ISIM Distortion Analysis Challenges

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Poster session preferred

Abstract

Very tight distortion requirements are imposed on the JWST's ISIM structure due to the sensitivity of the telescope's mirror segments and science instrument positioning. The ISIM structure is a three dimensional truss with asymmetric gusseting and metal fittings. One of the primary challenges for ISIM's analysis team is predicting the thermal distortion of the structure both from the bulk cooldown from ambient to cryo, and the smaller temperature changes within the cryogenic operating environment.

As a first cut to estimate thermal distortions, a finite element model of bar elements was created. Elements representing joint areas and metal fittings use effective properties that match the behavior of the stack-up of the composite tube, gusset and adhesive under mechanical and thermal loads. These properties were derived by matching tip deflections of a solid model simplified T-joint. Because of the structure's asymmetric gusseting, this effective property model is a first attempt at predicting rotations that cannot be captured with a smeared CTE approach.

In addition to the finite element analysis, several first order calculations have been performed to gauge the feasibility of the material design. Because of the stringent thermal distortion requirements at cryogenic temperatures, a composite tube material with near zero or negative CTE is required. A preliminary hand analysis of the contribution of the various components along the distortion path between FGS and the other instruments, neglecting second order effects were examined. A plot of bounding tube longitudinal and transverse CTEs for thermal stability requirements was generated to help determine the feasibility of meeting these requirements.

This analysis is a work in progress en route to a large degree of freedom hi-fidelity FEA model for distortion analysis. Methods of model reduction, such as superelements, are currently being investigated.

JWST ISIM Distortion Analysis Challenges

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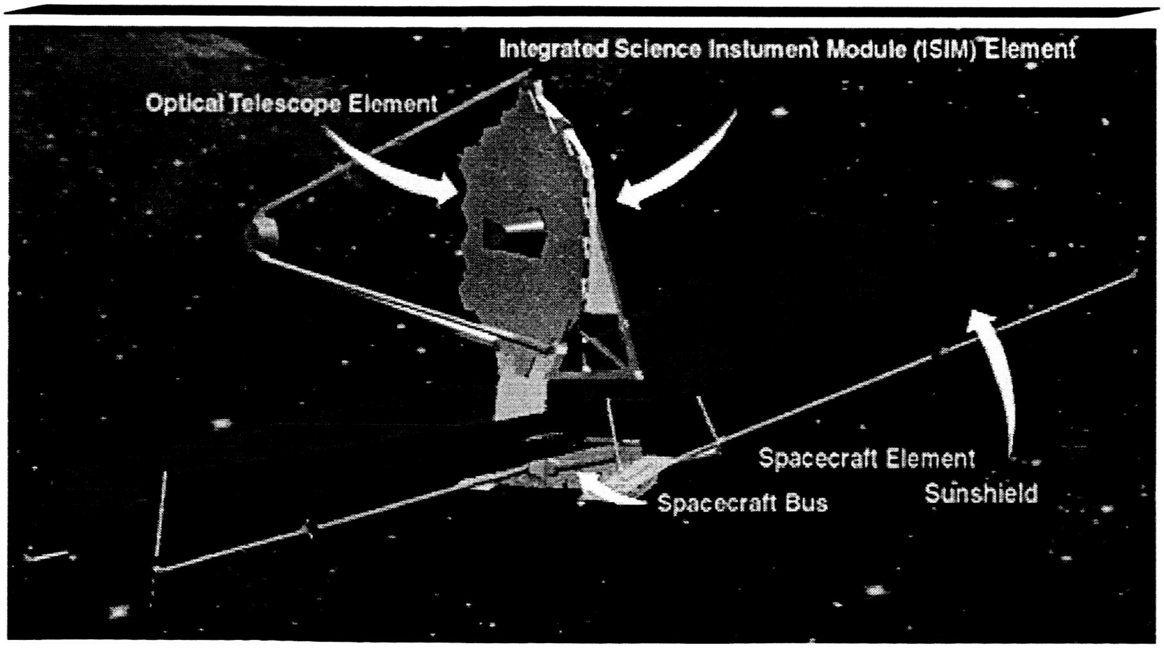
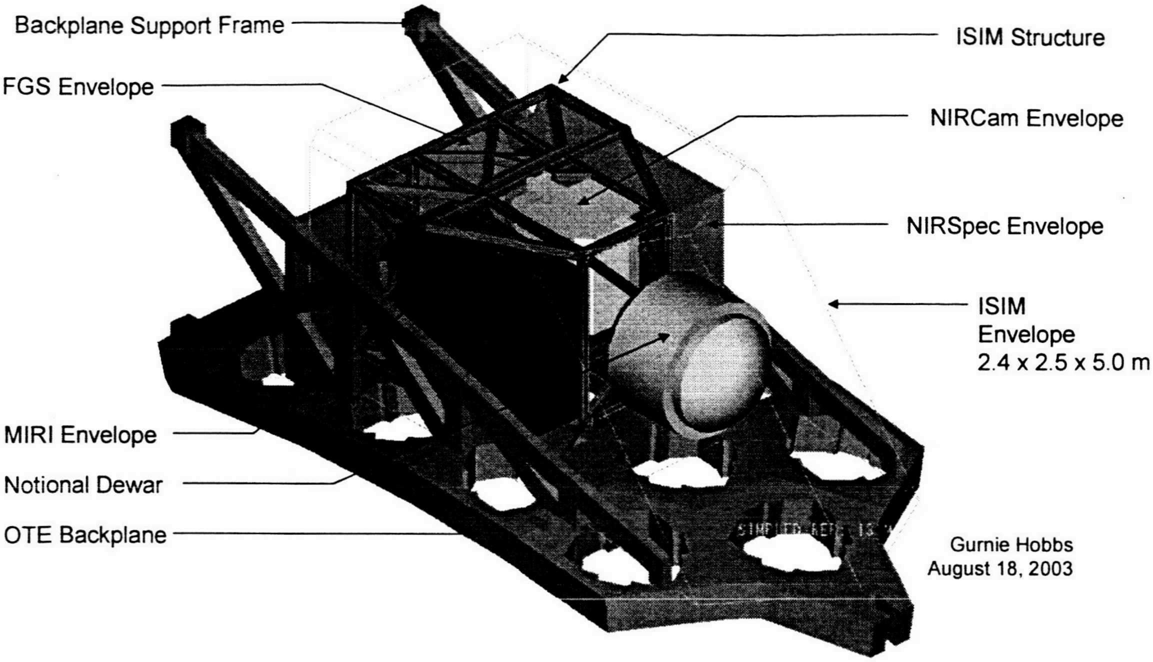
FEMCI Workshop - May 5-6, 2004

