MULTIBODY ANALYSIS OF SOLAR ARRAY DEPLOYMENT USING FLEXIBLE BODIES

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Final Presentation

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Introduction 1

The principal aim of this work is the generation of a multi-body flexible model for solar arrays deployment studies

This model has to be:

- ***Easy to generate***

  We want an easy way to generate flexible bodies using PATRAN user friendly interface avoiding or minimizing manual input in NASTRAN

- ***Compatible with previous rigid model***

  Since the first studies on a s/a deployment are made using an ADAMS rigid model the flexible bodies has to be easy importable in this rigid environment without many changes

- ***Fast to handle***

  We want an optimized flexible-model easy to run in ADAMS also on not particularly powerful machines

Introduction 2

Why a Flexible Model?...

- Confirm the results and verify the simplification of the RIGID MODEL

- Give a better and close to reality understanding of dynamic problem
  - *Check eventual high frequency effect*
  - *Check the effect of deformation on the mechanism (usually not critical for s/a)*
  - *Check stress & strain due to the dynamic in real time with the deployment*

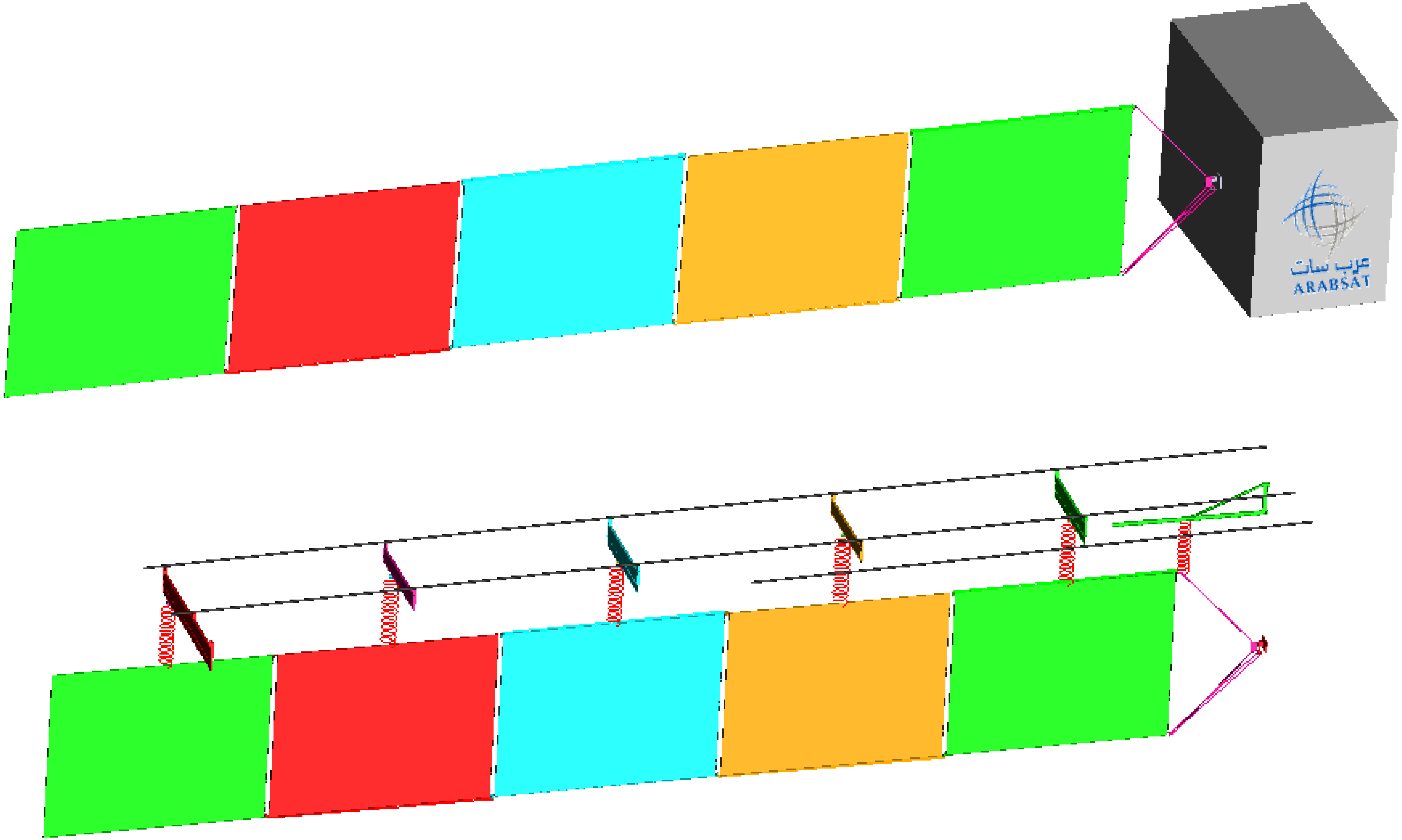
Main Topics

The topics of the presentation are

- **The Rigid model**
  - Introduction to the rigid model using two examples: *BEPI COLOMBO MPO s/a* and *AMOS-3 s/a*
- **Generation and optimization of a flexible body**
  - Theoretical background of the NASTRAN-ADAMS interface
  - Generation of flexible bodies in PATRAN using PLOTEL elements
- **The Flexible model**
  - Full-flexible & semi-flexible model
  - Comparison of results using the examples
- **Secondary applications**
  - Stress & Strain in ADAMS environment
  - Vibration analysis in ADAMS

The Rigid Model

Rigid Model – ARABSAT



Rigid Model

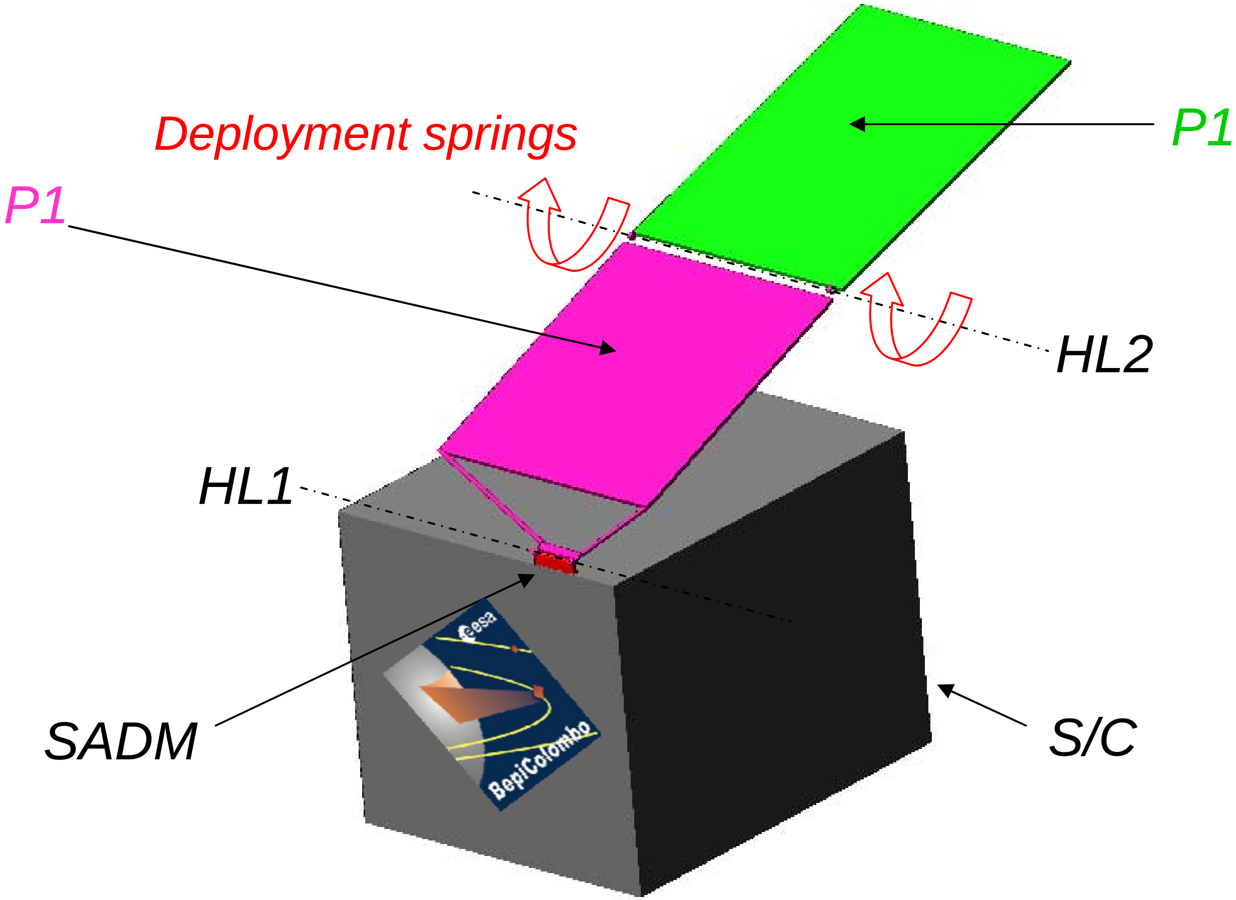
The main aims of the rigid model are two analysis

