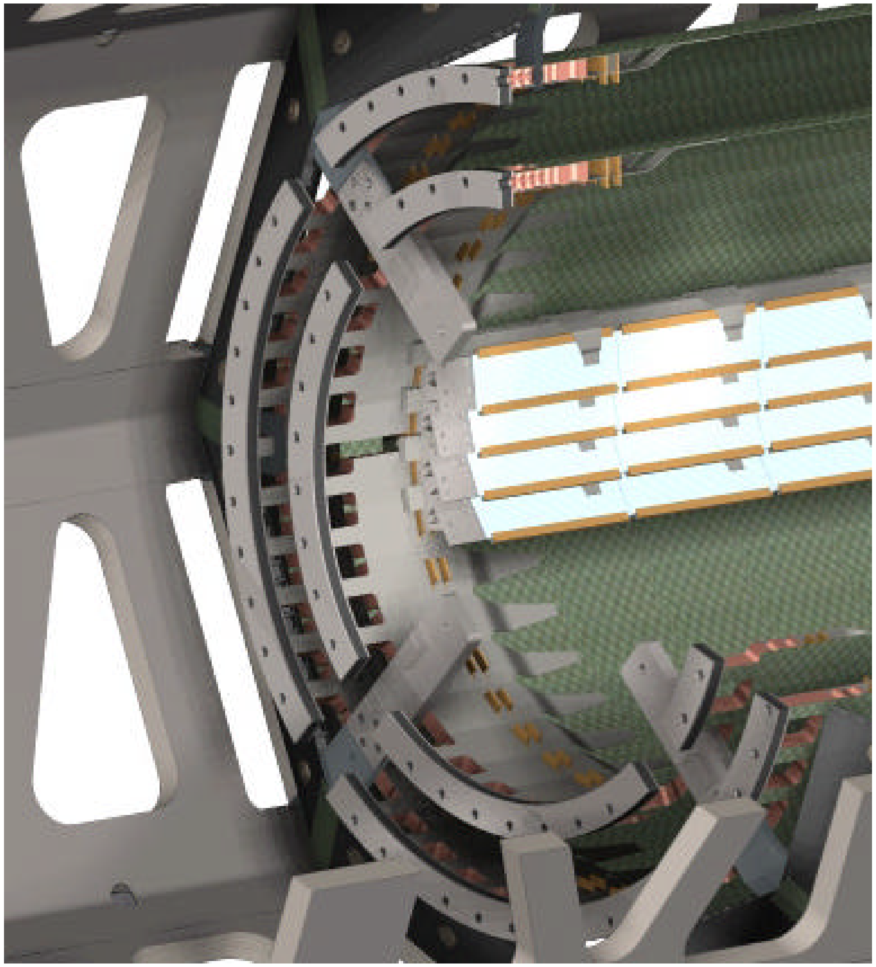
- Options for Achieving Increased Structural Stiffness
  - Over constraint at 4 corner support points
    - Possibly difficult to achieve now that Pixel Detector is insertable
  - Add end reinforcement plate at each end
    - Static solution
      - Gravity sag decreases to 11.3µm
      - Torsion, one unsupported corner still droops 53.5µm, a 8.1µm decrease
    - However, the 1st mode is now 89.07Hz, an increase of 33.6Hz

