Analysis of Cassiope Spacecraft using NX

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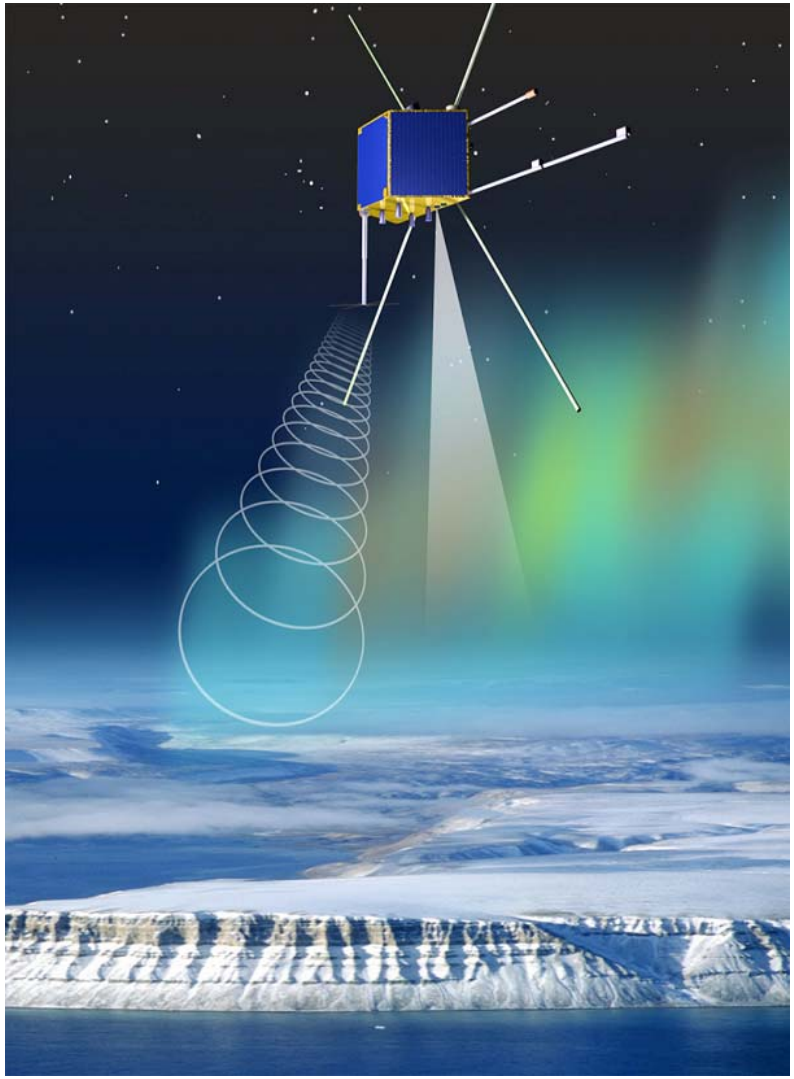
Cassiope



- Hybrid mission:
  - Digital broadband courier service for commercial use
  - Scientific payload ePOP (enhanced polar outflow probe), which will be used to study the ionosphere.
- Launch in Q1 2008
- Bus contractor: Bristol Aerospace
- Prime Contractor: MacDonald Dettwiler Associates
- Contracting Authority: Canadian Space Agency

Spacecraft Mechanical Environments

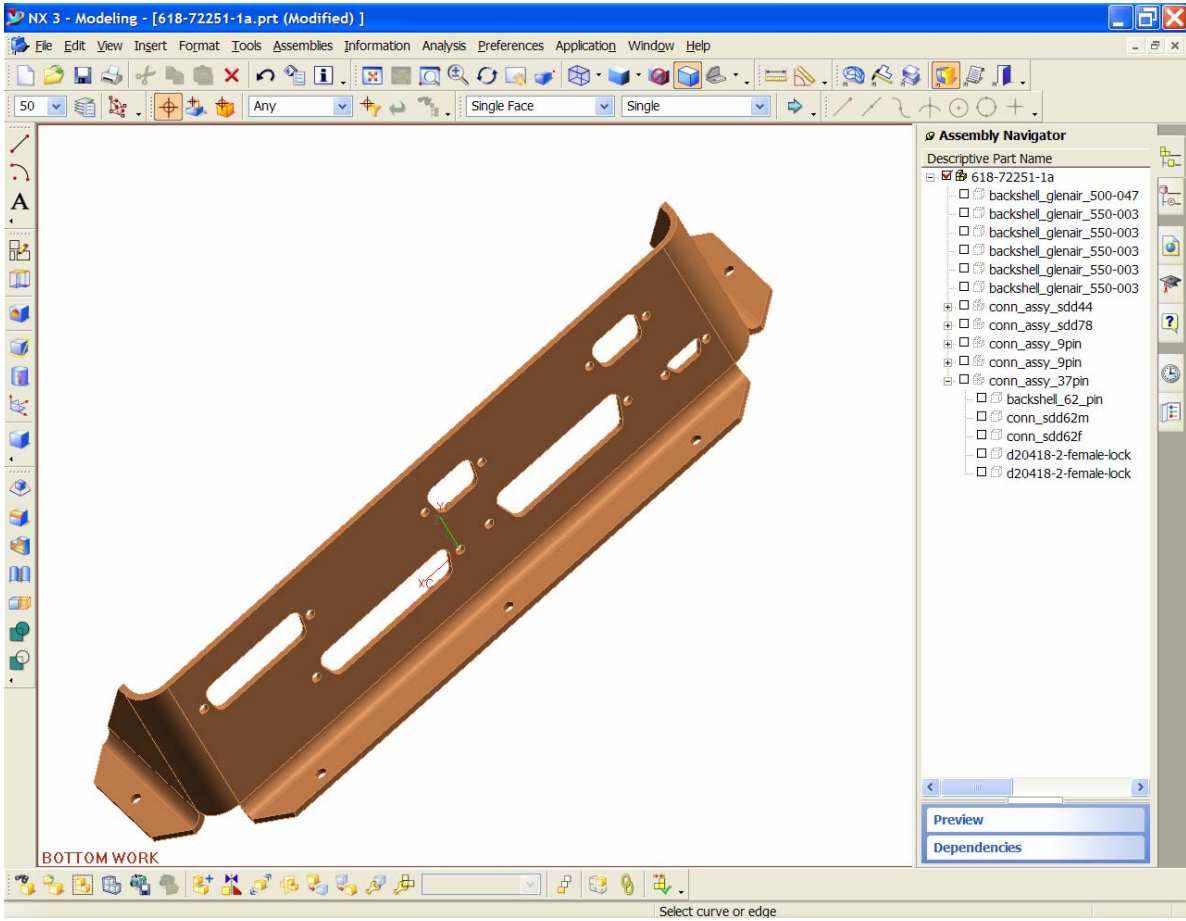
- Assembly & Integration
  - Handling
  - Transport

Linear static analysis

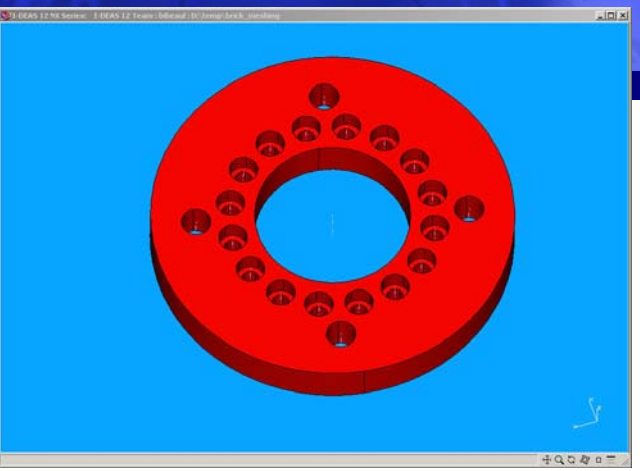
- Launch
  - Vibration — Harmonic+random dynamic analysis
  - Acoustic — Random dynamic analysis
  - Steady-state acceleration — Linear static analysis
- On-orbit
  - Thermal — Steady-state+ transient thermal analysis
  - Thermal distortion — Linear static analysis
  - Jitter — Transient dynamic analysis

UGNX/MasterFEM Interoperability

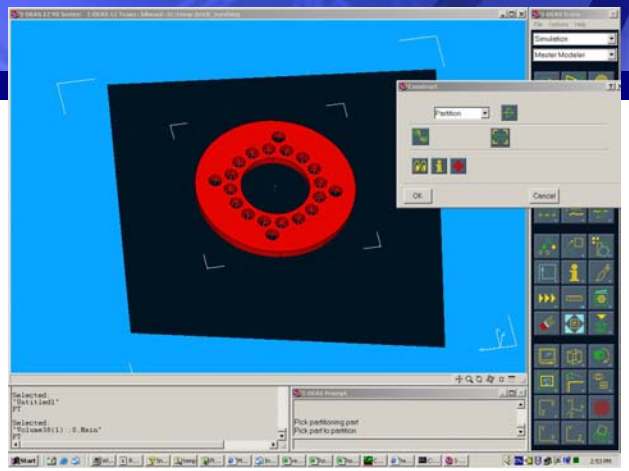
- Assembly opened in NX 3 and edited to remove detail
- Reduced assembly transferred to MasterFEM using “Unigraphics Open” or STEP.
- FEMs created for individual parts and Assembly FEM option used to create models of sub-assemblies.
- Assembly FEM used to create full model.