- **Torque Margin Analysis *(quasi-static)***
- **Dynamic Load Analysis**

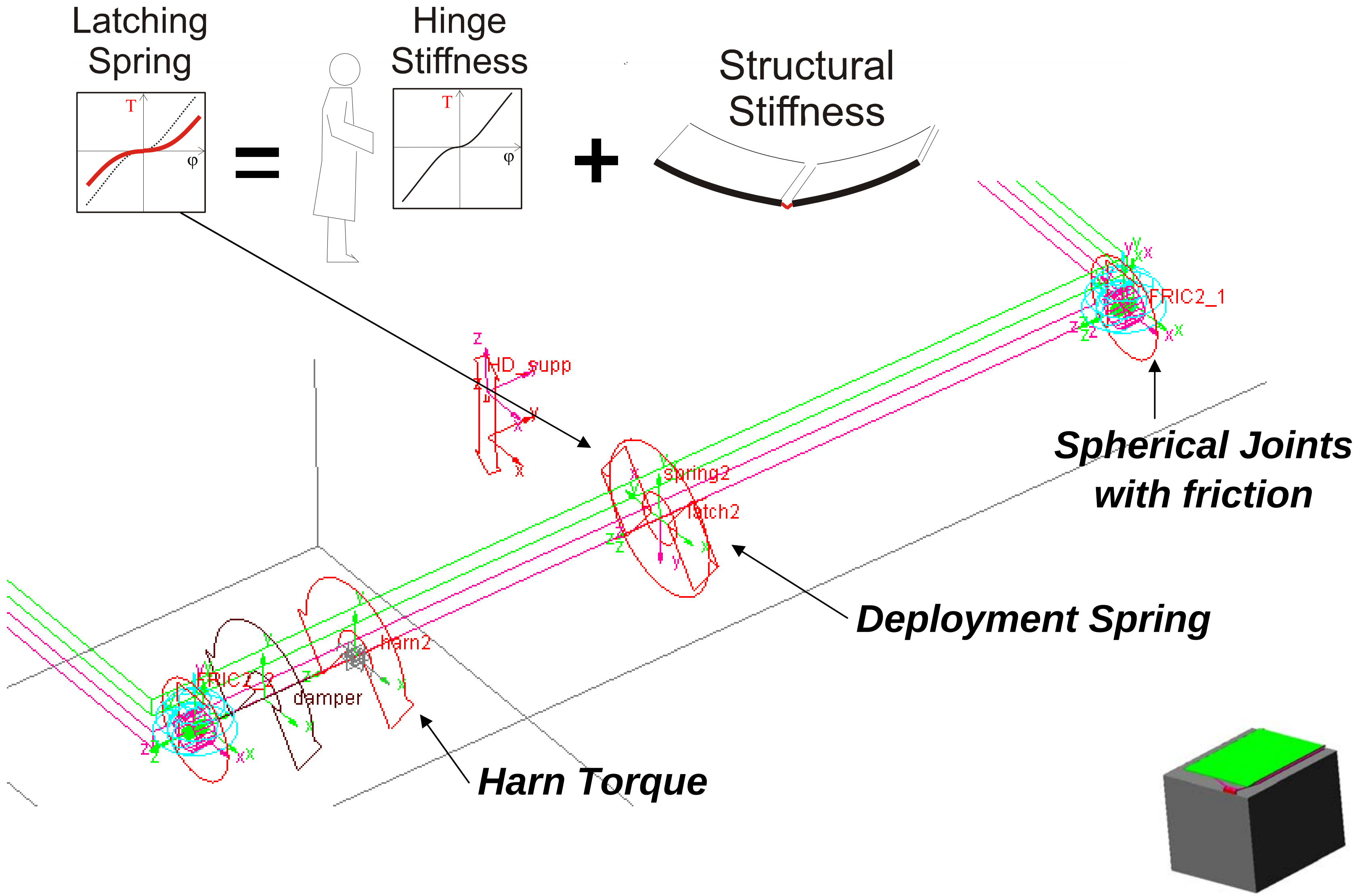
The element that it takes in consideration for these analysis are

- *Inertia of bodies*
- *Deployment Spring Torque*
- *Friction (**hot case** – **cold case**): Bearing Friction*
  Cam Friction (Latching mechanism)
- *Harness Torque Effects (**motor** – **resistive**)*
- *Latch up of deployment hinges*
- ***Bending Stiffness of S/A collocated in the HLs = All the flexible properties of the structure are condense in these springs (1 rot DOF)***
- *Eventual Close Cable Loop (CCL) mechanism (**hot case** – **cold case**)*
- *Eventual Dampers or engine holding torque*

