Pixel Support Tube: Design and Prototyping

PST Final Design Review

June 2002

Pixel Support Tube (PST) Overview

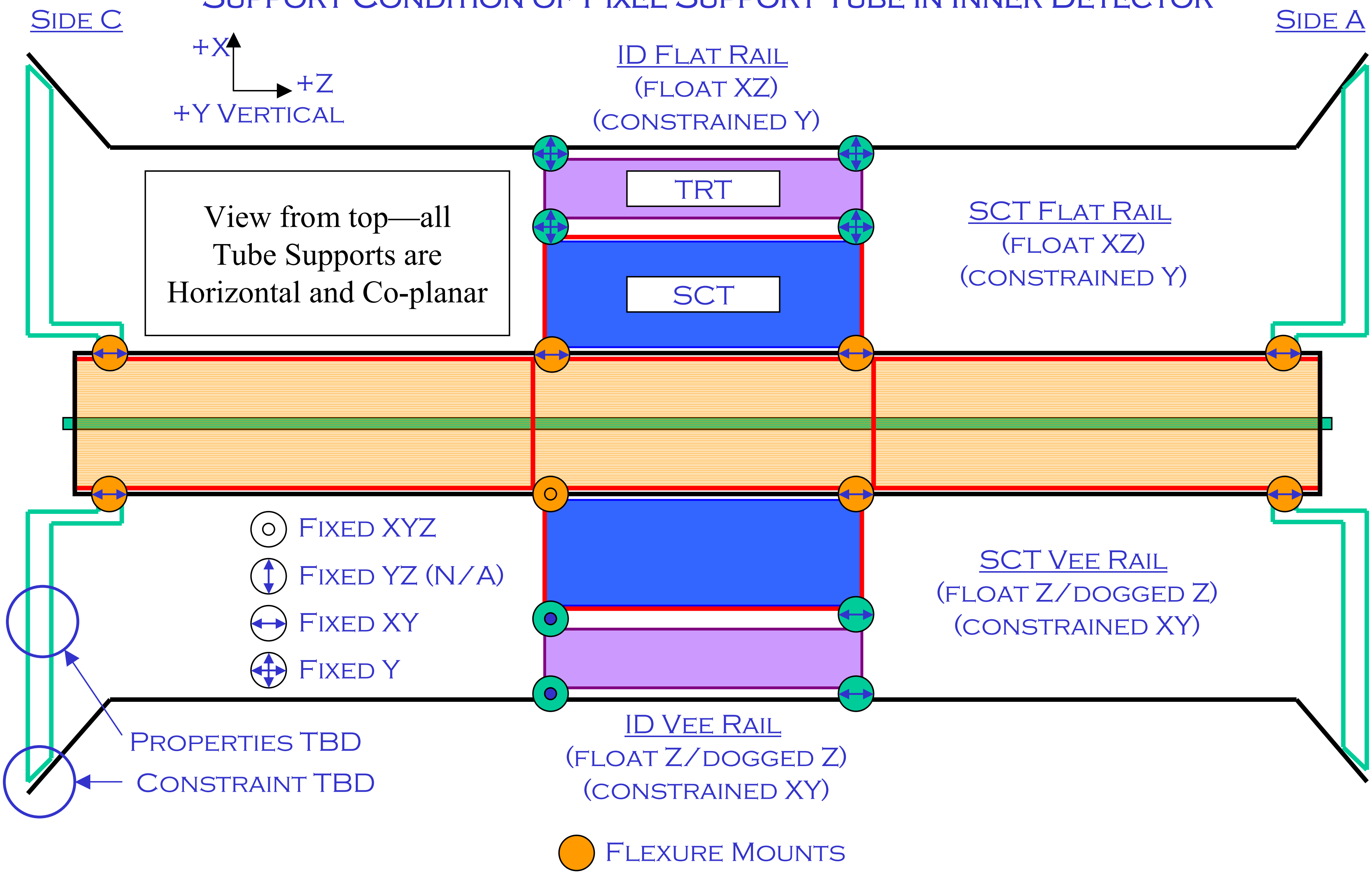
- **Design Components**
  - SCT and cryostat interfaces (flexures)
  - Pixel insertion components (rails, sliders)
  - PST structures (flanges, mount pads, stiffeners)
  - PP1 and beampipe interfaces (not covered here)
- **Key Analyses**
  - Installation (displacement of rails and flanges, unsupported shells)
  - Stability (vibration and stiffness of pixel mount pads)
  - SCT Impact (loads and deflections on SCT interlinks and barrels)
- **Prototyping Effort**
  - Material choices and characterizations
  - Final part sizing
  - Laminating and heater bonding techniques
  - Rail and shell structural measurements