JWST:James Webb Space Telescope



Courtesy of John Nella, et al. Northrop Grumman Space Technology

ISIM: Integrated Science Instrument Module



Gurnie Hobbs
August 18, 2003

ISIM Structure Requirements

- Driving requirements:
  - Nominal operating temperature: 32 K at BOL
  - On-orbit temperature shift: ~0.5 K
  - Instrument on-orbit stability (~200 nm, 120 milli-arc-seconds)
- Challenges:
  - ISIM Structure has very stringent thermal stability requirements.
  - Asymmetric gusseting and titanium fixtures, which affect the deformation and stability predictions, are difficult to account for in a bar model.
  - Composite CTE data at cryogenic temperatures is not well known.
  - Solid elements are proposed to model the full-up ISIM structure for final verification, and considerable model sizes are expected. Model reduction techniques are necessary for integrated modeling requirements.

Overview

- **Thermal Distortion Bar Model with Joint Effective Properties:** Liz Matzinger, NASA/GSFC Code 542
  - A first cut of estimating the effect of gussets and titanium fittings on bulk cooldown distortion and on-orbit stability
- **Effective BAR Element Properties for ISIM Joints:** Charles Kaprielian, Swales Aerospace
  - Derivation of effective joint properties for use in the thermal distortion bar FEM
- **Preliminary Assessment of Material Feasibility for the ISIM Composite Tubes:** Emmanuel Cofie, Mega Engineering
  - A study of the ISIM composite tube CTE envelope that is required to meet thermal stability
- **Superelements on the ISIM Structure:** Terry Fan, Swales Aerospace
  - A study of the use of superelements to manage the model DOFs of the ISIM FEM used for final verification of distortion requirements.

ISIM Refined Bar Distortion Model

Liz Matzinger
NASA/GSFC Code 542

Refined ISIM FEM

- Bar models are useful during the design development phase for quick turnarounds on design trades

- However, the current baseline finite element model (FEM) does not account for the presence of gussets and titanium fixtures, which will affect the deformation predictions

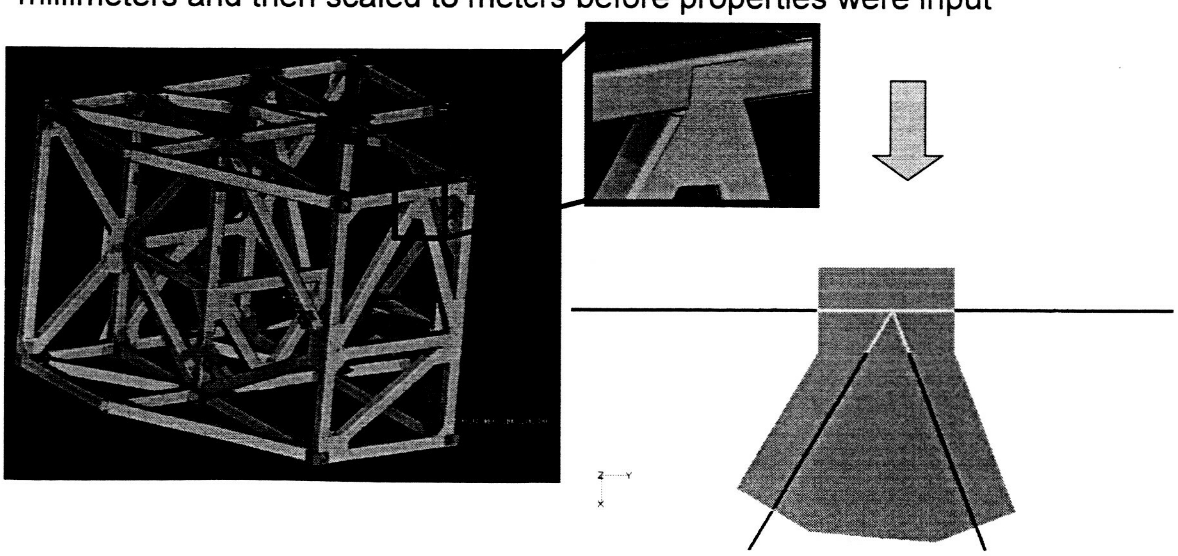
- A refined ISIM bar model was created as a first cut at taking into account local joint stiffnesses and CTEs

  - Important for thermal distortions because of asymmetric gusseting

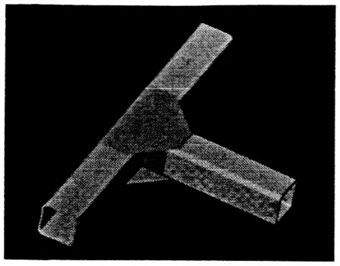
  - Created using the geometry from the Baseline SRR Pro/E model

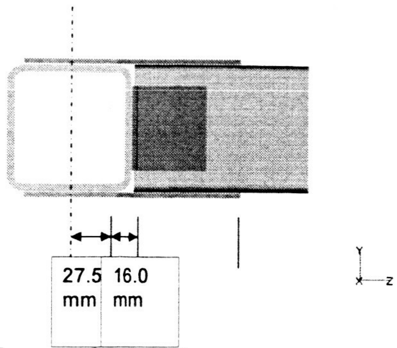
Gusset Layout

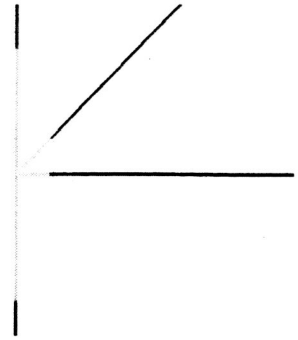
- Gussets were imported as an IGES file into FEMAP
- Because the Pro/E model is in millimeters, the FEM was created in millimeters and then scaled to meters before properties were input