Rigid Model - BEPI COLOMBO MPO s/a

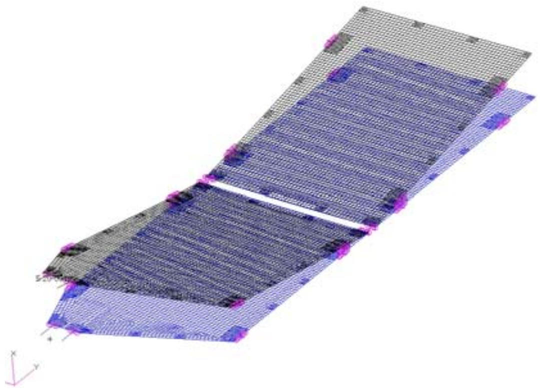


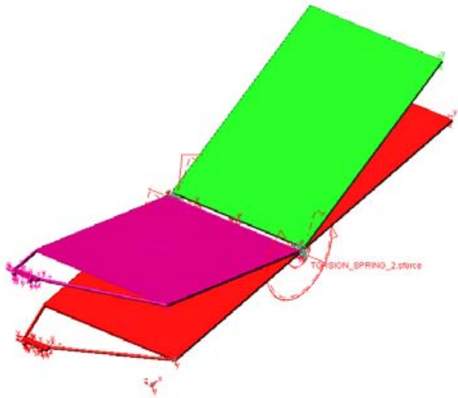
BEPI COLOMBO MPO s/a – ADAMS model



Rigid Model – Equivalent Stiffness

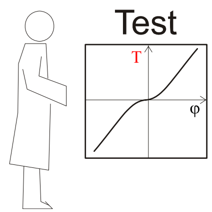
ADAMS way to calculate the equivalent stiffness…