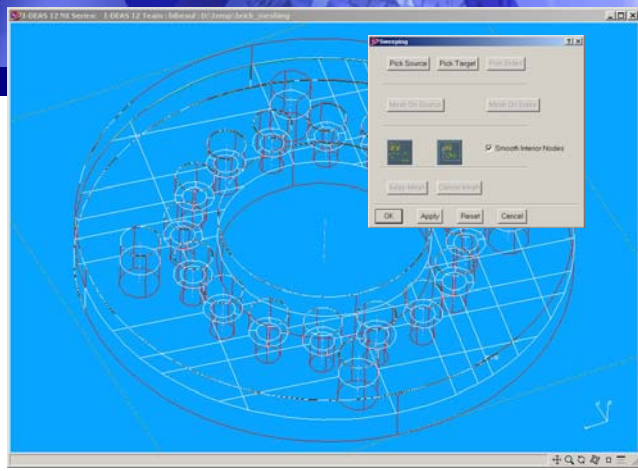
NX MasterFEM - Brick Meshing



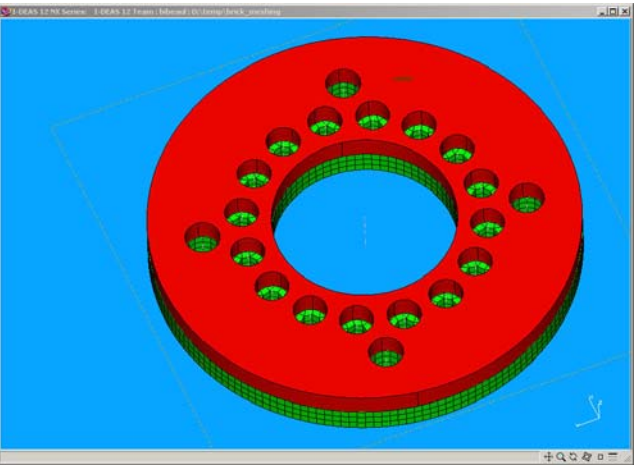
Counterbored disk

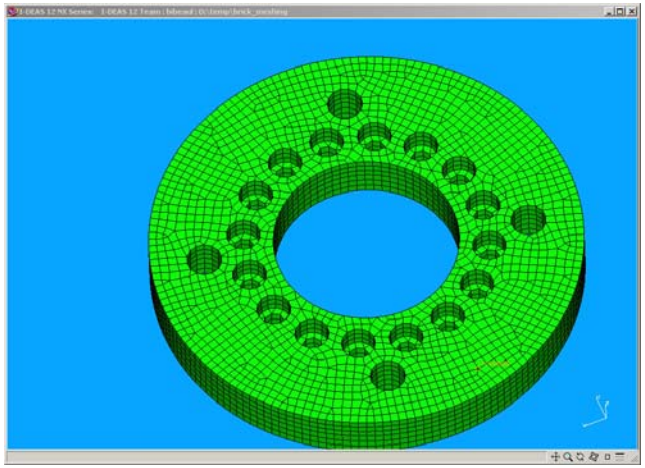


Partition at counterbore depth

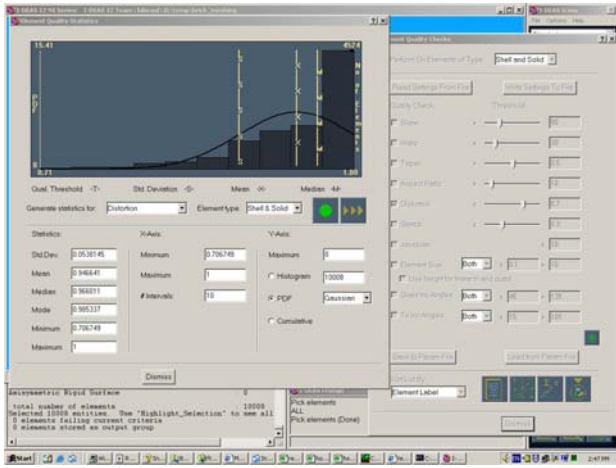


Sweep from bottom face to partition





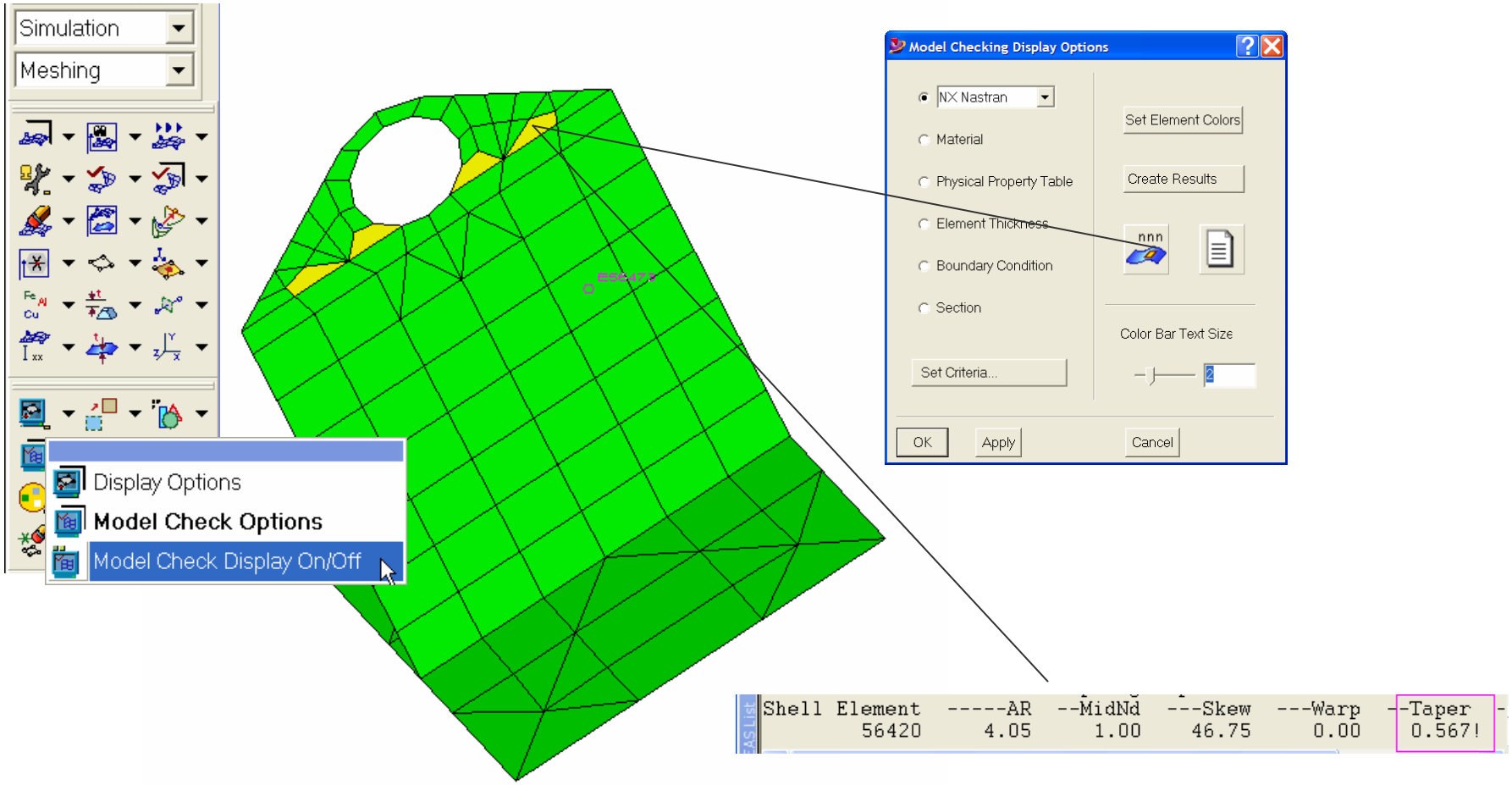
Sweep from partition to top face



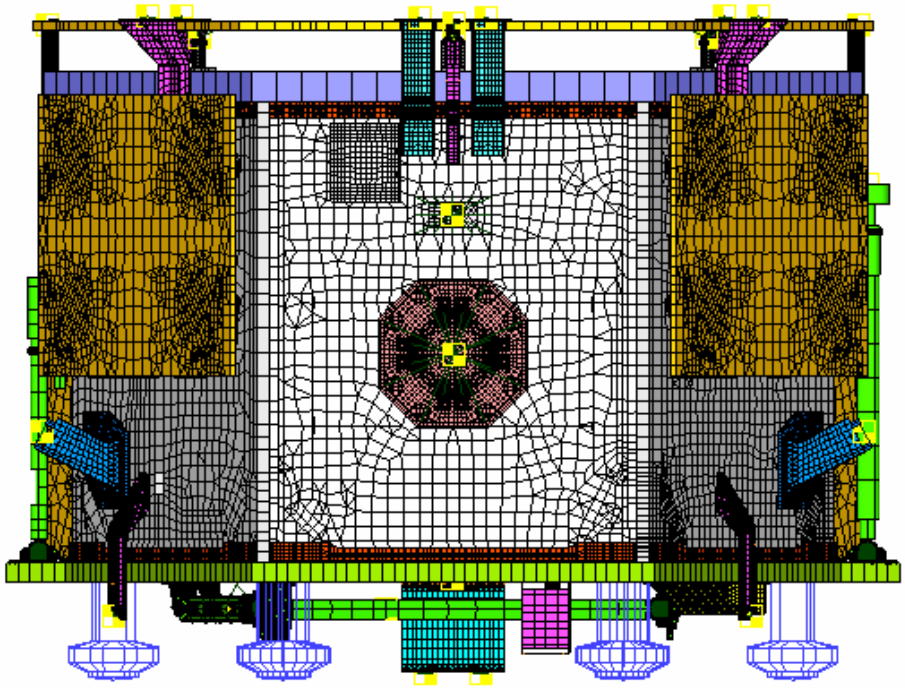
All elements passed NXNastran check (min. distortion of 0.7)

Elapsed Time: 5 mins

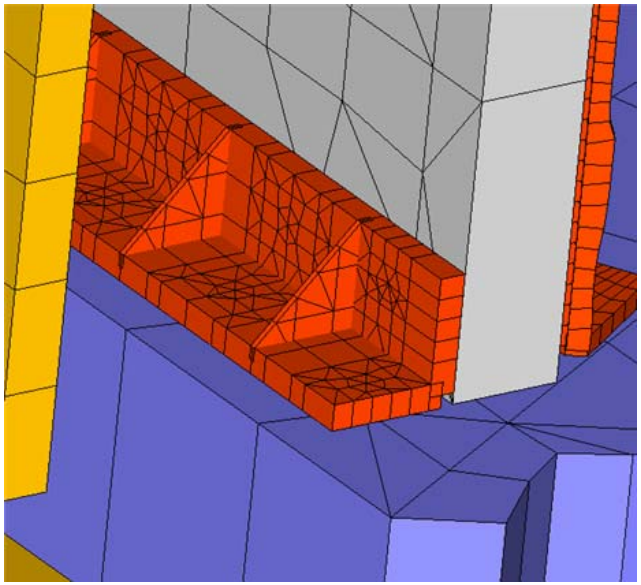
NX MasterFEM - Real Time Meshing Checks



NX MasterFEM – Structural Model



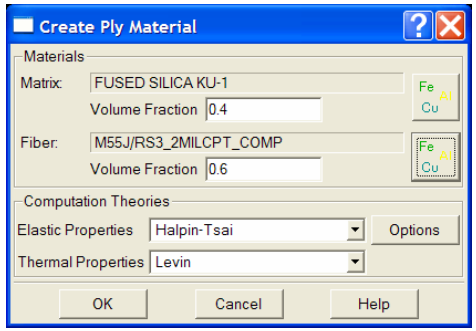
- Linear shell elements used for:
  - Honeycomb sandwich panels
  - Ties
  - Bracketry

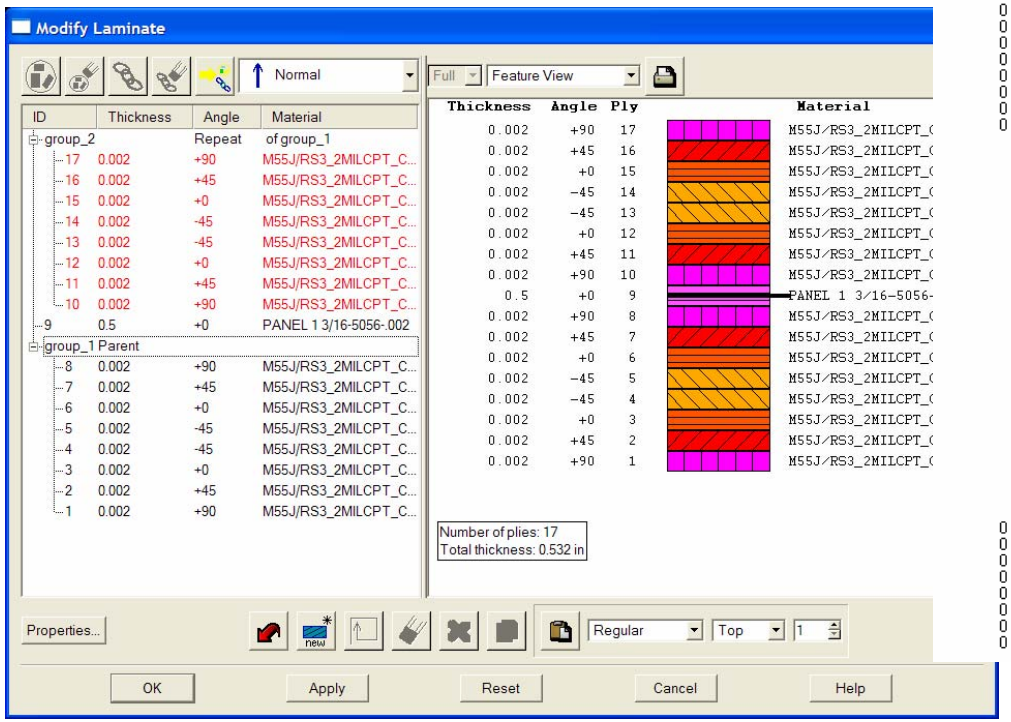


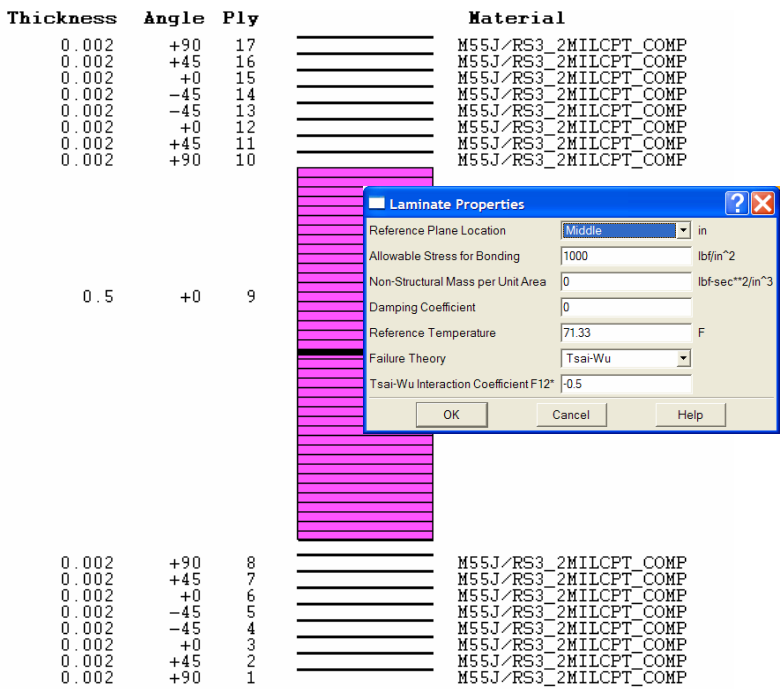
- Launch vehicle interface assemblies meshed with linear and parabolic solid elements
- Spring elements used to obtain all interface forces and moments
- Beam elements used for booms

