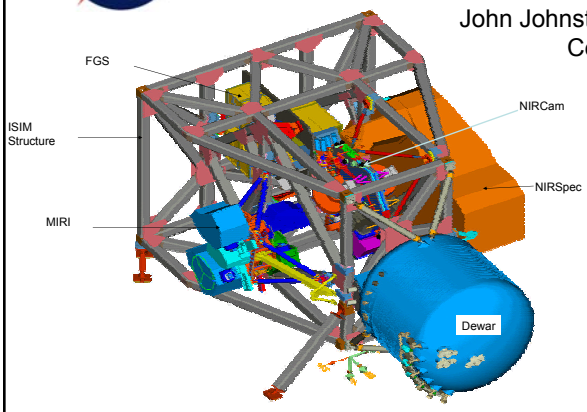
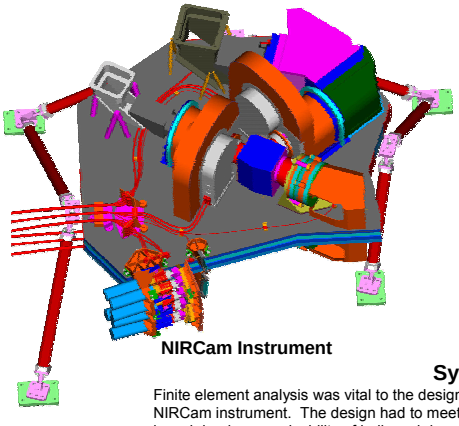
Design and Analysis of Kinematic Strut Mounts For NIRCam, a JWST ISIM Instrument

Daniel Young, Swales Aerospace
Andrew Bartoszyk, Swales Aerospace
Emmanuel Cofie, Mega Engineering
John Johnston, NASA Goddard Space Flight Center
Cengiz Kunt, Swales Aerospace



ISIM Structure & Instruments CAD Model View as of Jan. 2005



NIRCam Instrument

Background

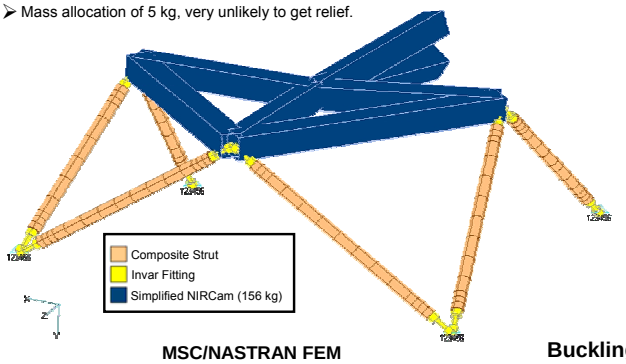
- NIRCam bench and optical assembly is being designed and built by Lockheed Martin.
- NIRCam Kinematic Mount Struts are being designed and built by GSFC to be delivered to NIRCam in Fall of 2005.
- Struts are in post PDR detailed design phase.

Synopsis

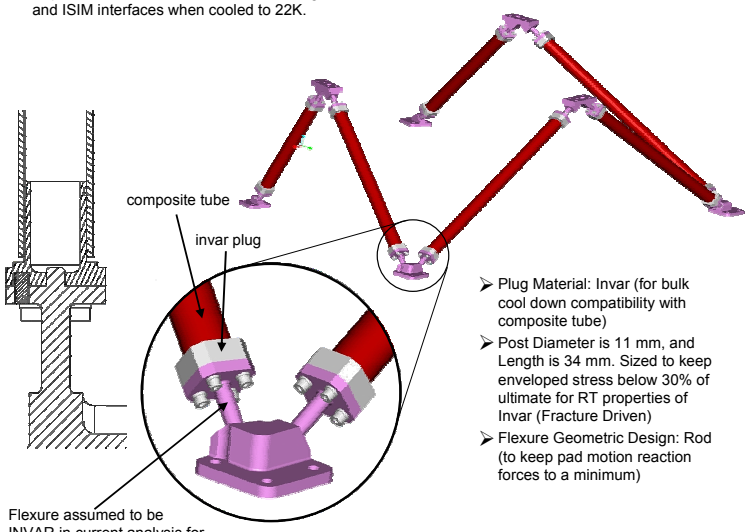
Finite element analysis was vital to the design and optimization of the kinematic mounts for the NIRCam instrument. The design had to meet dueling structural requirements driven by 12G launch loads, a survivability of bulk cool down from room temperature to 22 K, minimum first mode of 50 Hz and mass allocation constraints. Additionally the design has to meet stability requirements for the NIRCam bench along with limits to interface loads to both the instrument and ISIM interfaces when cooled to 22K.