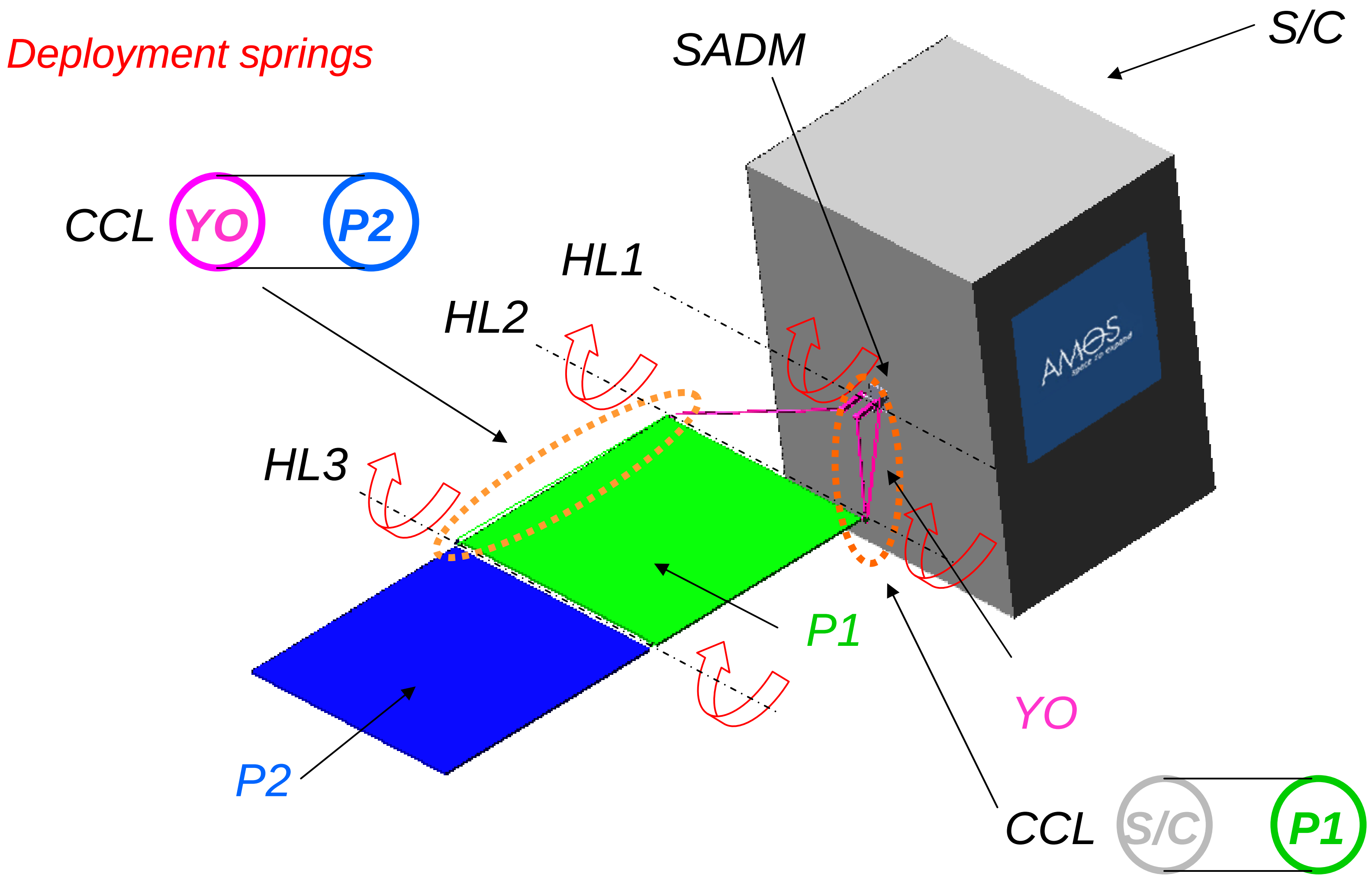


FEM Full – Flexible Model	$\rightarrow f_{TOT} \rightarrow$	**ADAMS Rigid Model**	$\rightarrow K_{TOT}$
FEM Semi – Flexible Model (rigid hinges)	$\rightarrow f_{STRUCT} \rightarrow$	**ADAMS Rigid Model**	$\rightarrow K_{STRUCT}$

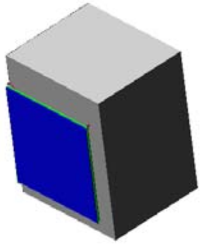
$$K_{TOT} \cong \left(\frac{1}{K_{STRUCT}} + \frac{1}{K_{HINGES}} \right)^{-1}$$