NX MasterFEM - Laminates

- Define unidirectional ply properties from resin and fiber properties
- Define layup



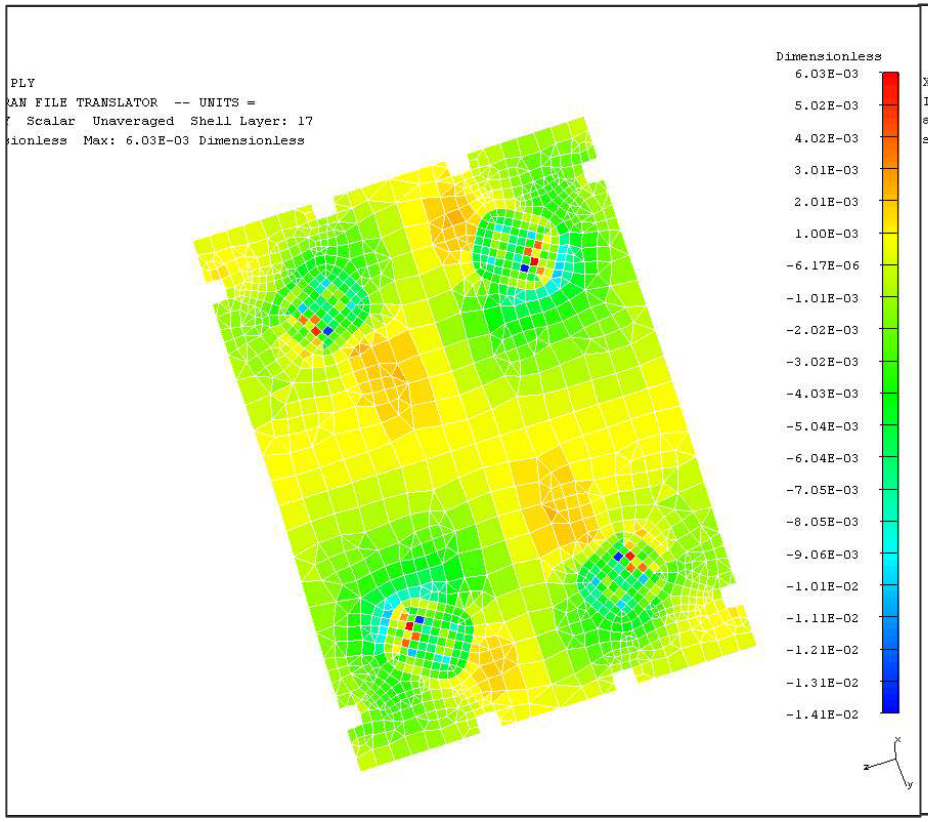


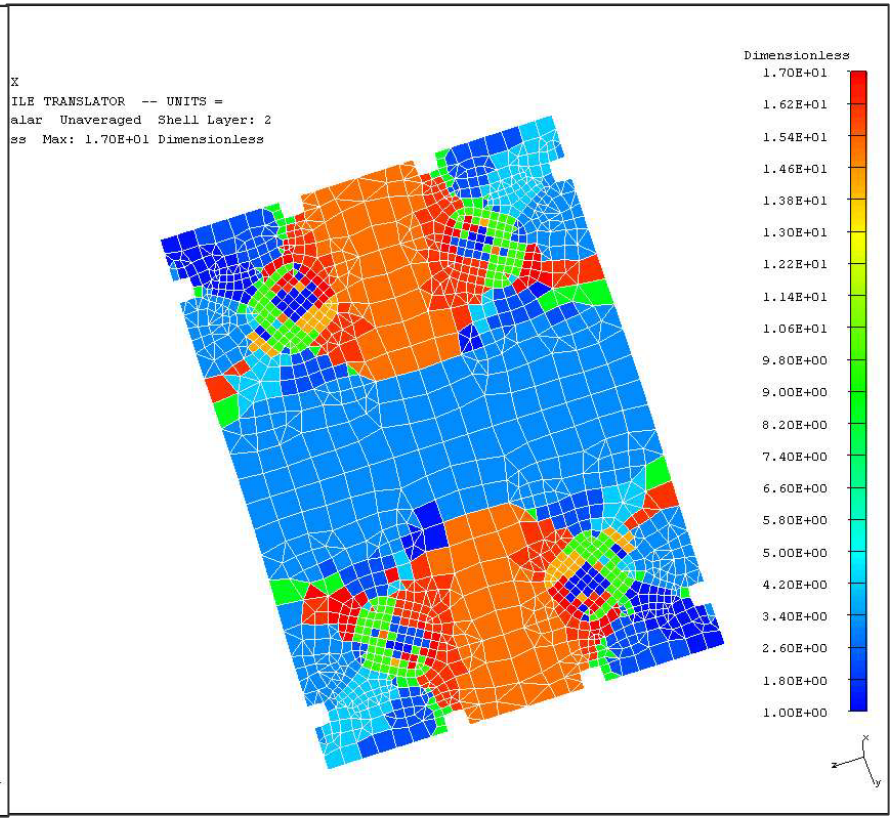


- Exported as PCOMP or PSHELL

NX MasterFEM - Laminates

- Post process ply failure indices and margins of safety

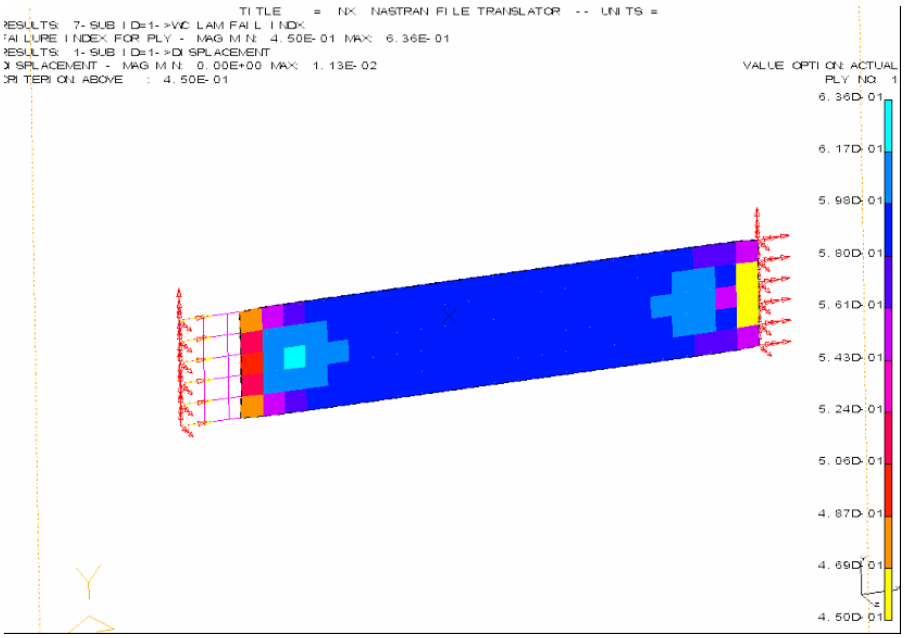


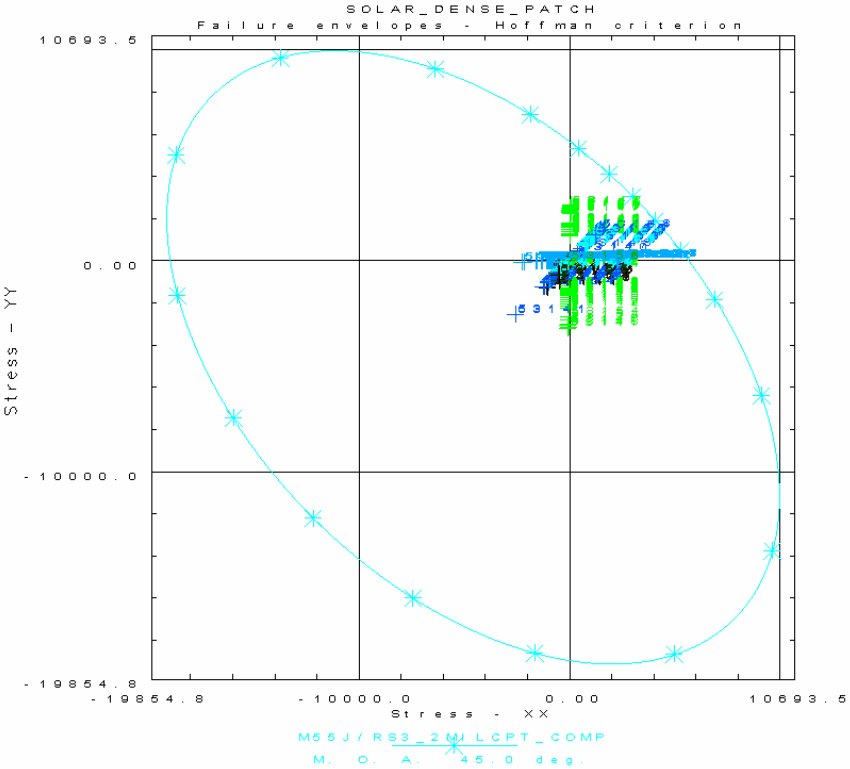


- PCOMP format gives ply-by-ply results

NX MasterFEM - Laminates

- Estimate first ply failure load/stress





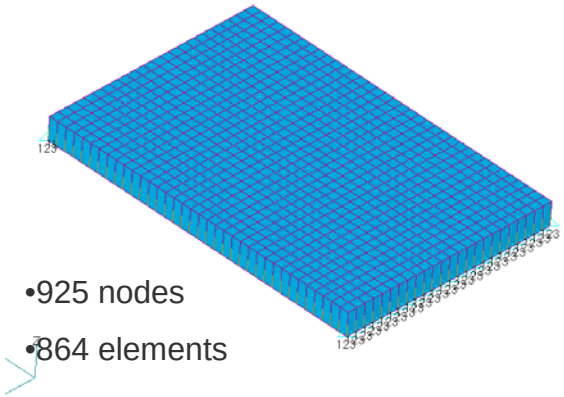
Minimum Margins of Safety Sorted by Stress Case

STRESS CASE	CASE TITLE	SUBCASE ID	Element ID		ELEMENT TYPE	FAILURE MODE	M.S. (%)
			NASTRAN	UNIQUE			
1	solar array panel LIGHT	1	51286	51286	CQUAD4	1st Ply Failure	4460.11
2	solar array panel DENSE	1	53141	53141	CQUAD4	1st Ply Failure	484.21

•Use PSHELL format with failure stress to obtain margins of safety for dynamic solutions