Effective Joint Properties





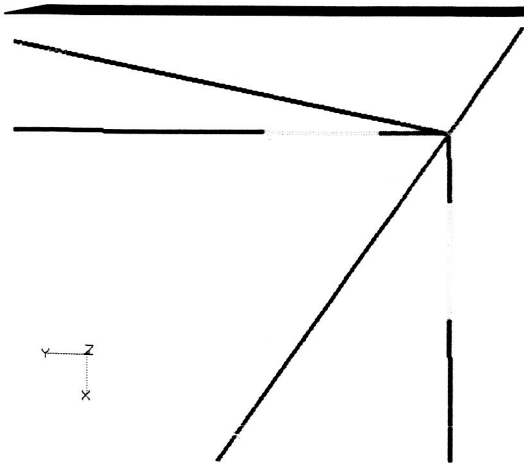


Top View, Joint 255

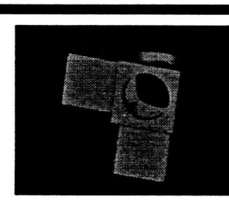
- Four primary properties:
  - ♦ Transverse tube: 27.5 mm (Orange)
  - ♦ Gusset and clip: 16.0 mm (Purple)
  - ♦ Gusset and tube: dependent on gusset geometry (Blue)
  - ♦ Continuous gusseted tube: dependent on gusset geometry (Green)

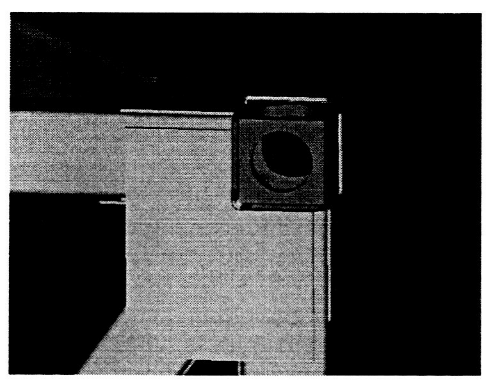
- Values for material and property cards for above properties are assigned based on analysis done by Chuck Kaprielian
  - ♦ Effective properties are based on a simple T-joint and used for all joint types

Titanium Fittings



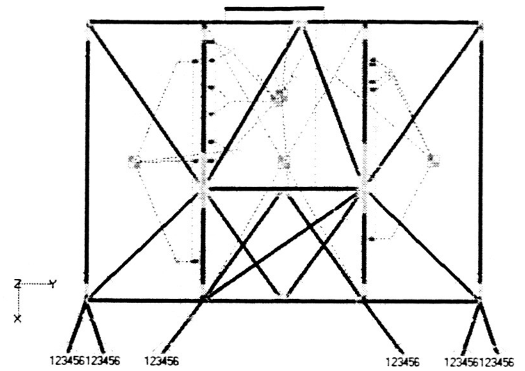
Joint 250



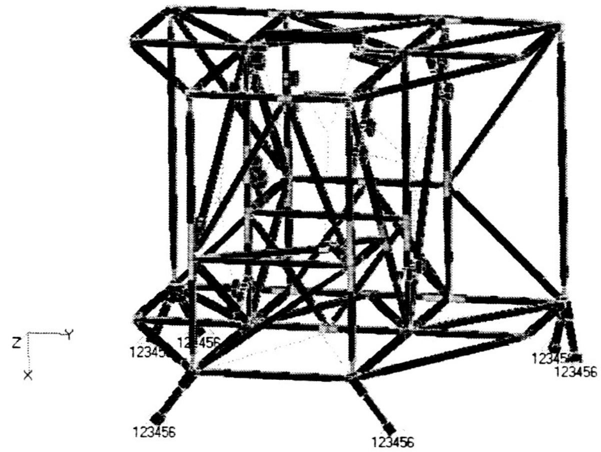


- Titanium (Red)
- Tube + Gusset (Blue)
- Titanium + Tube + Gusset (Turquoise)
  - ♦ Uses the same section properties as a nominal gusset and tube
  - ♦ For material card, the density and CTE are given from Ti-6Al-4V and E and G are taken from the composite laminate values

Finite Element Model



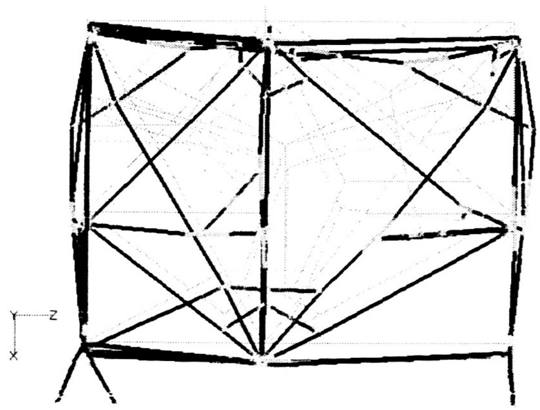
Front View



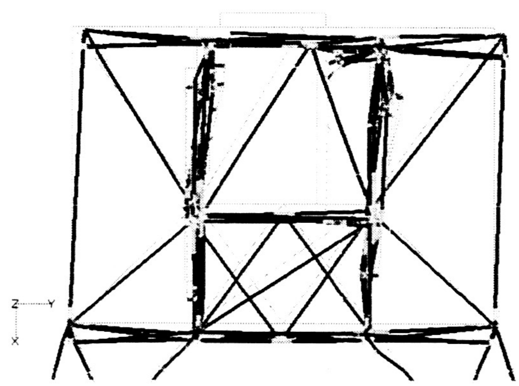
Inertia Ratios
(shown without instrument masses)

Gravity Sag Distortion

- Relative distortions between the NIRCam interface points may be an issue during integration due to joint compliance and titanium stiffness for NIRCam (titanium's modulus is about half that of the composite).



