FEMCI Workshop

at GSFC

17 May 2001

STOP Analysis & Optimization of a very Low-Distortion Instrument

HST WFC3 Case Study

by

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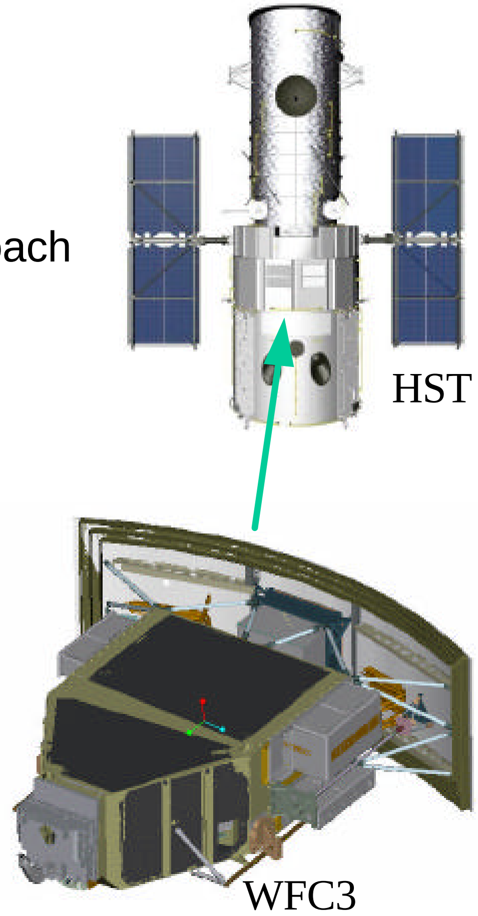
OUTLINE

WFC3 (Wide Field Camera 3) is a “radial” instrument under development to replace WF/PC2 (Wide Field Planetary Camera 2) of the Hubble Space Telescope (HST) in the next servicing mission.

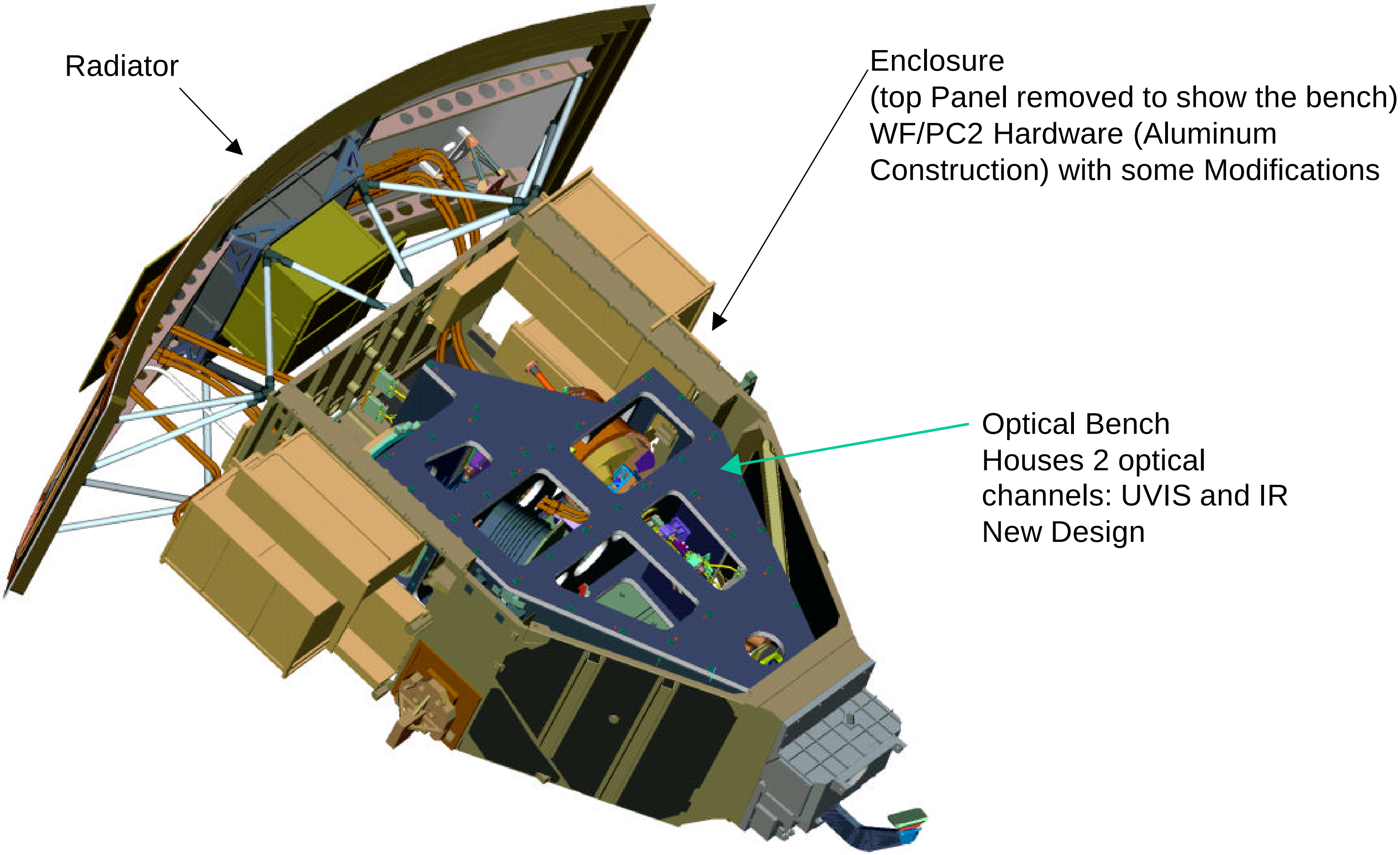
Presentation Outline

Instrument Overview
Optical Performance and Requirements
Structural-Thermal-Optical Performance (STOP) Analysis Approach
Multi-Disciplinary Systems Engineering Approach
Key Design Requirements
Optical Bench Structure and Materials
Detailed Structural Analyses
Structural Issues Critical to STOP Optimization
Thermal Design and Analysis
STOP Analysis Results
- Gravity Sag and Other Long-Term
- Short-Term

Conclusions and Recommendations



INSTRUMENT OVERVIEW



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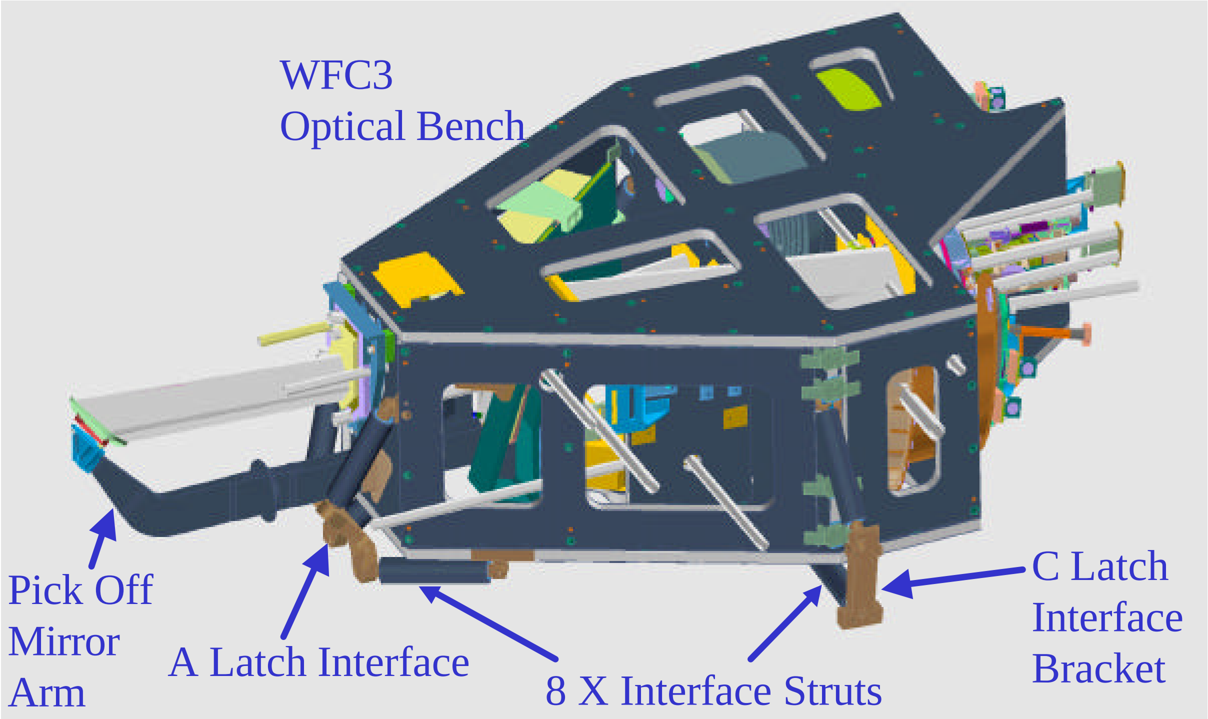
OPTICAL BENCH

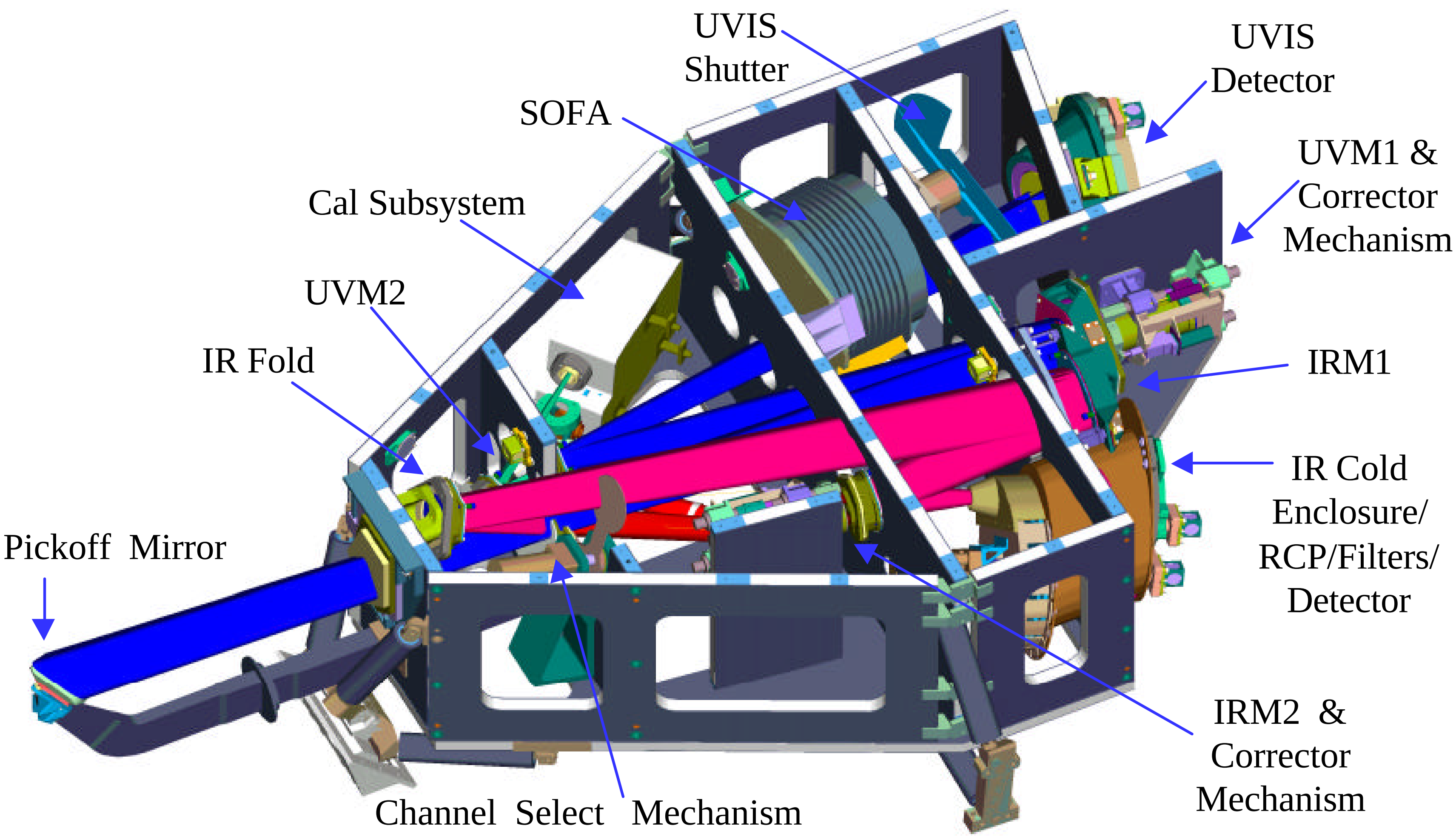
Low distortion characteristics of its Optical Bench are key to the optical performance of WFC3 since it houses all the critical optical components of the instrument.

WFC3 is configured as a two-channel instrument. The incoming beam from the HST is directed into the instrument using a pick off mirror and is then sent to either a near-UV/visible (UVIS) channel or a near-IR channel.



Optical Bench structure has been analyzed, designed, and fabricated by Swales Aerospace. It is now being assembled at Swales. It will undergo environmental qual testing next month at GSFC.

OPTICAL BENCH LAYOUT



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LINE-OF-SIGHT (LOS) & OPTICAL PERFORMANCE

WIDE FIELD CAMERA 3

- LOS Error due to the motion of the image across the Detector chip over a two-orbit interval

  LOS Error => Short Term Stability => Short Term Distortion Budget

- Scientists do not want more than 1/4 of a pixel motion so their software can adequately overlap successive images. If they cannot overlap successive images to this level the images will appear to be blurred and degrade resolution.

- Short Term Error Sources: On-Orbit Temperature Variations, Jitter

- Based on the Pixel sizes of its channels, the Short-Term Distortion Budget for the WFC3 instrument are:
  UVIS Channel: 39/4 ? 10 milli-arcsec
  IR Channel: 80/4 = 20 milli-arcsec

	UVIS	IR	
Format	4Kx 4K U. of A. UV or SITe Coating	1K x1K	pixels
Field Size	160 x 160	120 x 120	arcsec
Pixel Size	39	80	mas (milli-arcsec)
Spectral Range	200 to 1000	600 to 1800	nm

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WAVE-FRONT (WF) & OPTICAL PERFORMANCE

- Light enters the HST telescope as a set of individual parallel light rays that eventually come to focus at the instrument detector. If all the mirrors were perfectly figured and perfectly aligned, then all the light is contained within the tightly focused image at the detector. The size of the spot is then only controlled by diffraction (light bending around edges) due to the size of apertures. When the mirrors move or distort so they are not perfectly aligned anymore, the light rays no longer focus at the same spot on the detector. In other words the ideal wave-front now has an error.

WF Error => Long Term Stability => Long Term Distortion Budget

- The WF error does have an impact on resolution. If the WF error gets worse, the spot size on the detector grows larger or odd shaped thereby degrading resolution.