NX NASTRAN - Honeycomb Sandwich Modeling

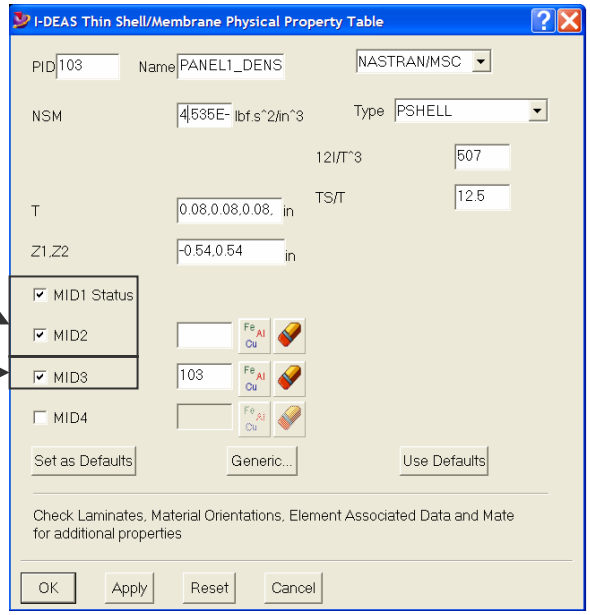
Shell Model



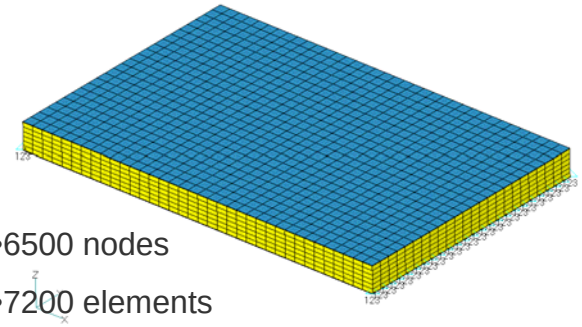
- 925 nodes
- 864 elements

- Linear shells located at panel neutral axis:
- CTRIAR
- CQUADR
- PSHELL

- Membrane and bending behavior: MAT1
- Transverse shear behavior: MAT8

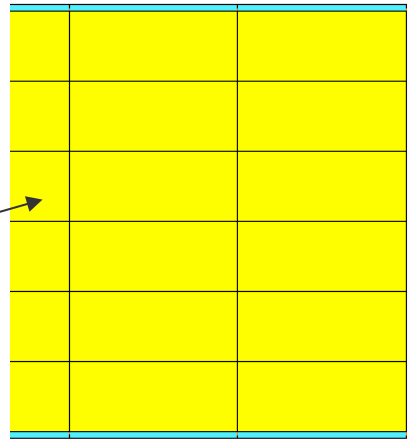


Solid Model



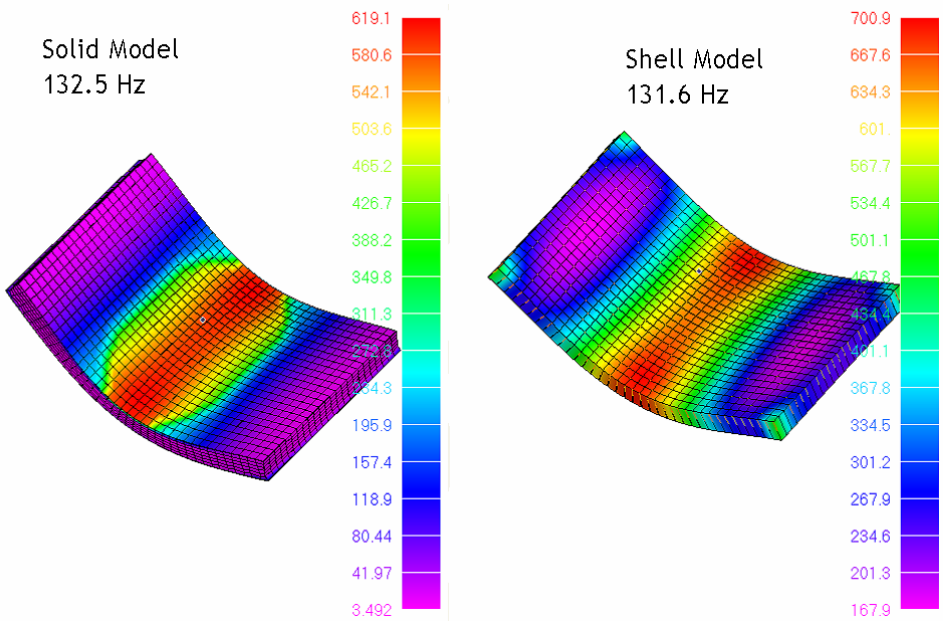
- 6500 nodes
- 7200 elements

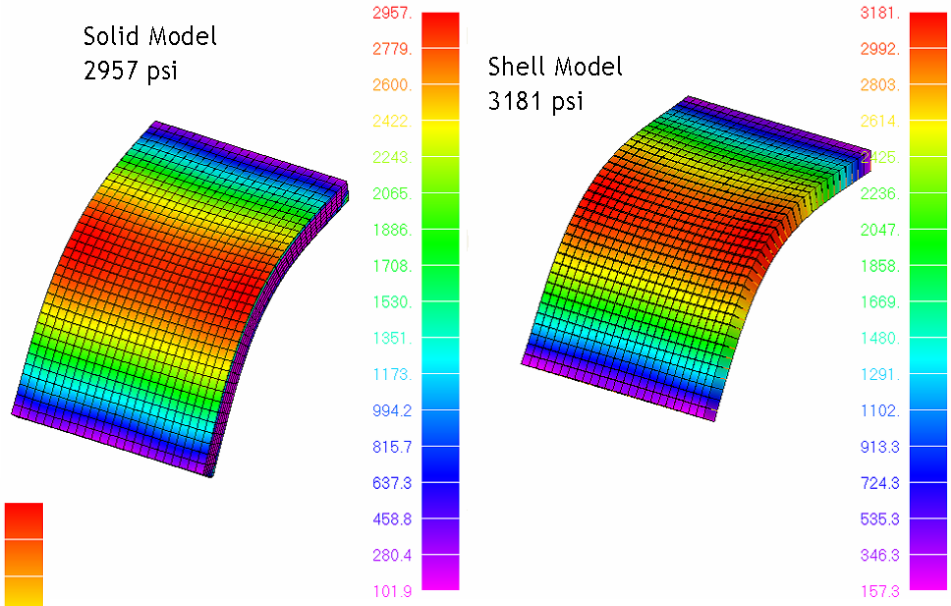
- Facesheets:
  - CTRIAR/CQUADR
  - PSHELL/MAT1
- Core:
  - Linear solids CHEXA
  - PSOLID/MAT9



Honeycomb Sandwich Modeling

First natural frequency

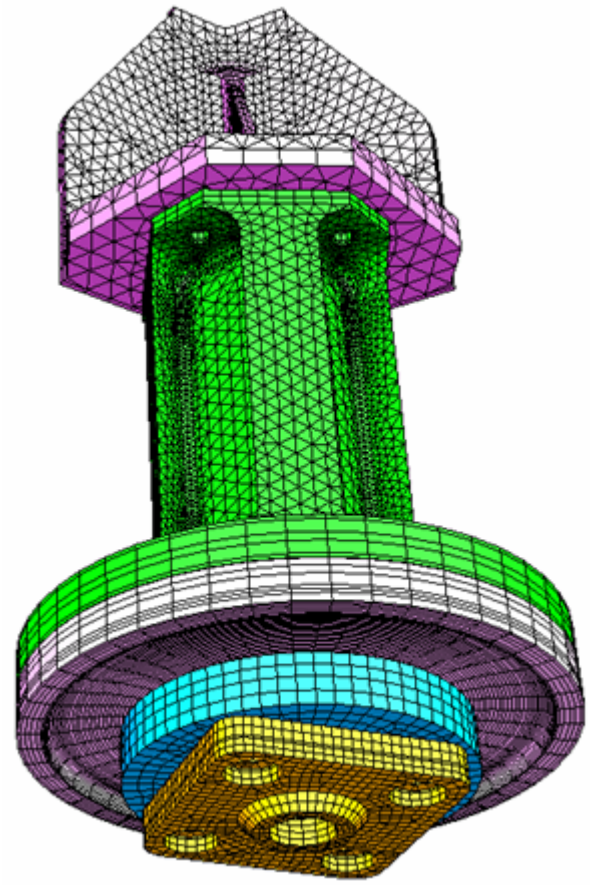




30 G out-of-plane load

NX NASTRAN Superelements

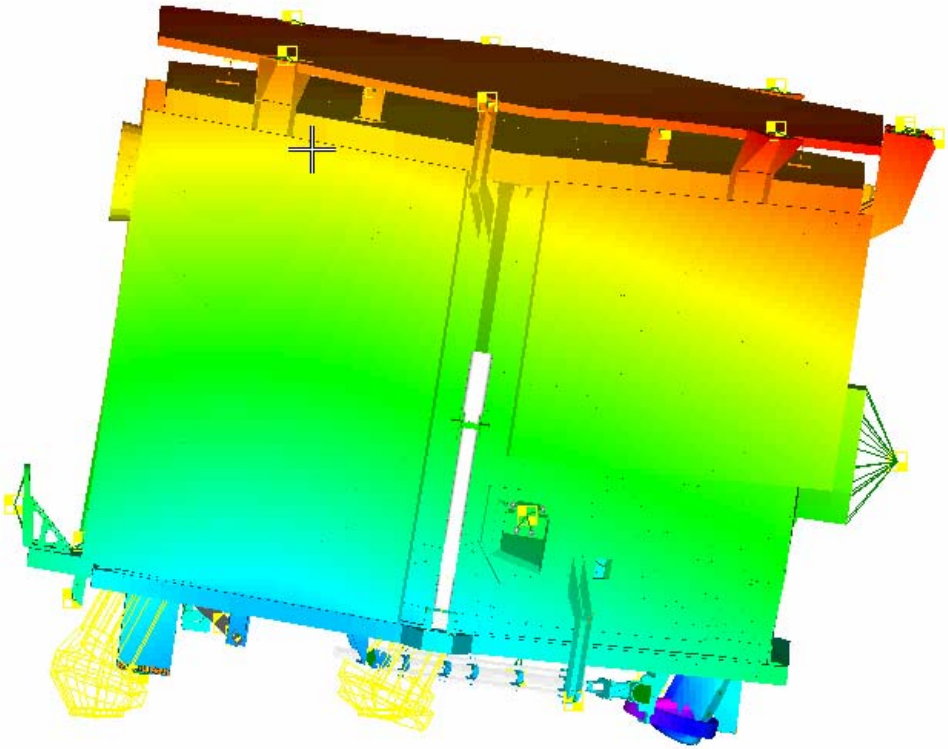
- Launch vehicle interface assemblies (6 places) contain stress-critical features
  - Meshed using solid elements
- To limit spacecraft model size, each interface assembly reduced using NASTRAN external superelements
- Advantage of external superelements:
  - Superelement stored to disk and retrieved by assembly solution
  - Reduces assembly solution time



Total number of nodes: 150,000
Total number of elements: 97,000

NX NASTRAN Superelements

- Reduced Spacecraft Model
  - Residual size
    - 132,500 nodes
    - 135,700 elements
  - SOL 103 solution time
    - 30 mins
- Full Spacecraft Model
  - Size
    - 1,032,000 nodes
    - 735,000 elements
  - SOL 103 solution time
    - > 3 hours



Linear Static Analysis

- Launch vehicle handling and launch envelopes provided as separate quasi-static acceleration cases

		LV interface			
		Longitudinal		Lateral	
Load Case	Description	Static	Dynamic (+/-)	Static	Dynamic (+/-)
1	Launch Vehicle movement inside Silo	2.5	0.7		0.3
2	After Launch vehicle exit from Silo		1		0.8
3	1st stage burn - Maximum Dynamic head	3	0.5	0.5	0.5
4	1st stage burn - Maximum Longitudinal Acceleration	7.5	0.5	0.1	0.5
5	2nd stage burn maximum longitudinal acceleration	7.8	0.5	0.2	
6	Transportation of Launch vehicle (and Spacecraft) to Silo - Gravity Direction		0.4	1	0.7
7	Transportation of Launch vehicle (and Spacecraft) to Silo - Non Gravity Direction		0.4		0.5

When all permutations and orientations are accounted for, the resulting number of cases can be large

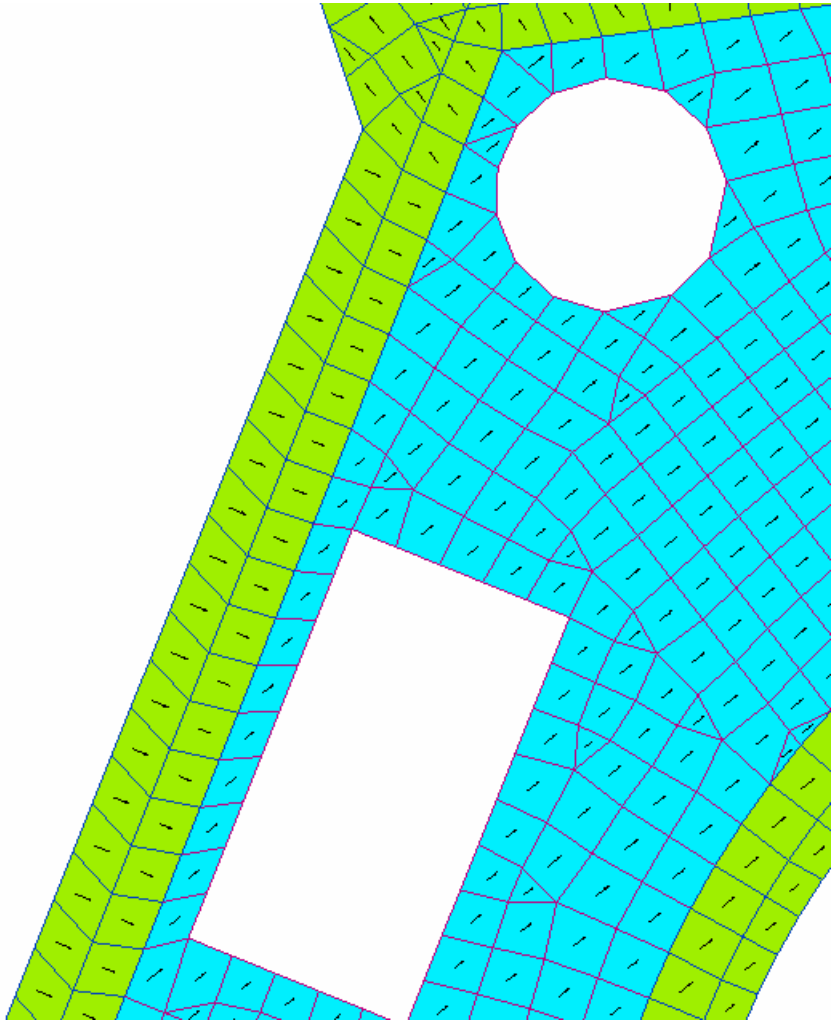
Linear Static Analysis

- Can reduce solution time by using SUBCOM card
  - First 3 subcases:
    - 1G in X
    - 1G in Y
    - 1G in Z
  - Following 40 SUBCOMs are linear combinations of the 3 subcases

```
$
SUBCASE 1
LABEL = 1G in +X
LOAD = 100
$
SUBCASE 2
LABEL =  1G in +Y
LOAD = 200
$
SUBCASE 3
LABEL =  1G in -Z
LOAD = 300
$
SUBCOM 4
SUBSEQ = 1.50,0.00,5.00
SUBCOM 5
SUBSEQ = -1.50,0.00,5.00
SUBCOM 6
SUBSEQ = 0.00,1.50,5.00
SUBCOM 7
SUBSEQ = 0.00,-1.50,5.00
SUBCOM 8
SUBSEQ = 1.06,1.06,5.00
SUBCOM 9
SUBSEQ = 1.06,-1.06,5.00
SUBCOM 10
SUBSEQ = -1.06,1.06,5.00
```