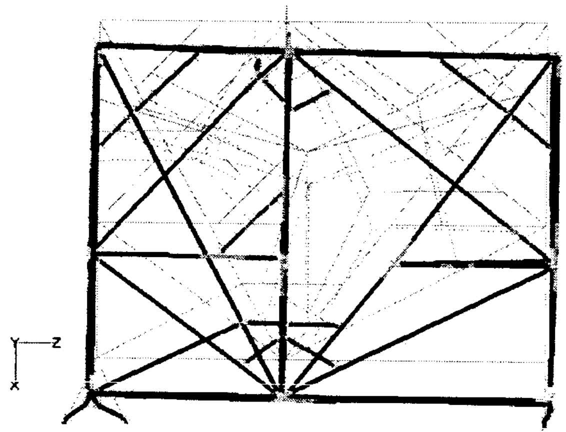
Side View Deformed, Scale = 5



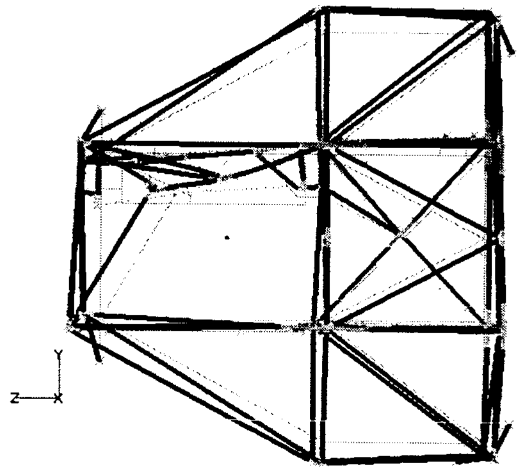
Front View Deformed, Scale = 5

Bulk Thermal Cooldown Distortions

- Stack-up of gussets on vertical members lead to ~200 micron difference from baseline in V1 translation (depending on the gusset size near a particular instrument
- Also, asymmetric gusseting induces rotations at the instrument interface points



Side View Deformed, Scale = 10



Top View Deformed, Scale = 30

Conclusions

- The baseline model can account for joint compliance reasonably well when analyzing normal modes and gravity sag

- The asymmetric gusseting causes thermal distortions that the baseline model does not capture

- Therefore, this level of fidelity is necessary and more refined models will be required as the design progresses in order to adequately predict performance

Effective BAR Element Properties for ISIM Joints for use in the All-Up "Stick" FEM

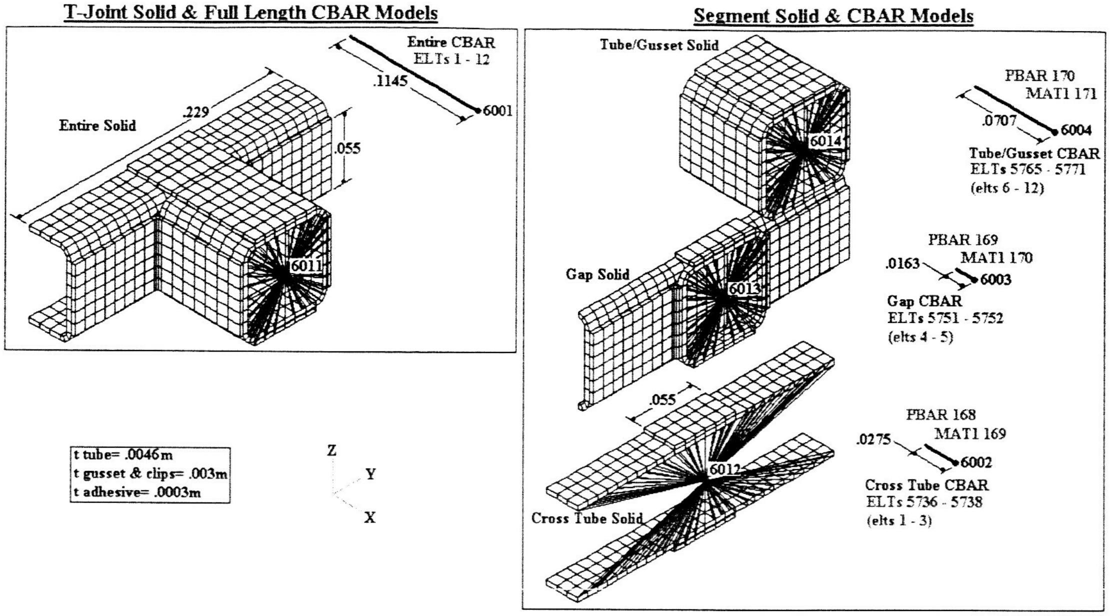
Charles Kaprielian
Swales Aerospace

- **Objectives**
  - Determine "Effective" or "Smeared" CTE and Cross-Sectional Properties for the Joints of the All-Up ISIM "Stick" FEM
  - The Effective Properties determined need to be "Sufficiently Accurate". It is stipulated that the Effective Properties Yield Deformations within 5% of the Actual Deformations.
- **Approach**
  - Generate a detailed FEM of a given Joint using Solid Elements.
  - Generate a corresponding BAR Element Version of the same Joint
    - In general, more than one Property Set is necessary to reach the desired Prediction Accuracy
  - Exercise both Models under Mechanical & Thermal Loading & adjust the BAR Sectional Properties & CTE to get the desired Agreement between the detailed Solid Model and BAR Element Model Deformations

Case of "T-Joint" Solid & BAR Element Models

T-Joint Solid & Full Length CBAR Models

Segment Solid & CBAR Models



T-Joint Comparison of Tip Deflections under Mechanical Loading

"Stick" Model of Joint within 3.3% of Solid Model of Joint

Three Different Sets of Properties employed by the BAR Element Model

Solid FEM Mesh Sensitivity Study performed to determine Prediction Accuracy & to guide Solid Element Models of other Joints

	SUBCASE 1			Fx= 10000 N		
GRID	Δx	Δy	Δz	Φx	Φy	Φz
6001	.000015	.000000	.000000	.000000	.000000	.000000
6011	.000015	.000000	.000000	.000000	.000000	.000000
	-.168%					