- The amount of mirror motion required to distort the image on the detector is actually much larger than the LOS budget. Therefore, the short term distortions have negligible effect on the Wave-Front Error.
WF Error => Long Term Stability => Long Term Distortion Budget

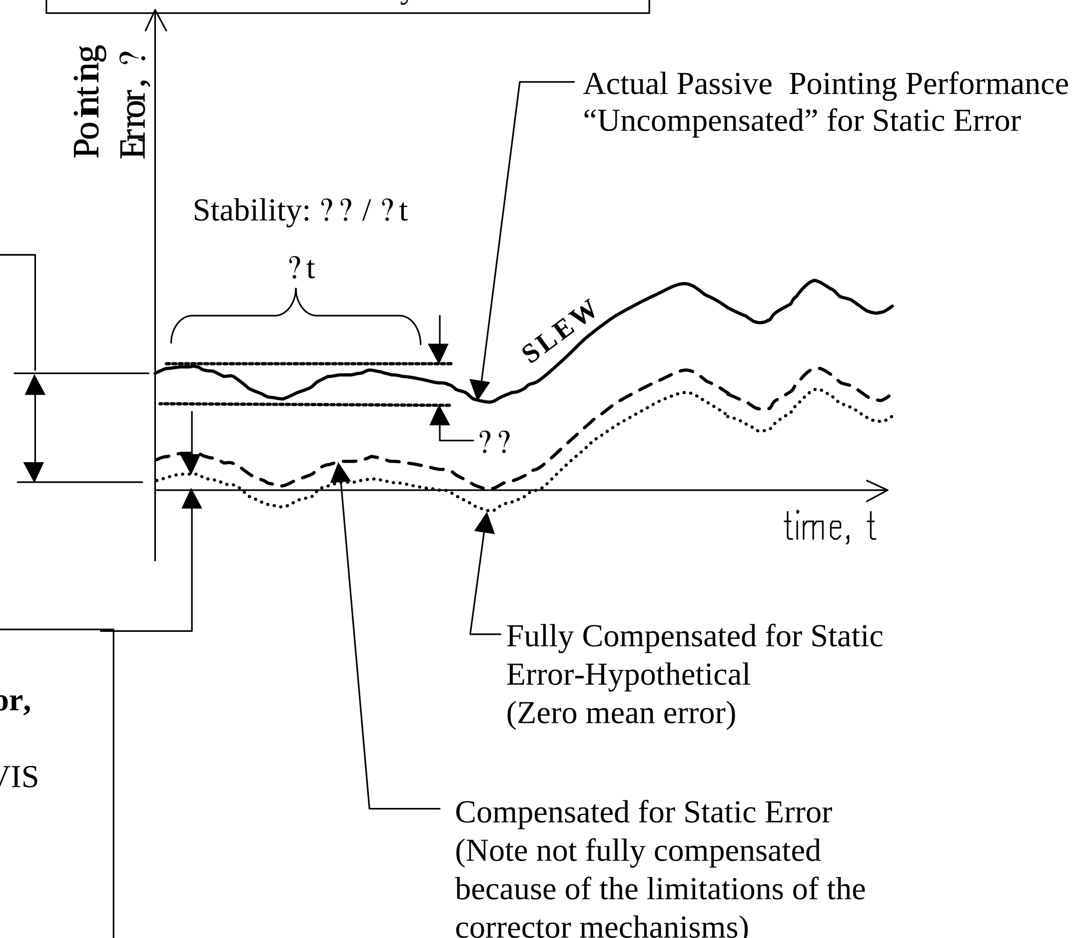
- Long Term Error Sources: Gravity Release, Ground-to-Orbit Temperature (Set Point) Change, Desorption, Launch Shift

- WFC3 Long Term Distortion Budget ? 50 arcsec for both UVIS and IR Channels

POINTING PERFORMANCE
ERROR ANALYSIS & SOURCES

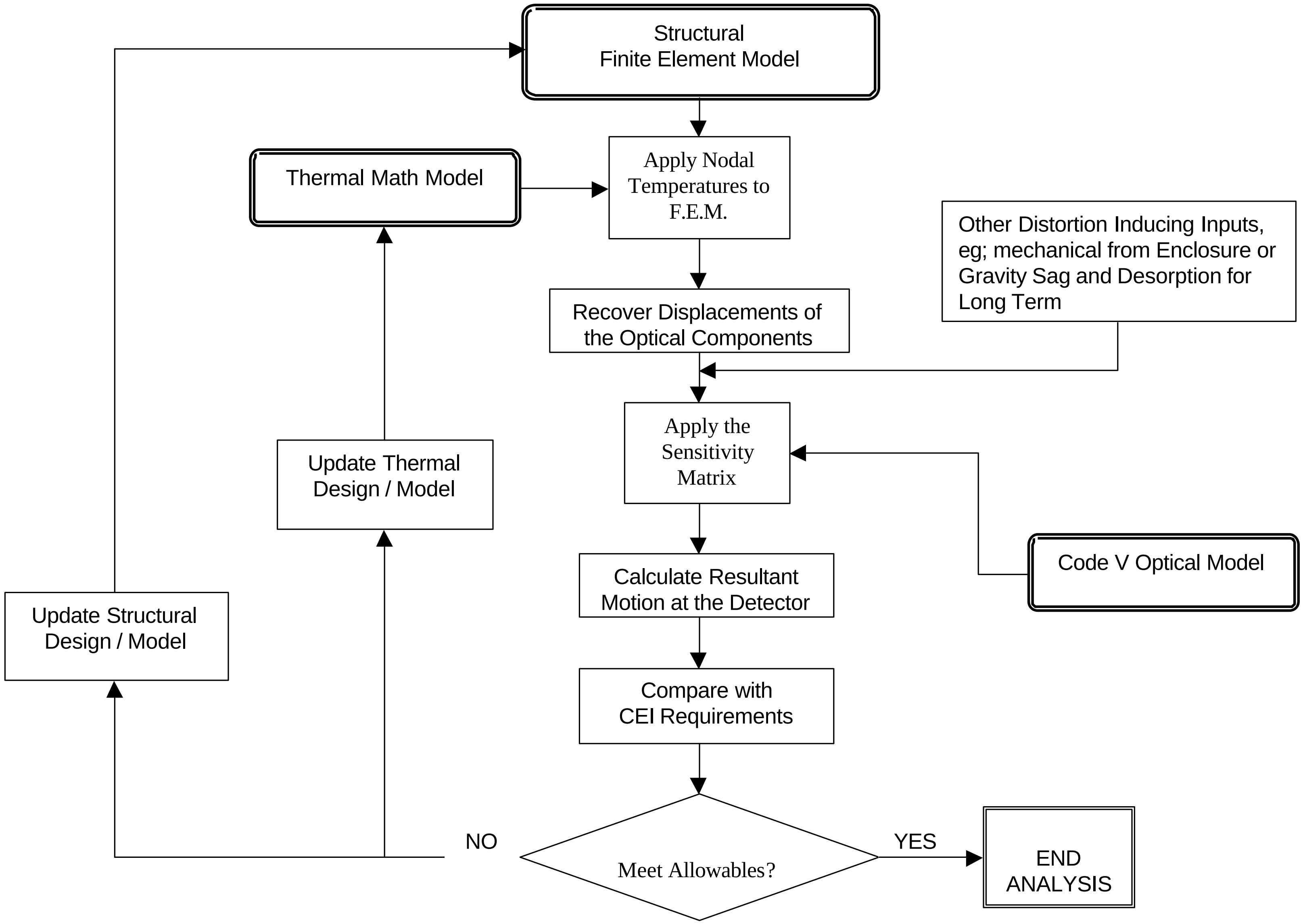
POINTING (Alignment) ERROR
Sum of “Static” and “Dynamic” Errors

STATIC ERROR
(Long Term or Wave-Front Error, Accuracy)
WFC3 Budget ? 50 arcsec
“One-Time” Shift from Ground Alignment to Orbit Operation
Major Sources:
Gravity Release (Gravity Sag)
Temperature Change (Set Point Shift)
Moisture Desorption
Assembly/Integration Induced
Launch Loads Induced (Launch Shift)
Mechanically Transmitted
Rigid Body Motion



DYNAMIC ERROR
(Short Term or Line-of-Sight Error, Knowledge)
WFC3 Budget 10 milli-arcsec for UVIS Channel
Major Sources:
On-Orbit Temperature Changes
Jitter
Mechanically Transmitted
Rigid Body Motion

STOP ANALYSIS FLOW



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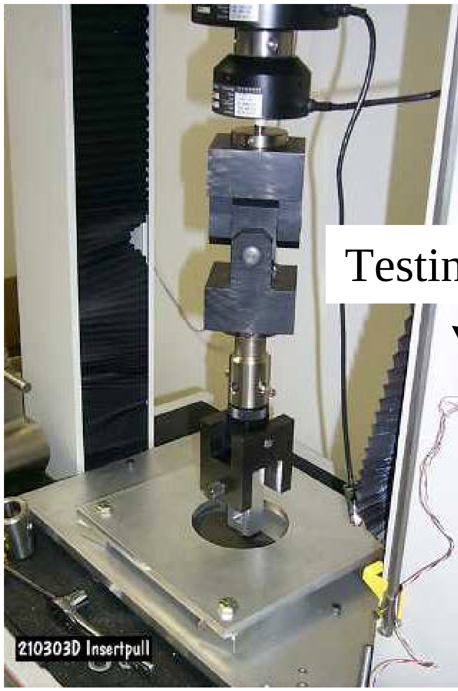
MULTI-DISCIPLINARY SYSTEMS ENGINEERING APPROACH

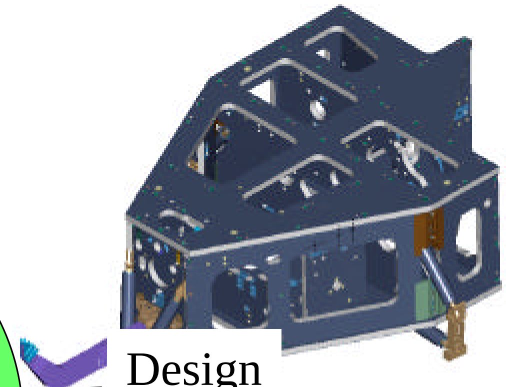


Testing

Requirements Definition

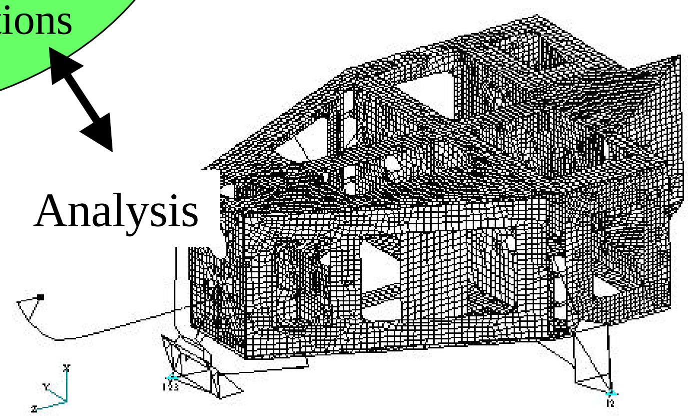
<u>Multi-Disciplinary Systems</u>

Structural Engineering
Materials Engineering
Thermal Engineering
Alignment Planning & Metrology
Attitude Control
Observatory Operations



Design

Manufacturing



Analysis

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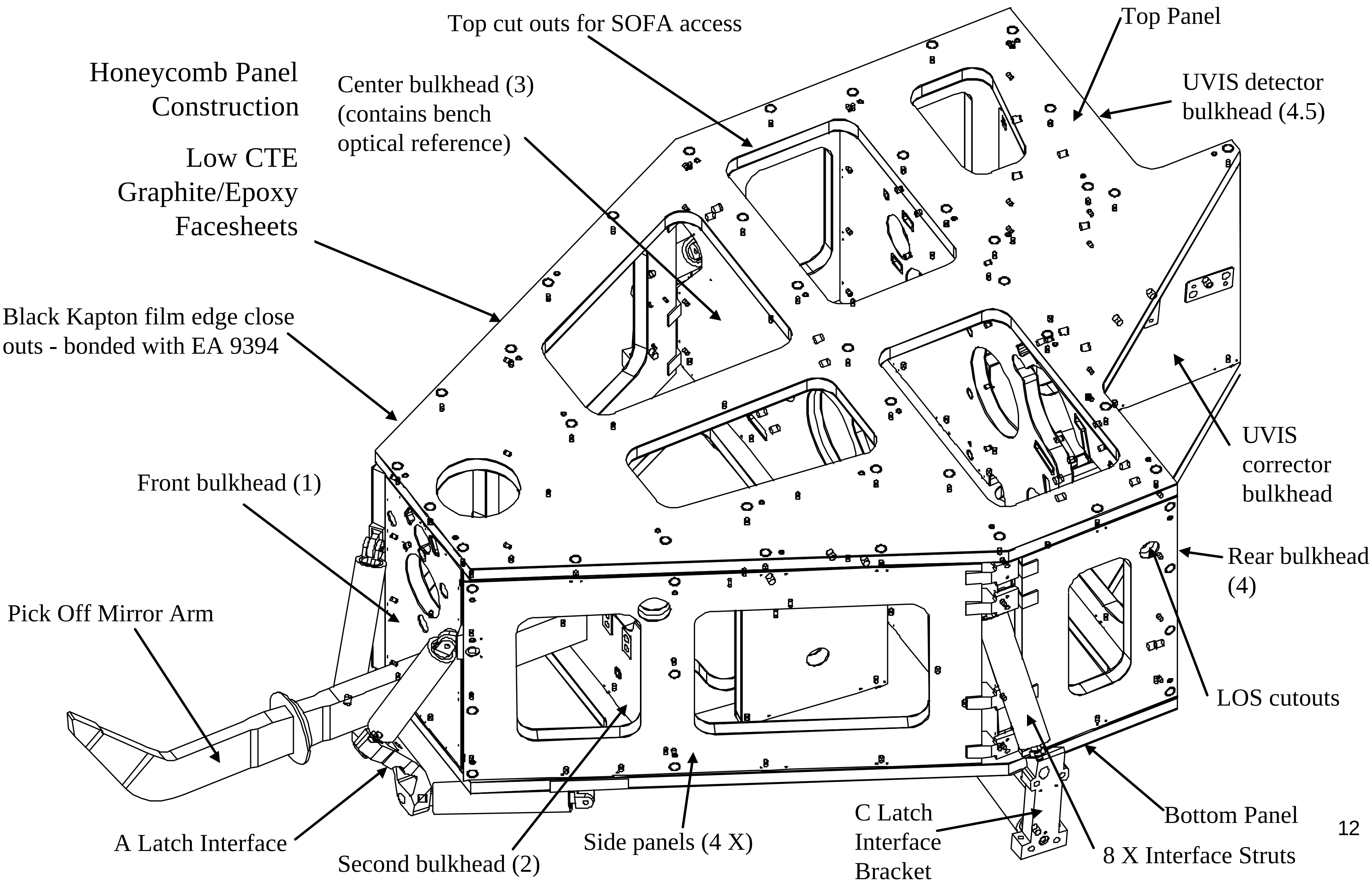
OPTICAL BENCH
KEY DESIGN REQUIREMENTS

- Meet WFC3 Optical Pointing Requirements
- Provide support for the WFC3 Optical System and package to fit into existing Enclosure
- Provide easy access for components throughout integration
- Meet the HST SM4 Structural Requirements
- Interface to HST: Meet the flow down requirements of ST-ICD-03F: Space Telescope, Level II, ICD… "Radial Scientific Instruments to Optical Telescope Assembly and Support Systems Module"
- Provide an interface with adequate mechanical and thermal isolation from the WFC3 enclosure.
- Meet the flow down instrument mass requirements
- Meet the HST and Optical System contamination requirements
- Support late-in-the-flow change-out requirements of the detectors and filters per the WFC3 CEI spec
- Reuse WF/PC1 hardware where possible