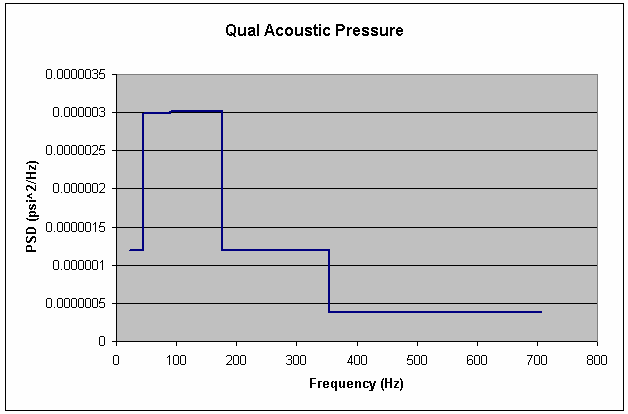
NX NASTRAN DMAP

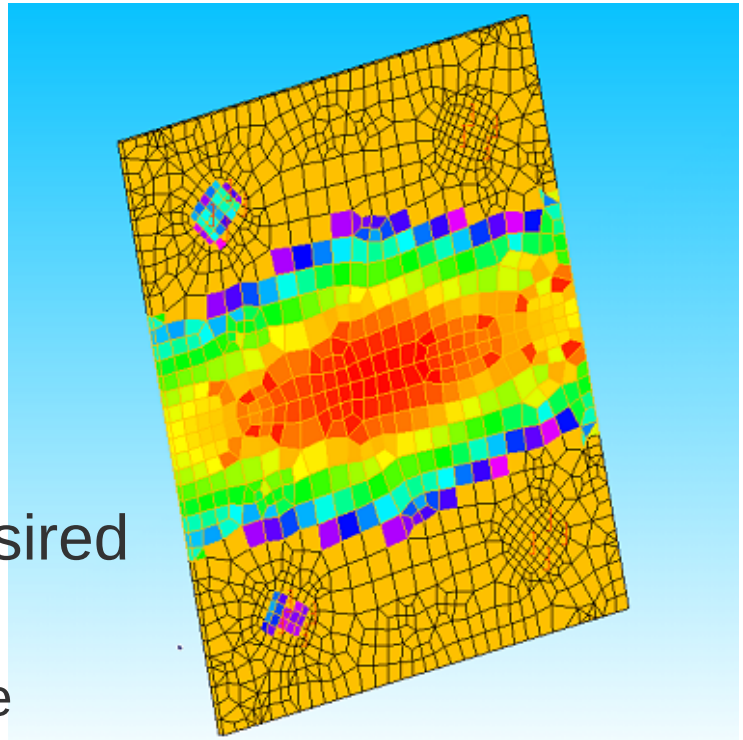
- Purposes of DMAP
  - Modify standard solution sequence
    - Compute and store dynamic analysis data in a normal modes SOLution 103
      - Response Analysis Solution
- `
  - Output data in non-standard formats
    - Write element forces in material coordinate system to .op2 file



NX NASTRAN - Acoustic Analysis

- Transform sound pressure to random pressure power spectral density





- Apply to outer surfaces using desired correlation
  - SOL 111 modal frequency response
- Fluid-structure interaction is ignored

NX NASTRAN - Acoustic Analysis

- Unit static pressure load applied to external elements
  - PLOAD4 card
- Pressure power spectral density
  - TABRND1 card
- Correlation of pressure PSD:
  - RANDPS card

Vibration - NASTRAN & Response Analysis

- Base driven random and sinusoidal excitation
- Can be performed using NX NASTRAN SOLutions:
  - 108: direct frequency response, OR
  - 111: modal frequency response
- Simpler and more efficient to use combination of:
  - NX NASTRAN SOLution 103, AND
  - NX Response Analysis OR
  - FEMAP SAtoolkit

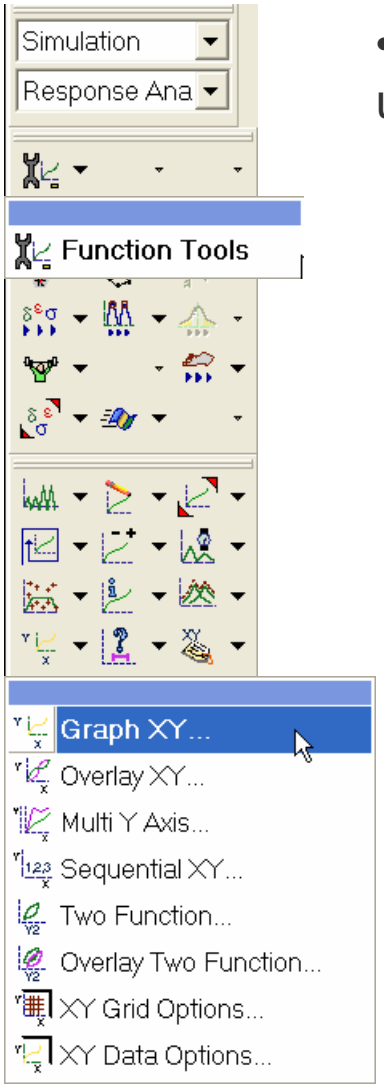
Vibration - NASTRAN & Response Analysis

- Advantages of Response Analysis method
  - User interface lets you define
    - Forcing functions
    - Damping
    - Modes to consider
    - Data recovery
  - Von Mises stress recovery
    - Not computed by NASTRAN SOLs 108 and 111
  - Efficient handling of modal truncation effects
  - Powerful function tools for detailed post-processing
  - Excel interface

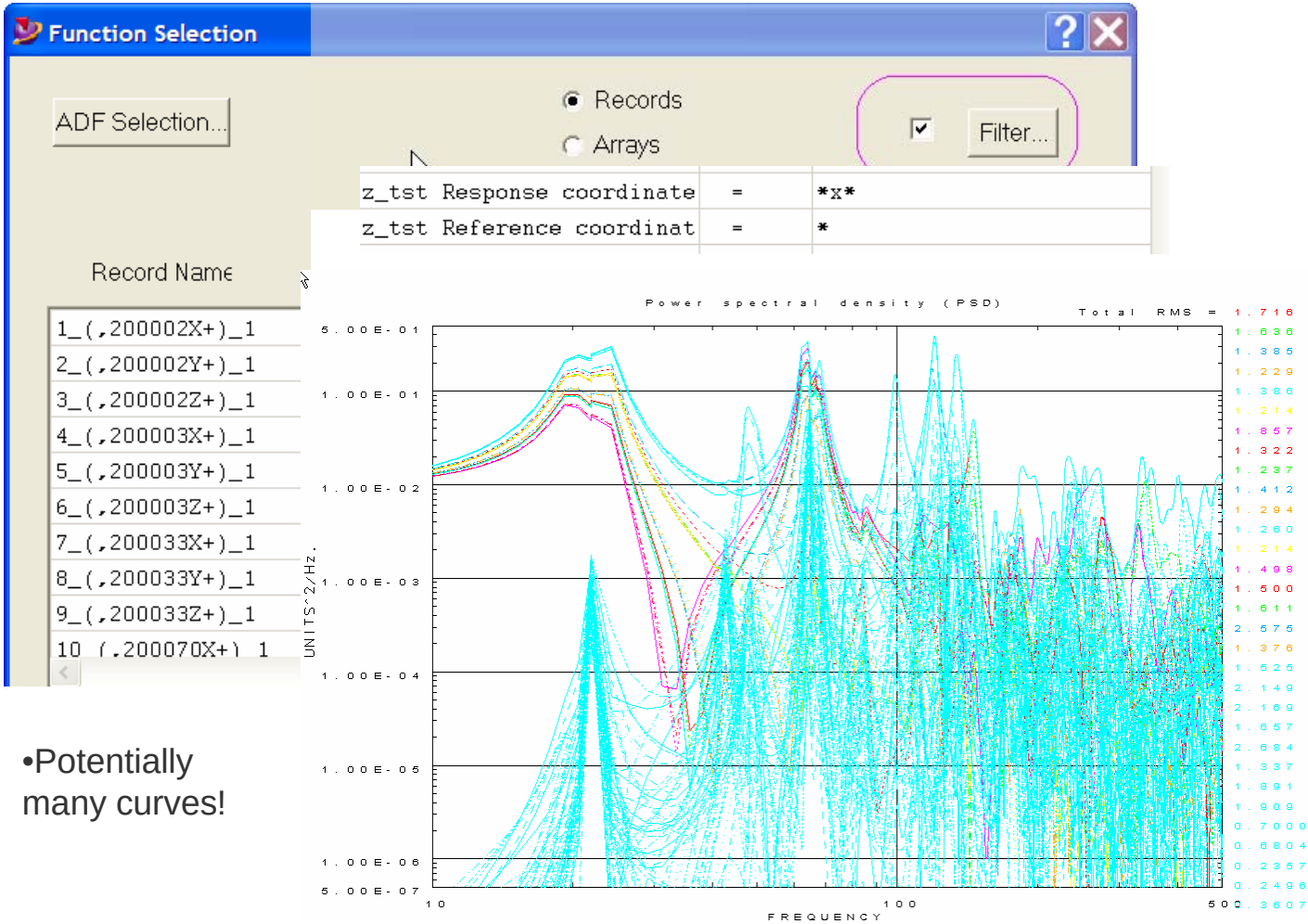
Vibration - NASTRAN & Response Analysis

- Von Mises stress recovery
  - Random excitation
    - Typical workaround of combining stress components can result in overestimation of Von Mises stress
      - Phasing is lost in this type of calculation
      - Time consuming for large models
    - RA provides correct Von Mises stress
  - Harmonic excitation
    - Stress tensor is complex
    - Von Mises stress is a real value
    - RA provides maximum possible Von Mises stress taking into account the stress tensor component phasing