Overview, Materials, Components

ATLAS

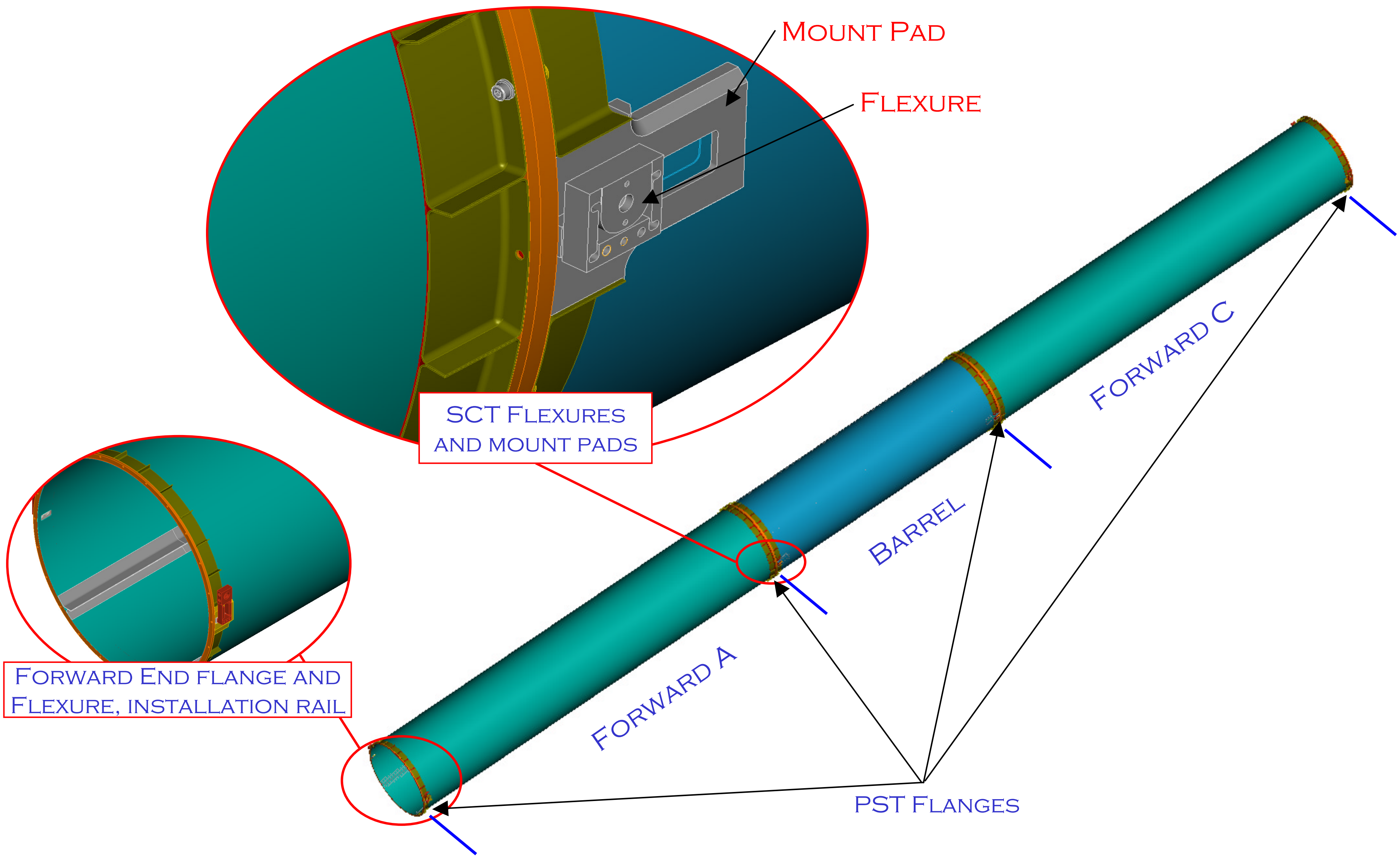
Pixel Detector

Support Condition of Pixel Support Tube in Inner Detector



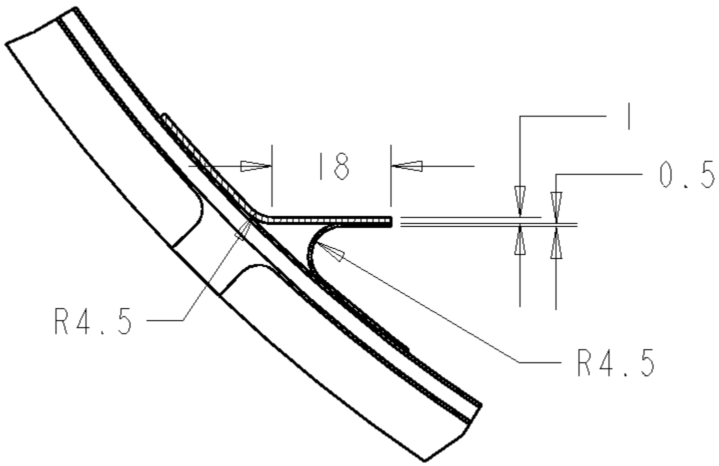
Pixel Detector

PST Key Structures

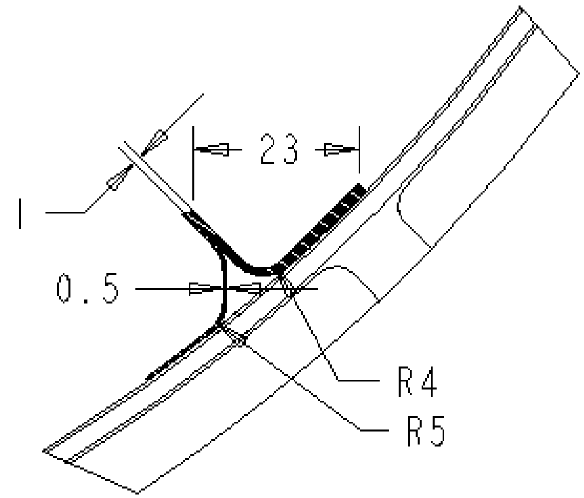


Pixel Detector

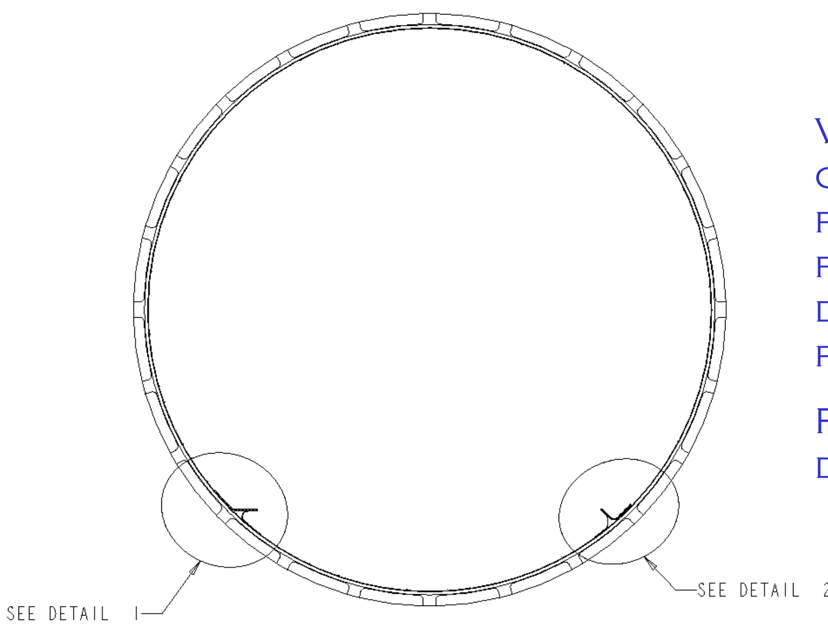
Rail Design



DETAIL 1



DETAIL 2



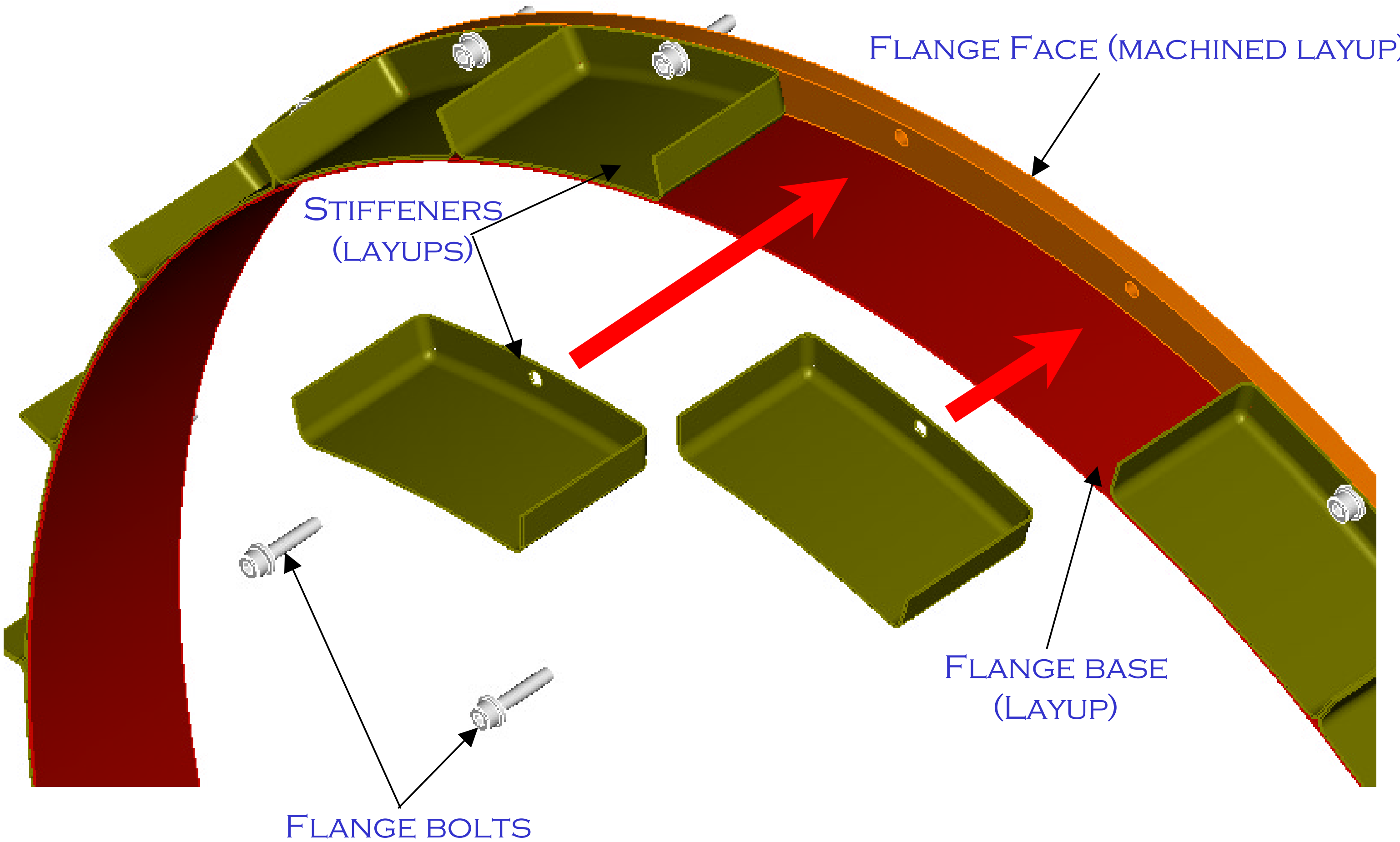
SECTION A-A
SCALE 0.375

Vee and Flat rails were chosen to provide pseudo-kinematic support for the detector during delivery to the support points.

Rails are used only for delivery, not support.

Pixel Detector

Support Flange Bonded Assembly



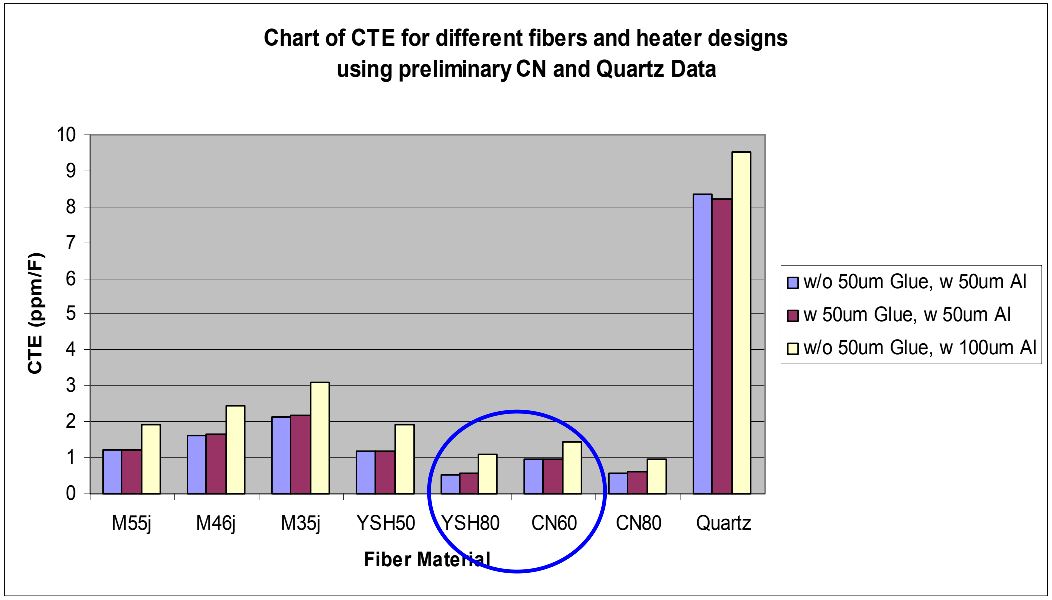
Material Selection for PST

- **All Laminates for Skins of PST will have heaters laminated to them**
- **Forward PST sections will have fiberglass skins to reduce stiffness**
  - CTE not an issue, taken up by flexures at end of PST
  - Strength of Quartz fiber highest–simple choice of fiber
  - Possibility of hybrid carbon/quartz laminate
- **Barrel will be high modulus graphite to best match the CTE of the SCT**
  - CTE of fibers selected must be very negative to beat CTE of Aluminum in Heaters
  - Cost, Modulus, thickness all factors in selection
- **Bryte EX1515 selected as matrix for all**
  - 137C cure temp vs 180C for RS3
  - Proven radiation tolerance
  - Quick vendor turn around

Pixel Detector

Fiber Selection Candidates

- CTE of Barrel primary driver in material selection
- CTE of laminates include Heater layer laminated together in skin
- 100micron Al is thicker EMI shield material
- 50microns glue is for lamination of heaters (goes to Zero with co-cured heaters)
- COST per candidate also considered



CTE of SCT Barrel is ~1.2 to 1.5 ppm/C so our target is on the order of 1ppm. Will consider CTE mismatch of less than 0.5ppm 'Zero' (relative mismatch for temperature change on order of 20micron)

Pixel Detector

Summary of Materials and Properties Used in PST

Laminate	Fiber	Fiber E (GPa)	Fiber CTE (ppm/K)	Direction	Laminate E (GPa)	Laminate CTE (ppm/K)	Thickness (mm)
Barrel Shell	YSH80	798	-1.6	QI	134	0.65	0.650
Forward Shell (all glass)	AQII	84	6.4	QI	23	14.71	0.650
Forward Shell (hybrid)	AQII/YSH80	84/798	6.4/-1.6	Axial	24	13.49	0.650
Forward Shell (hybrid)	AQII/YSH80	84/798	6.4/-1.6	Hoop	135	0.72	0.650
Flanges/Mount Pads	CN60	557.9	-1.49	QI	113	-0.17	N/A
Rails	CN60	79.7	-1.49	Axial	111	-0.21	1.005
Hoop Stiffeners	CN60	79.7	-1.49	Hoop	132	-0.51	0.852
Mount Flexures	Titanium	N/A	N/A	Isotropic	116	9.20	N/A

Notes:
1. All laminates use a cyanate ester resin system.
2. All shell laminates include heater/EMI panels in the modulus and CTE calculations.
3. CN60 laminates are plain weave cloth; all others are unidirectional tape.
4. Properties are for the specified direction only, except where 'QI' (quasi-isotropic) is noted.

Summary of Raw Materials Used in Prototyping

Material Type	Precure Thickness (um)	Postcure Thickness (um)	Resin Areal Weight (gsm)	Fiber Areal Weight (gsm)
YSH80 UDT	125	92	37	80
AQ II UDT	125	92	45	80
AQ II Mat (prepreg)	200	88	196	34
AQ II Mat (dry)	50	N/A	N/A	10
CN60 PW Cloth	375	275	145	300
EX1515 Film	25	N/A	29	N/A

Notes:
1. UDT = Uni Directional Tape prepreg. PW = plain (square) weave cloth.
2. AQ II is Astro Quartz trade name for quartz fiber.

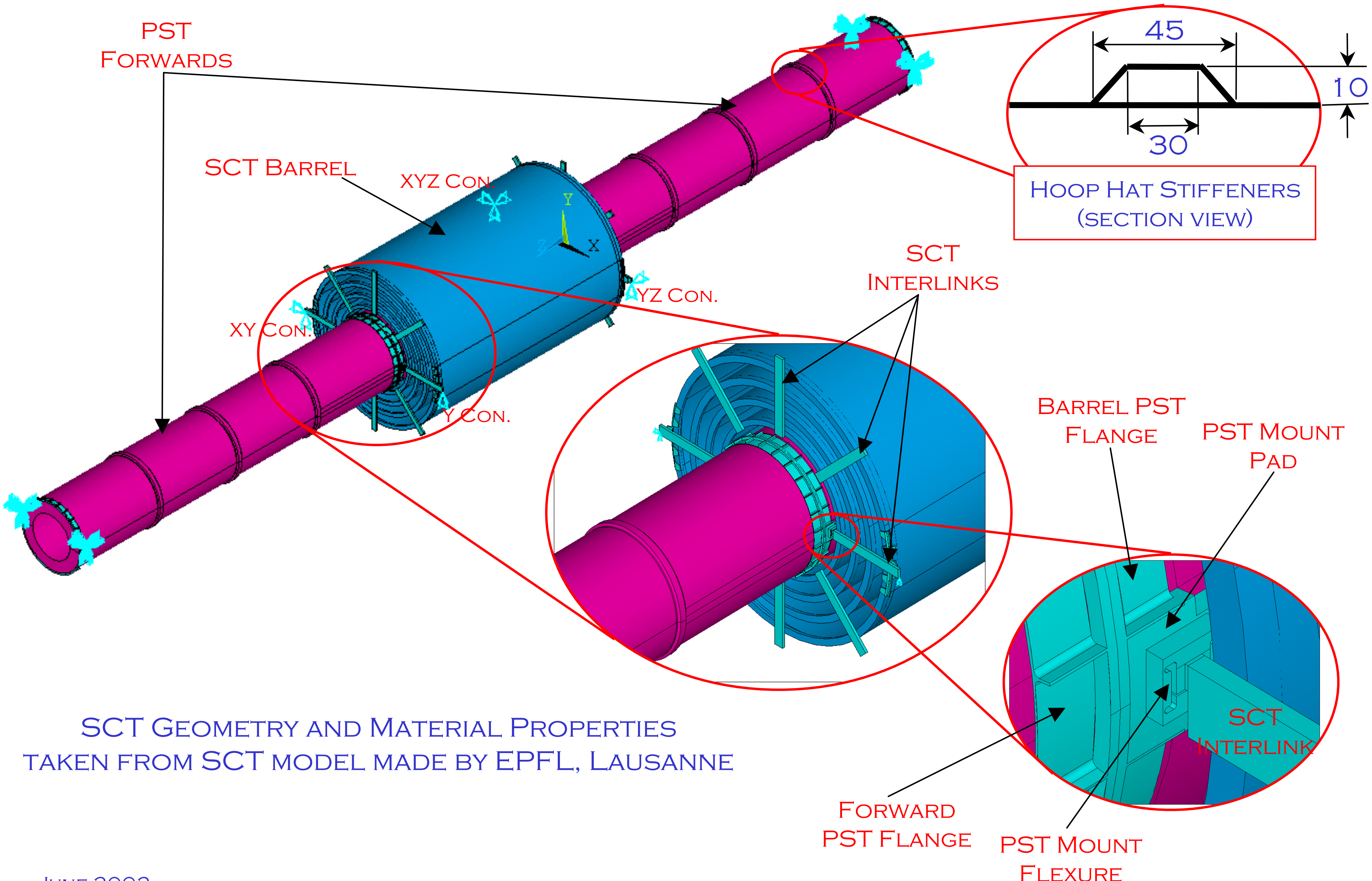
Pixel Detector

Nominal Laminates

- **Shells**
  - All shell laminates are 6 ply UDT
    - Barrel is quasi-isotropic YSH80
    - Forward has two options
      - Quasi-isotropic AQ II [90/30/150]$_S$
      - Hybrid YSH80/AQ II
        - » YSH80 Hoop Plies [90] (axis of tube is 0 degree direction)
        - » AQ II inner plies [30/150]
  - All shells have heater panels laminated to them
    - Composition given in interface/services presentation
  - All shells have an insulative inner layer
    - Prevents damage to plies and liberation of carbon dust
    - Composed of EX1515 film/dry glass mat sandwich (film/mat/film)
- **Rails**
  - Rails are fabricated from CN60 plain weave cloth
    - 3 layers [(0/90)/(+45/-45)/(0/90)]
- **Stiffening Hoops**
  - Fabricated from CN60 plain weave cloth
    - 2 layers [(0/90)/(+45/-45)]
- **Flanges, mount pads**
  - CN60 plain weave cloth laminated into 5 mm thick plates, then machined
    - Quasi-isotropic laminate [(0/90)/(+45/-45)]$_N$
    - Average 5 mm plate will be 13 layers thick

Design Calculations and Analyses

PST/SCT Combined Model



SCT Geometry and Material Properties
taken from SCT model made by EPFL, Lausanne

Materials and Assumptions for PST/SCT FEA Models

Application	Material Approximated	E1 (GPa)	E2 (GPa)	Poisson's Ratio	Density (kg/m^3)	CTE (ppm/K)	Thickness (mm)
SCT Shells	XN50 Sandwich	6	6	0.37	303	N/A	6.000
SCT Flanges/Interlink Supports	XN50	116	116	0.32	1760	N/A	2.000
Interlinks	Aluminum Equiv.	70	70	0.30	2800	N/A	N/A
Pixel Barrel Shell	YSH80	190	190	0.30	1650	0.51	0.437
Pixel Forward Shells	AQII	19	19	0.30	1750	14.29	0.437
Pixel Hoops, Flanges, Rails	CN60	126	126	0.30	1650	-0.28	0.863
Pixel Mount Flexures	Titanium	126	126	0.30	4430	9.20	N/A
Pixel Shell (Rail model ONLY)	YSH80/AQII	166	23	0.30	1700	N/A	0.437

Assumptions:

1. All SCT materials were assumed orthotropic for modeling purposes (except interlink material).
2. All PST materials were assumed isotropic for modeling purposes (except for pixel shell in rail model only).
3. Heater panel contributions to modulus and thickness were neglected for all pixel models.
4. CTE of heater panel was included in CTE's for thermal expansion models.
5. Hybrid shell laminate (carbon/quartz) was not modeled in forward shells (except in rail model only).
6. Rails were included in rail model only, not in PST or PST/SCT models.