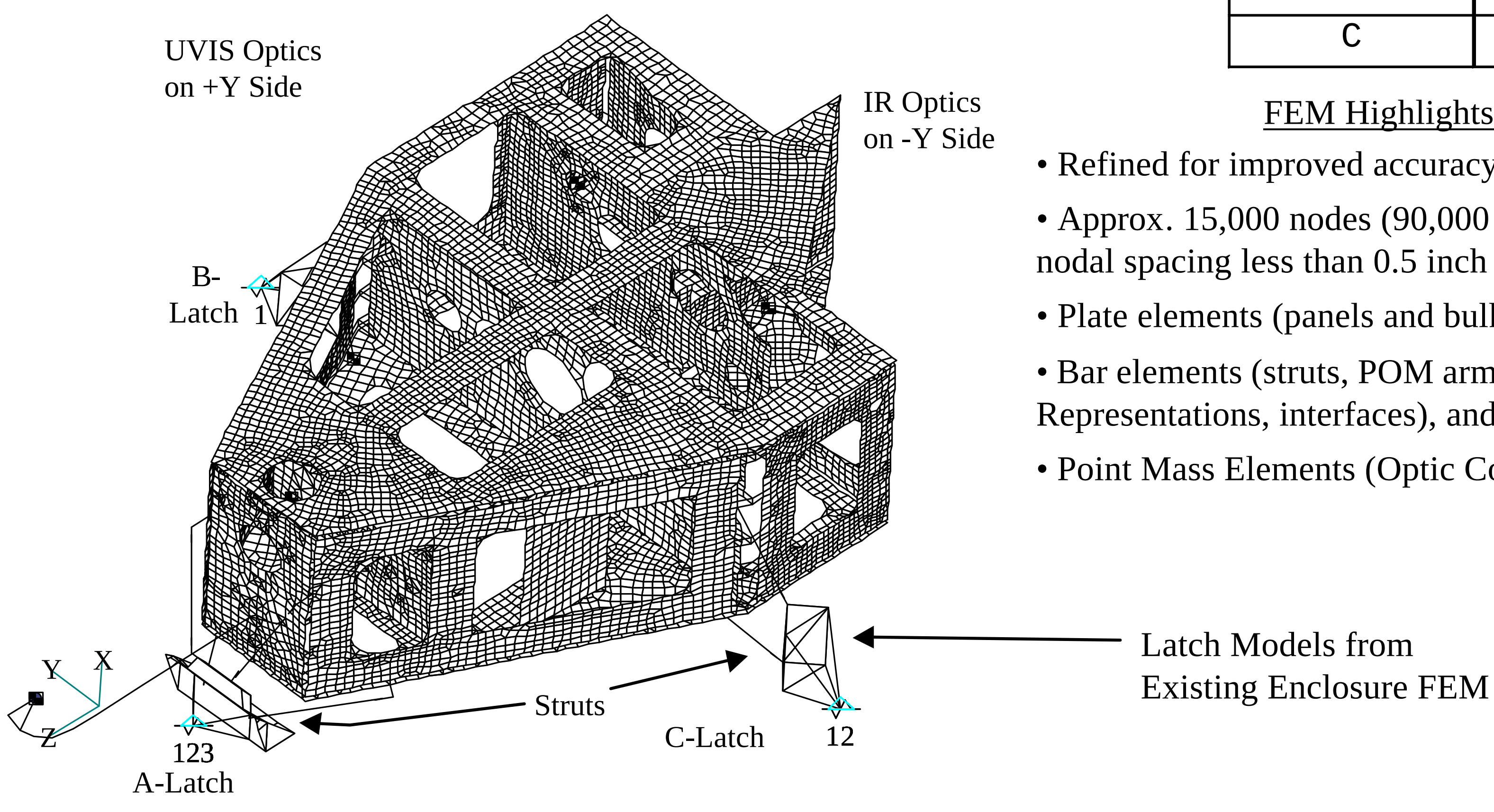
OPTICAL BENCH STRUCTURE



OPTICAL BENCH STRUCTURAL ANALYSIS & FINITE ELEMENT MODEL (FEM)

- NASTRAN (70.5) FEM for Structural Normal Modes and Distortion Predictions
- Bench is kinematically supported at A, B, & C Latch Points.
- For STOP analysis, FEA predictions manipulated in spreadsheet to calculate Optical degradation
- Stress Analysis by NASTRAN FEA and Analytical Calculations

Boundary Conditions (Kinematic)	
Latch Point	Constraints
A	X,Y,Z
B	X
C	X,Y



FEM Highlights

- Refined for improved accuracy and resolution
- Approx. 15,000 nodes (90,000 DOF) and nodal spacing less than 0.5 inch on the average
- Plate elements (panels and bulkheads)
- Bar elements (struts, POM arm, Optic Representations, interfaces), and
- Point Mass Elements (Optic Components)

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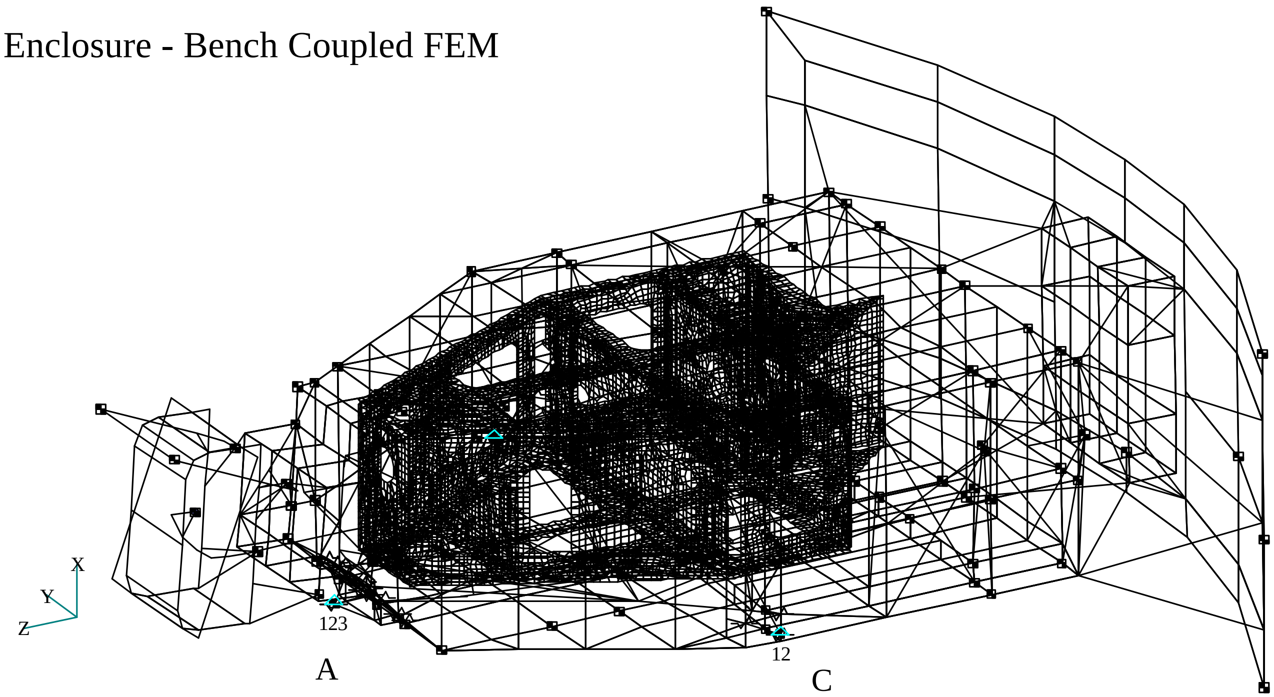
STRUCTURAL ANALYSIS
BENCH & ENCLOSURE COUPLED FEM

- Finite Element Model (FEM) of OB updated and coupled into the Existing Enclosure FEM.
- Assembly is kinematically supported at A,B & C Latch Points
- Coupled FEM used for Stress and Distortion Analysis of the Bench
- OB standalone FEM used for Normal Modes Analysis.

Boundary Conditions (Kinematic)	
Latch Point	Constraints
A	X,Y,Z
B	X
C	X,Y

Enclosure - Bench Coupled FEM



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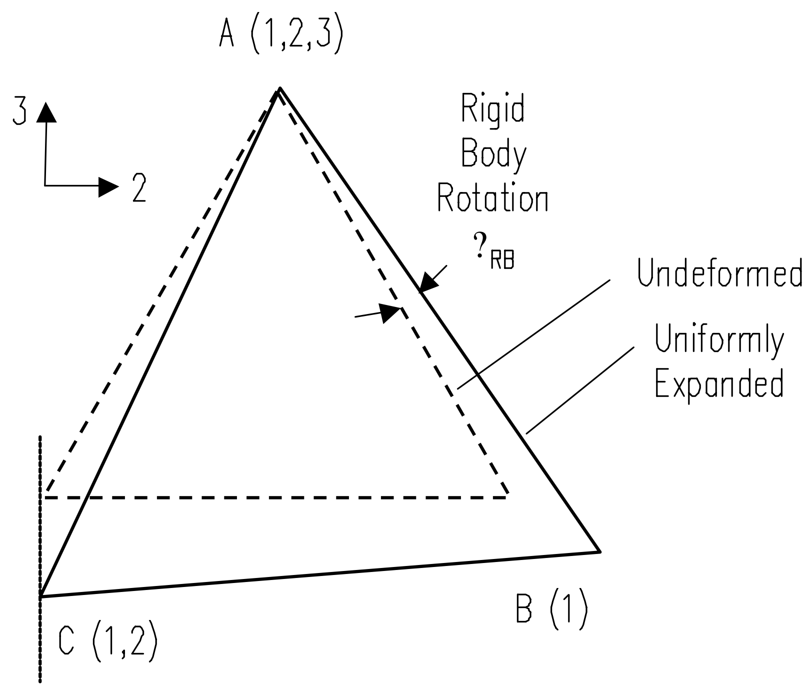
KINEMATIC MOUNTING SYSTEM

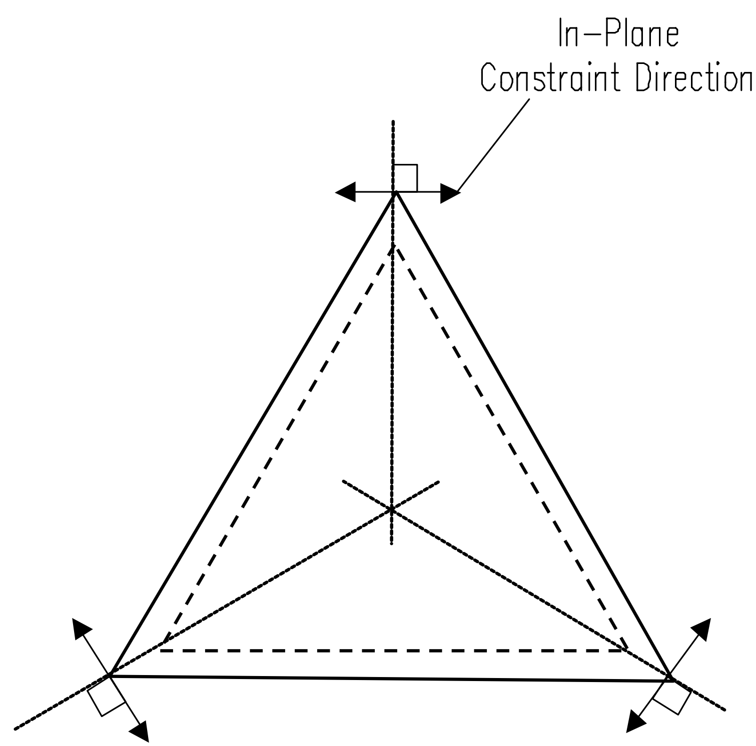
WFC3 Kinematic Mount System



Pivoting Kinematic Mount System causes rigid body rotation, $?_{RB}$ with proportional differential motion. But $?_{RB}$? 0 for a bench with .zero. CTE and .zero. CME.

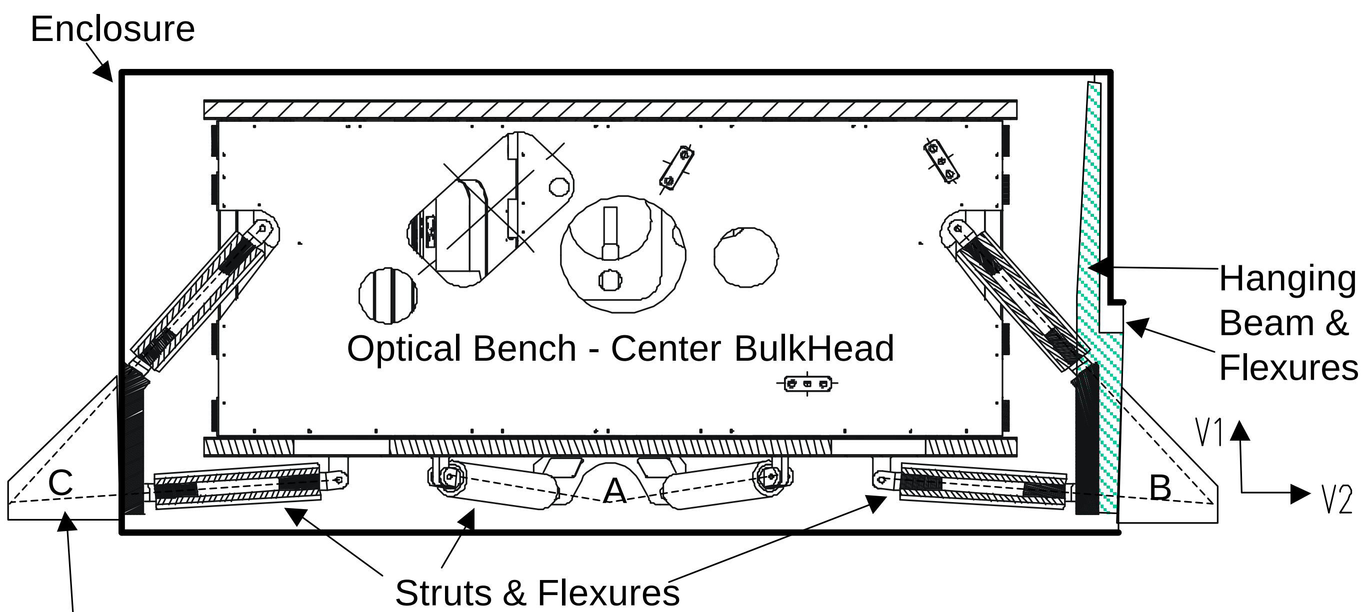
Another Type of Kinematic Mount System

No Rigid Body Motion



ENCLOSURE FLEXURE INTERFACE TO BENCH

- Enclosure which is a primarily Aluminum Structure gets bolted to the Latch Interface Plates
- It is very important to maintain a “weak” mechanical coupling between the bench and the enclosure to minimize the thermal distortion effects of the enclosure on the bench
- “Hanging Beam” and its diaphragm flexures (WF/PC1 Design) isolate the bench from the enclosure the V2 Direction.
- Struts and their blade flexures (New Design) isolate the bench from the enclosure in the V3 Direction.



Existing HST Latch Hardware is primarily Titanium with a “high” CTE. Struts need to be designed with a negative CTE to athermalize the latch-strut assemblies at A, B, and C.