NX Response Analysis Function Tools

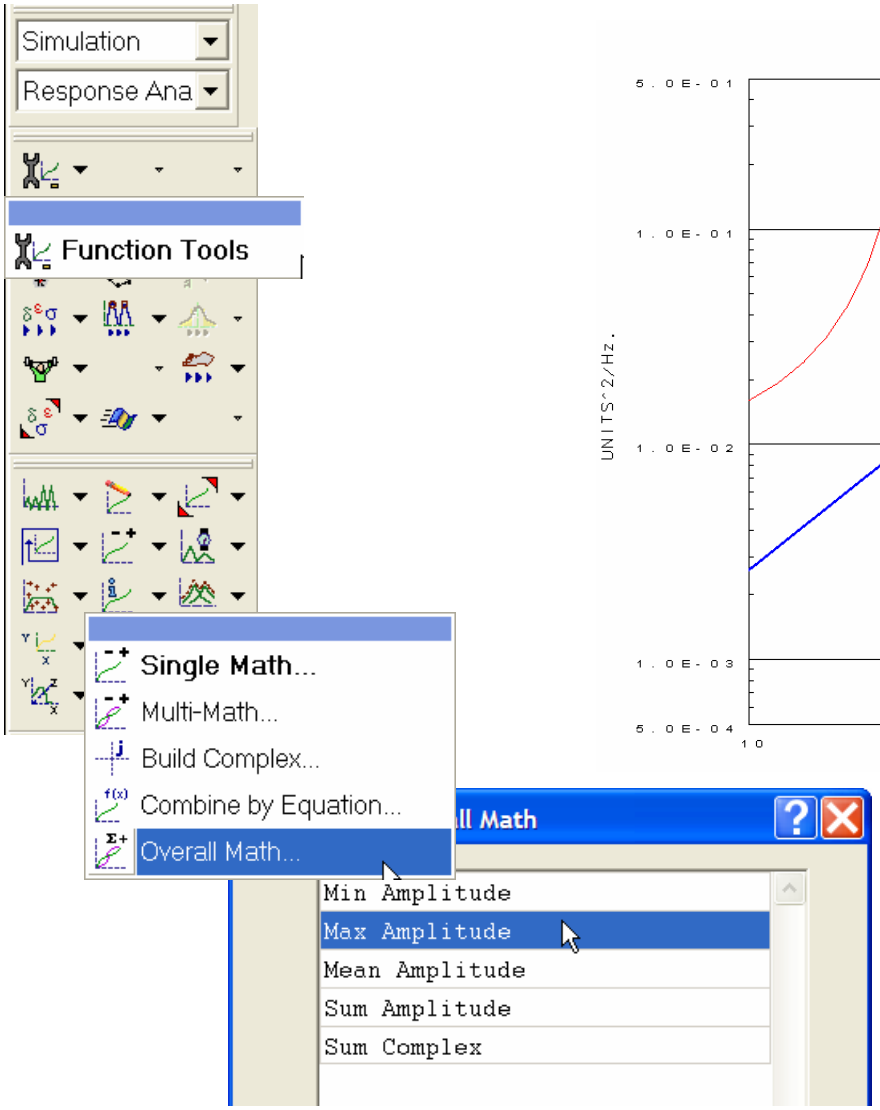


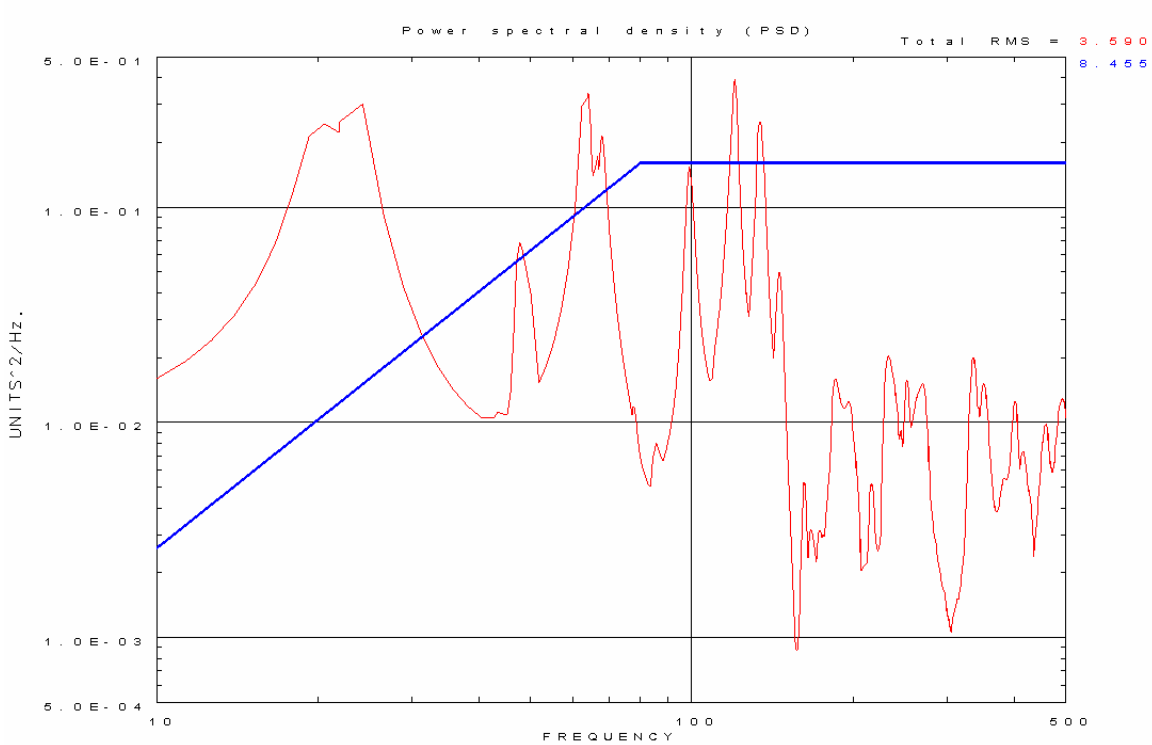
- Example: comparing spacecraft random responses to unit specifications



- Potentially many curves!

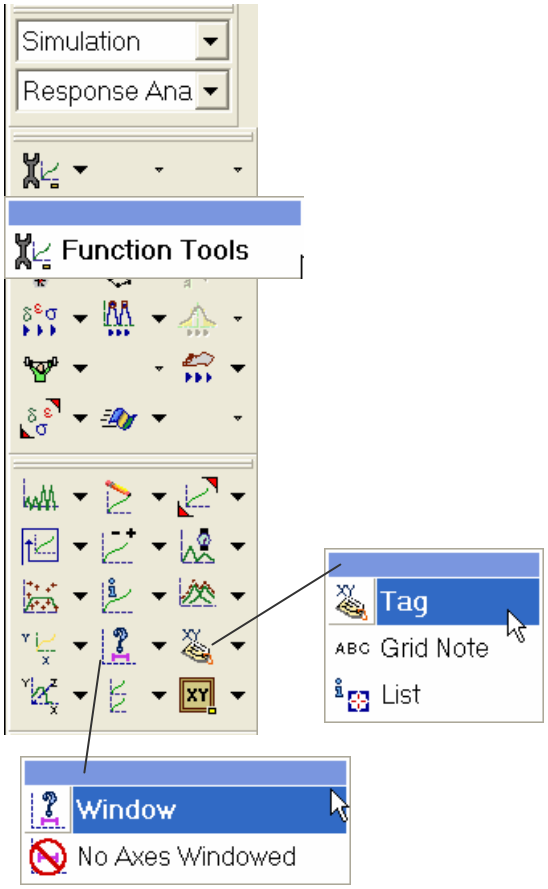
NX Response Analysis Function Tools

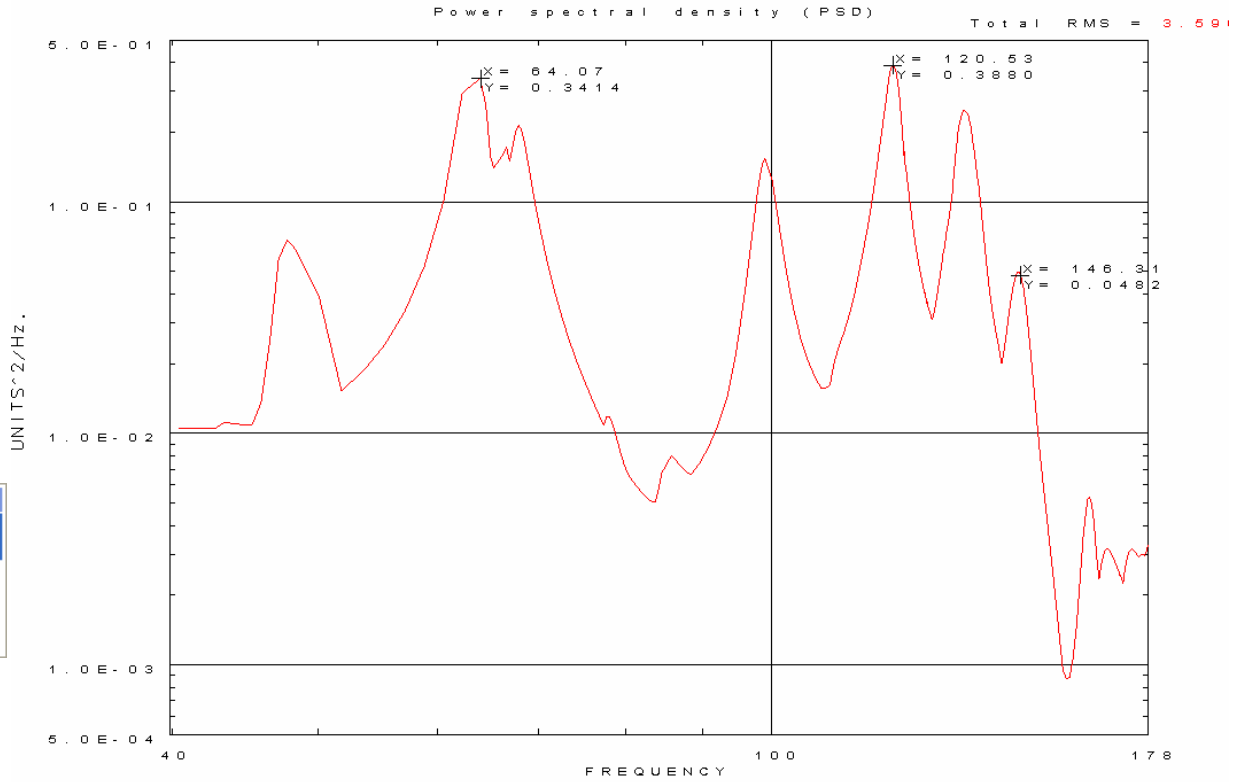




- Reduce the amount of data by creating a ‘maximum envelope’ curve that bounds all responses in any given axis
- Overlay specification curve