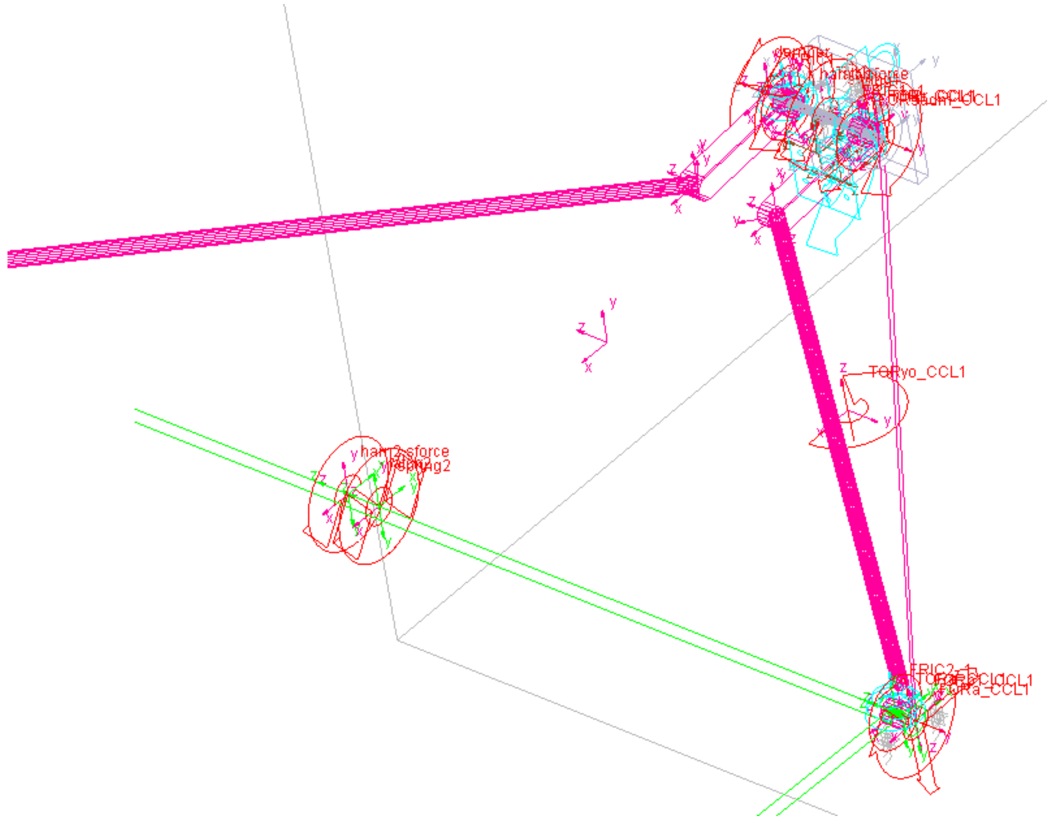


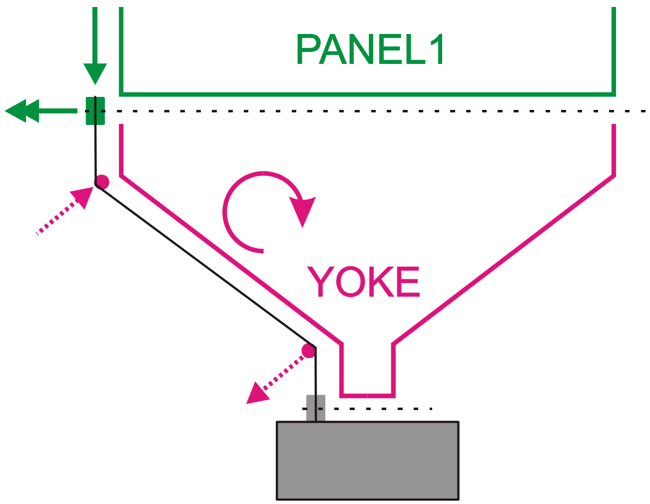
Rigid Model – AMOS-3 s/a



AMOS-3 s/a – ADAMS Model







Generation and optimization of a flexible body

Modal Superposition

The high number of FEM DOF has to be reduced for generate a flexible body

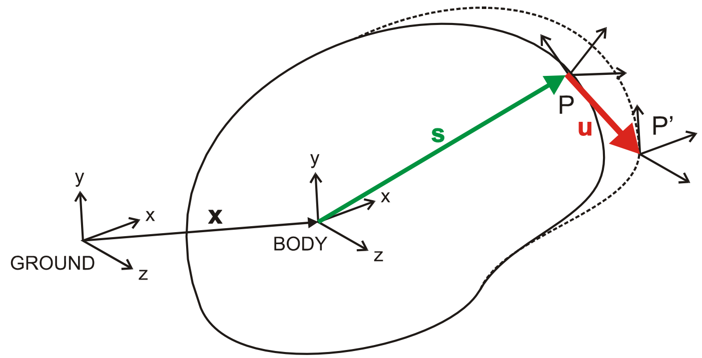
- **Modal superposition**

  We consider only small deformations relative to a local reference frame

$$\mathbf{u} = \sum_{i=1}^{M} \phi_i q_i$$

$\boldsymbol{q_i}$ = *modal coordinates*

$\boldsymbol{\phi_i}$ = *shape vectors*



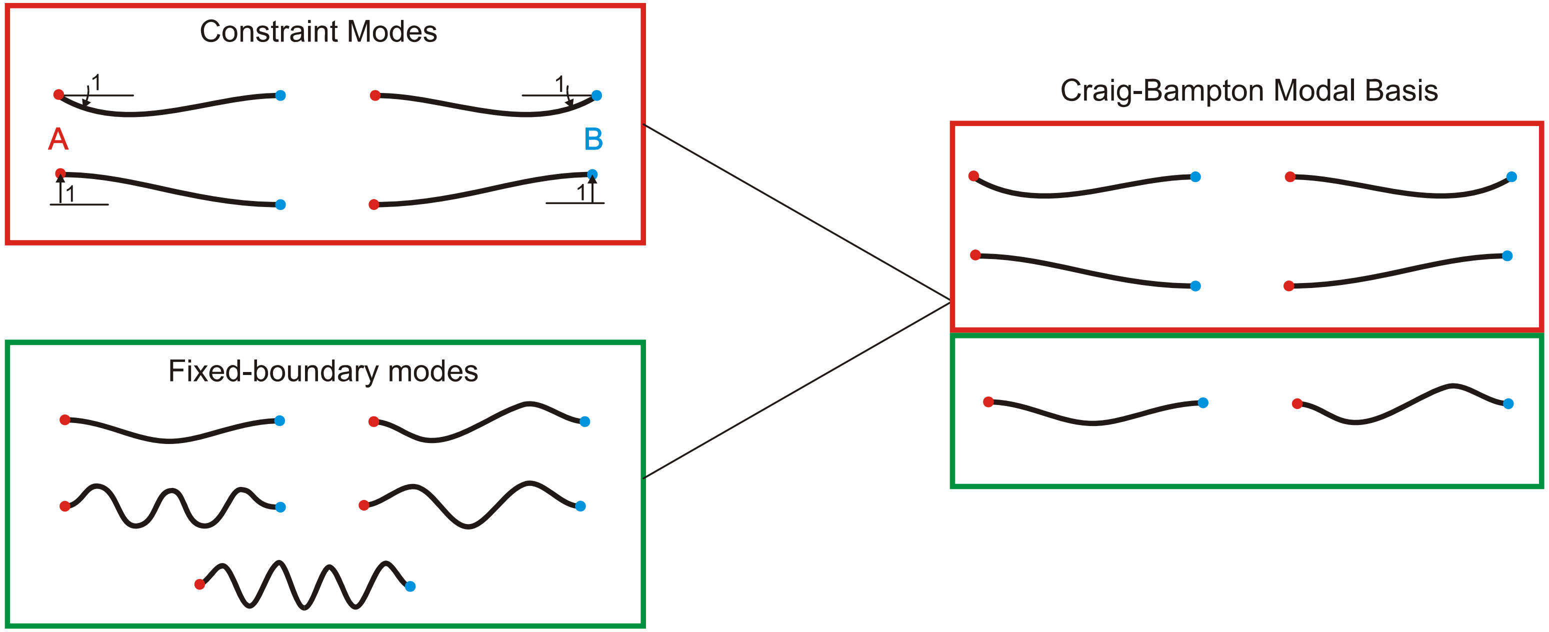
A flexible body deformation can be captured with a reduced number of modal DOF = *modal truncation.*