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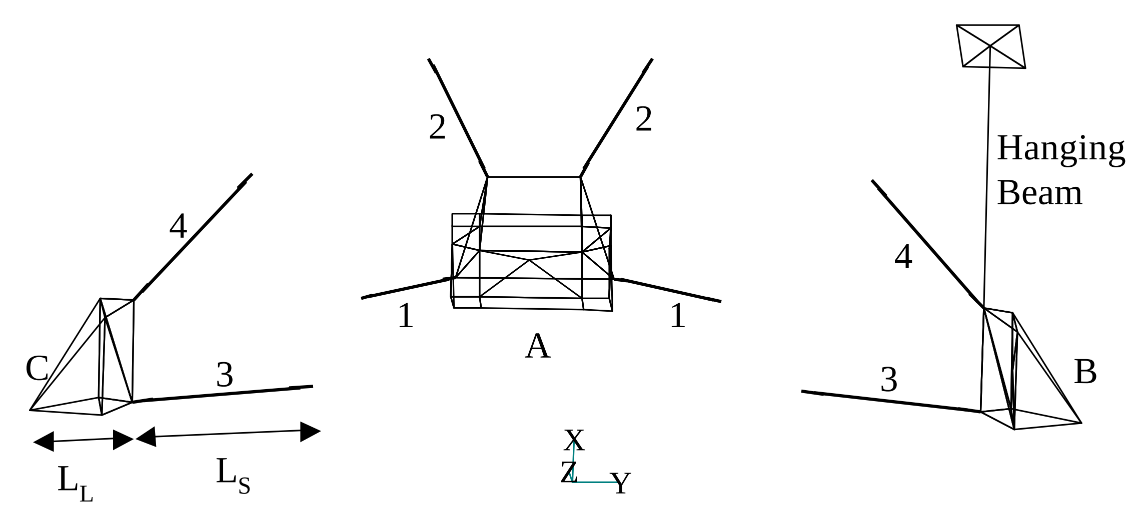
STRUT - LATCH ATHERMALIZATION

- Strut CTE's determined to negate Short Term Thermally Induced Motions of the Latches based on a Temperature Change Relationship of $?T_{latches} = ?T_{struts}$. Latches and Struts are thermally strongly coupled to each other and this is confirmed by thermal model predictions.
- 4 pairs of struts with each pair requiring a different negative CTE as calculated below.



Strut Pair #		1	2	3	4
Latch Length, LL=	inch	4.406	4.734	5.350	6.890
Strut Length, LS=	inch	8.00	8.00	8.00	8.00
Latch Effective CTE, CTEL=	ppm/C	9.72	9.72	9.72	9.72
Strut Effective CTE, CTES=	ppm/C	-5.35	-5.75	-6.50	-8.37
dT of Latch, dTL=	C	1.00	1.00	1.00	1.00
dT of Strut, dTS=	C	1.00	1.00	1.00	1.00
Net Thermaly Induced Displacement of Latch and Strut:					
dx=LL*CTEL*dTL+LS*CTES*dTS=	inch/1E6	0.03	0.01	0.00	0.01

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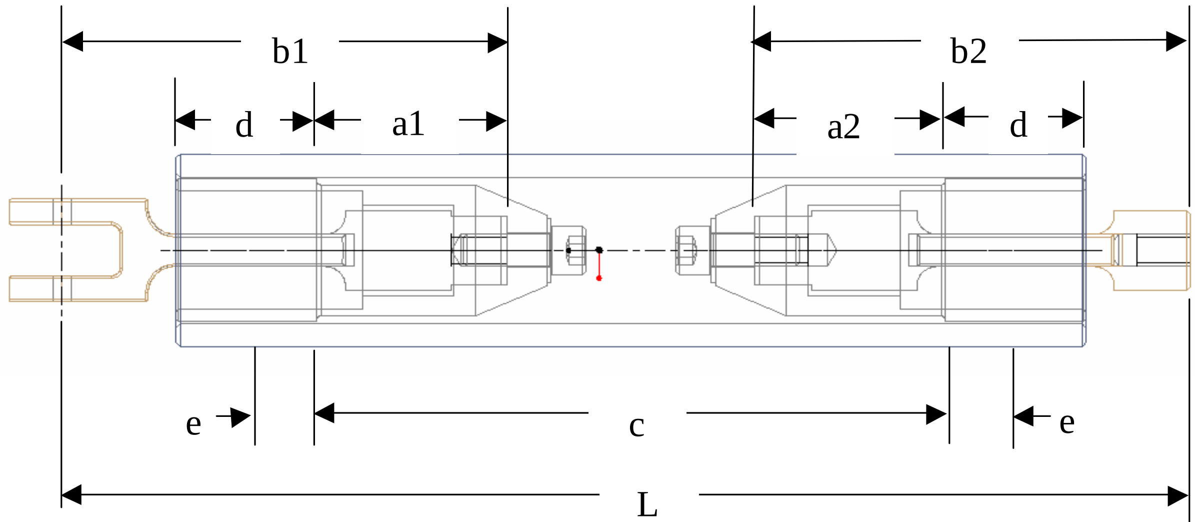
STRUT INTERNAL DIMENSIONS FOR STRUT-LATCH ATHERMALIZATION

For each strut pair, strut internal dimensions are determined to result in the required negative CTE for that Strut pair.



THERMAL LENGTHS
(used in End-to-End CTE Calculation)
a1, a2: Sleeves (bench and Latch sides)
b1, b2:Flexures (bench and latch sides)
c: Composite Tube
e: Bonded Joint effective
L: Strut end-to end Length = 8.0 “
d: Bonded Joint total Overlap Length

STRUT PAIR#1 CTE ANALYTICAL APPROACH		
Data: SLEEVE, CTEa=	ppm/C	15.30
INVAR FLEXURE BLADE, CTEb=	ppm/C	0.89
COMPOSITE TUBE, CTEc=	ppm/C	-2.90
BONDED JOINT EFFECTIVE, CTEe=	ppm/C	14.00
CTE of Bolt Effective Length, CTEbe=	ppm/C	4.72
EFFECTIVE LENGTHS:		
EFFECTIVE LENGTHS: SLEEVE, bench	inch	1.090
SLEEVE, latch side, a2=	inch	1.090
FLEXURE, bench side, b1=	inch	2.899
FLEXURE, latch side, b2=	inch	2.829
Bolt effected Length. Lbe=	inch	1.407
OUTER TUBE, c=	inch	4.50
BONDED JOINT EFFECTIVE, e=	inch	0.50
TOTAL LENGTH, L=	inch	8.00
STRUT ASSEMBLY END-TO-END CTE:		
CTEs=[- (a1+a2)*CTEa+(b1+b2-be)*CTEb+be*CTEeb+c*CTEc-e*CTEe	ppm/C	-5.36

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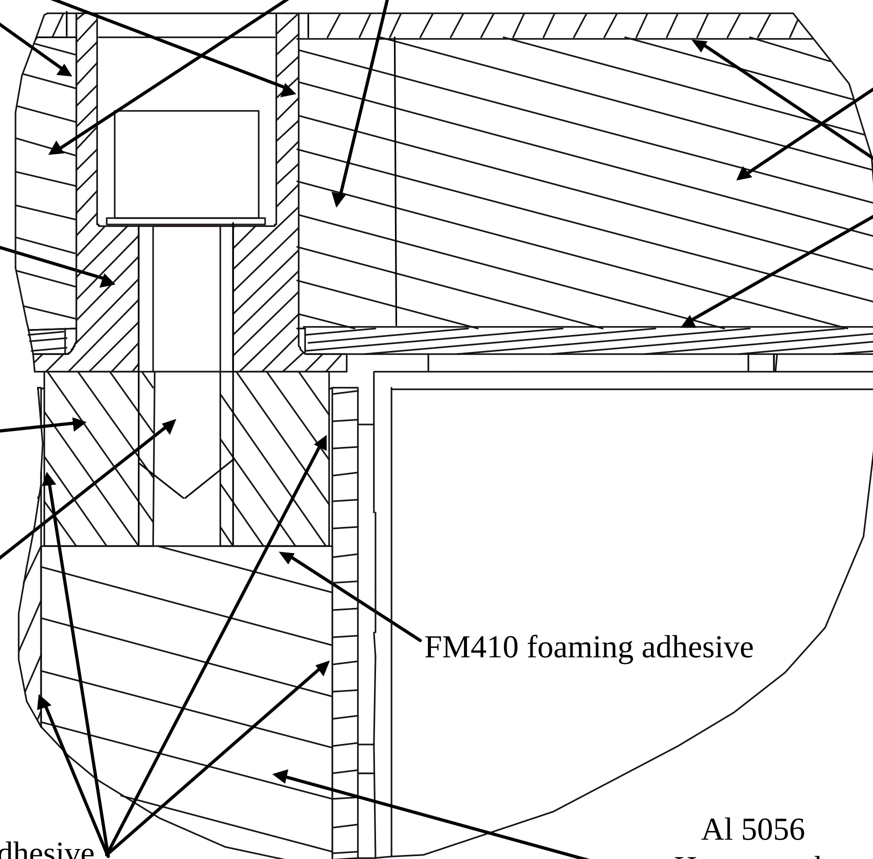
INTERFACES: PANEL-TO-PANEL



Similar arrangement for pins .0002 to .0004 interference fit

Threads and pin heads staked with Uralane

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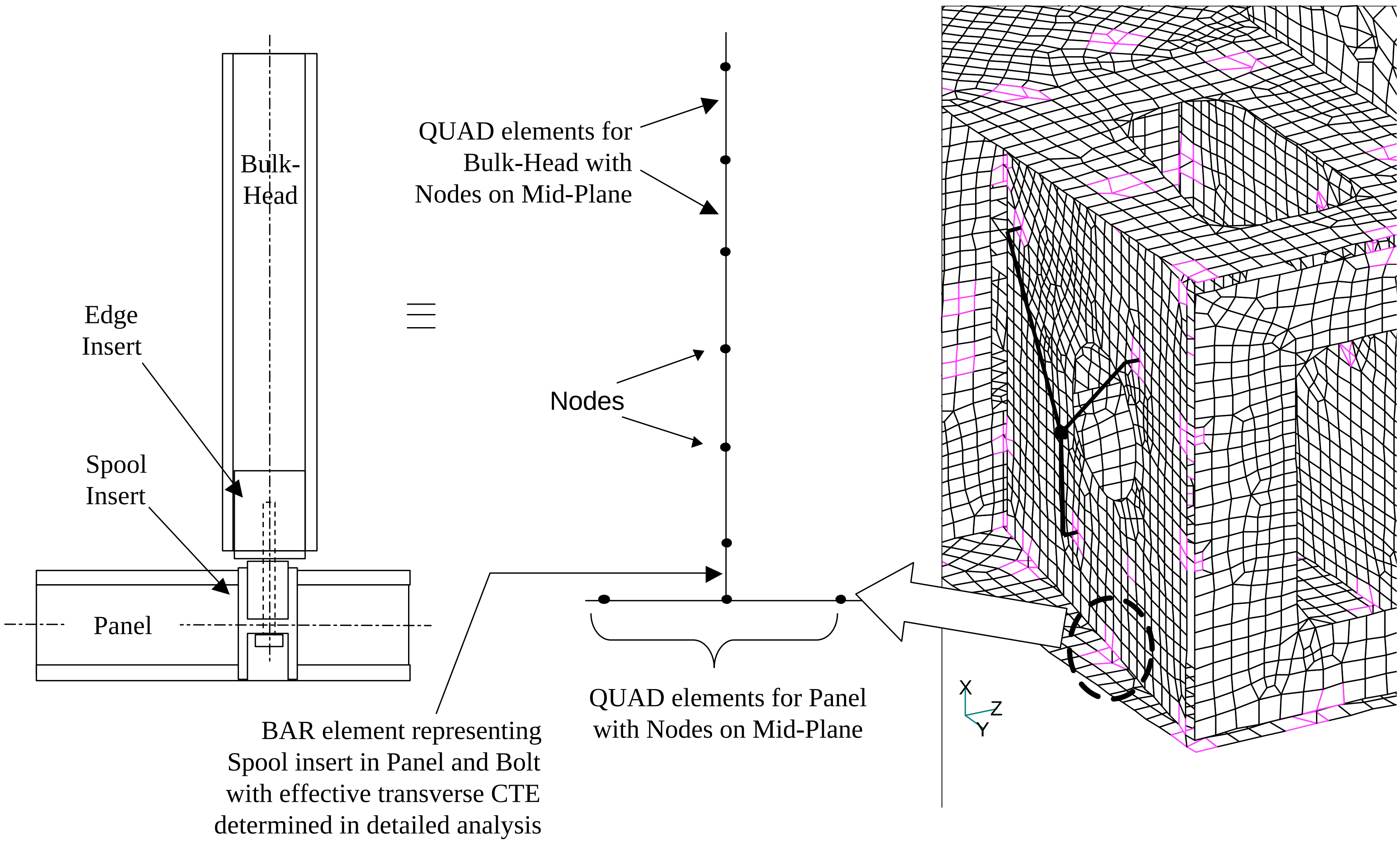
PANEL-TO-PANEL INTERFACE MODELS FOR THERMAL DISTORTION ANALYSIS

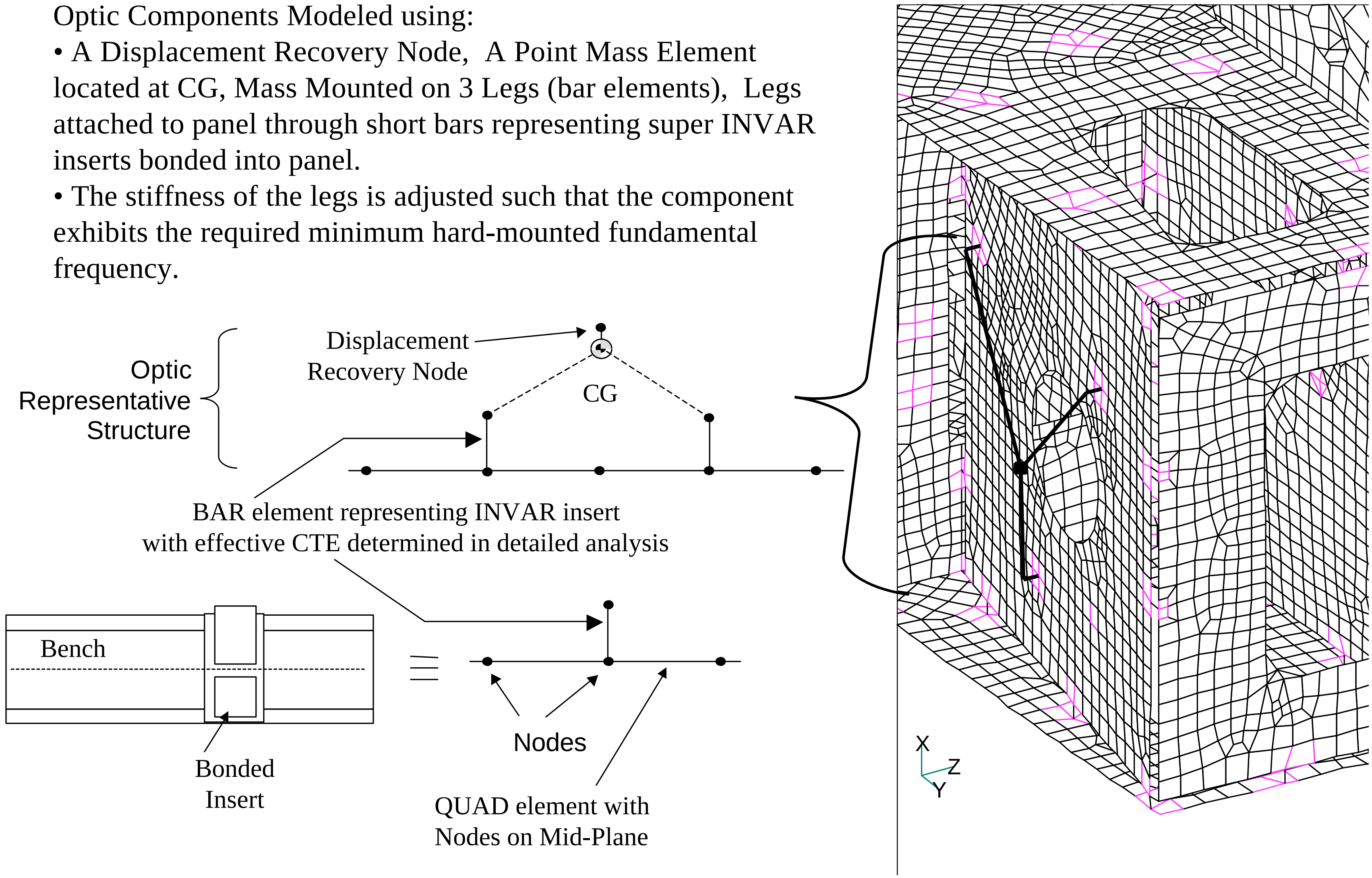


OPTIC-TO-BENCH INTERFACE MODELS FOR THERMAL DISTORTION ANALYSIS

Optic Components Modeled using:

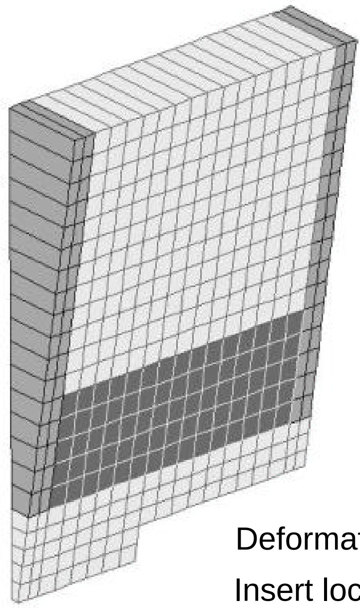
• A Displacement Recovery Node, A Point Mass Element located at CG, Mass Mounted on 3 Legs (bar elements), Legs attached to panel through short bars representing super INVAR inserts bonded into panel.