Pixel Detector

Comparison of SCT models from LBNL and EPFL

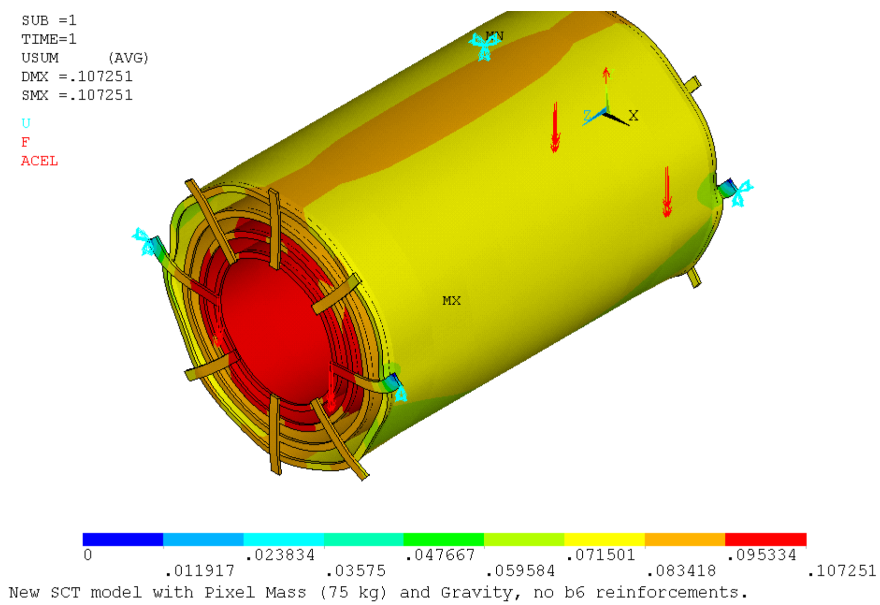
(Under Gravity)

Assumptions:

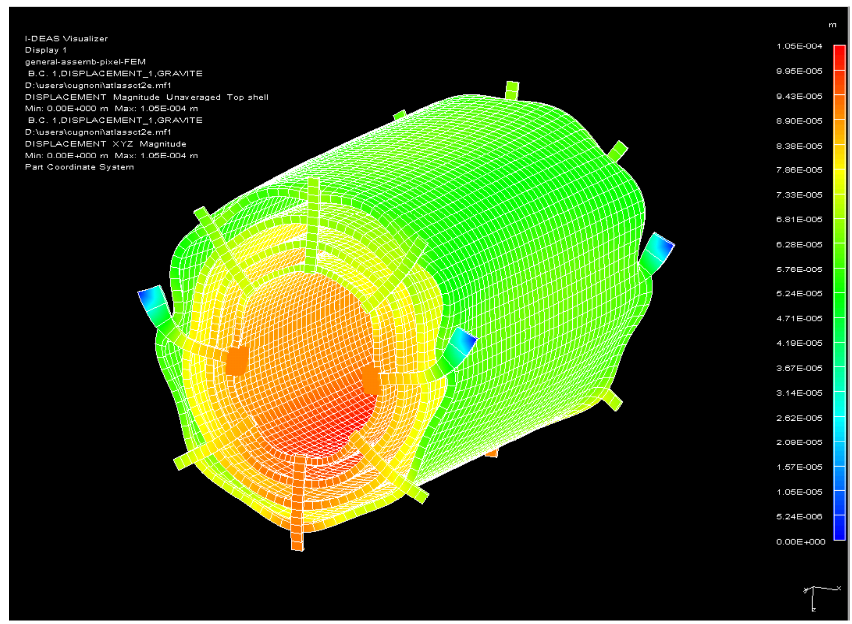
Pixel Mass = 75 kg (over 4 points)

SCT not fixed across Diameter

All SCT properties from EPFL model



Displacements with Pixel Detector, max = 107 µM



EPFL model, max = 105 µM

Pixel Detector

Summary of Loads/Displacements Induced in SCT

That impact *long term* stability

PST/SCT Load Comparisons										
Model Details		Max. Force on Interlinks			Max. Force at Forwards			Max. disp. in SCT Structure		
Load Direction	Load Case	FX (N)	FY (N)	FZ (N)	FX (N)	FY (N)	FZ (N)	dr (um)	dphi (um)	dZ (um)
Y	dyA = dyC = 2 mm	0	57	1	1	55	2	8	8	0
Y	dyA = 2 mm	1	146	3	1	55	2	-16	18	7
X	dxA = dxC = 2 mm	61	2	56	57	3	68	22	14	-6
X	dxA = 2 mm	123	12	32	54	3	64	41	-27	-13
X	dxC = 2 mm	130	10	88	57	4	69	41	-27	-16
CTE	Symmetric, 30 degrees C	N/A	N/A	N/A	N/A	N/A	N/A	-10	-5	-12
CTE	Asymmetric, Side A, 30 degree	N/A	N/A	N/A	N/A	N/A	N/A	-45	12	196
G	gravity, pixel load of 75 kg	2	207	1	0	10	0	78	-75	-4

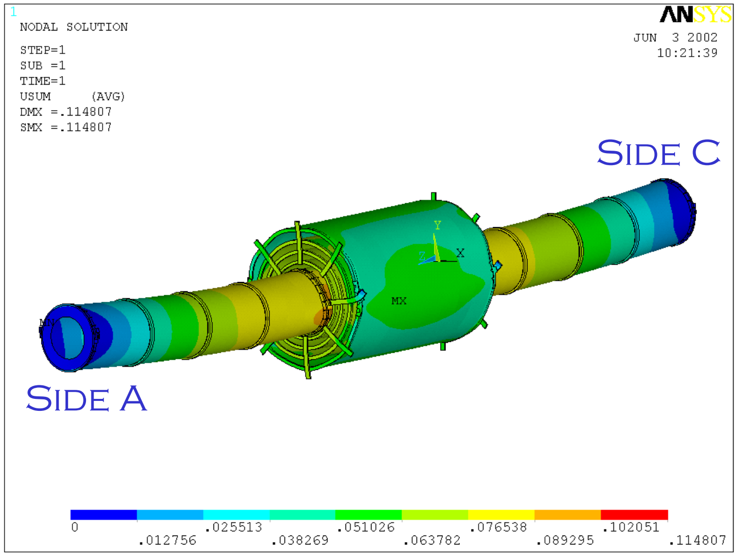
NOTES: Maximum forces and displacements shown for any given load case do not necessarily occur simultaneously on one interlink or at one shell location; these are component maximum values. Force results come from PST model alone, constrained with flexures at all mount locations. One mount provides Z constraint at barrel, on C side. Displacement results come from integrated PST/SCT model, where PST to SCT constraint is made with identical flexure scheme. Asymmetric CTE load case is not an operational condition. Intrinsic short term RMS SCT resolution (for reference) is: R=100 um; Phi=12 um; Z=50 um (tolerance range is

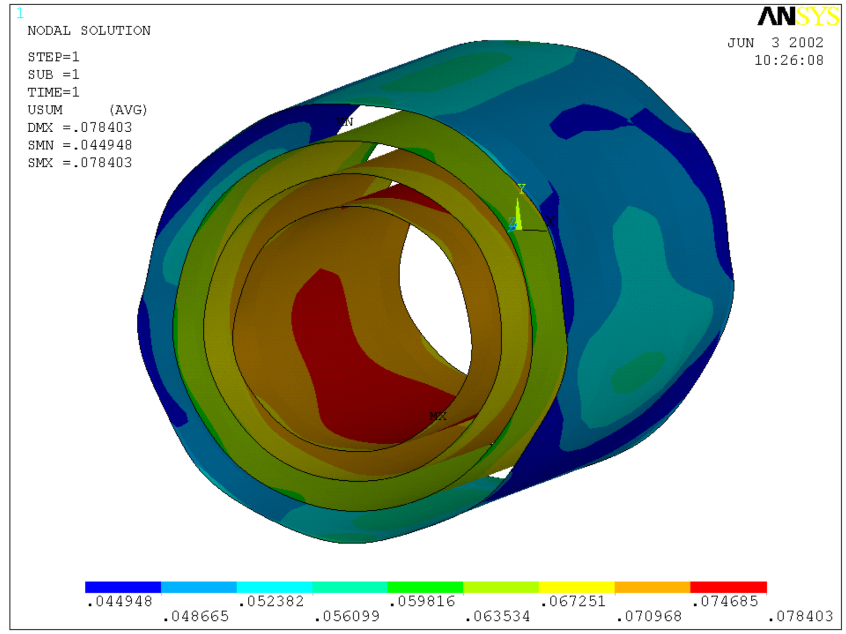
Z constrained flexure is located on side C, negative X (in this coordinate system).

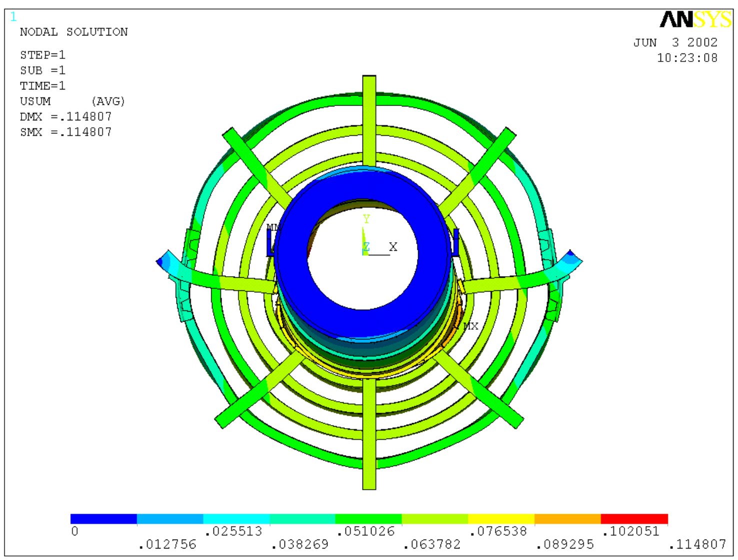
Pixel Detector

Load Case: Gravity and Pixel Load

(Pixel and service loads approximated as 75 kg, applied at Pixel Mounts on PST)