	SUBCASE 2			Fy= 10000 N		
GRID	Δx	Δy	Δz	Φx	Φy	Φz
6001	.000000	.000253	.000000	.000000	.000000	.002638
6011	.000000	.000253	.000000	.000000	.000000	.002620
		.034%				.664%

	SUBCASE 3			Fz= 10000 N		
GRID	Δx	Δy	Δz	Φx	Φy	Φz
6001	.000000	.000000	.000165	.000000	-.000740	.000000
6011	.000000	.000000	.000165	.000000	-.000717	.000000
			-.078%		3.315%	

	SUBCASE 4			Mx= 10000 m-N		
GRID	Δx	Δy	Δz	Φx	Φy	Φz
6001	.000000	.000000	.000000	.019563	.000000	.000000
6011	.000000	.000000	.000000	.019566	.000000	.000000
				-.015%		

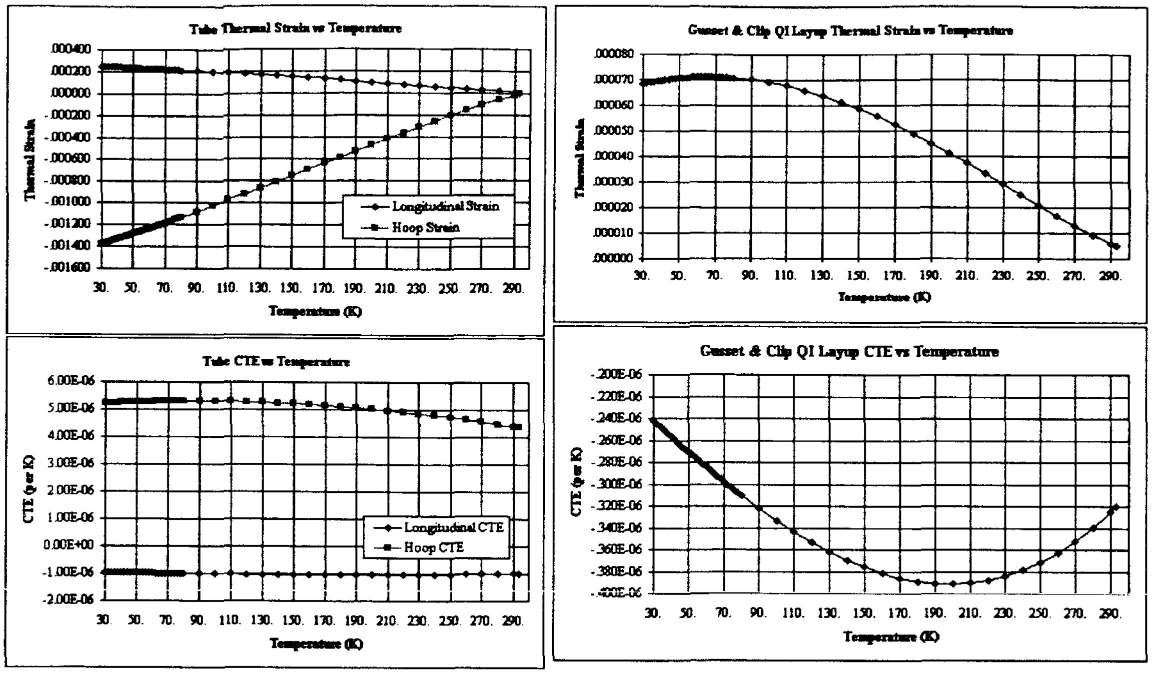
	SUBCASE 5			My= 10000 m-N		
GRID	Δx	Δy	Δz	Φx	Φy	Φz
6001	.000000	.000000	-.000740	.000000	.010478	.000000
6011	.000000	.000000	-.000717	.000000	.010836	.000000
			3.315%		-3.309%	

	SUBCASE 6			Mz= 10000 m-N		
GRID	Δx	Δy	Δz	Φx	Φy	Φz
6001	.000000	.002638	.000000	.000000	.000000	.035710
6011	.000000	.002620	.000000	.000000	.000000	.035900
		.664%				-.529%

Tip GRID 6001 belongs to Stick FEM

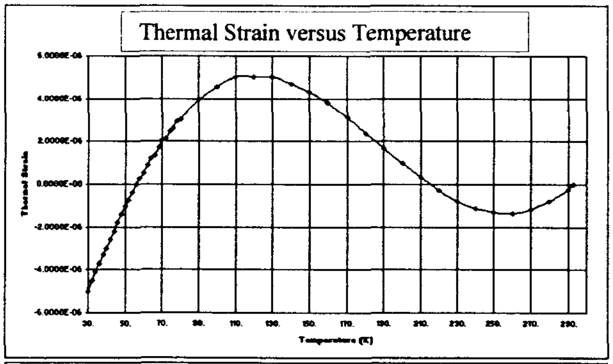
Tip GRID 6011 belongs to the Solid FEM

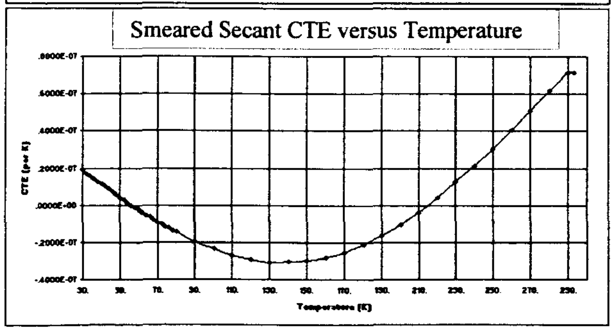
Constituent CTEs used in Computation of T-Joint Smeared Temperature Dependant CTE



T-Joint Smeared Secant CTE Results

- Temperature dependent CTEs are input for the materials in the solid model.
- 48 Bulk Temperature Drop cases are run, each from 293 K to a temperature of interest and the X displacements are recovered for GRID 6011 of the Solid Model. Using the X displacements combined with the Length (.1145 M) and change in Temperature, Thermal Strain and CTE is determined for each temperature considered.
- The set of calculated CTE values becomes the temperature dependent CTE for the bar model.
- As a final check, the 48 cases are run again with the X displacements at GRIDs 6001 & 6011 compared. Stick Model agrees with the Solid with negligible error.