Derived Requirements for the NIRCam Kinematic Struts

- Fundamental Mode Frequency of at least 50Hz for the NIRCam bench as mounted on the struts
  - Bench hard mounted (without struts) frequency requirement is 60 Hz.
  - Maintain a margin of 15% at PDR and 5% at CDR
- Survive Launch Design Limit Loads of Single Axis 12 G Loads
- Survive Bulk Cool Down (BCD) load from 293K → 22K
- Standard Analysis Safety Factors including 1.50 on composites and bonded Joints ultimate failure under both mechanical and thermal environments.
- Cool-Down induced interface Reactions must be less than 330 N shear force and 65N-m moment per pad at ISIM interface.
- Cool-Down Reactions shall be less than 66 N shear and 12.2 N-m moment (maybe higher if Lockheed OK's) at NIRCam bench interface.
- ISIM cool-down induced motions are enveloped by the so-called "Pad Motions," 0.6 mm or 6 arc min for each pad at ISIM interface in any direction.
- Mass allocation of 5 kg, very unlikely to get relief.



MSC/NASTRAN FEM



- Plug Material: Invar (for bulk cool down compatibility with composite tube)
- Post Diameter is 11 mm, and Length is 34 mm. Sized to keep enveloped stress below 30% of ultimate for RT properties of Invar (Fracture Driven)
- Flexure Geometric Design: Rod (to keep pad motion reaction forces to a minimum)

Summary of Loading used to predict Cool-Down Interface Reactions

- The following 2 load cases are run to determine Interface Reactions:
  1) ISIM Pad Motions, 36 separate pad motion sub-cases are considered to envelope all possible pad motions.
  2) A Bulk-Cool-Down, 293K → 22K, (BCD) case for the NIRCam bench and struts only.
- Results of these 2 cases are combined as follows:
  - The absolute max value for each reaction component of each strut end is found under the Pad Motions. This value is added to the corresponding absolute value obtained from the bulk cool down case.
    - **Row labeled "AMAX" lists the final combined results**
    - Row labeled "BCD" lists the reactions only due to Bulk Cool Down of the NIRCam bench and the struts. It is included for reference only.

Buckling of Composite Tubes, Pin - Pin

E_{tube} = 1.46E11Pa SF = 1.5

L = 0.71 m (longest length)

R = 0.0137 m
I = 1.138E-8 m^4
t = 0.0017 m

Composite Tube 3 Stacks Thick

$P_{cr} = \frac{\pi^2 EI}{L^2}$ = 32.5kN MS = $\frac{P_{cr}}{SF*P_{max}} - 1$ = +0.93

R = 0.01427 m
I = 1.628E-8 m^4
t = 0.00227 m

Composite Tube 4 Stacks Thick

$P_{cr} = \frac{\pi^2 EI}{L^2}$ = 46.5kN MS = $\frac{P_{cr}}{SF*P_{max}} - 1$ = +1.76

Note: Stepped beam analysis will be calculated for final design.