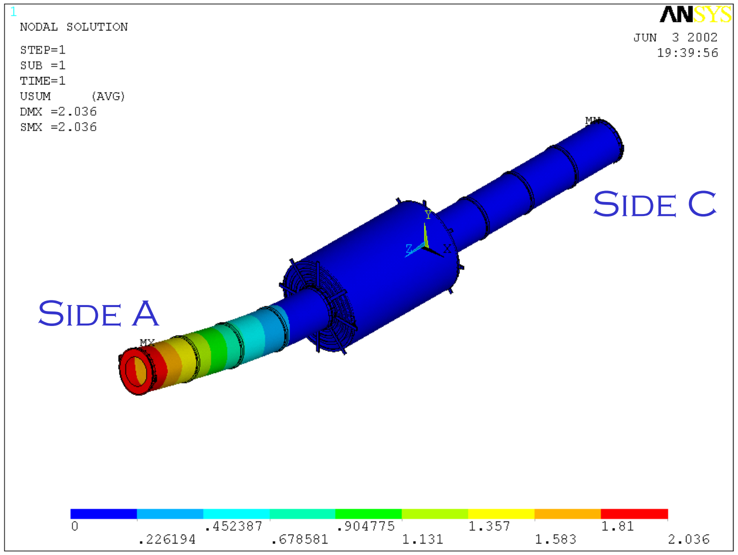


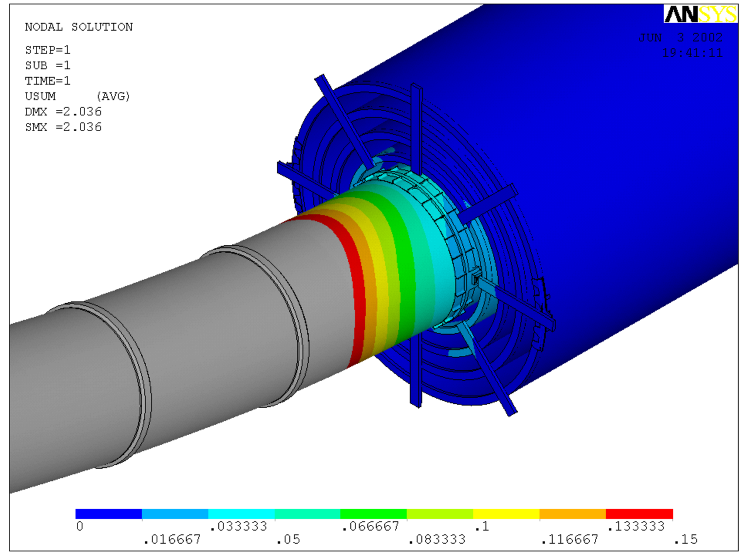
DR = 77 microns
DPHI = -75 microns
DZ = -4 microns

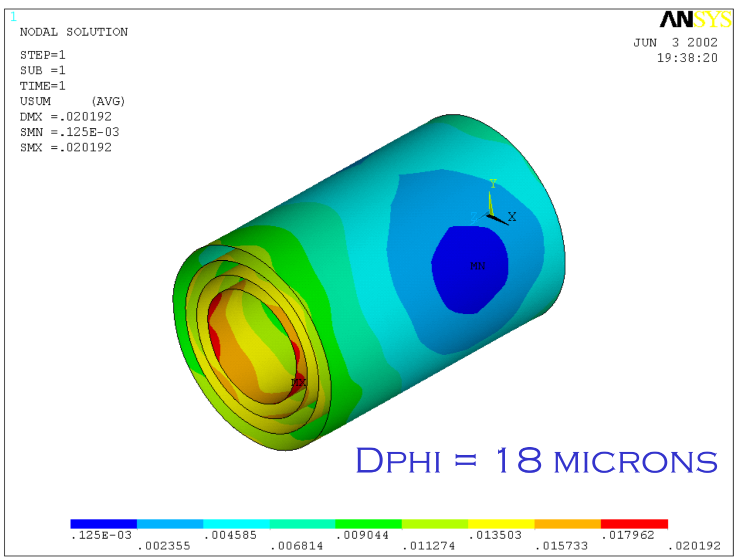
Pixel Detector

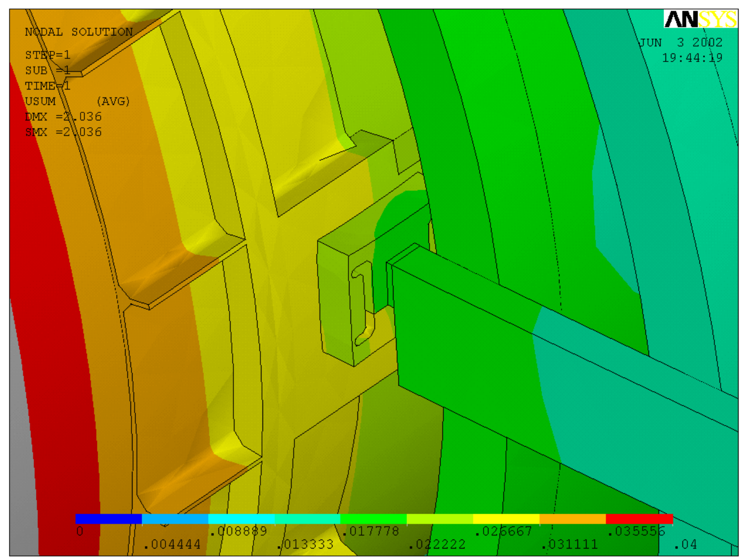
Load Case: dyA = 2 mm

(forward end, side A, displaced 2 mm in Y – no gravity or pixel load)





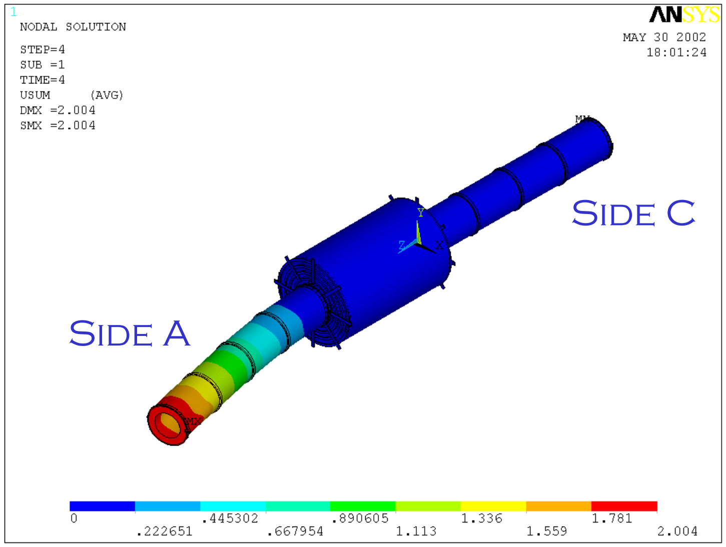


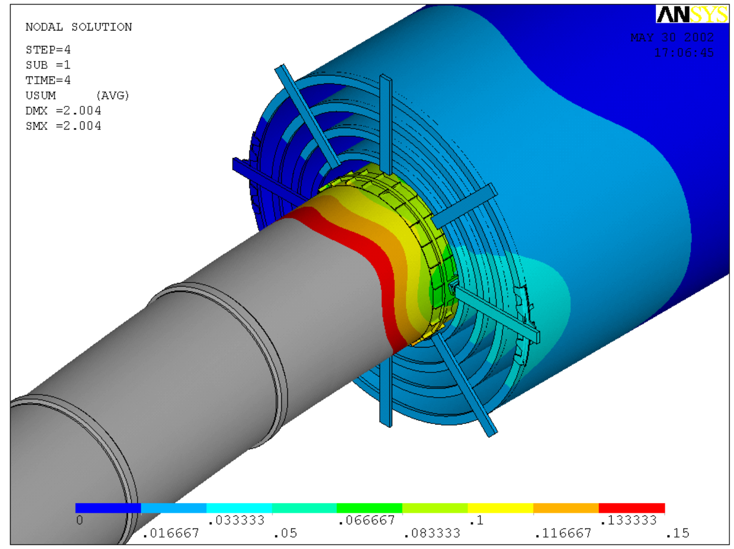


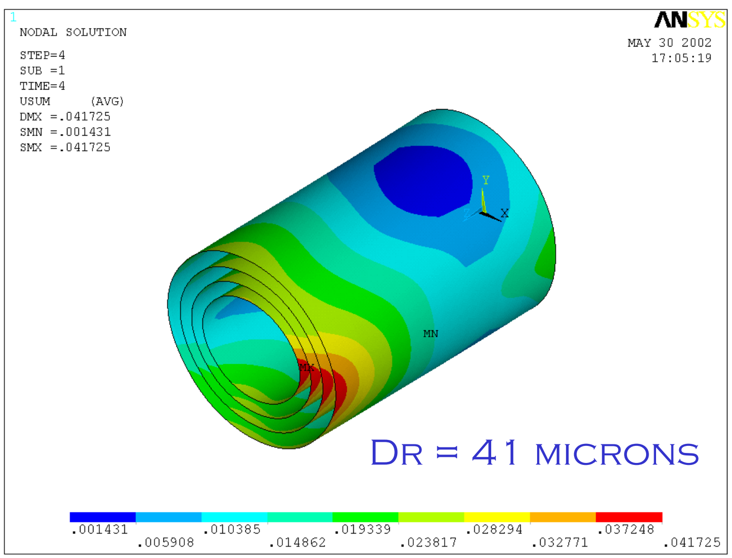
Pixel Detector

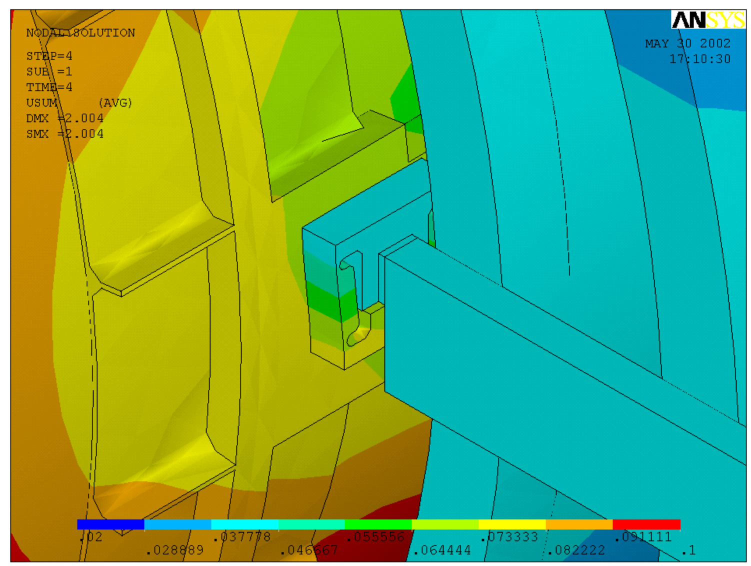
Load Case: dxA = 2 mm

(forward end, side A, displaced 2 mm in X – no gravity or pixel load)

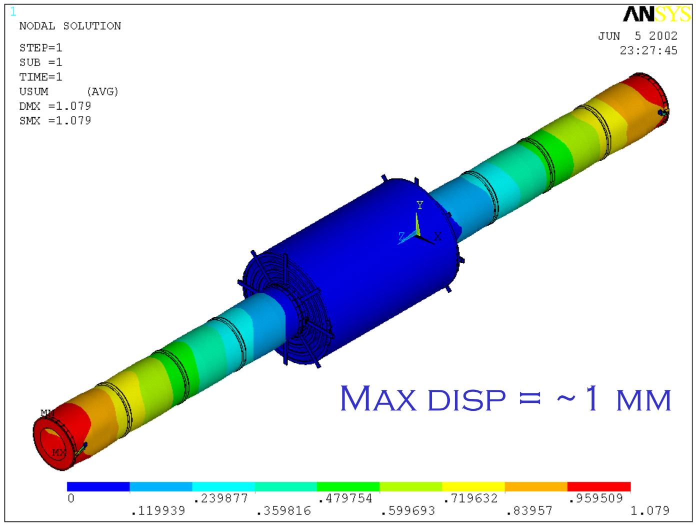




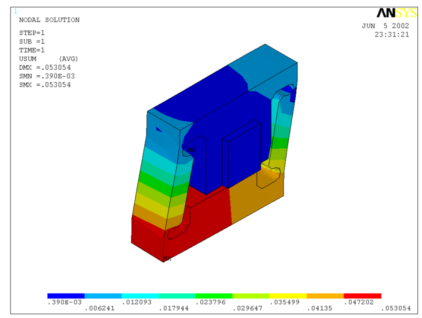




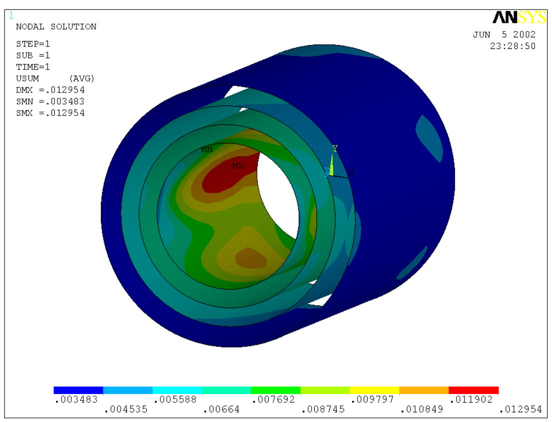
CTE Calculations - Symmetric



- **Assumptions**
  - PST increase in temp relative to SCT by 30 degrees C
  - PST CTE's all assumed isotropic
- **Results**
  - SCT displacements are minimal
  - Flexure displacements are reasonable
  - Load case is very conservative (most likely dT is less than 20 degrees)