Preliminary Assessment of Material Feasibility for the ISIM Composite Tubes

Emmanuel Cofie
Mega Engineering

Introduction

- **ISIM Structure Requirements & Challenges**
  - ISIM Structure has very stringent thermal stability requirements(200nm, 120mas)
  - This poses several challenges to the ISIM material design team
  - Preliminary assessment of material feasibility is important

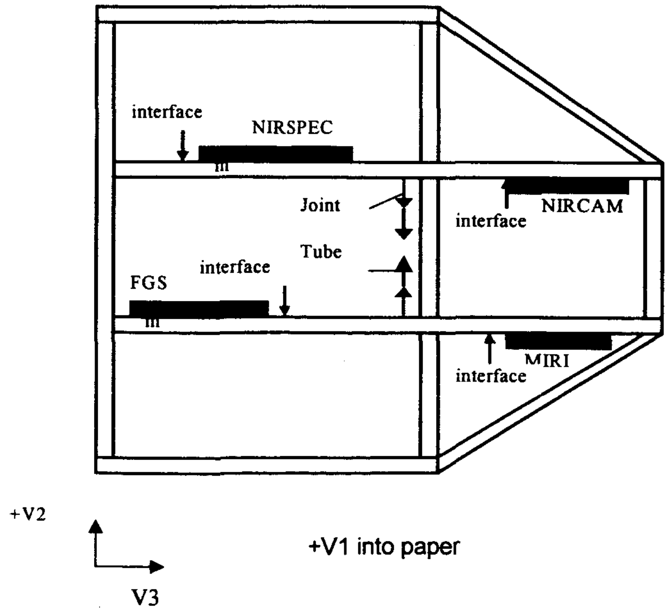
- **Purpose of Analysis**
  - Determine envelope of Required ISIM composite tube CTE @ cryogenic temperature Required to Meet Thermal Stability
  - To get an understanding of how stability requirements can be achieved
  - Study what components significantly affect stability motion

Approach and Assumptions

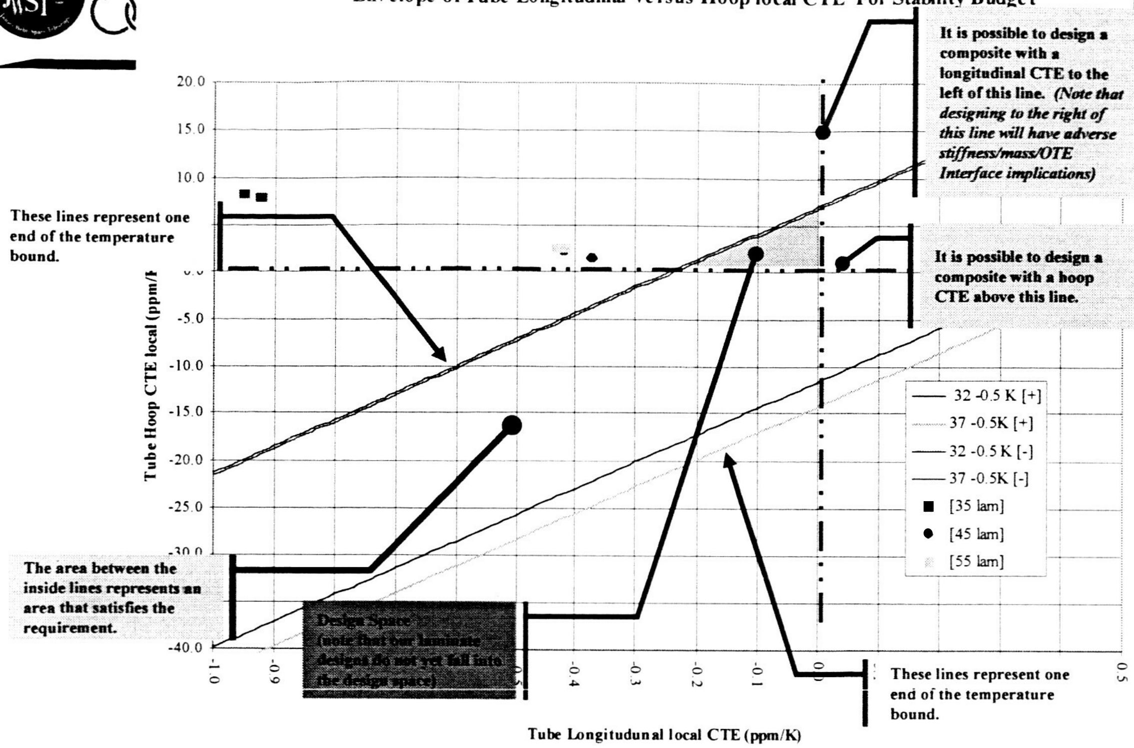
- **Analytical Approach**
  - Short Term Stability - 0.5K Bulk Temperature change
  - Interface motion of SI with respect to FGS
  - Expansion/Contraction of Material Stack-up along Path
  - Saddle,Epoxy,Joint/Gusset,Tube,Bonded interface
- **Assumptions**
  - Unrestrained Expansion of material stack-up
  - Use Local CTE derived from expansion-temperature curves
  - 0.5 K temperature change at 32 K & 37 K
  - ISIM "smeared" Joint CTE used
  - Relative motion between FGS & NIRCAM considered critical
  - A margin of 2 used to account for material & joint uncertainty & 2nd order effects
  - Stability Requirement budget used as bounding constraint
  - Hoop and Axial CTE of ISIM composite tube used as variable in design