Vibration no longer an issue



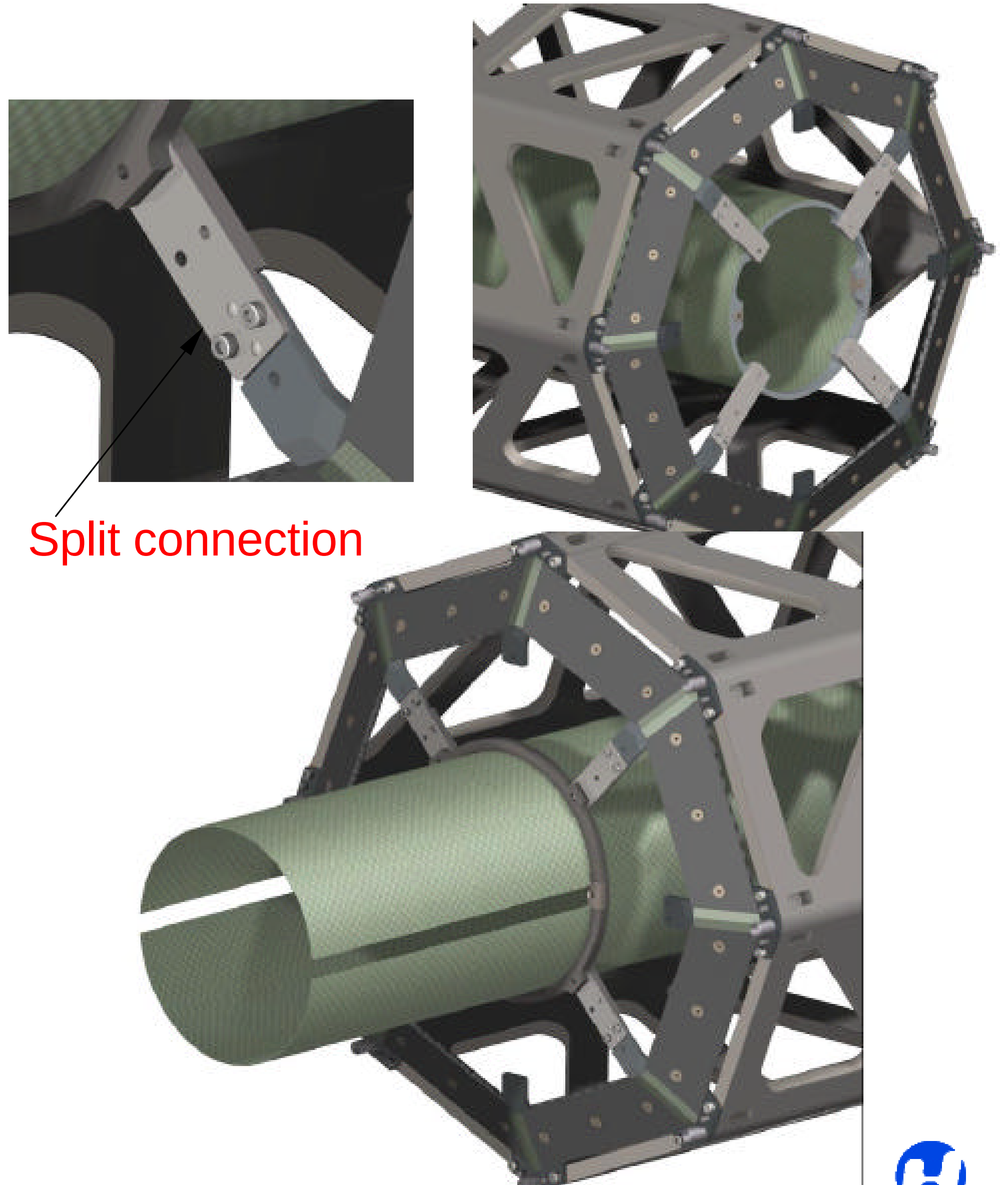
Barrel Layers L1 and L2

- Global Supports/Barrel Interfaces
  - Status
    - Interface control drawing exists
    - Defines interface between the End Cone mounting tabs
      - Side A
      - Side C
    - Layer L2 connects via 8-tabs to outer frame
    - Layer L1 connects via 4-tabs to outer frame
    - Issues/Remaining Work
      - Fold structural details of layers L1 and L2 Support Shells into Global Supports FEA
      - Update non-structural mass contributions in Global Supports FEA from layers L1 and L2
      - Finalize Global supports FEA



B-Layer Support

- Global Supports/B-Layer Interfaces
  - Concept definition is emerging
  - Major points
    - B-Layer support Tube connects to End Cones via radial tabs, 4 places
    - Radial tabs are split to facilitate assembly of Barrel Layers L1 and L2
  - Issues/Remaining Work
    - Details of B-Layer Support Tube construction need to be advanced further
    - Design aspects need to be folded into Global Supports FEA



Summary

- Milestones Completed
  - Design envelopes for frame, end cones, disk support rings (including mounts), and barrel elements, L1, L2, B-Layer are complete
  - Finite element analyses of the conceptual design that confirm the fundamental design approach are complete
    - Assuming we employ two end reinforcement plates
  - Prototype testing of all Global Support structural components, exclusive of the end cone are complete
- Work planned
  - Complete the end cone evaluation (using the 500mm dia frame configuration)
    - Complete FEA of end cone(500mm dia frame)
    - Test for stiffness, compare with FEA
  - Prepare detail construction drawings for all components
    - Prepare fabrication plans
    - Obtain cost estimates
  - Finalize Global Supports FEA by incorporating final information on:
    - Outer support shell/Global Supports connection
    - B-Layer Support Tube/non-structural mass components
  - Prepare for PDR