NX Response Analysis Function Tools

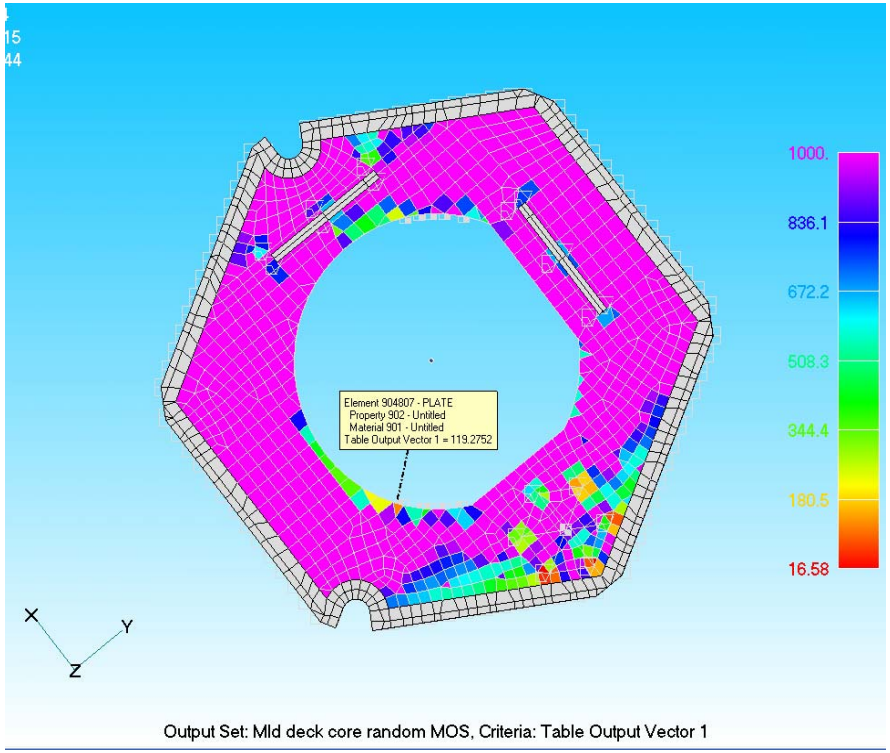




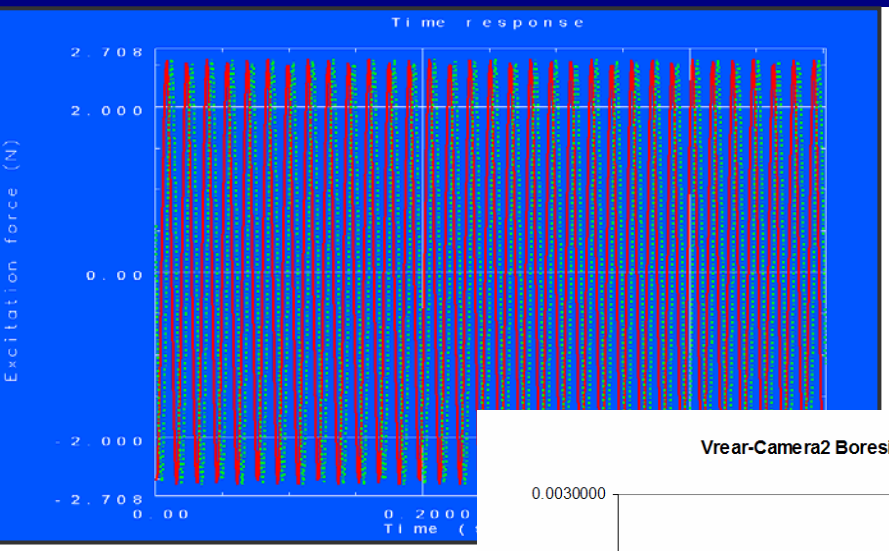
- Windowing and Tagging

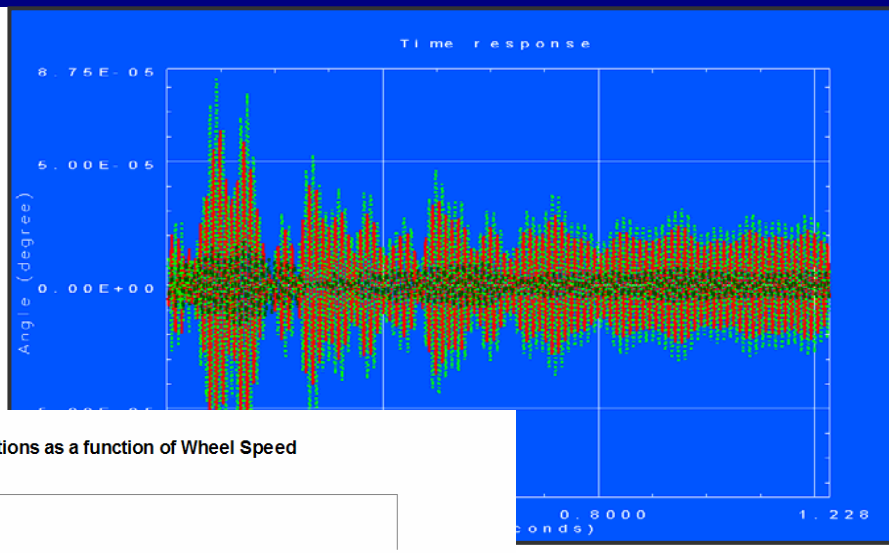
NX Response Analysis Excel Interface

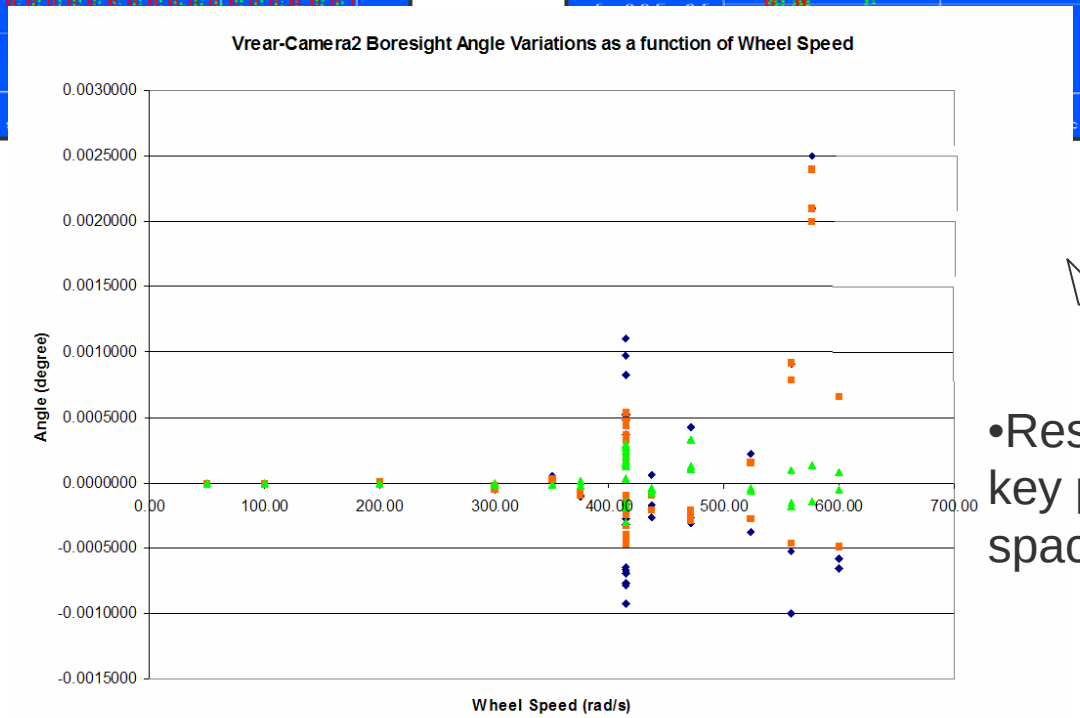
- Computing honeycomb panel core shear margins of safety
  - RA computes 3-sigma element forces
  - Export forces to Excel
  - Process margins of safety using macros
    - NASTRAN forces are forces per unit length
    - Divide Qx and Qy by core thickness
    - Compare to ribbon and cross-ribbon shear strengths



Jitter Analysis - NASTRAN & Response Analysis





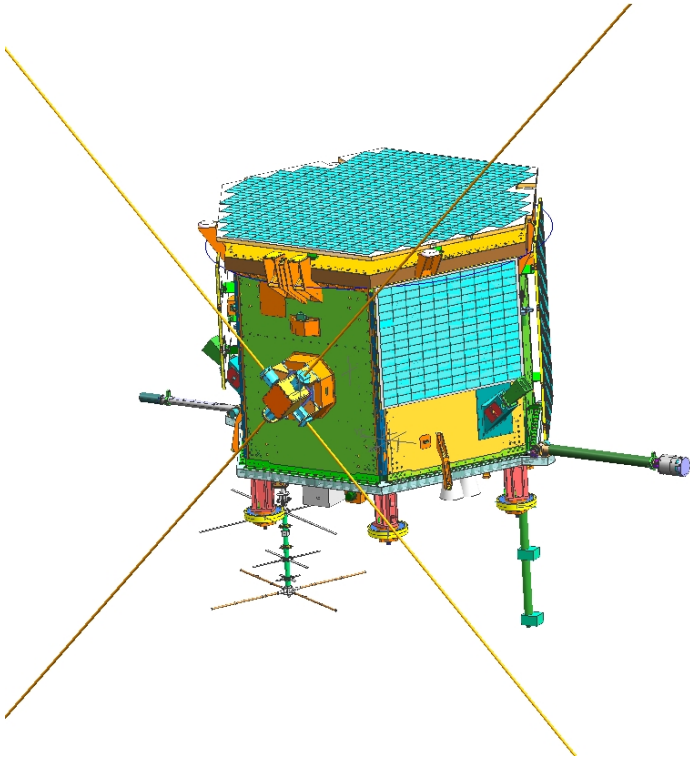


- Transient load input at momentum wheels
- Phasing and speed are variables

- Responses at key points on spacecraft

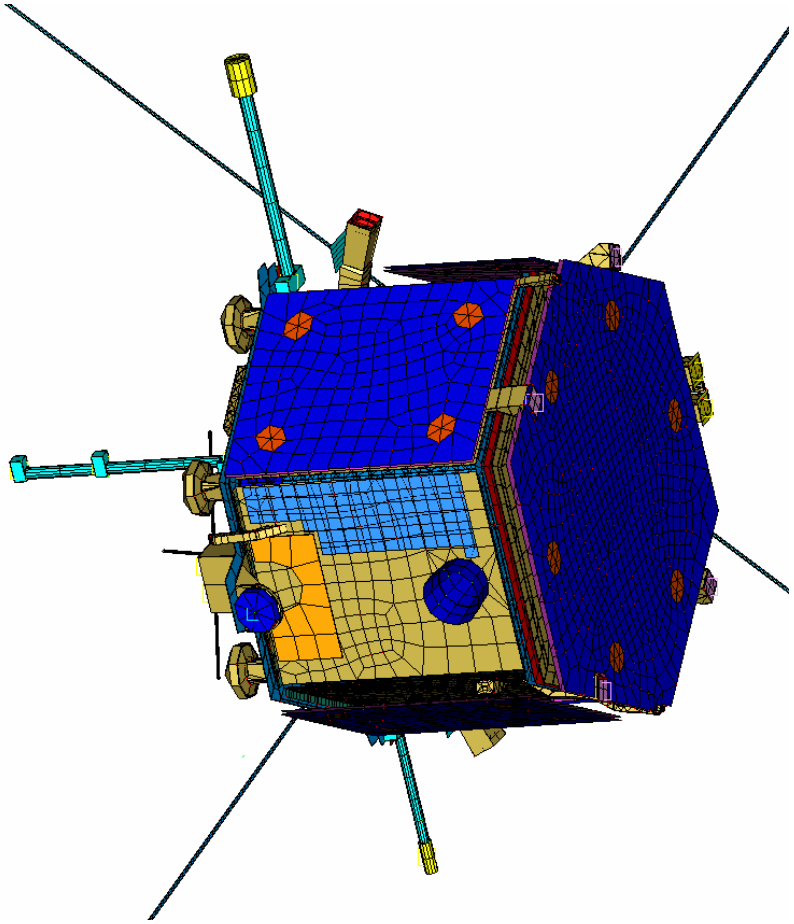
NX TMG Thermal Mathematical Model (TMM)

- Thermal Model created in I-DEAS TMG v11.
- Initial thermal model testing was performed at sub-assembly level:
  - Continuity Check – Conduction and Thermal Couplings
  - Radiation – Shell element normals and View Factor Sums
- Assembly FEM used to create full model.
  - The complete model consists of 24581 elements (beam and thin-shell) and 92 lumped mass elements.
- Association to geometry broken when design matured.



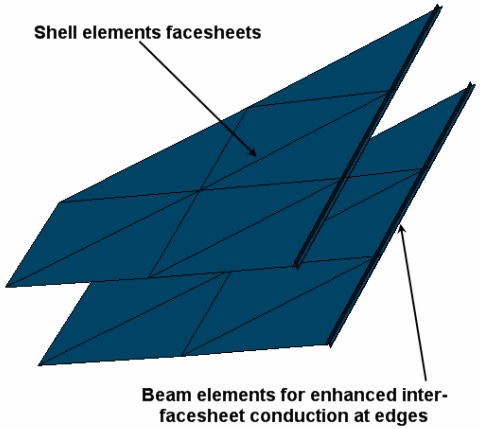
NX TMG - TMM Overview

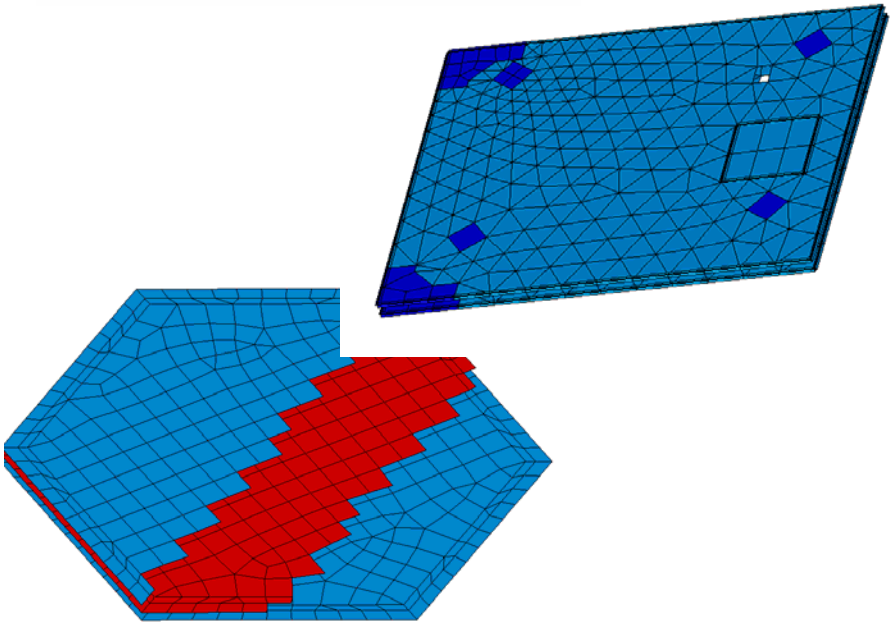
- Cold and hot cases use BOL and EOL material assumptions, cold and hot environmental heat loads, and MLI effective emittance, e* of .05 and .01 (respectively)
- Brackets to which structural panels are mounted are explicitly modeled. Panels are connected to brackets with a coupling coefficient of 640 $Wm^{-2}K^{-1}$
- Footprint elements are “floating” so they can be easily moved to a new position
- Radiator elements are “floating” so they can be easily moved or changed to a new size
- Inside of the hex structure has assumed an anodized black finish (e = 0.80) to better distribute heat within the spacecraft (per black BR127 internal coating)
- Radiation view factor sums are corrected with self-view option. This correctly models radiation from partly covered elements, for example MLI elements partially covered by a floating radiator
- Battery is isolated from rest of the spacecraft and has its own radiator