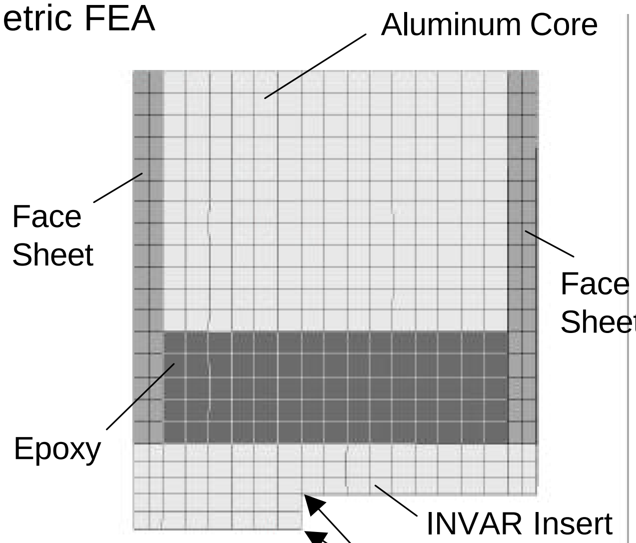
• The stiffness of the legs is adjusted such that the component exhibits the required minimum hard-mounted fundamental frequency.



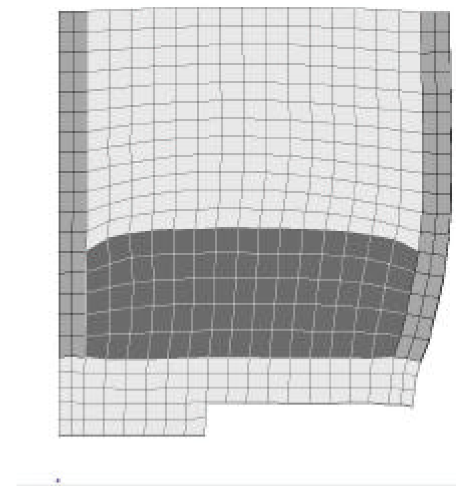
EFFECT OF BONDED INSERTS ON TRANSVERSE CTE OF SANDWICH PANEL

Axi-symmetric FEA





Deformed Shape due to ? T

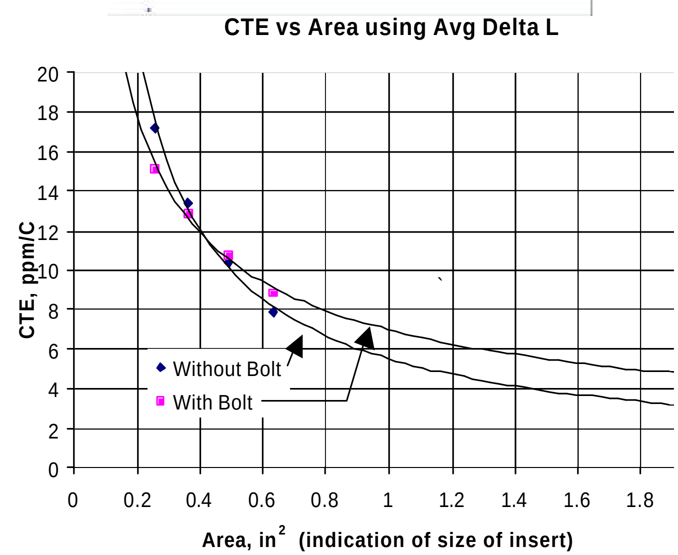


Deformation measured from these nodes to calculate CTE

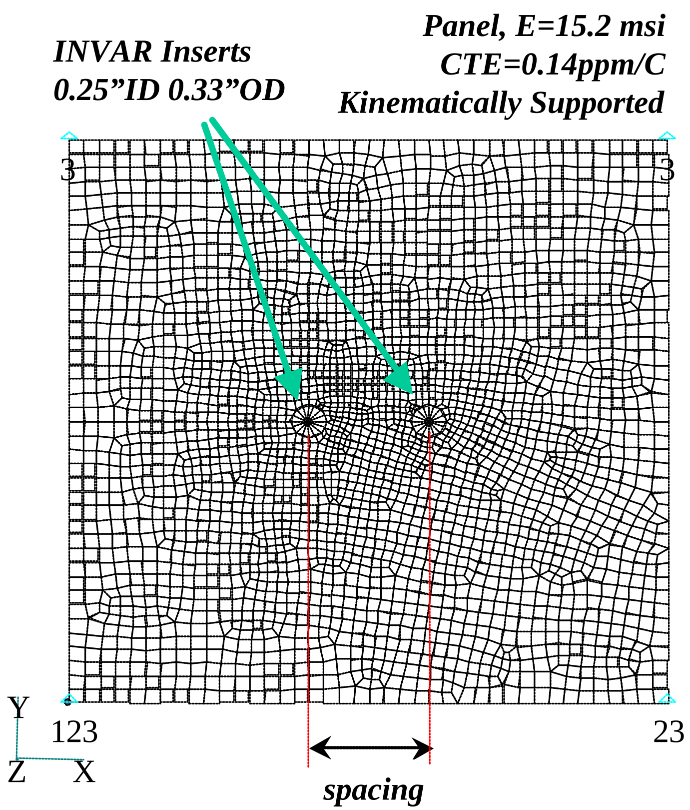
Insert located "away" from the panel edge

	OD	ID	Area	CTE Calculation Without Bolt Delta L1	Delta L2	Avg Delta L	CTE eff (avg L) ppm/C
CASE 1	0.924	0.221	0.631874	1.84	3.66	2.75	7.9
CASE 2	0.82	0.221	0.489494	2.54	4.71	3.625	10.4
CASE 3	0.716	0.221	0.364095	3.42	5.93	4.675	13.4
CASE 4	0.612	0.221	0.255677	4.55	7.4	5.975	**17.2**

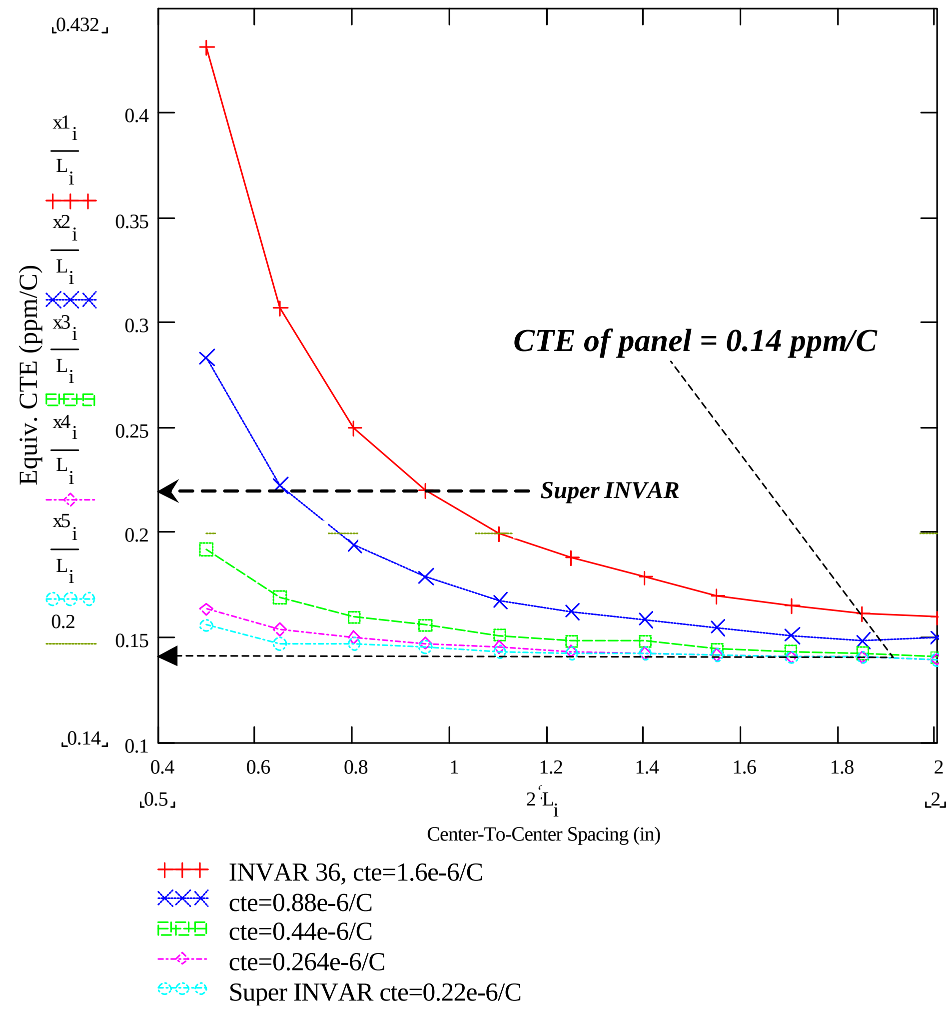
	OD	ID	Area	CTE Calculation With Titanium Bolt Delta L1	Delta L2	Avg Delta L	CTE eff (avg L) ppm/C
CASE 1	0.924	0.221	0.631874	3.06	3.13	3.095	8.9
CASE 2	0.82	0.221	0.489494	3.6	3.91	3.755	10.8
CASE 3	0.716	0.221	0.364095	4.18	4.76	4.47	*12.8*
CASE 4	0.612	0.221	0.255677	4.83	5.69	5.26	**15.1**



EFFECT OF BONDED INSERTS ON IN-PLANE CTE OF PANEL



In-plane CTE = Delta X between inserts per deg C / spacing



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OPTICAL BENCH MATERIAL SYSTEM

Application	Material	Key Properties	Outgassing (ASTM E595)		
			%TML	%CVCM	%WVR
Facesheet, Athermalized Strut Tube, and P/O Mirror Arm	XN50A/996	Negative CTE, Modulus, Low Moisture Absorption, Thermal Conductivity, Strength, Outgassing	0.10	0.02	0.04
Honeycomb Core	Al-¼-5056-.001P	Strength, Thermal Conductivity, Processing	N/A	N/A	N/A
Facesheet-to-Core Adhesive	FM 73U, 0.03 PSF	Areal Weight, Cure Temp., Processing, Strength, Outgassing	0.70	0.05	0.14
Foaming Splice Adhesive	FM 410	Strength, Processing, Outgassing	0.55	0.01	0.54
Optical Bench Insert	Super Invar 32-5	CTE, Strength, Machinability	N/A	N/A	N/A
Strut end fittings	Invar 36	CTE, Strength, Machinability	N/A	N/A	N/A
Al 7075-T7351	Strut fittings	Strength, high CTE	N/A	N/A	N/A
Insert & Strut Bonding Adhesive	EA 9394	Strength, Tg	0.60	0.00	0.26
Insert/Core Potting Adhesive	SLE-3010	CTE, Modulus, Strength, Density, Processing, Outgassing, Tg	0.82*	0.01*	0.19*

*Post cured @ 120^{0}C for 1 Hr.

STRUCTURAL CHECKLIST FOR STOP OPTIMIZATION

- Mechanical Interfaces
  - Kinematic Mounting (Statically Determinate) Is there any Rigid Body Rotation with Uniform Growth?
  - Semi-Kinematic, eg; Flexure Mounts. Does it provide sufficient mechanical Isolation?
  - Is Athermalization needed?
- Overall CTE and Overall Coefficient of Moisture Expansion (CME) should be “small” enough.
- Keep Design Limit stresses as low as possible to minimize Launch Shift and Micro-Yielding.
- Structural Math Model should be refined enough to capture important details and deformations.
- Perform Model Validity Checks and Reviews for Critical FEMs. Also correlate them by test.
- Interfaces and Joints should be designed to have sufficiently “low” CTE (in-plane and transverse)
  - perform detailed analysis and development testing,
  - Minimize use of high CTE and high Elastic Modulus materials. For example “too much” epoxy core fill may cause a critical interface to have a high local transverse CTE or cumulatively lead to an excessive in-plane CTE.
- Don’t mount optical components on bulkheads which have low local stiffness (detailed FEM will help identify any weakness).
- Critical Optical Components should be represented accurately for Stiffness, CTE, and Distortion Recovery.
- Perform Sensitivity Studies of critical design parameters, eg; Effect of Local Interface CTE on STOP and Effect of Material Choice on Local CTE (Titanium, INVAR 36, Super INVAR).
- Perform material and development tests for all critical features of design such as sandwich panel strength and CTE.
- Carefully plan and execute test verification program to avoid over test.
- Consider Secondary Distortion Sources such as due to Flex Lines, MLI, and harnesses.

- Fully Populated Optical Bench (OB) Supported at A, B, & C Latches to have a Min Frequency of 35 Hz. Comply by Analysis & Test.
- Strength Margins of Safety to be positive for the OB under the following Design Limit Load Factors. Demonstrate by analysis using the Safety Factors listed and by Structural Qualification Tests (Sine Burst, Static Pull, Honeycomb Panel Tension and Shear)

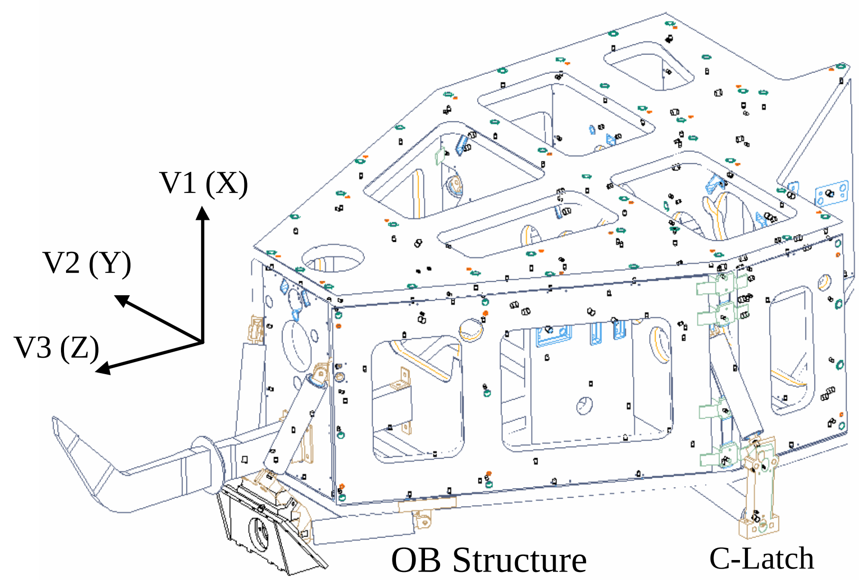
Design Limit Load Factors (G=386.4 in/s^2)

	X	Y	Z	RSS
Liftoff*	5.0	3.5	2.6	6.63
Landing*	3.6	2.0	4.0	5.74
Handling	2.0 in any one axis			

* Component Load Factorsare in the Shuttle Coordinate System and simultaneously applied in all ± combinations.