The problem that raises is…*How can we optimize the modal basis to use*?

Craig-Bampton method

- **Craig-Bampton method**
  The user has to select a subset of DOF = *Boundary DOF*
  This Boundary DOF are preserved in CB modal basis = *no loss of resolution*

  The modal space in CB method is divided in **Constraint modes** $\mathbf{u}_B$
  and **Fixed-boundary normal modes** $\mathbf{u}_I$
  The modal truncation is applied only on the $\mathbf{u}_I$



Orthogonalized Craig-Bampton method

$$\mathbf{u} = \begin{Bmatrix} \mathbf{u}_B \\ \mathbf{u}_I \end{Bmatrix} = \underbrace{\begin{bmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{\Phi}_{IC} & \mathbf{\Phi}_{IN} \end{bmatrix}}_{\mathbf{\Phi}} \begin{Bmatrix} \mathbf{q}_C \\ \mathbf{q}_N \end{Bmatrix}$$

$$\hat{\mathbf{K}} = \mathbf{\Phi}^T \mathbf{K} \mathbf{\Phi}$$

$$\hat{\mathbf{M}} = \mathbf{\Phi}^T \mathbf{M} \mathbf{\Phi}$$

- **ADAMS method (Orthogonalized Craig-Bampton method)**
  We have to orthonormalize the CB basis obtained because
  - We want to easily deactivate rigid body modes inside CB basis
  - We want to have a frequency for each mode ($\mathbf{u}_B$ had not associated freq)

Eigenvalue Problem

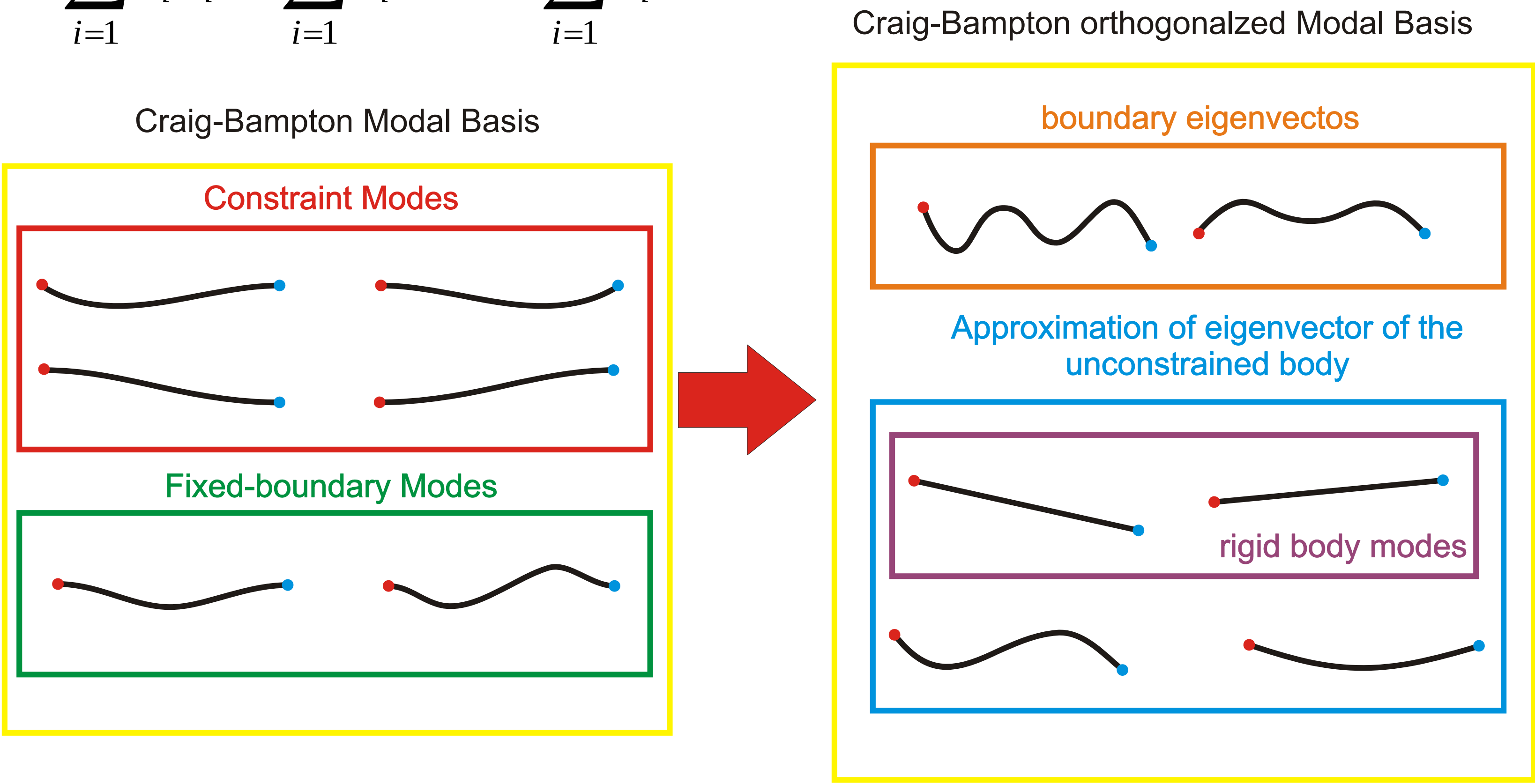
$$\hat{\mathbf{K}}\mathbf{q} = \lambda \hat{\mathbf{M}}\mathbf{q} \longrightarrow \mathbf{N}$$ *Transformation Matrix (eigenvectors)*