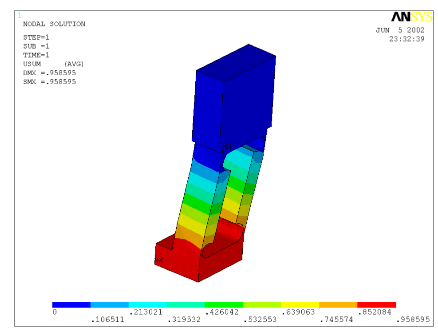


Barrel Flexure, dmax = 53 um



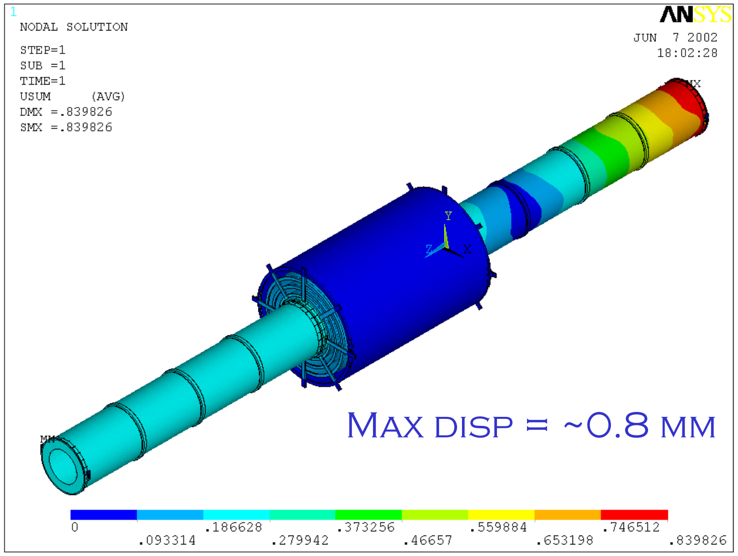
SCT Barrels, max Z = -12 microns

Max. disp. in SCT		
dr (um)	dphi (um)	dZ (um)
-10	-5	-12

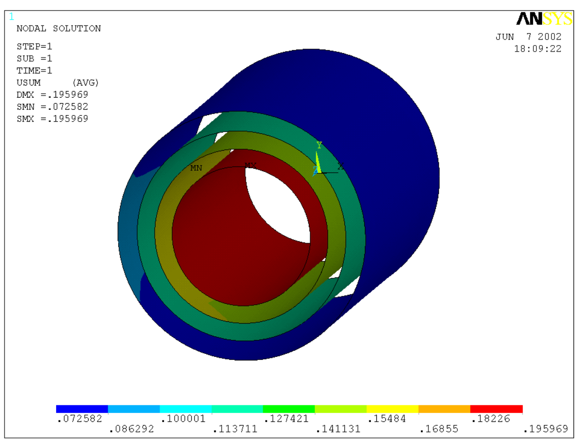


Forward Flexure, dmax = 959 um

CTE Calculations - Asymmetric

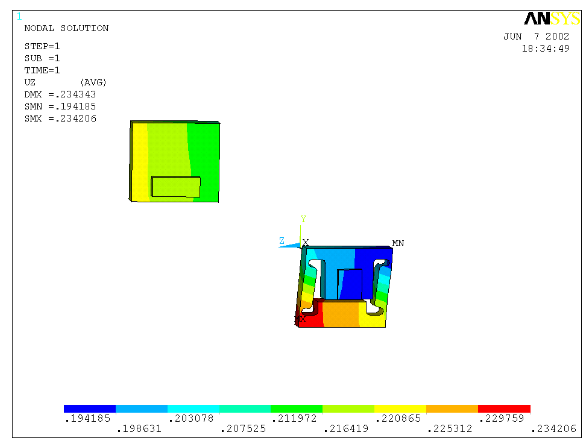


- **Assumptions**
  - ID gas seal leaks on one side of detector, necessitating heaters to be turned on in PST in one forward (assumed C side)
  - SCT does not change temperature
- **Results**
  - SCT displacements are large
  - This load case is unlikely, and can be easily compensated for by turning on all PST heaters
  - Safest solution for Pixels is to avoid all possibility of condensation, and thus use all heaters
  - This is a ***failure*** scenario, not operational



SCT Barrels, max Z = 196 microns

Max. disp. in SCT		
dr (um)	dphi (um)	dZ (um)
-45	12	196

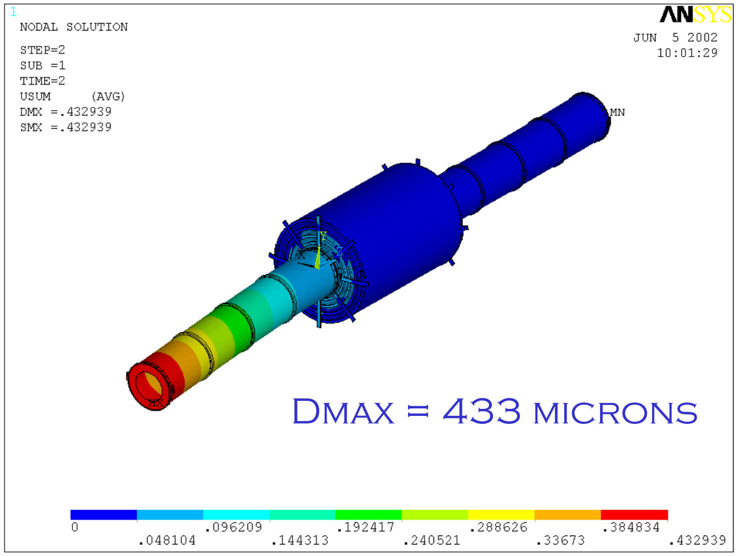


Barrel Mounts, dmax = ~40 um

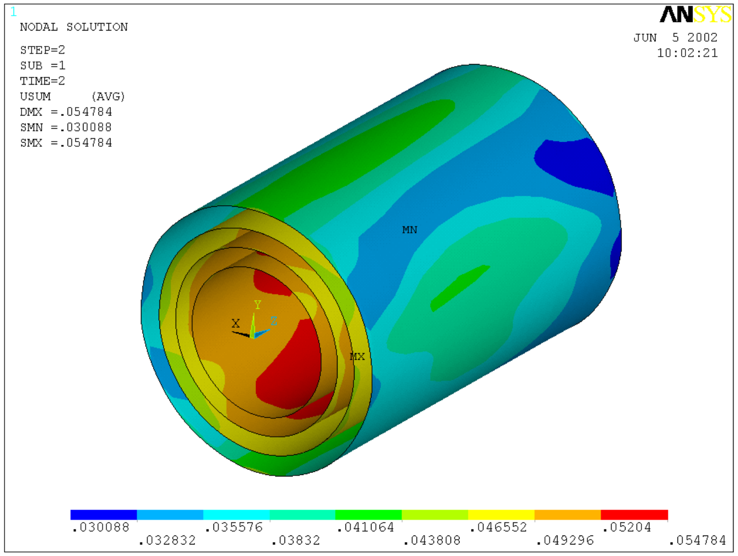
Pixel Detector

Forward Gravity Sag during ID Installation Conditions

During ID installation, the PST Forwards must be cantilevered from the SCT barrel, but with no service or pixel masses present.



Max displacement in SCT shells in this condition = 55 microns.

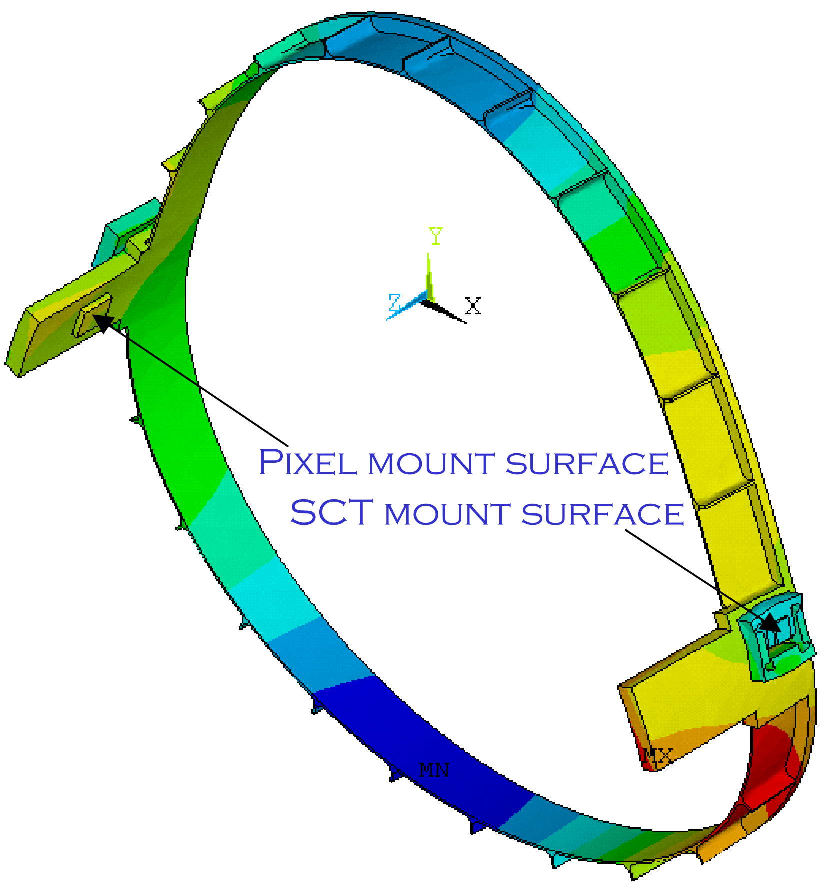


Loads and displacements applied to SCT.

Model Details		Max. Force on Interlinks			Max. Force at Forwards			Max. disp. in SCT Structure		
Bend Direction	Load Case	FX (N)	FY (N)	FZ (N)	FX (N)	FY (N)	FZ (N)	dr (um)	dphi (um)	dZ (um)
Y	Installation (side A)	0	-43	0	0	-2	0	59	-54	14

Pixel Detector

Pixel/PST Stability – Dynamic (Mount Stiffnesses)

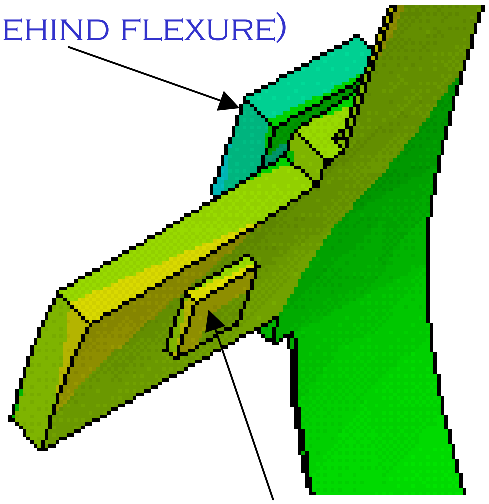


Barrel PST Flange, Mount Pads, and Flexures
(under gravity and pixel loads)

- **Pixel "Dynamic" Stability Budget**
  - Overall Stability Budget based on simple frequency calculation
    - $f=(1/2\pi * (g/\delta)^{1/2})$
    - Desire f of 80 Hz ~ 40 microns displacement under gravity
  - Displacements of Pixel to PST Mounts
    - Budget is 20 microns
    - See Interface/Mounts presentation
  - Displacements of PST to Pixel Mount Surface
    - Nominal budget is 10 microns
    - Coupled to shell stiffness
  - Displacements of PST to SCT flexure
    - Nominal budget 10 microns
    - Coupled to stiffness/deflection of shell
- **PST Mount Pad deflections**
  - Overall relative displacements between SCT/Flexure interface and Pixel/PST interface are shown
  - Overall Budget of 20 microns is met
    - ~6 microns in mount pad
    - ~13 microns in flexure itself
      - Flexure could be stiffened to reduce displacement

Model Description	Maximum Pixel Mount Deflection (microns)	Relative to
PST, rigid (no flexures)	3	PST flexure mount surface
PST, flexures	19	SCT flexure mount surface
PST/SCT, flexures	21	SCT flexure mount surface
PST/SCT, flexures	93	SCT rail (global)

Pixel Stability – Mount deflections under load

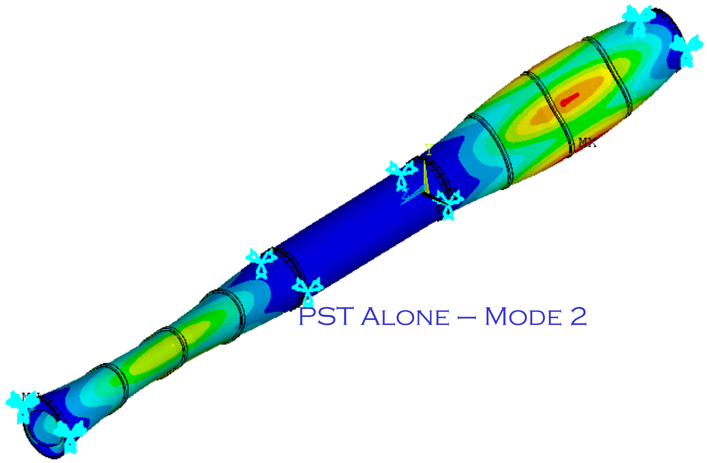


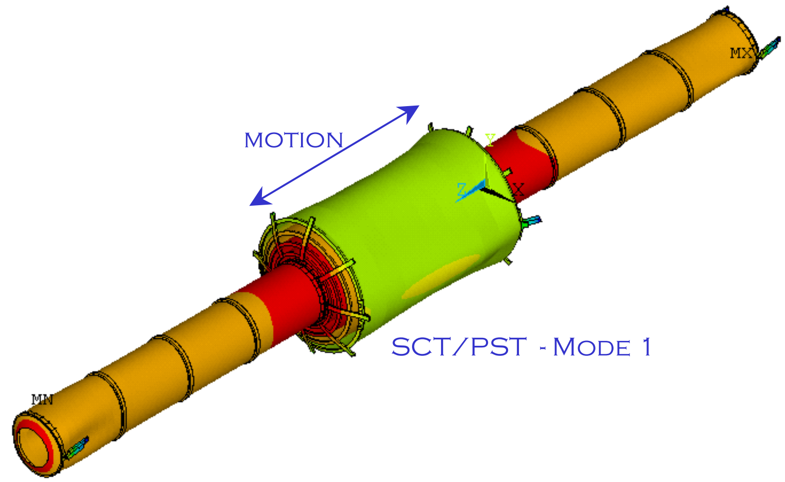
Pixel Mount Deflections Under Load						
Load Case	Pixel Disp. Relative to SCT			Max. Absolute Pixel Disp.		
	dr (um)	dphi (um)	dZ (um)	dr (um)	dphi (um)	dZ (um)
Gravity	19	20	1	26	-73	1
dyA = 2 mm	5	4	2	4	25	3
dxA = 2 mm	21	5	22	59	3	25