NX TMG - Panel TMM

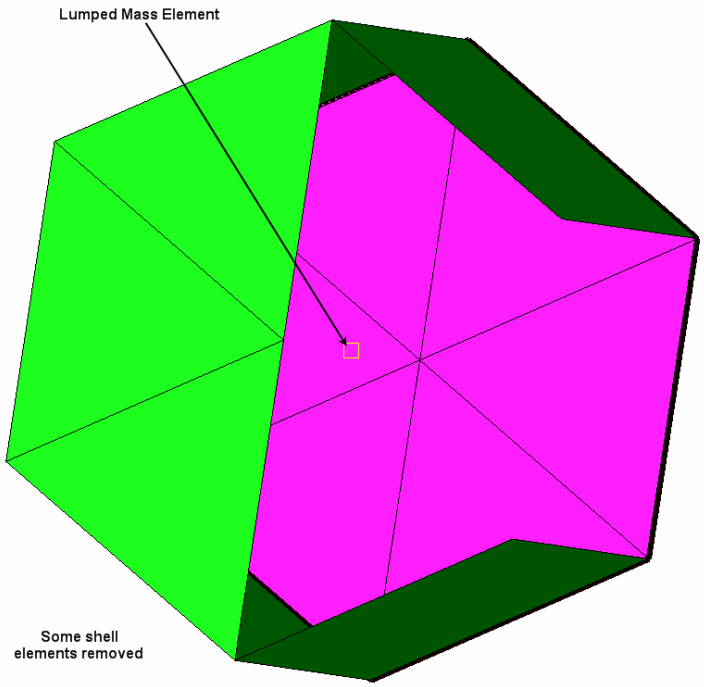
- Honeycomb panels modeled with 2 thin-shell element face sheets, coupled together across the entire surface with a thermal coupling value that represents the thickness, construction and material of the honeycomb.
- Density of the face sheet elements was also adjusted to account for the mass of the honeycomb material.
- Conductivity of facesheets adjusted to include core in-plane conduction.
- Thermal conductivity of the CFRP solar panel substrates was calculated with laminate analysis.
- Structure panels included inserts and denser core around the periphery, these were modeled with beam elements that represented the additional mass; the beam elements of opposing facesheets being connected with a thermal coupling to represent the increased conduction resulting from the inserts and denser core.
- Payload panel cooling is by heat storage and dissipation over full orbit. Temperatures strongly dependent on capacitance. Lumping all capacitance on facesheets is least conservative solution. For payload panel model used 3 layers of shells:
  - Top facesheet
  - Core
  - Bottom Facesheet





NX TMG TMM- Unit Thermal Models

- Most units modeled:
  - 1 lumped mass element at geometric centre, assigned all unit capacitance.
  - Shell elements model surfaces, generally 1 per surface.
  - Non contacting surfaces radiate.
  - Shell elements on mounting faces thermally coupled to panels.
  - Lumped mass and shells merged during solution to give single temperature for unit.
- One unit used detailed (15 element) conductance/capacitance model from supplier.
- Small components used lumped mass only.

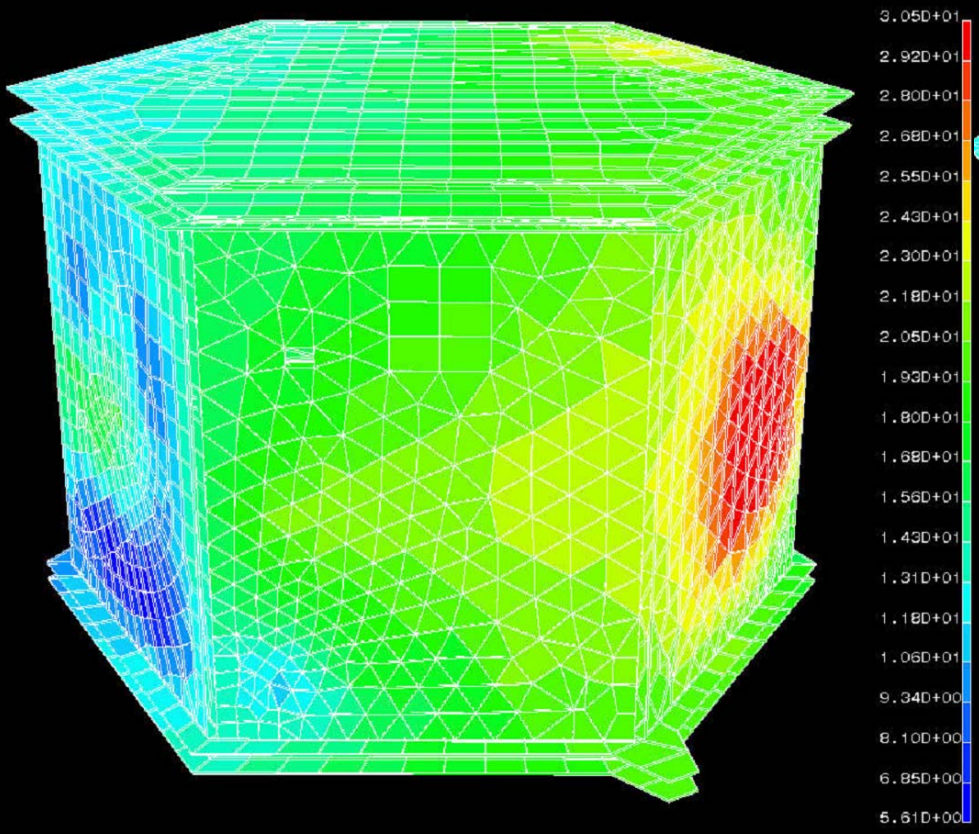


NX TMG TMM- MLI

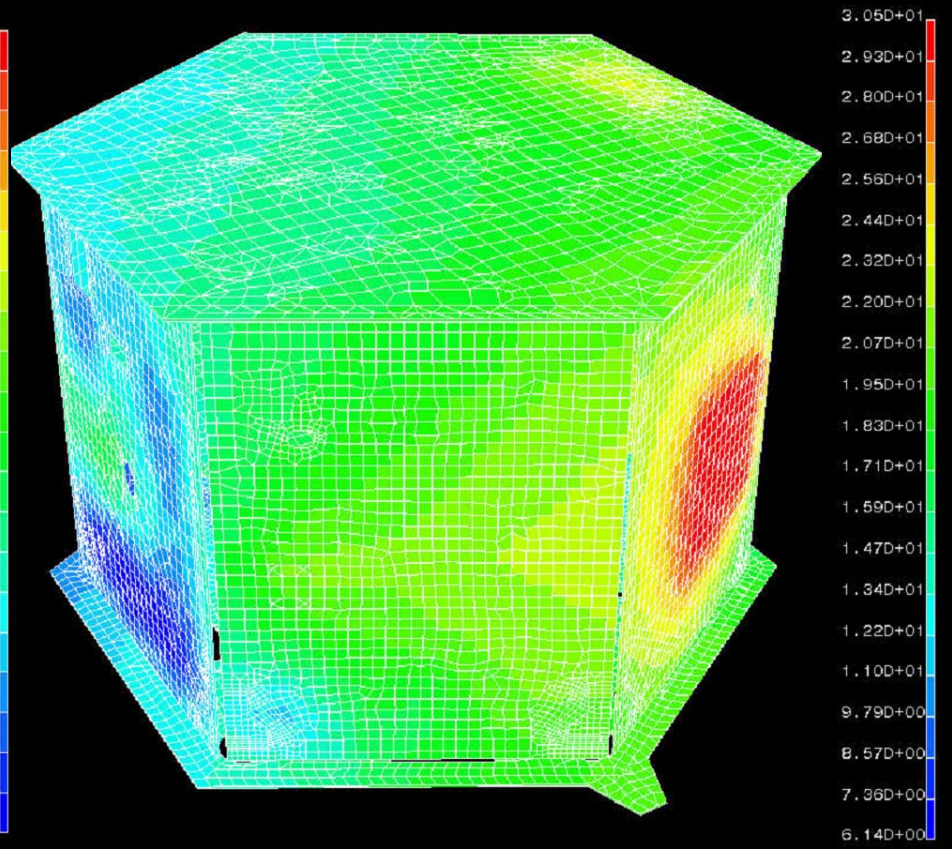
- MLI effective emissivity, ε^*, assumed to lie between 0.01 and 0.05.
- These are typical values used on other space programs.
- For MLI under solar panels:
  - Hot Case: Use e* = 0.05 to maximize heat transfer through blanket from hot solar panels.
  - Cold Case; Use e* = 0.01 to minimize heat transfer through blanket from hot solar panels.
- For remaining MLI:
  - Hot Case: Use e* = 0.01 to minimize heat loss through blanket to space.
  - Cold Case; Use e* = 0.01 to maximize heat loss through blanket to space.

Temperature mapping

Thermal Model

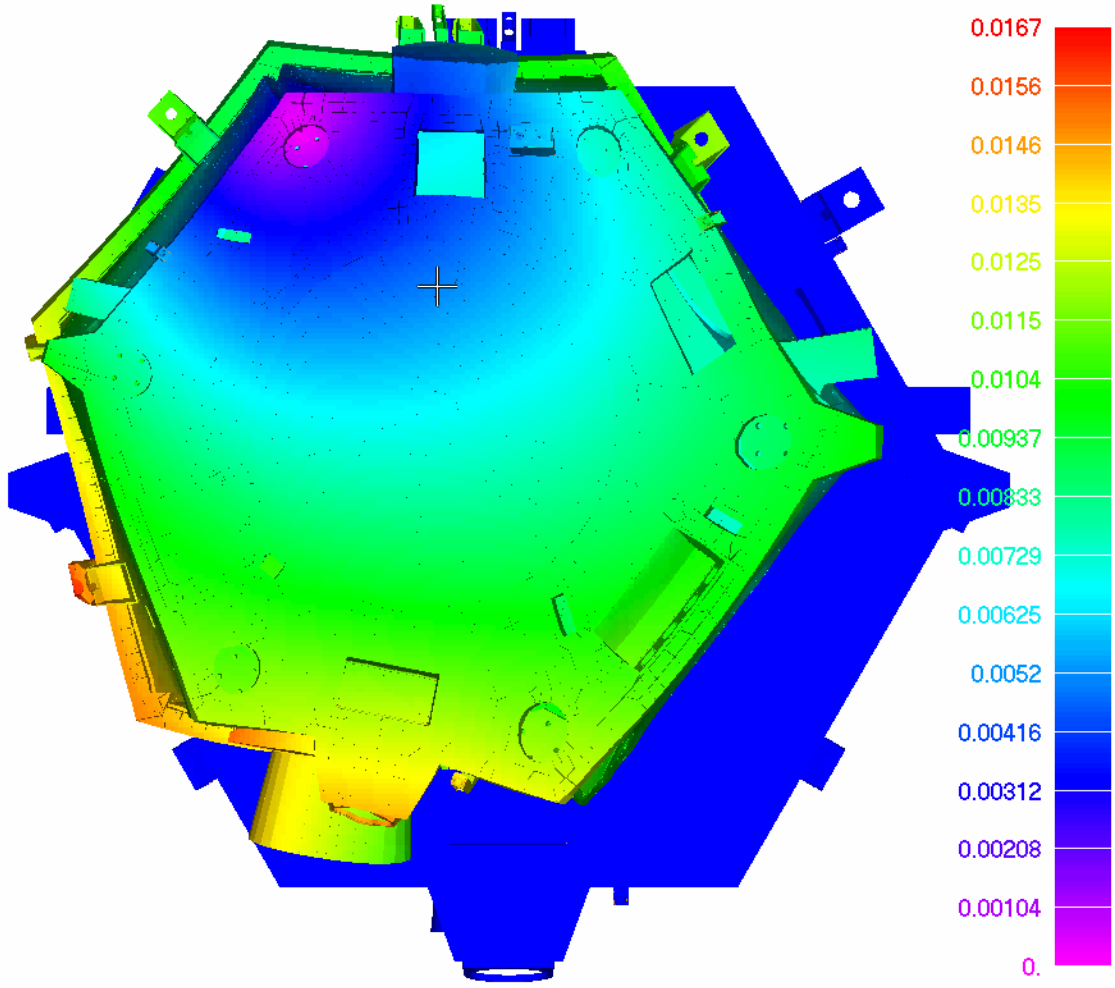


Structural Model



Thermal Distortion

- Perform TMG thermal analysis
- Select thermal cases and/or time steps using TMG report writer
- Map thermal model to structural model using TMG temperature mapping
    - Converts thermal temperature results to NASTRAN nodal and elemental temperature loads
- Perform NASTRAN linear static analysis



Output Set: EPOP HOT CASE 26 DISTORTI, Animate(0.0167): Total Translation, Contour: Total Translation