Natural Frequency Analysis of Bench on Struts
Strut Design Sensitivity Studies

Strut Design Case Descriptions								
Composite Tube No. of Stacks	7	5	5	5	5	5	5	4
Flex. Length (mm)	PDR	17	17	34	34	50	34	34
Flex. Diam. (mm)	PDR	10	6	10	12	10	11	11
Mode	Frequency (Hz)							
1	55.6	55.5	53.8	54.8	55.4	54.3	55.2	54.6
2	78.4	77.4	73.8	76.0	77.3	74.7	76.7	75.2
3	96.7	92.0	82.5	88.0	91.5	84.6	89.9	85.8
4	106.6	108.6	104.4	107.3	108.5	105.9	108.0	106.8
5	113.8	112.2	106.5	109.8	111.9	107.7	111.0	108.9

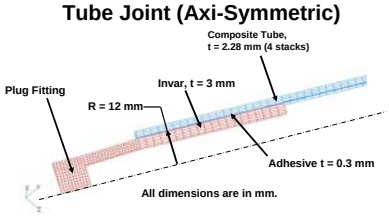
Note: Bench hard mounted frequency (without struts) is tuned to 60 Hz.

Max. Combined Bar Element Stress From 12 G Single Axis Launch Limit Loading

No. of Stacks	5	5	5	5	5	5	5	5	5	5	4
Flex. Length (mm)	17	17	17	34	34	34	34	34	50	34	34
Rod Diameter (mm)	10	8	6	10	12	13	14	15	10	11	11
Stress (MPa)	162	213	372	137	108	99.4	98.5	98.3	137.7	114.4	119

Note: 30% of 413MPa = 123.9 MPa for low risk fracture analysis with Invar

Bulk Cool Down (293K → 22K) Stress FEM of Bonded Plug - Composite Tube Joint (Axi-Symmetric)



Plug-Tube Bonded Joint Safety Factors from Interaction of FEM Element Stresses under BCD Loading

						Calculated Ply Safety Factors			
Design No.	Clevis	Clevis Material	Clevis Thickness (mm)	Composite Thickness (mm)	Stacks (No.)	SF (1) M55J	SF (2) M55J	SF (1) T300	SF (2) T300
6	Outside	Ti-6Al-4V	3	1.7	3	1.33	2.07	1.39	1.64
8	Inside	Invar	3	1.7	3	2.98	3.36	3.61	3.62
9	Inside	Invar	3	2.2758	4	2.05	2.50	2.72	2.85
10	Outside	Ti-6Al-4V	2	1.7	3	1.48	2.31	1.53	1.82
11	Outside	Ti-6Al-4V	2	2.2776	4	1.40	1.94	1.47	1.74
12	Inside	Ti-6Al-4V	2.21251	1.7	3	1.09	1.26	1.27	1.45
13	Outside	Ti-6Al-4V	1.6	2.2776	4	1.52	2.08	1.57	1.87
14	Outside	Ti-6Al-4V	1.6	1.7	3	1.59	2.58	1.62	1.95

Design (No.9) meets Cool-Down Survivability Requirement of Calculated Safety Factor > 1.65 (=1.5 * 1.1 where 1.1 accounts for any mechanical loading present)

M55J: Ft = 20 MPa, S = 46MPa
T300: Ft = 30 MPa, S = 65MPa

ISIM Interface

	FX	FY	FZ	FRSS X & Z	MX	MY	MZ	MRSS X&Z
	N				N-m			
AMAX	64.2	70.9	51.5	73.3	9.3	8.4	10.1	11.0
BCD	31.1	18.7	22.8	38.5	3.0	3.8	4.8	5.1

Meet ISIM requirement of 330 N shear force and 65N-m moment

NIRCam Interface

	FX	FY	FZ	FRSS X & Z	MX	MY	MZ	MRSS X&Z
	N				N-m			
AMAX	70.5	25.8	55.8	90.8	9.1	4.4	12.9	14.2
BCD	41.5	7.8	25.0	48.5	3.2	1.7	7.9	8.0

Lockheed verified BCD and pad motion reactions are acceptable.