    (laminate CTEs can be design by varying laminate stack-up and angles

ISIM Instrument Layout



Envelope of Tube Longitudinal Versus Hoop local CTE For Stability Budget



Summary & Conclusions

- Stability Requirement is dominated by Tube Hoop CTE
- Interface bracket design can be modified to limit lateral motion
- Even though Current material model falls outside envelope, design of composite tube which meets stability is feasible
- Feasible region requires tube with axial CTE of (-0.2 -0) ppm/K.
- Making Local changes at ISIM-SI interface can improve stability
- Existing material meets stability budget remaining SIs

Superelements on the ISIM Structure

Terry Fan
Swales Aerospace

Introduction

- Very tight distortion requirements are imposed on the JWST's ISIM structure .
- The ISIM structure is made of composite materials. The CTEs of the structure are designed to be near zero at CRYO temperature.
- Traditional stick model, used for design iterations, may not capture the transverse effect of the composite joints.
- Verifications through testing at CRYO temperature is not feasible.
- Solid elements are proposed to model the full-up ISIM structure for final verification.
- Considerable model sizes are expected.
- Superelements are proposed to reduce the model size.

Pros & Cons of Superelements

- PROS
  - The creation of the reduced sets, [K], [M], [B], & [P] are automatic
  - ISIM can meet SE-16 DOFs requirements
  - Dofs of ISIM instruments mounts can be placed on the residual structure, which will be solved during JWST system run
  - Costs for data recovery are minimum
  - S.E. has been successfully used in Aerospace Industry
  - Costs imposed by design changes are limited to associated superelements
- CONS
  - Learning curves
  - Need coordination between JWST & ISIM as well as other subsystems
  - Data storage and management for S.E. database

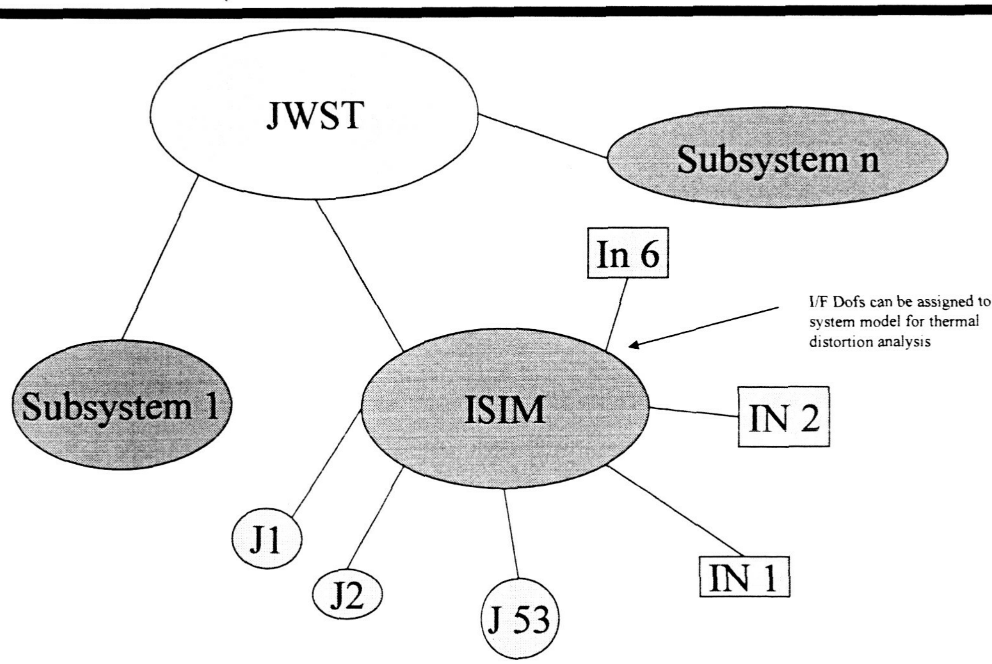
ISIM Structure Superelement Highlight (1/2)

- I/F Definitions between systems
  - Element types
  - Coordinates & Coordinate systems
- DOFs requirements
  - JWST overall requirements
  - ISIM and other subsystems (SE-16)
  - Numbering of FE Models for various substems (SE-16)
    - Although the new MSC.Nastran S.E. does allow duplicate numberings.
    - Unique numbering system shall be used(SE-16), due to lack supports of pre- & post-processors (FEMAP, PATRAN, etc.)
- Load cases & Boundary Conditions
  - LCS. and BCS. shall be defined from top down
  - All LCs. and BCs. shall be predefined for all S.E.s
- ISIM Load Cases
  - Within ISIM operating temperature ranges (30° K ~ 38° K), due to the fact of CTEs of ISIM structure are highly temperature dependent, every ½° K load steps (for example, 30° K ~ 30.5° K, 32.5° K ~ 33° K, etc.) shall be specified as an individual load case.
  - S.E. will generate proper boundary loads at the I/F points based on the LCs. specified
  - A lookup table that define the boundary loads can be generated and provided to JWST for system thermal distortion analysis

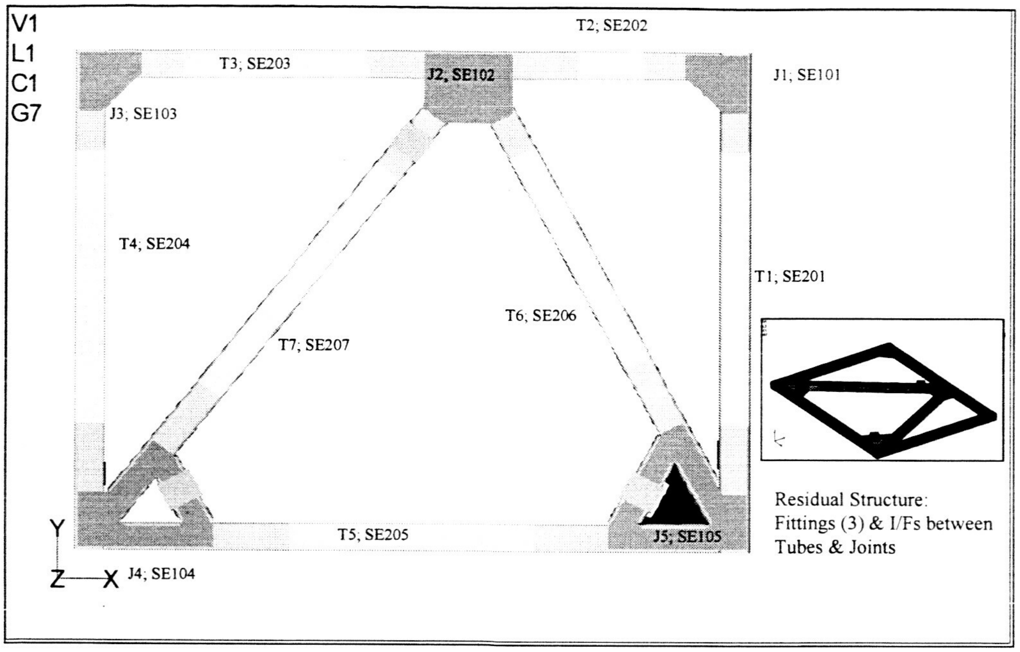
ISIM Structure Superelement Highlight (2/2)