Safety Factors

	New Hardware		Heritage Hardware	
	Analysis Only	Analysis & Test	Analysis Only	Analysis &Test
Yield	2.0	1.25	1.25	1.1
Ultimate	2.6	1.4	2.0	1.4



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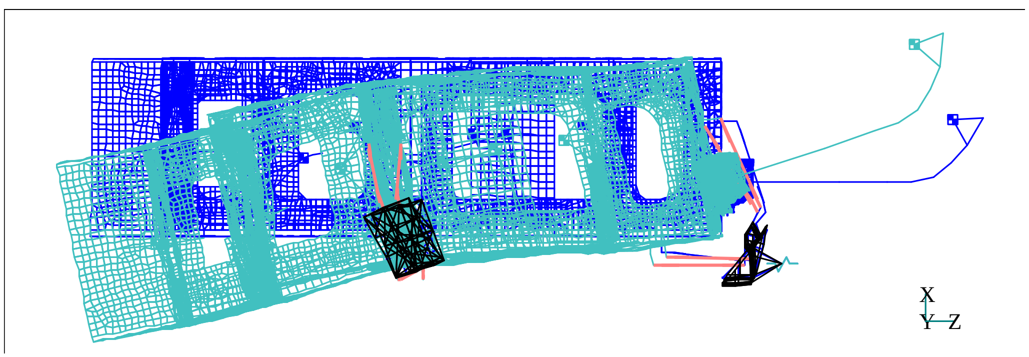
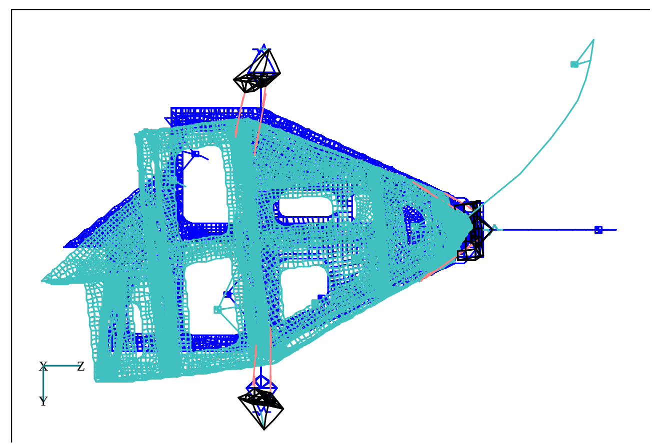
NORMAL MODES
AS SUPPORTED ON LATCHES

				WFC3 BENCH ONLY			**5/10/01**	**C.Kunt/SAI**
Weight				**MODAL MASS &**			**9.21E+04**	**= X-Inertia, LB.IN^2**
325.9				**INERTIA PARTICIPATION**			**6.92E+04**	**= Y-Inertia, LB.IN^2**
LB							**3.70E+04**	**= Z-Inertia, LB.IN^2**
MODE	**fn (Hz)**	**X**	**Y**	**Z**	**RX**	**RY**	**RZ**	**Mode Shape**
#		**%**	**%**	**%**	**%**	**%**	**%**	**Description**
1	38.6	43	9	13	4	25	1	Fundamental Lateral-X
2	45.3	2	35	11	36	3	0	Fundamental Lateral-Y
3	52.7	10	0	48	4	6	0	Fundamental Z
4	57.0	0	12	0	5	0	0	
5	59.3	0	0	1	0	0	0	
6	61.1	0	0	0	0	0	0	
7	64.8	0	1	0	0	1	9	
8	67.0	1	2	5	3	1	0	
9	67.4	0	2	0	1	0	0	





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SUMMARY OF SELECTED MS STRENGTH MARGINS OF SAFETY

#	PART OR LOCATION	FAILURE MODE	LIMIT* FORCE or STRESS	ALLOWABLE yld / ult	MS
1	H/C Panel Facesheets	Compression	9.9 ksi	27 ksi ult	+0.95
2	Core	Transverse Shear	38 psi	62 psi ult	+0.17
3	Strut Assembly	Stepped Column Buckling	1970 lb	24.7 kip ult	+Large
4a	Flexures	Column Buckling	1970 LB	95.7 kip ult	+Large
4b		Comp + Bending	35.3 ksi	60.8 ksi yld	+0.38
4c		Beam-Column	1970 lb + 600 in.lb	24,700 LB +1540 in.lb	+0.52
5a	Strut Sleeves	Tens + Bending	21.8 ksi	56 ksi yld	+1.06
5b		Crippling	21.8 ksi	33.2 ksi ult	+0.09
6a	Strut Lugs	Shear Tear-Out	4.0 ksi	40 ksi yld	+Large
6b		Bearing	16.0 ksi	80 ksi yld	+3.0
7	Lugs on Bench	Tens + Bending	20.2 ksi	40.0 ksi yld	+0.58
8	Strut Pins:1/4”	Shear + Bend	66.6 ksi	160 ksi ult	+0.72
9	Flexure Bolts 5/16”-24	Tension	4350 LB ult	9290 LB ult	+1.14
10	Panel-Panel Bolts #10-32	Tension	1370 LB ult	3200 LB	+1.33
11	Bolt Spool Inserts	Pull-Out	75 LB	157 LB ult	+0.49
12	Panel-Panel Pins: 0.12”	Shear	330 LB	91 ksi	+1.2
13	Pin Spool Inserts	Facesheet Interlaminar Shr	2570 psi	4000 psi ult	+0.11

Notes:

Based on the design limit load cases and SF of 1.40/1.25

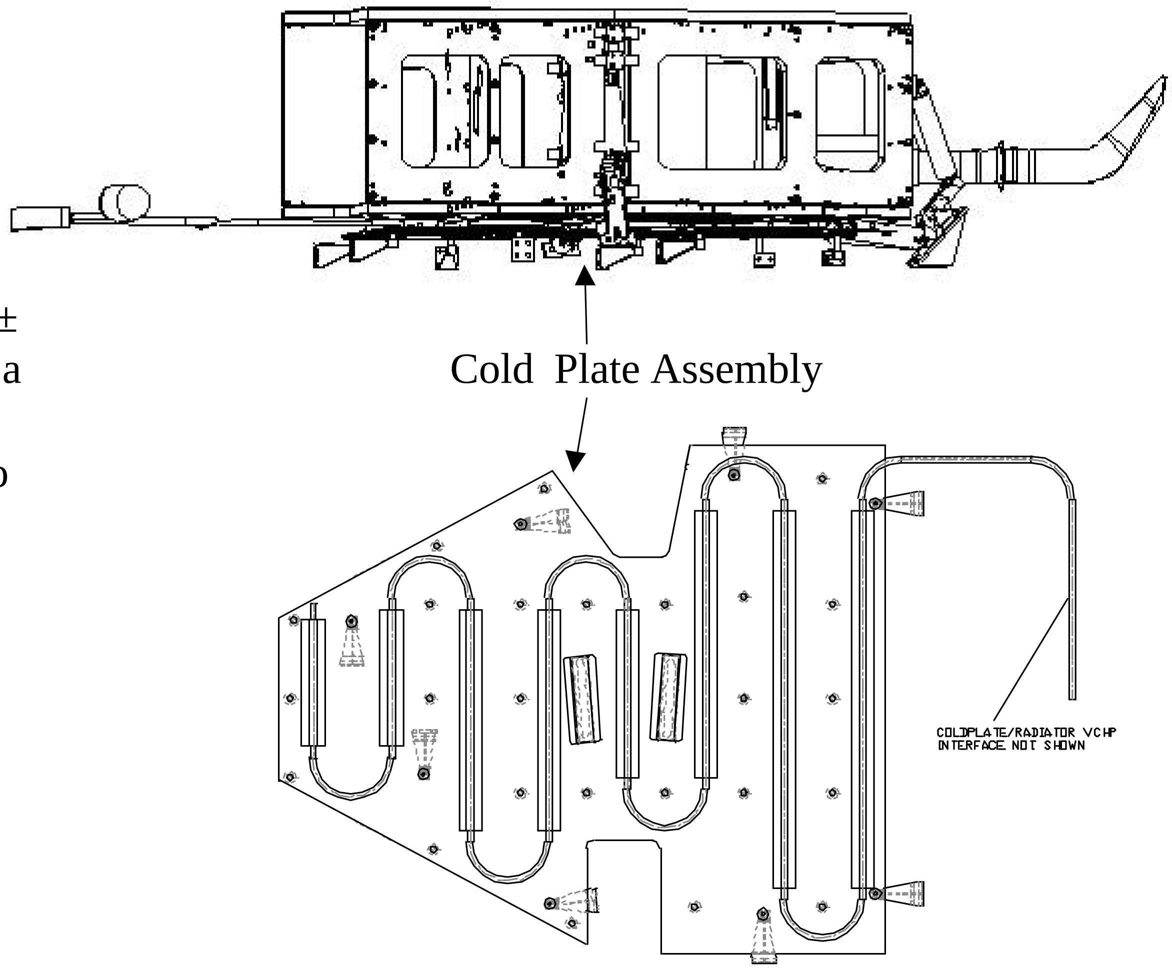
* Force or stress at limit level unless otherwise noted

1 Facesheets not critical under dimpling or wrinkling.

2 Conservative; based on Core W direction minimum shear strength allowable.

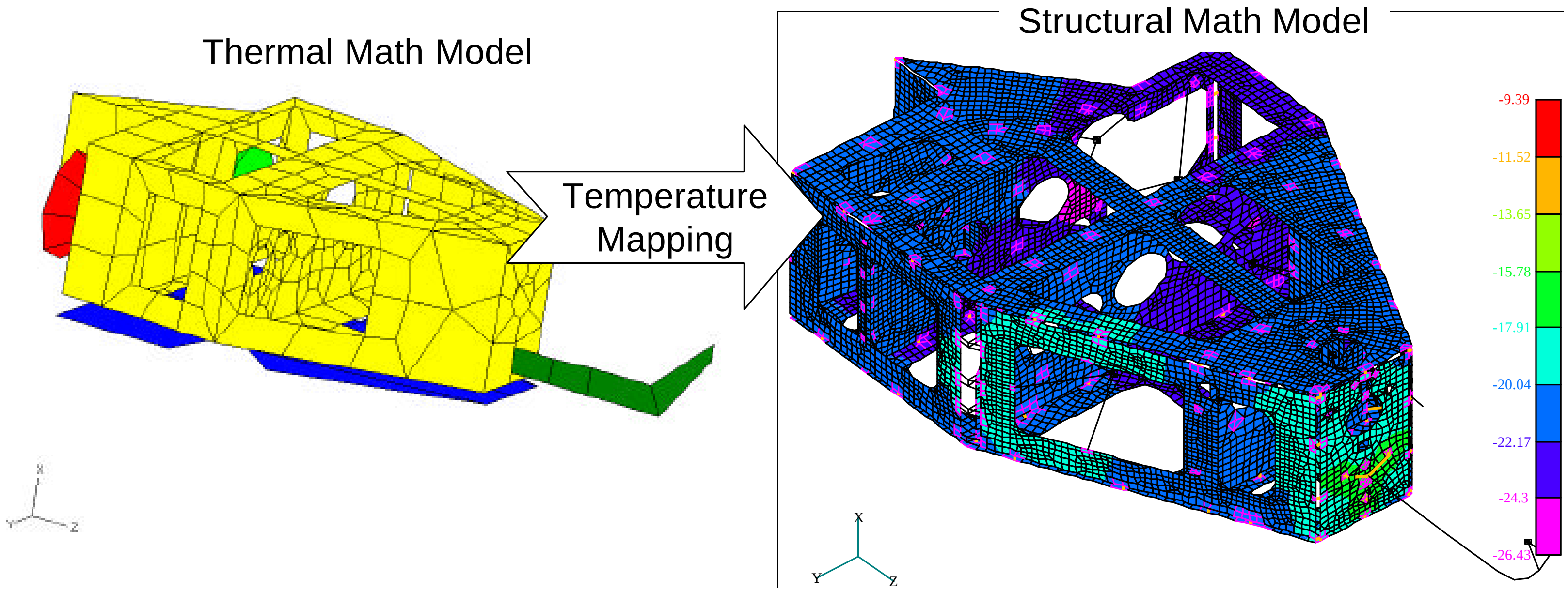
SWALES AEROSPACE

THERMAL CONTROL



Optical Bench is kept at 0 ± 2 C° on Orbit by means of a Cold Plate located under and very close (?2 inch) to the bench. They are not physically connected (Radiation Coupling)