- **Relative pixel deflections**
  - Given by difference in displacement between Pixel mount pad and SCT mount pad (interlink arm at flexure interface)
  - Indicates how pixel mounts move inside PST as SCT/PST structure is loaded
- **Load cases**
  - End deflection of pixel forward tube (standard 2 mm offset)
    - In Y, pixel moves with SCT almost exactly
    - In x, flexure mounts allow Pixel to move laterally wRT SCT interlinks
  - Gravity
    - Load case given as comparison, but does not vary in operation
    - 20 micron "stiffness budget" between SCT and pixel is shown

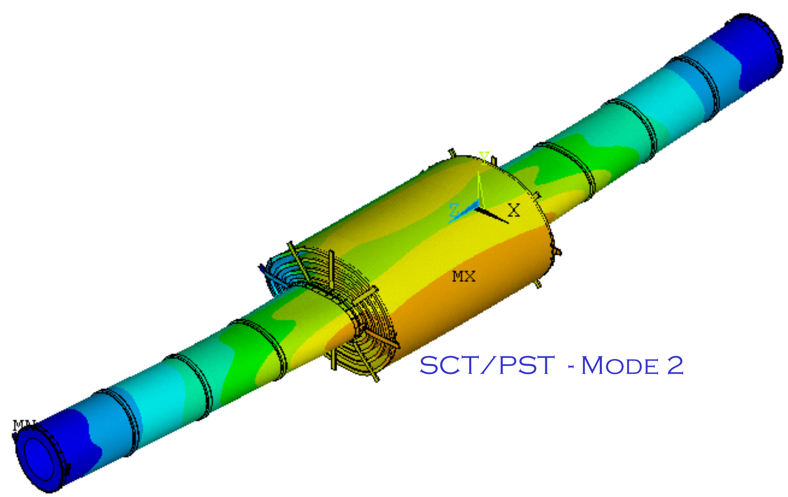
Pixel Detector

PST Stability – Vibration





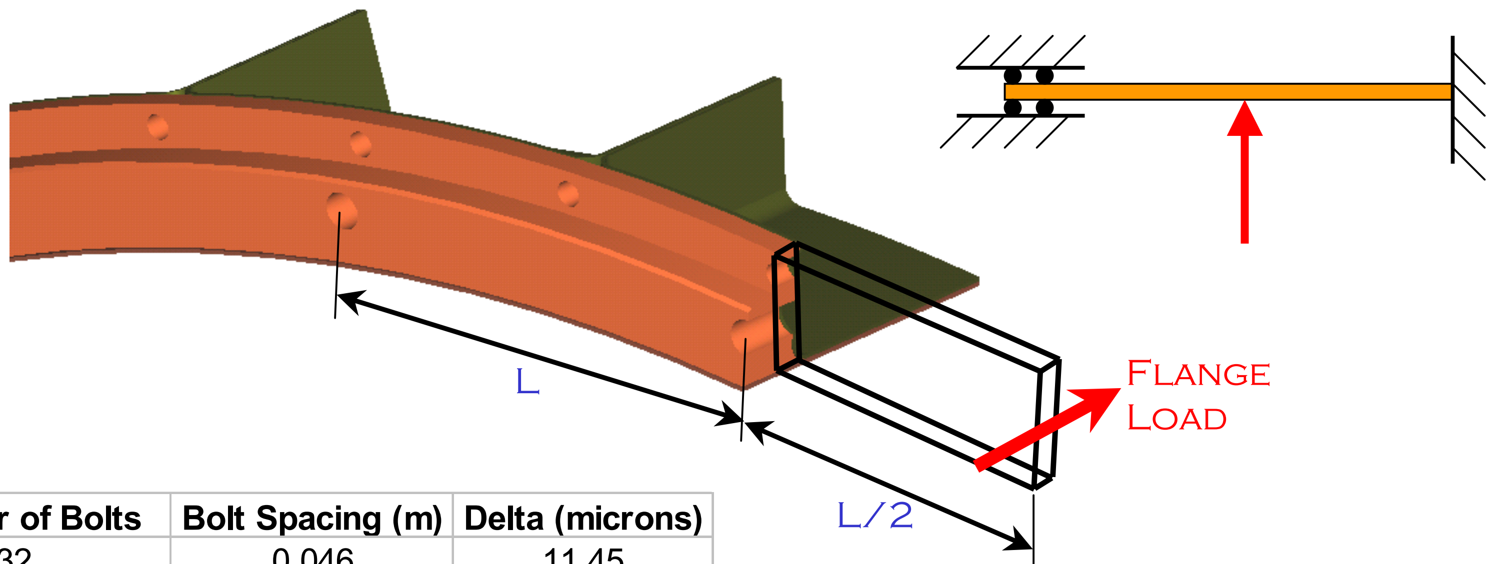
PST Alone		
Mode	**Frequency**	**Action**
1	110	Forward Shell Mode
2	112	Forward Shell Mode
PST/SCT Combined		
Mode	**Frequency**	**Action**
1	25	SCT Piston Motion (Z)
2	43	Full SCT/PST Shell Mode



Pixel and service masses are not included here, but coupling is low due to degrees of freedom built into pixel detector mounts.

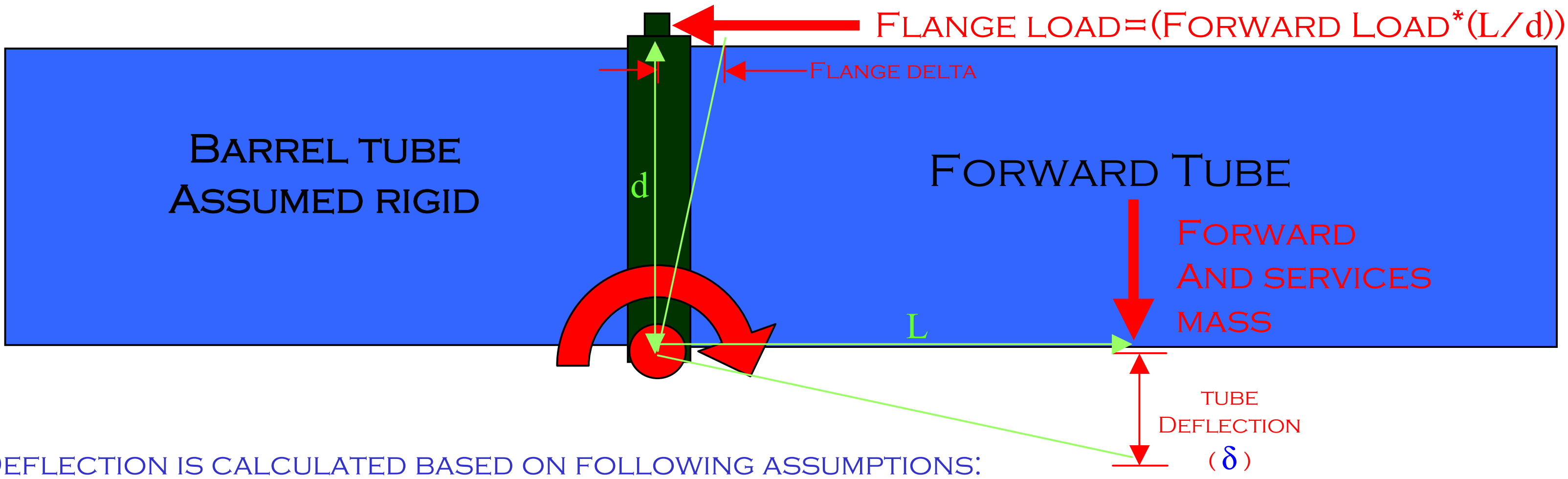
Flange Bolt Spacing Calculations

Flange is conservatively modeled as a simple beam:
- modeled as guided beam with length of bolt spacing/2
- cross section is assumed to be smallest flange section (forward)
- flange force given by support tube loads (next slide)



Number of Bolts	Bolt Spacing (m)	Delta (microns)
32	0.046	11.45
40	0.037	5.86
48	0.031	3.39
56	0.026	2.14
64	0.023	1.43

Flange Bolt Spacing Calculations (cont.)



Tube Deflection is calculated based on following assumptions:

- forward tube pivots rigidly about bottom of flange
- total forward tube mass (including services) is cantilevered
- full flange load is taken by upper bolts only (3 bolts)
- all structures rigid

Frequency is estimated based on tube deflection using $f=(1/2\pi * (g/\delta)^{1/2})$

Number of Bolts	Delta Tube (microns)	Frequency
32	64.55	62.64
40	33.05	87.55
48	**19.13**	**115.08**
56	12.04	145.02
64	8.07	177.18

Desire frequency > 100 Hz

Number at left assumes no ribs

-ribs act like bolt constraints

-evenly spaced ribs allow half the number of bolts

Design for 24 bolts in flange

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Rail FEA Model

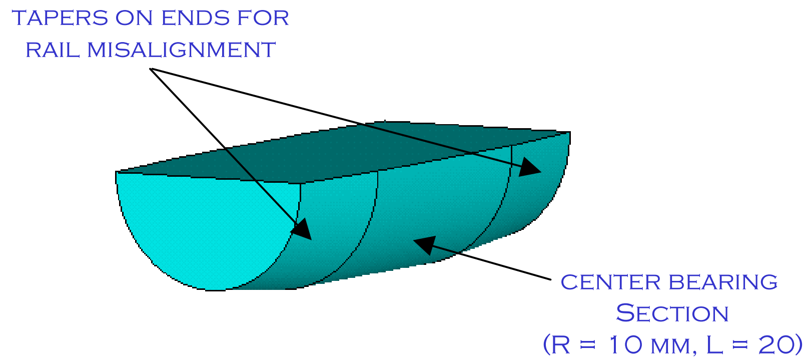
Model simulates prototype of rails and 300 mm long shell (under construction now).

Pixel Mass (1/4 of 35 kg) applied to PEEK slider.

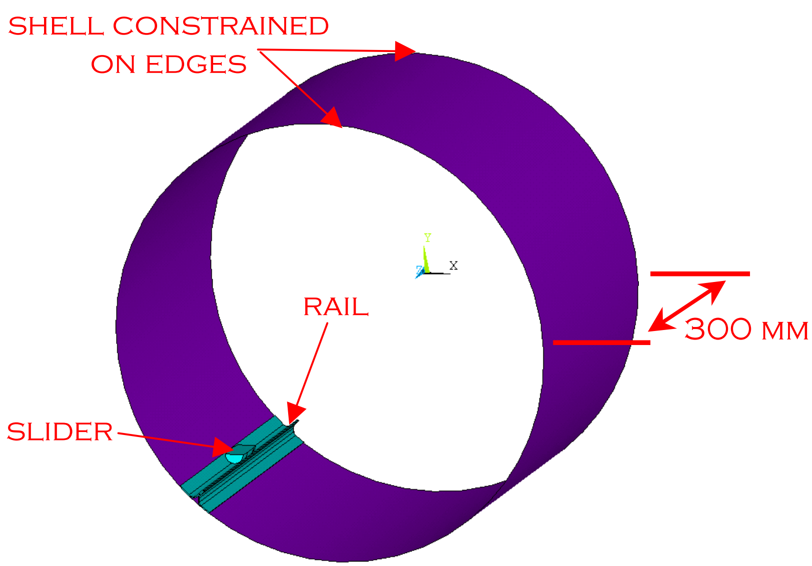
Slider impacts rail through contact elements.

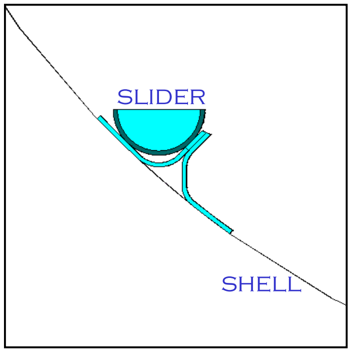
Shell is constrained along edges (where flanges or stiffeners would be).

Shell modeled as both quasi-isotropic glass laminate and composite hybrid laminate of carbon and glass.