- Formats of S.E.s
  - Traditional S.E.s
    - All S.E.s Bulk data provided to JWST
    - Larger file sizes
    - LCs. can be changed at system level
    - Run on the reduced size model
  - External S.E.s
    - Only [K], [M], & [P} are provided to JWST
    - By binary or DMIGs format
    - File size are smaller
- A-Set DOFs
  - Critical I/F points, e.q. mounts of ISIM instruments, can be specified on the A-set
  - Distortion data are readily available for JWST system level analysis.

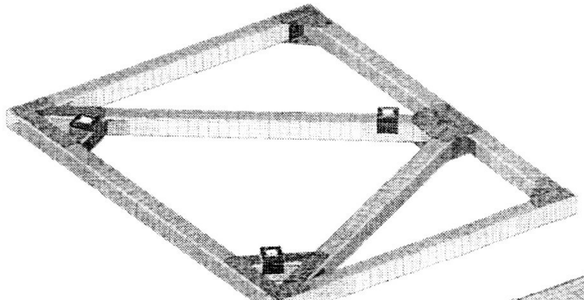
Conceptual ISIM Superelement

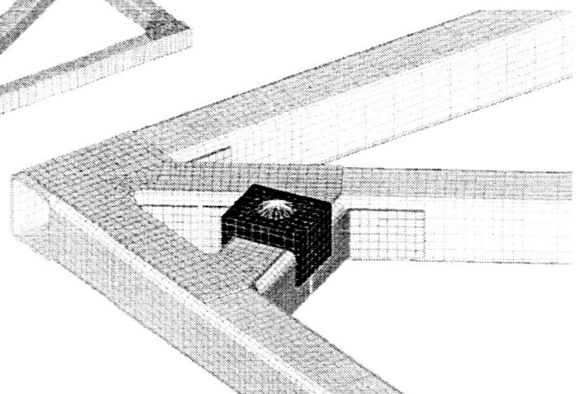


A Sample Superelement Model
for a 2-D Frame per SOW Figure 13



Model Detail





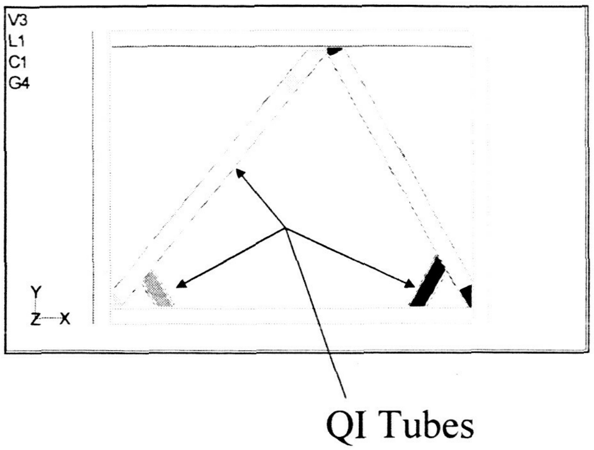
Model Size:

61179 Nodes

35140 Brick Elements

A Sample S.E. Run (1/2)

Thermal Stability due to Material Properties Change



- Baseline tubes (3) were replaced by QI-tubes as indicated
- Affected Superelements: 102 (J2), 104 (J4), 105 (J5), & 207 (T7)
- Thermal stability analysis

A Sample S.E. Run (2/2)

Thermal Stability due to Material Properties Change

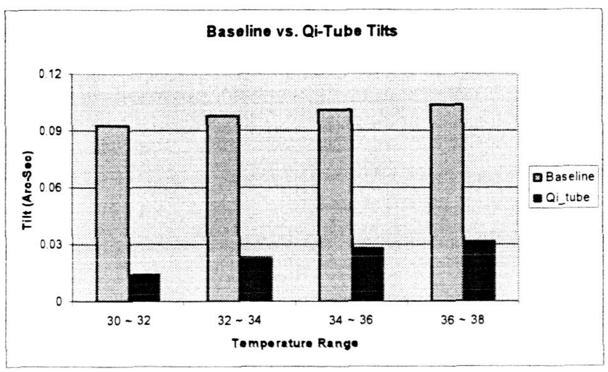
Thermal Stability Baseline vs. Qi-Tube

Baseline

Tilt Angles			
Operating Temperature range	Tilt (Arc-Sec)	25% of 2 K Delt T Tilt	Delt T
30 ~ 30.5	0.0228		0.5
30 ~ 32	0.0924	0.0231	2
32 ~ 34	0.0978	0.0244	2
34 ~ 36	0.1009	0.0252	2
36 ~ 38	0.1037	0.0259	2

QI_Tube

Tilt Angles (Arc-Seconds)			
Operating Temperature range	Tilt (Arc-Sec)	25% of 2 K Delt T Tilt	Delt T
30 ~ 30.5	0.0043		0.5
30 ~ 32	0.0144	0.0036	2
32 ~ 34	0.0232	0.0058	2
34 ~ 36	0.0280	0.0070	2
36 ~ 38	0.0316	0.0079	2



QI-Tube configuration tilts are about 20% of Baseline's