TEMPERATURE PREDICTION AND MAPPING

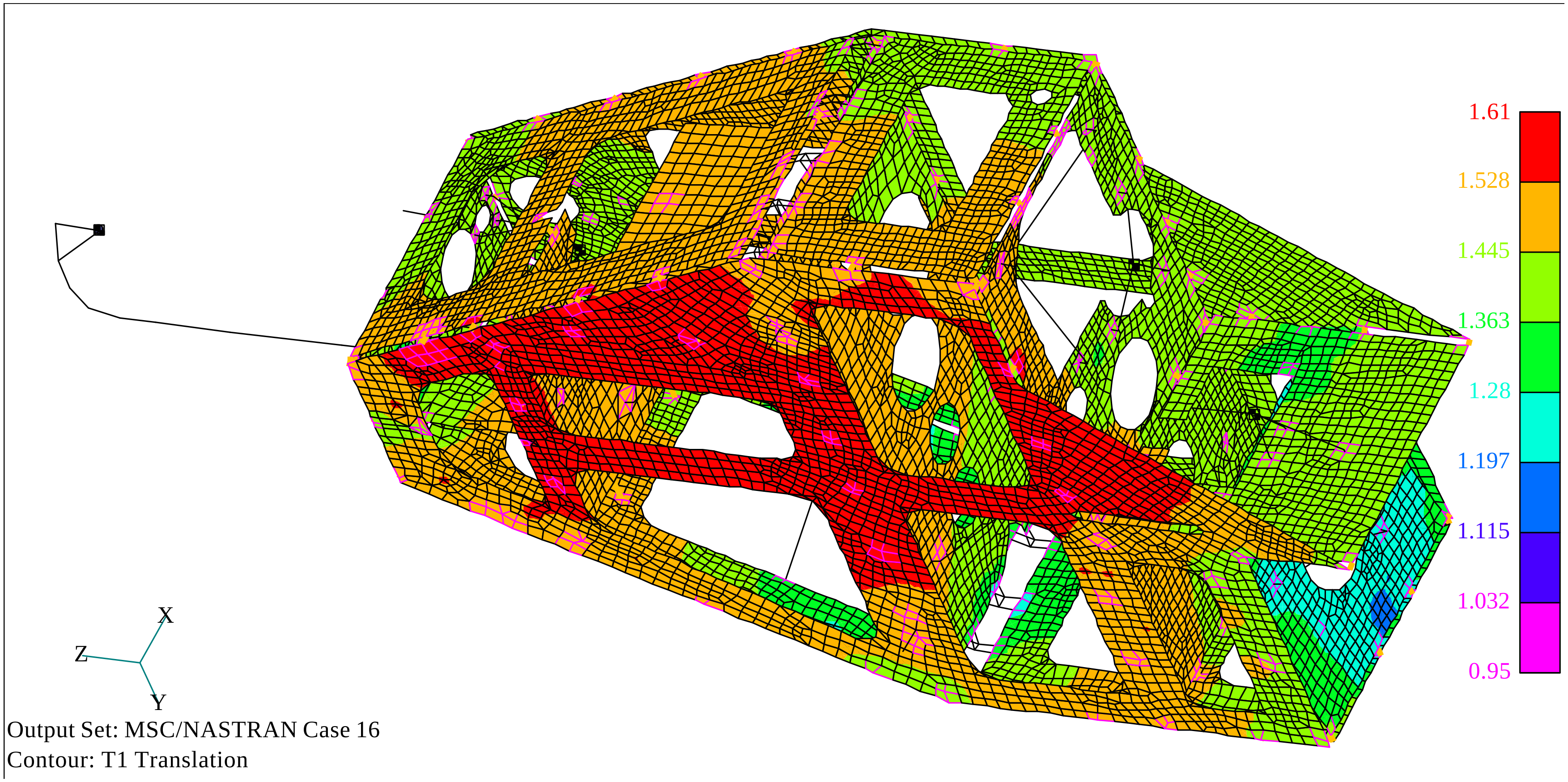


Sample Input Temperature Distribution
Ground to Cold Orbit Temperature Changes

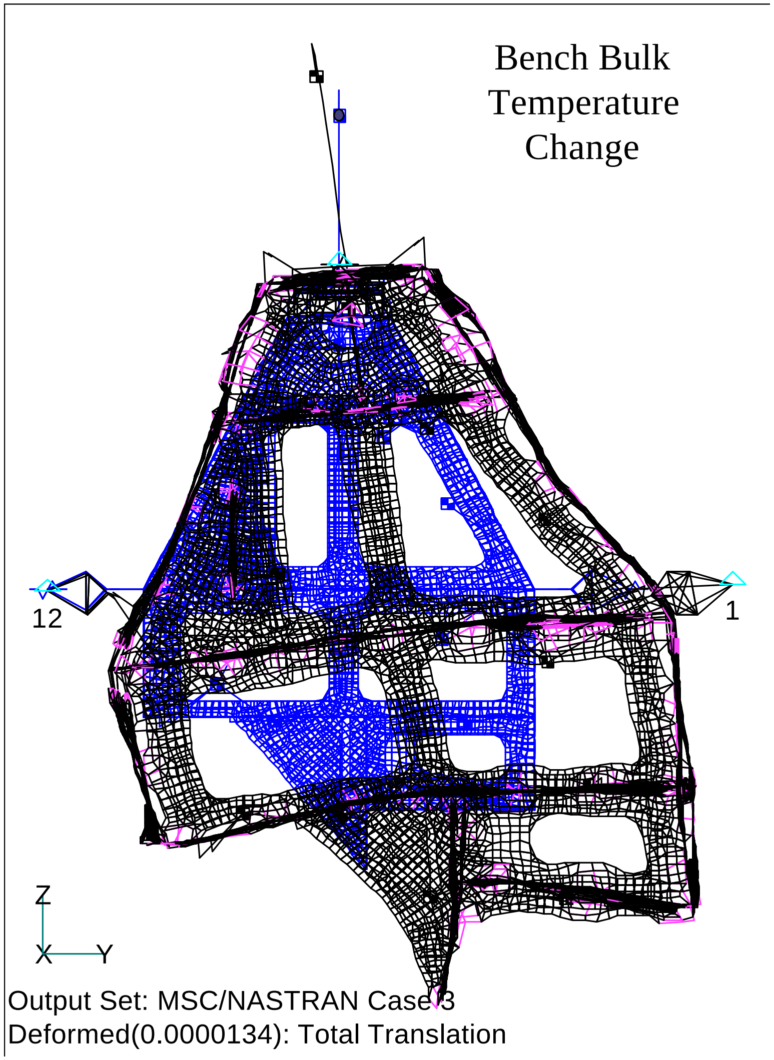
- About 350 Nodal Seed Temperatures from Thermal Model used to create the full (15,000 nodes) Temperature Distribution in the Structural FEM.
- Temperature Changes in C going from ground to the cold orbit
- Note warmer temperatures (smaller temperature drop) in the front bulkhead and colder temperatures (greater temperature drop) at the rear bulkhead

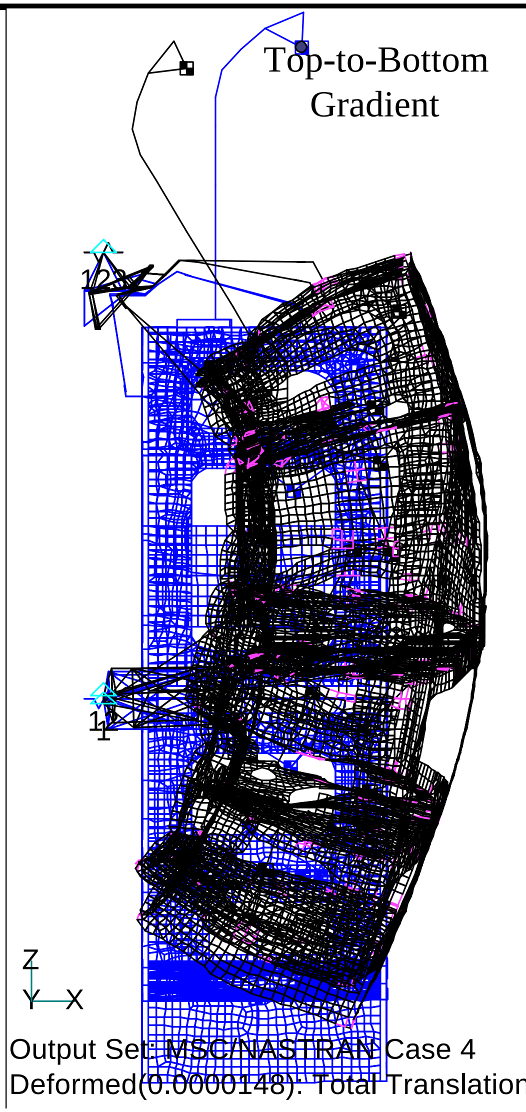
SAMPLE INPUT TEMPERATURE DISTRIBUTION
SHORT TERM HOT-HOT TEMPERATURE CHANGES

- Short Term Hot-Hot Temperature Change Prediction Distribution; ie; change between hot nominal and its hot extreme. Temperatures in C.
- Steady State Predictions shown Transient Changes are smaller in value.

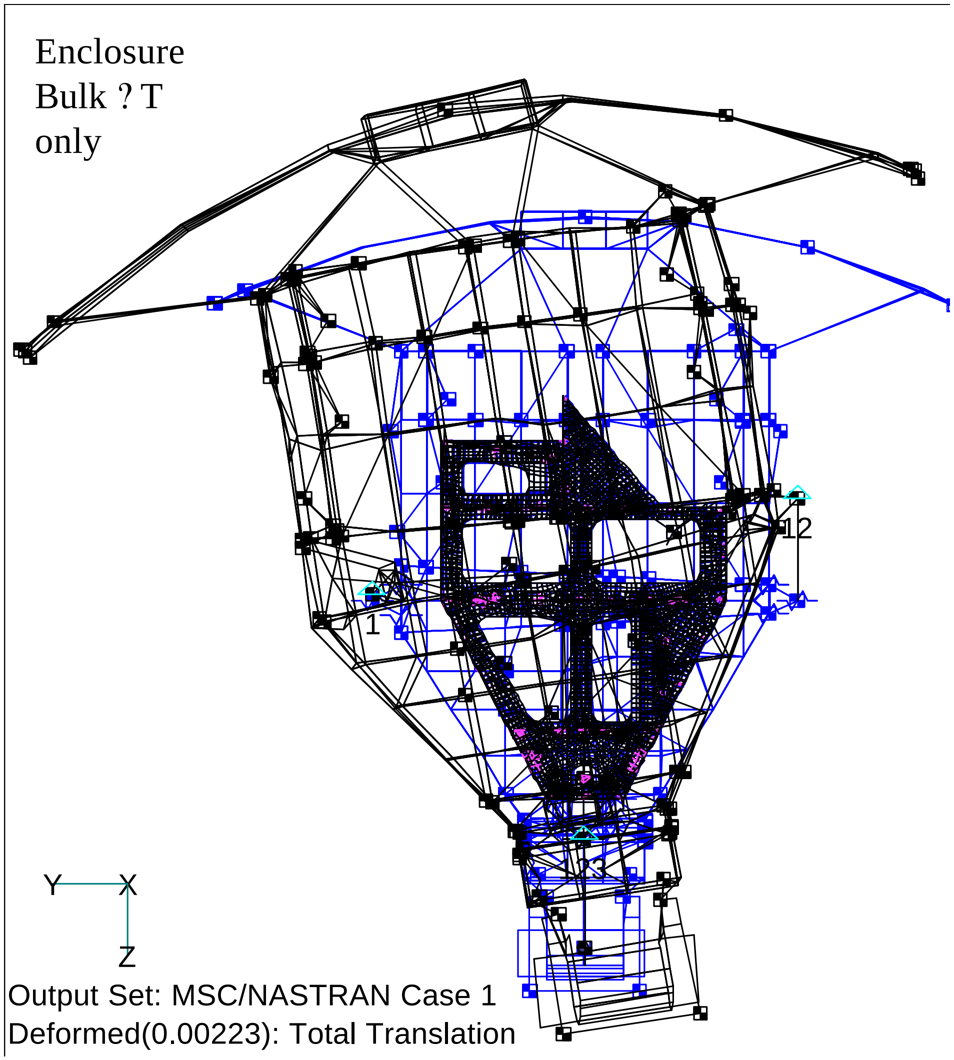


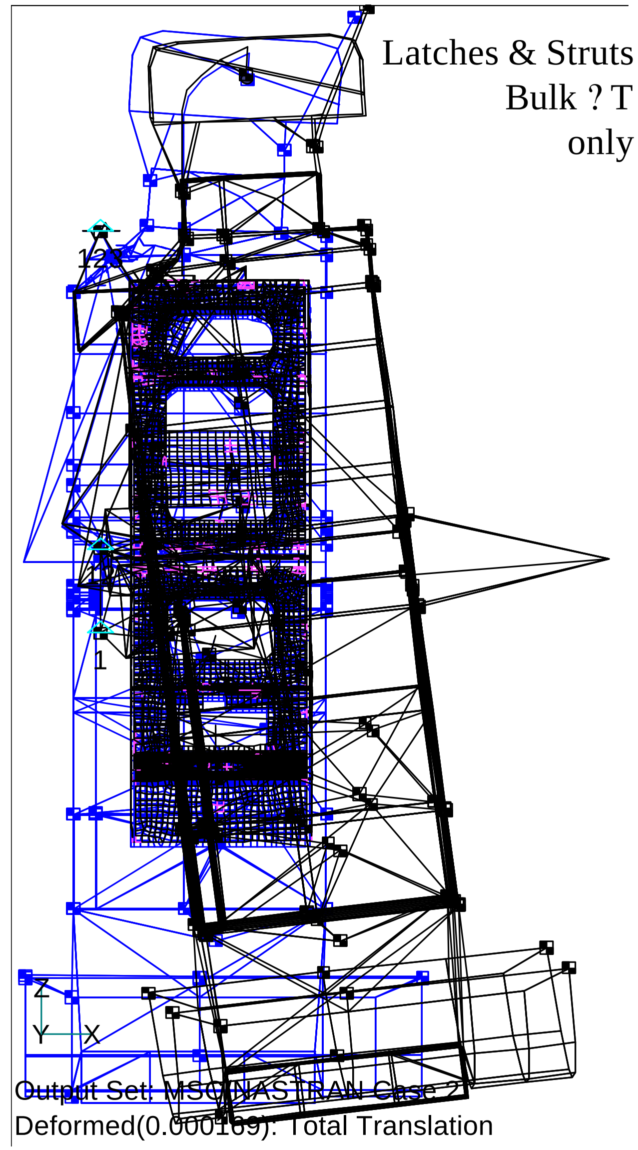
OB Bulk Temperature Change & Gradient Change Deformed Shapes



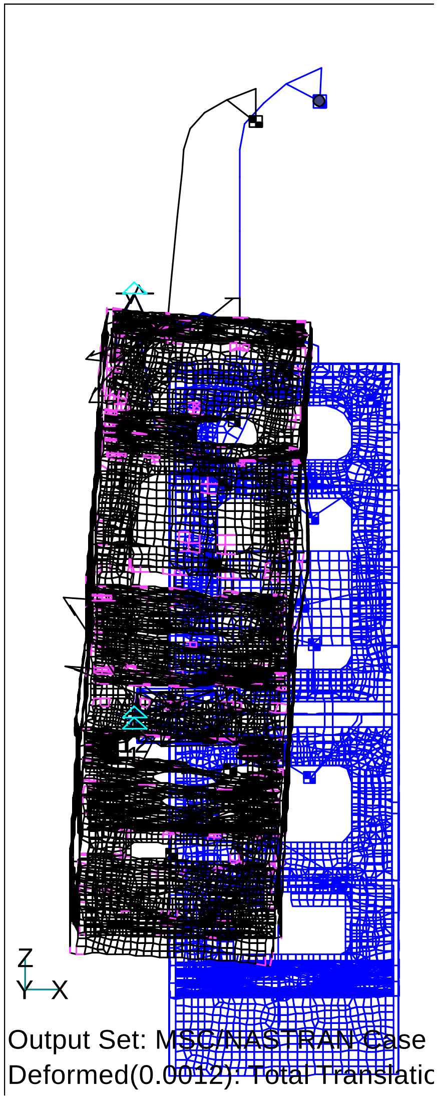


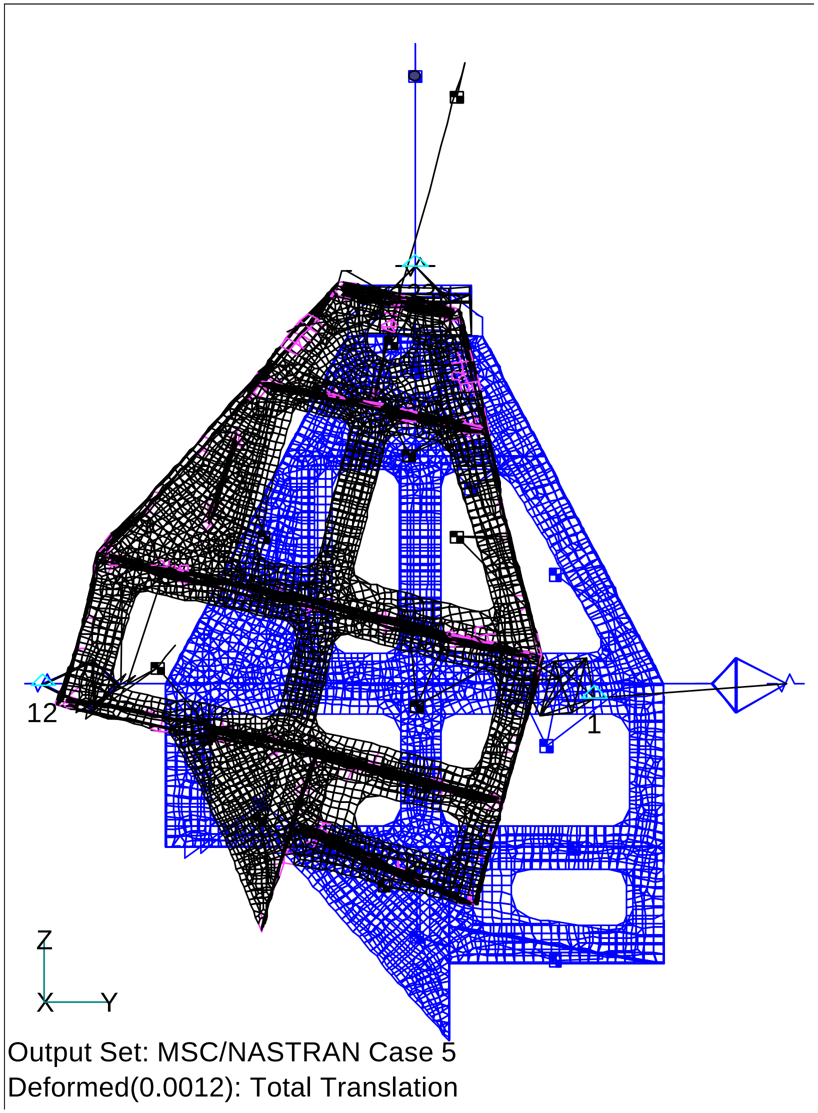
Enclosure & Latch ?T Effects
Deformed Shapes