Prototype PEEK slider





Cross section of V-rail and slider

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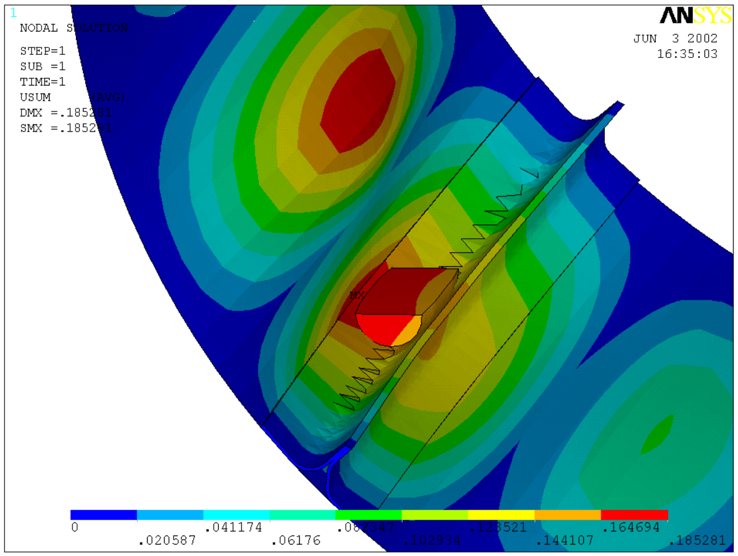
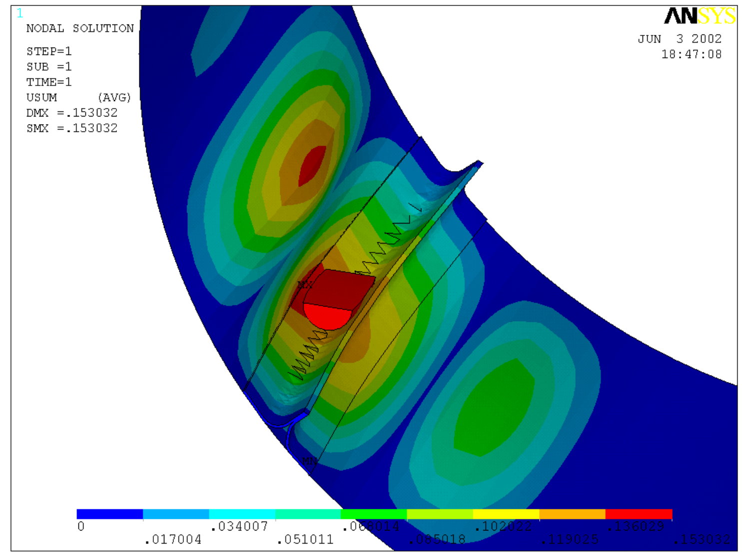
Rail Analyses





Quasi-isotropic Glass Shell
E = 19 GPa

Slider made from PEEK
E = 3.5 GPa

Rail Quasi-isotropic CN60
E = 126 GPa

Load Applied = 8.75 kg

Dmax = 185 microns

Hybrid Shell reduces rail displacement by 20%

Composite Carbon/Glass Shell
(Carbon in Hoop Direction)
E_{axial} = 21 GPa; E_{hoop} = 147 GPa

Slider made from PEEK
E = 3.5 GPa

Rail Quasi-isotropic CN60
E = 126 GPa

Load Applied = 8.75 kg

Dmax = 154 microns

Prototyping

MATERIAL TESTS

- **CURED PLY THICKNESS TEST**
  - DETERMINES BOTH CPT AND NET RESIN CONTENT (NO BLEED)
- **BLEED STUDIES**
  - NEED TO ASCERTAIN WHETHER BLEEDING IS POSSIBLE AND NECESSARY
  - CO-CURING OF HEATERS POTENTIALLY MEANS NO BLEEDING OF PRE-PREG
  - THICK FLANGE LAMINATE WILL BE BLED ACCORDING TO THESE RESULTS
- **FULL PANELS, NOMINAL LAMINATE (8-PLY QUASI-ISO) ALL MATERIALS, WITH AND WITHOUT HEATERS**
  - DETERMINE MODULUS AND RESIN CONTENT BY EXTERNAL VENDOR
  - DETERMINE CTE OF MACRO PANEL WITH AND WITHOUT HEATERS USING IN-PLANE CAPABILITY OF TVH SYSTEM
- **WILL USE RESULTS OF THESE TESTS TO SELECT FINAL MATERIALS FOR PST, AND USE PROPERTY DATA AS INPUT FOR SCT/PST MODELING EFFORT**
- **SHELL PROTOTYPE FABRICATION**
  - PROTOTYPE RAILS WILL BE BONDED IN PLACE
  - DEFLECTIONS UNDER LOAD WILL BE MEASURED AND CORRELATED TO MODELS

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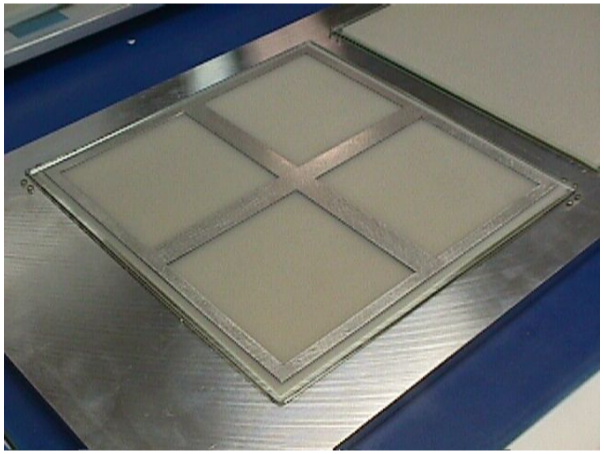
Flat Panel Tools



Single Glass Layup Plate

- **Tools for fabricating flat test panels**
  - 325 mm square glass plates for tooling surface
  - Can be laid up as 300 mm square panels, or 4 150 mm square panels (as shown left)
- **Aluminum tooling plates support glass**
  - 3 glass plates per tool, 2 tools
  - Tools can be stacked to cure in autoclave simultaneously

Ready to Vacuum Bag

Bagged and Ready for Autoclave

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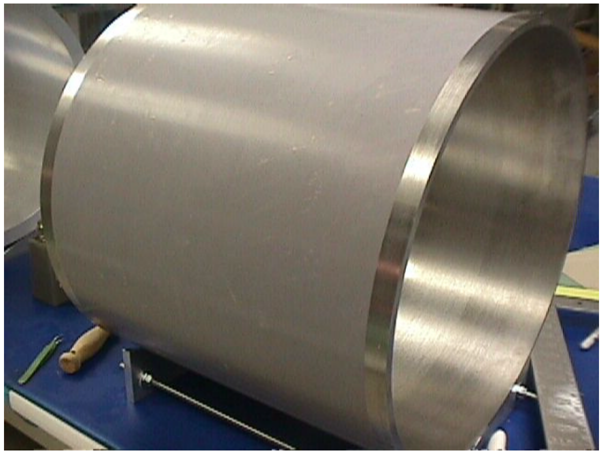
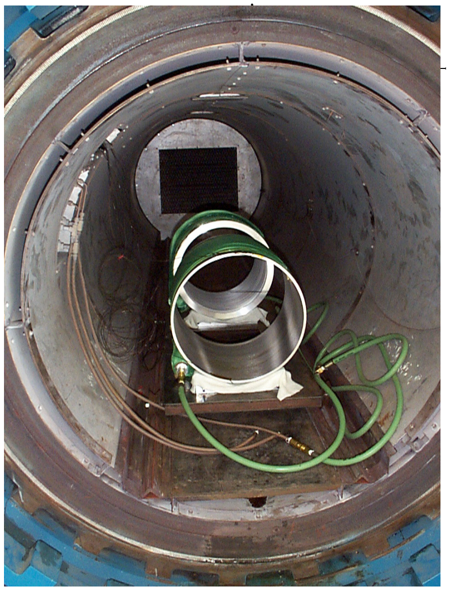
Mandrels



Steel Tool with Teflon Release Film

- **Cylinders for fabricating prototype shells**
  - 400 mm long for 300 mm shell length
  - Thickness sized to allow fast heat transfer in autoclave while retaining dimensional stability
- **Different mandrel for each section**
  - Aluminum mandrel for forwards
    - Glass laminate requires tool with higher CTE in order to guarantee release after cure
  - Steel mandrel for barrel section
    - Carbon laminate can use steel tool (raw material cheaper and more available)
  - Both mandrels sized to achieve laminates with identical radii
    - Based on rough CTE calculations given

Mandrel Bagged for Cure



Both Mandrels Positioned in Autoclave

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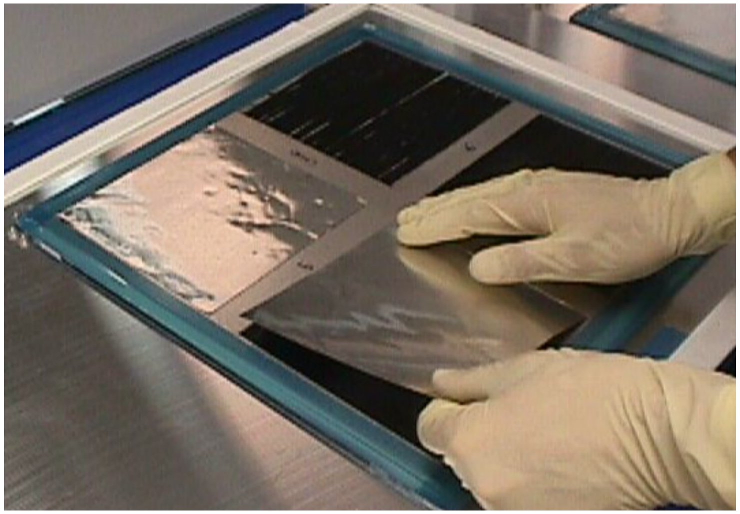
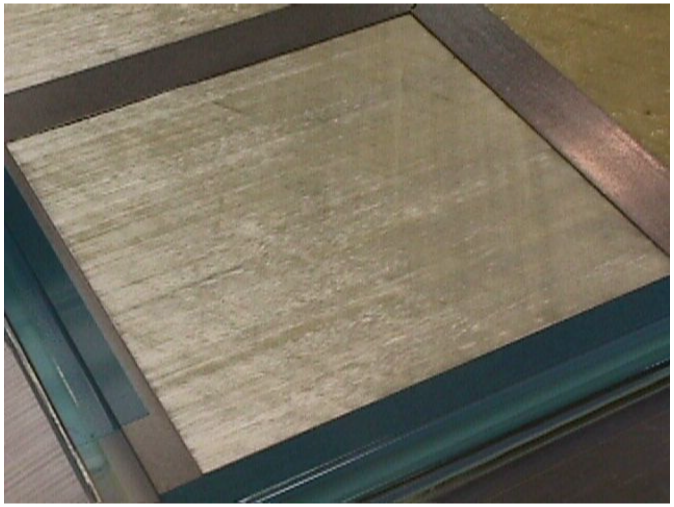
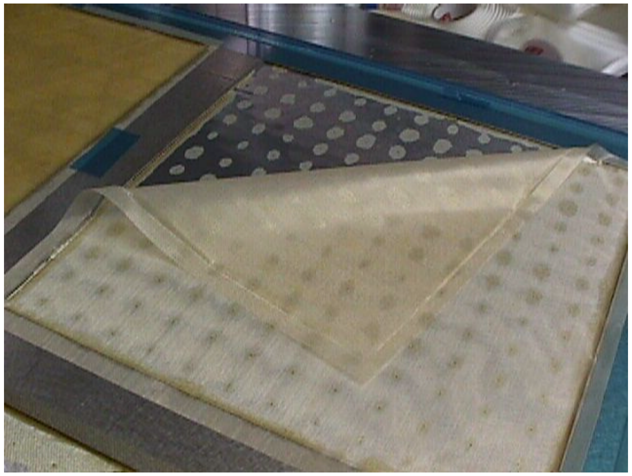
Flat Panels



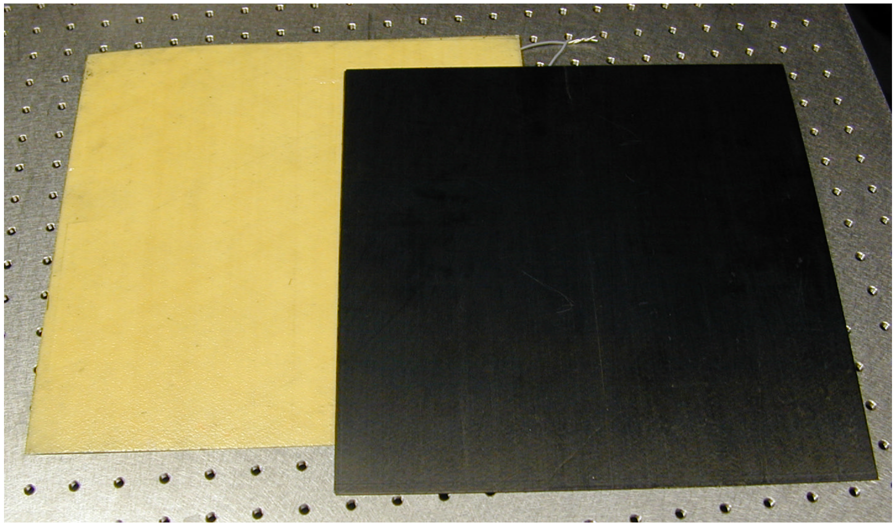
Bleed Studies being laid up with perforated aluminum sheet in order to simulate bleeding through heater panel.



Quartz Test panel before bagging and curing.



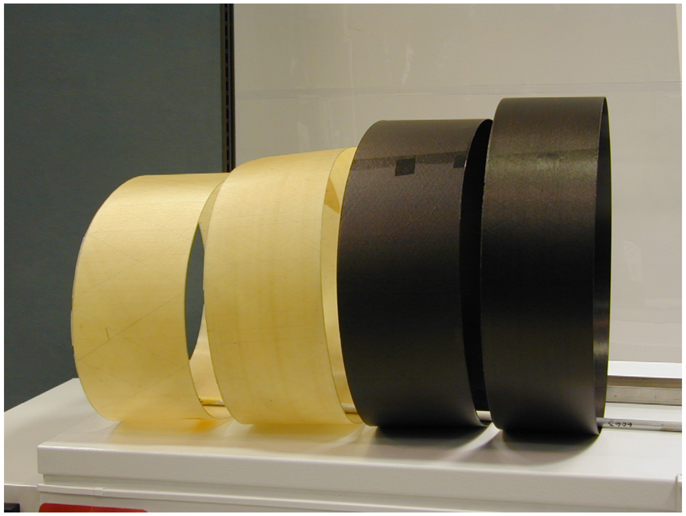
Resin bleeding through perforations in mock heater.



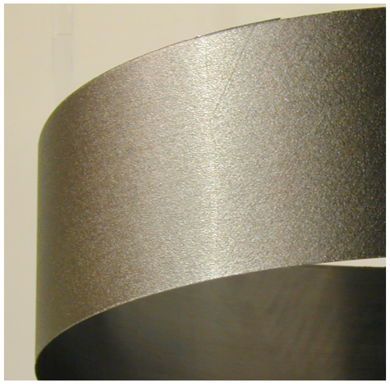
Cured glass (L) and carbon (R) test panels

Prototype Shells

- **Four 150 mm long shells fabricated**
  - Two all glass (AQII)
    - 1 shell with 90 degree (hoop) inner and outer plies [90/30/150]S
    - 1 shell with 0 degree (axial) inner and outer plies [0/60/120]S
  - Two all carbon (YSH80)
    - 1 shell with 90 degree (hoop) inner and outer plies [90/30/150]S
    - 1 shell with 0 degree (axial) inner and outer plies [0/60/120]S
- **Qualitative Results**
  - Shells with axial plies were very flexible in the shell normal direction
  - It was decided to use the hoop fiber orientation



Axial glass, hoop glass, axial carbon, and hoop carbon shells. Gravity sag between different laminates is easily observed.

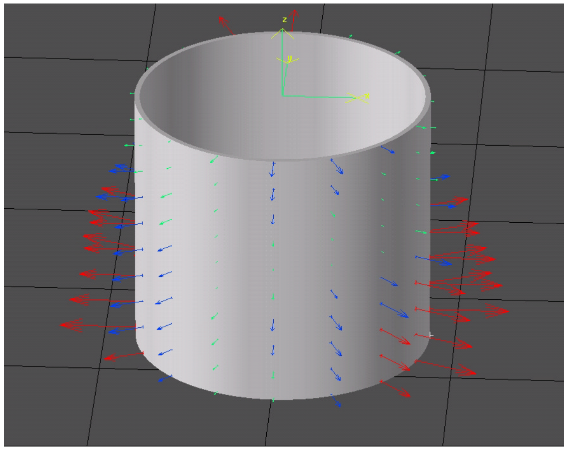


Carbon shell closeup.

MANDREL DIAMETER CALCULATIONS

- **FOR PRODUCTION IT IS CRITICAL TO FABRICATE PST FORWARDS AND BARRELS TO THE SAME DIAMETER, FROM POTENTIALLY DIFFERENT TOOLS, WITH DIFFERENT MATERIALS**
- **TEST SHELLS WERE USED TO MEASURE HOW WELL DIAMETER COULD BE DETERMINED FROM CALCULATIONS**
  - MANDRELS WERE MEASURED WITH CMM
  - SHELLS WERE FABRICATED FROM MANDRELS
  - SHELL DIAMETERS MEASURED AFTER CURE WITH PI-TAPE
  - CALCULATED AND MEASURED DIAMETERS WERE COMPARED
    - LAMINATE CTE'S CALCULATED WITHOUT HEATERS (TEST SHELLS HAD NO HEATERS ON THEM)
    - MANDREL CTE'S TAKEN FROM MIL HANDBOOK 5, ASSUMED CONSTANT WITH TEMPERATURE

Mandrel	Mandrel CTE (ppm/K)	Part	Part CTE (ppm/K)	Mandrel RT Diameter (mm)	Cure Temp (C)	Mandrel/Part at Temp Diameter (mm)	Calculated Part Diameter After Cure (mm)	Measured Part Diameter After Cure (mm)	Difference from RT (mm)	Difference from Calc. (mm)
Steel	12.24	YSH80	-0.94	455.701	120	456.231	456.266	456.667	0.965	0.400
Aluminum	22.95	AQII	9.08	455.574	120	456.568	456.228	457.251	1.676	1.023



CMM DATA FOR STEEL MANDREL SHOWING LARGE TAPER

- **AGREEMENT IS POOR BETWEEN CALCULATIONS AND SHELL MEASUREMENTS**
  - DIFFERENCES IN MEASURING TECHNIQUE
    - CMM USED FOR MANDREL MEASUREMENTS
    - PI TAPE USED FOR SHELLS (LESS COST AND TIME)
  - MANDRELS WERE OUT OF SPEC
    - LARGE TAPER FOUND ON STEEL MANDREL
    - MAKES DIAMETER COMPARISON DIFFICULT TO DO
  - MATERIAL INFORMATION IS SUSPECT
    - GENERAL VALUES COME FROM MANUFACTURER
    - PROTOTYPE LAYUPS BEING MEASURED CURRENTLY
  - ASSUMPTIONS MADE
    - RELEASE FILM THICKNESS ASSUMED FROM MANUFACTURER'S INFORMATION – NOT MEASURED
    - ACTUAL GEL TEMPERATURE OF RESIN IS UNKNOWN

Pixel Detector

Hybrid Shell Option

- **Hybrid shell (YSH80/AQII) has many advantages over Quasi-isotropic AQ II Shell**
  - Bending stiffness does not increase
    - YSH80 plies in hoop direction only
  - CTE's match better - hoop CTE closely matches that of barrel shell
    - May need only one mandrel
      - Saves cost and time
      - Eliminates need to match diameters of shells from two different mandrels
    - Shell CTE matches better with hoop stiffeners and flanges
      - Less stress during temp changes
      - Bonding process is easier (can be heated to cure without problems)
  - Shell stiffness of forwards is increased
    - Rail deflections are lower (~20% as shown in simple model)
    - Modal frequencies will increase (most are shell modes)
- **Possible disadvantages**
  - YSH80 is more expensive than AQ II
    - This is small (at most ~2k)
    - May be offset by savings in having only one mandrel
  - CTE Mismatch between glass and carbon may cause wrinkling during cure
    - Differences in stiffness indicate this is unlikely
    - Regardless, prototype shell is being constructed in order to test this

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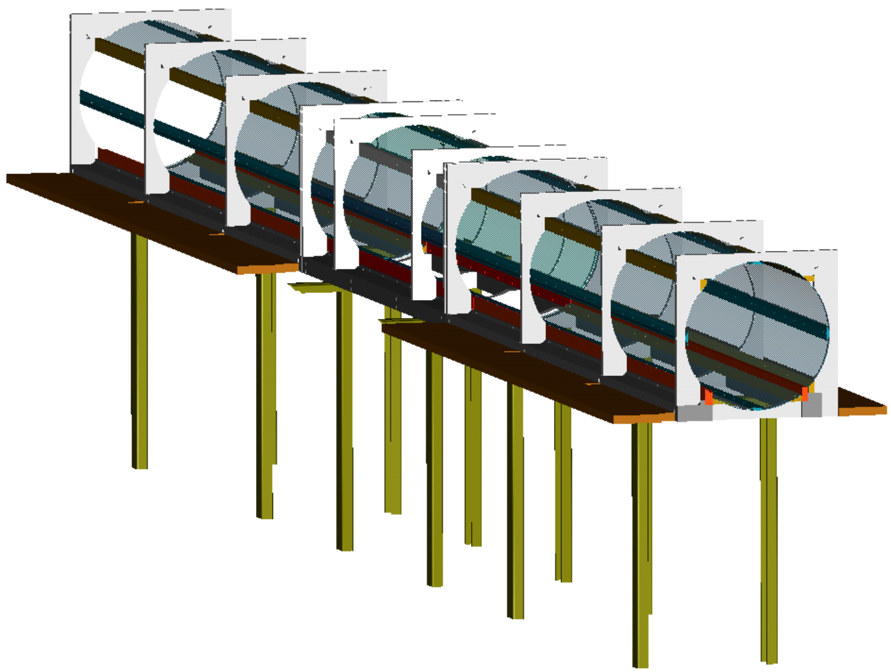
Pixel Support Tube Mockup



- **Mockup simulates entire PST tube (in 3 sections)**
- **Goal is to simulate installation scenario**
  - Mockup rails (aluminum) installed
  - Rails can be changed out to simulate other designs
- **Detector rails and sliders will be tested**
  - Slider material and shape validated
  - Rail geometry modified if necessary

Pixel Detector

Results & Conclusions

- **Prototyping**
  - Bleed Studies
    - Bleeding through perforated heater panel is ineffective
    - There is plenty of resin to co-cure heaters without additional adhesive
  - Flat Plates
    - Resin content and modulus testing are being conducted currently
  - Prototype shells
    - Mandrel diameters are hard to calculate and match with our current information
      - Need test results
      - Must fabricate mandrels to higher tolerance
      - Higher accuracy may be difficult – must be able to compensate
    - Shell laminates with hoop direction plies are advantageous for performance and handling
- **Rails**
  - Displace more in beam mode than shell mode (displacements are primarily not in the cross sectional plane)
    - Would benefit from a closed section rail, rather than the open one shown
    - Initial estimates suggest a closed rail could be 50% stiffer in bending, but with less cross sectional area than the current rail
      - Allows use of less stiff material (P30 or T300 Fiber)
      - Has lower contribution to shell bending stiffness
  - Analysis suggests that more hoop stiffeners will be necessary (at 300 mm spacing, rather than ~600 mm)
  - Requires validation of slider shape before design can be accepted
    - Must rule out the possible need of a rolling mechanism in the event of high friction

Pixel Detector

Results & Conclusions cont.

- **Pixel Support Tube**
  - Loads and deflections on SCT and mounts appear to be in the acceptable range for stiffnesses shown, but these numbers are **approximate**
    - Actual fiber ply thicknesses not yet determined to high accuracy
    - Fiber stiffnesses not yet experimentally measured
    - Rails have been omitted from models
      - Rails will stiffen the shell in bending
        - » Increased cross sectional area
        - » Stiffer material than shell itself
      - Rail designs have not been optimized
      - Potential increases in SCT loads by 15-20%
    - **FEA models generate stiffnesses almost always higher than in reality**
      - This will mitigate the rail contributions and uncertainty in material data
  - Vibrational modes are far above the frequencies that are needed (SCT stiffness dominates)
  - Flanges and mount pads are stiff enough to satisfy pixel stability budget
  - Flanges and PP1 have not yet been optimized
    - PP1 design in model is simple flat plate
      - Real design will be stiffer
      - Connector masses have not be accounted for and are not yet known
    - Flanges have been roughly designed but not optimized
      - Flange length may be shortened to save mass
      - Number of ribs may be increased or decreased depending on manufacturing concerns
  - Hybrid shell appears to be desireable
    - Simplifies manufacturing by matching CTE's for flanges and hoops
    - Improves rail performance with minimal increase in shell bending stiffness

Pixel Detector

Prototyping Plans

- **Immediate (within next two months)**
  - Fabricate 300 mm long shells with heater panels (both hybrid and carbon)
  - Perform CMM measurements of shell laminates (to compare with mandrels)
  - Fabricate test rails
  - Bond test rails to flat panel and shell, measure deflections
  - Fabricate tooling for flange parts
  - Test slider materials and determine target material
- **Short Term (within 6 months)**
  - Order production materials
  - Fabricate full length (2.8 m) mandrel for forward shells
  - Fabricate all flange parts
  - Bond flanges to prototype shells
  - Fabricate full length rail tools (2.8 m)
  - Layup full length test rails
- **Long Term (within next year)**
  - Fabricate full forward length PST shell
  - Fabricate flanges for forward shell
  - Fabricate mount pads
  - Bond full forward PST assembly (will be usable article if no errors are made, but budget allows for one prototype full length forward before production begins)