OB Desorption Deformed Shape





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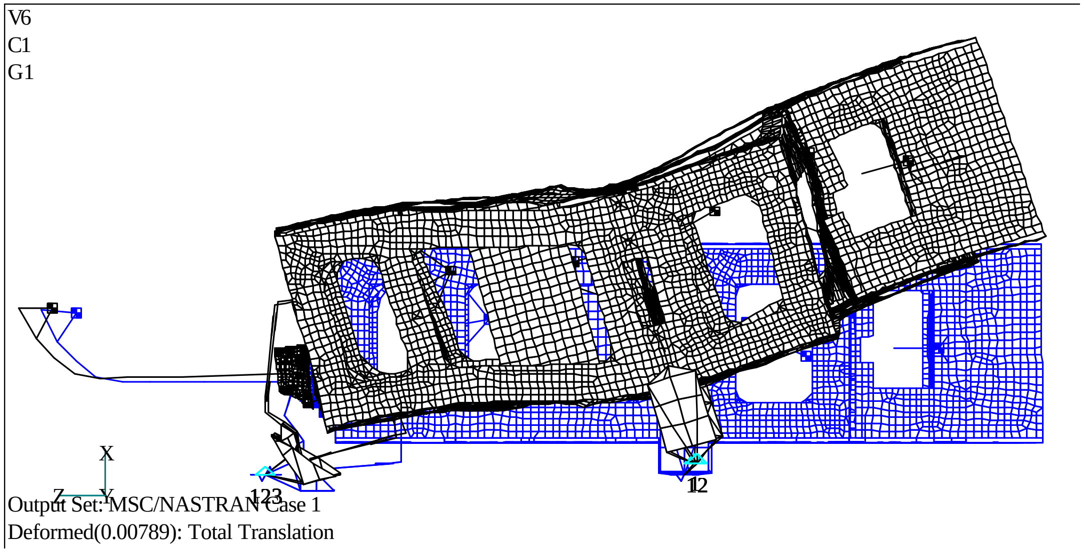
GRAVITY SAG
(1-G RELEASE IN THE X-DIRECTION)



UVIS CHANNEL GRAVITY SAG DISTORTIONS

X,Y,Z is the Hubble Coordinate System(V1,V2,V3).

X,Y,Z: micrometer. RX,RY,RZ : arcsec

ID	OPTIC	DOF	1 G Sag X
1	POM	X	-8.8
		Y	6.0
		Z	13.7
		RX	-6.39
		RY	-1.36
		RZ	-2.68
2	UVIS Corrector	X	148.1
		Y	-34.4
		Z	21.0
		RX	-7.20
		RY	-29.59
		RZ	16.47
3	UVIS-M2	X	32.1
		Y	-14.7
		Z	25.2
		RX	-4.22
		RY	-31.49
		RZ	-1.93
4	SOFA	X	90.0
		Y	-26.3
		Z	19.5
		RX	-5.48
		RY	-55.27
		RZ	2.38
5	UVIS DETECTOR	X	163.3
		Y	-39.0
		Z	13.6
		RX	-6.25
		RY	-37.11
		RZ	2.19
	MAX DISP	**10^{-6}m**	163.3
	MAX ROT	**arcsec**	55.27
19	Bench Rigid Body Motion Measured at Bench to Strut I/Fs	X	43.6
		Y	
		Z	
		RX	
		RY	-28.39
		RZ	

- Gravity Sag of the Bench is marginal (high RY and X). The initial design margin was not sufficient and component weight increases caught up with it. A gravity sag test is planned to verify these results and the FEM.

- There is a significant amount of Rigid Body Motion which is not subtracted out. The corrector mechanisms can compensate for only a certain level of rigid body motion. Repointing the HST can actually help with respect to the rigid body motion but again only to a certain level. If we had a gimbal that could pivot the WFC3 about the focal point of the HST, then this could be used to remove all the rigid body effects.

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LONG-TERM DISTORTION RESULTS

- Following Long-term effects were considered and summarized in the spreadsheet:

1- Enclosure Ground-to-Orbit ?T and Mechanical Distortion trickling into the bench

2- Latch & Strut Ground-to-Orbit ?T

3- Bench Ground-to-Orbit ?T

4- Bench Desorption

5- Gravity Sag (1-G Release)

6- Assembly Induced Stresses

- Gravity Sag distortions dominate by far

- Ball Aerospace evaluated these results and found them to be acceptable but without much margin.

- IR Channel Distortions are lower than than those of UVIS Channel.

UVIS CHANNEL LONG TERM STABILITY

X,Y,Z is the Hubble Coordinate System(V1,V2,V3).

DISPLACEMENTS (X,Y,Z): micrometer, ROTATIONS (RX,RY,RZ) : arcsec

ID	OPTIC	DOF	CASE-1 ENC dT	CASE-2 L&S dT	CASE-3 OB dT	CASE-4 deM 50-0%	CASE-5 1 G Sag X	CASE-6 Assembly Z=0.003"@
1	POM	X	2.9	1.1	3.9	-11.4	-8.8	-0.2
		Y	-1.0	-1.7	-0.1	5.7	6.0	1.2
		Z	0.0	-0.7	-3.3	8.7	13.7	0.7
		RX	0.36	1.15	0.08	-3.66	-6.39	-0.07
		RY	0.63	-0.77	1.21	-1.83	-1.36	-0.25
		RZ	-0.22	0.08	0.06	-0.04	-2.68	0.52
2	UVIS Corrector	X	-1.1	6.2	2.3	-4.3	148.1	0.5
		Y	1.4	6.0	2.0	-18.8	-34.4	-0.8
		Z	0.2	-0.9	-0.3	19.1	21.0	0.6
		RX	0.33	1.15	1.71	-4.61	-7.20	-0.32
		RY	0.59	-0.76	-0.10	-0.92	-29.59	-0.16
		RZ	-0.18	0.06	0.24	-0.16	16.47	0.08
3	UVIS-M2	X	0.9	3.7	1.1	-7.3	32.1	0.3
		Y	0.2	2.2	0.1	-7.3	-14.7	0.5
		Z	0.2	-0.2	1.5	13.1	25.2	0.5
		RX	0.34	1.15	-0.85	-3.68	-4.22	-0.26
		RY	0.56	-0.76	-0.26	-0.99	-31.49	-0.14
		RZ	-0.17	0.07	0.10	-0.07	-1.93	0.34
4	SOFA	X	-0.1	5.2	1.1	-5.2	90.0	0.2
		Y	1.1	4.6	-0.9	-15.3	-26.3	-0.4
		Z	0.3	0.4	5.7	12.1	19.5	0.3
		RX	0.32	1.15	0.13	-3.68	-5.48	-0.33
		RY	0.59	-0.76	0.89	-1.29	-55.27	-0.12
		RZ	-0.16	0.06	0.05	-0.01	2.38	0.10
5	UVIS DETECTOR	X	-1.2	6.6	2.0	-3.6	163.3	0.5
		Y	1.5	6.7	-1.8	-21.6	-39.0	-0.9
		Z	0.6	0.3	6.8	13.6	13.6	0.2
		RX	0.33	1.15	-0.14	-3.70	-6.25	-0.31
		RY	0.57	-0.76	-0.18	-0.86	-37.11	-0.13
		RZ	-0.18	0.06	0.80	-0.25	2.19	0.10
	MAX DISP	**10^{-6}m**	2.9	6.7	6.8	21.6	163.3	1.2
	MAX ROT	**arcsec**	0.63	1.15	1.71	4.61	55.27	0.52

UVIS Short Term STOP Analysis Results based on Steady-State Temperature Predictions

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- RSS Focal Plane Distortion is 0.97 with sufficient margin compared to the budget.
- Notes:
  Transient temperatures also predicted and used in STOP analysis. Using Steady-State Temperatures turned out to be more conservative than using Transient Temperatures in this case.

  Not all the secondary distortion effects such as due to flex hoses have been considered yet.

DISPLACEMENTS (X,Y,Z): micrometer, ROTATIONS (RX,RY,RZ) : arcsec

Error Calculation using NEW Sensitivities

X,Y,Z is the Hubble Coordinate System(V1,V2,V3). (Sensitivities in Hubble Coordinate System)

ID	OPTIC	DOF	CASE-1 Enc Bulk dT	CASE-2 Latch & Struts dT	CASE-3 OB only hot-hot	CASE-4 OB only hot-cold	UVIS Sens. dX	Focal for dY	OB Error Sum micron arcsec	UVIS dX micron	Focal dY micron
		Coef for OB Error Sum =>	1.0	1.0	0.0	-1.0					
1	POM	X	-0.039	-0.065	-0.031	0.011	1.020	-0.950	-0.114	-0.117	0.109
		Y	-0.142	-0.129	-0.021	0.020	0.000	0.000	-0.292	0.000	0.000
		Z	-0.083	0.133	0.224	-0.189	-1.090	1.020	0.240	-0.261	0.244
		RX	0.066	0.029	0.009	-0.009	-3.060	-3.270	0.103	-0.315	-0.337
		RY	-0.004	-0.011	0.067	-0.063	-6.130	5.730	0.048	-0.296	0.277
		RZ	-0.031	-0.004	-0.012	0.010	-2.850	-3.050	-0.046	0.130	0.139
2	UVIS Corrector	X	0.077	0.031	-0.053	0.042	-1.139	1.134	0.066	-0.075	0.075
		Y	0.157	0.079	-0.095	0.078	1.213	1.218	0.158	0.191	0.192
		Z	-0.085	0.127	-0.302	0.253	-0.027	-0.027	-0.210	0.006	0.006
		RX	0.039	0.031	0.052	-0.046	-7.230	-7.260	0.115	-0.834	-0.838
		RY	-0.015	-0.009	0.017	-0.006	-6.760	6.730	-0.018	0.122	-0.122
		RZ	-0.026	0.002	0.024	-0.020	0.450	-0.450	-0.003	-0.001	0.001
3	UVIS-M2	X	-0.004	-0.028	-0.130	0.110	-0.561	0.559	-0.142	0.080	-0.080
		Y	0.049	-0.031	0.107	-0.089	0.591	0.594	0.107	0.063	0.064
		Z	-0.062	0.142	0.012	-0.011	0.118	0.119	0.090	0.011	0.011
		RX	0.046	0.027	0.151	-0.124	6.200	6.220	0.197	1.221	1.225
		RY	-0.005	-0.006	0.066	-0.056	5.780	-5.750	0.045	0.258	-0.257
		RZ	-0.031	-0.002	-0.018	0.016	0.000	0.000	-0.049	0.000	0.000
4	SOFA	X	0.119	0.016	-0.117	0.098	0.000	0.000	0.037	0.000	0.000
		Y	0.140	0.038	0.150	-0.126	0.000	0.000	0.305	0.000	0.000
		Z	-0.059	0.159	-0.116	0.094	0.000	0.000	0.006	0.000	0.000
		RX	0.051	0.027	-0.005	0.004	0.000	0.010	0.074	0.000	0.001
		RY	-0.033	-0.008	0.019	-0.013	0.010	0.000	-0.027	0.000	0.000
		RZ	-0.004	0.001	-0.001	0.004	0.000	0.000	-0.007	0.000	0.000
5	UVIS DETECTOR	X	0.114	0.034	-0.065	0.046	0.730	-0.680	0.102	0.074	-0.069
		Y	0.179	0.096	0.148	-0.127	-0.730	-0.780	0.402	-0.294	-0.314
		Z	-0.043	0.160	-0.333	0.276	0.000	0.000	-0.159	0.000	0.000
		RX	0.041	0.031	0.004	-0.005	-0.780	-0.830	0.078	-0.061	-0.064
		RY	-0.017	-0.009	-0.010	0.016	-0.770	0.730	-0.042	0.033	-0.031
		RZ	-0.026	0.002	0.011	-0.006	0.000	0.000	-0.018	0.000	0.000
	MAX DISP	10^{-6}m	0.179	0.160	0.333	0.276			sum	-0.06	0.23
	MAX ROT	arcsec	0.066	0.031	0.151	0.124			RSS	0.24	micron
	Bench	X	0.029	0.003	-0.208		coef	1 1 1 0	-1 1 1 0	1 -1 1 0	1 1 -1 0
	Rigid Body	Y	0.139	0.011	0.037		RSS	0.43	0.87	0.68	0.97
19	Motion	Z	-0.131	0.102	0.034						
	Measured at	RX	0.040	0.031	0.010		max RSS = 0.97				
	Bench to	RY	-0.019	-0.017	0.004						
	Strut I/F	RZ	-0.036	0.001	-0.004		CDR Max was: 0.91			budget=	1.58

coef	RSS
1 1 1 0	0.43
-1 1 1 0	0.87
1 -1 1 0	0.68
1 1 -1 0	0.97
1 1 0 1	0.78
-1 1 0 1	0.54
1 -1 0 1	0.69
1 1 0 -1	0.24

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CONCLUSIONS AND RECOMMENDATIONS

- WFC3 Optical Bench design analytically shown to meet all the challenging Requirements:
  - Very tight Short-Term STOP Budget
  - Long-Term Distortion Budget including Gravity Sag
  - High Strength Margins of Safety and Minimum Fundamental Frequency
  - Weight Budget, Packaging and Access
- To meet challenging STOP Requirements, It is recommended to:
  - Establish and Understand the Long-Term, Short-Term, and Slew Requirements very well
  - Maintain good Communication between all the Disciplines involved, Conduct in-depth Peer Reviews
  - Address all the Critical Structural Analysis and Design Issues listed previously under “Structural CheckList”
  - Implement Thermal Control to minimize on-orbit temperature variations
  - Consider both Steady State and Transient Temperature Predictions in STOP Analysis
  - Design in ample Margin for Gravity Release
  - Perform Checks and Tests to validate Math Models

REFERENCES

- WFC3 Optical Bench Test Procedures (Vibration, One-G Sag, Thermally Induced), Doug McGuffey, Chris Fransen, May 2001.
- Correspondence with Joe Sullivan on WFC3 Optical Performance, Ball Aerospace, April 2001.
- Swales Internal Presentation, STOP Analysis, Jim Pontius, September 2000.
- WFC3 Optical Bench CDR, Jill Holz, Jordan Evans, Chris Lashley, Danny Hawkins, Ben Rodini, Bill Chang, John Haggerty, and Cengiz Kunt, June 2000.
- NEC Optical Bench CDR at Swales Aerospace, Chiachung Lee & Cengiz Kunt, April 1998.