$$\mathbf{N}\mathbf{q}^* = \mathbf{q}$$ *Modal coordinates of the new orthoganal basis*

Orthogonalized Craig-Bampton method 2

The superposition formula become

$$\mathbf{u} = \sum_{i=1}^{M} \phi_i q_i = \sum_{i=1}^{M} \phi_i \mathbf{N} \mathbf{q}^* = \sum_{i=1}^{M} \phi_i^* \mathbf{q}^*$$



Generation of flexible bodies in PATRAN

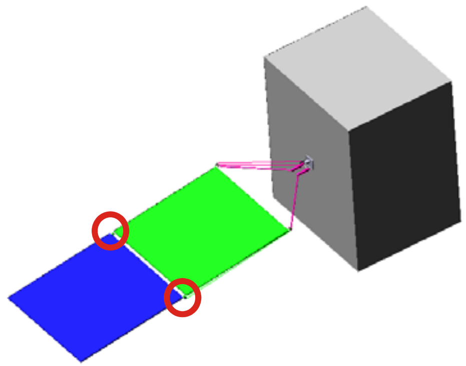
The steps necessary to generate an ADAMS flexible body (mnf file) from a FEM representation of one body are 3

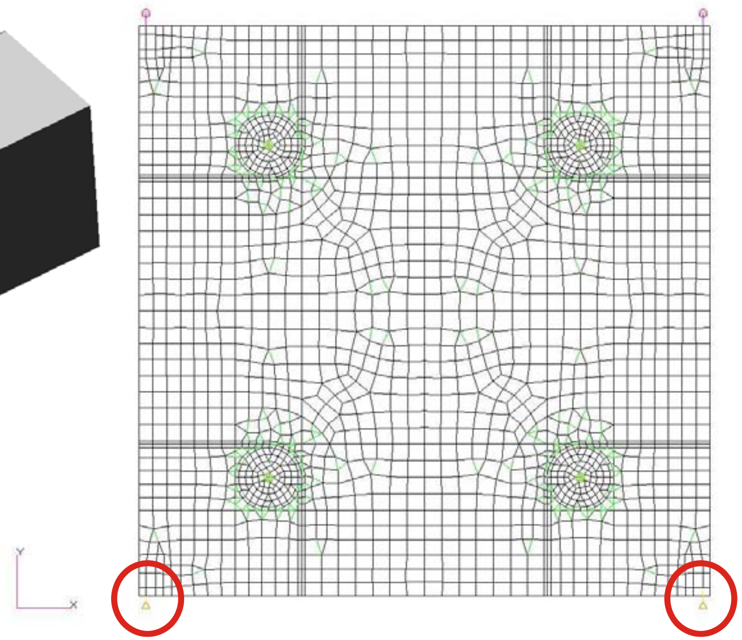
1. Definition of boundary DOF
2. Numbers of fixed-boundary normal modes to consider
3. Generation of PLOTEL elements grid

- **Definition of boundary DOF**

  We have to define a DOF list with the boundary nodes and their related DOF

  <u>All the interface nodes</u> of one body have to be included and all their 6 DOF has to be selected



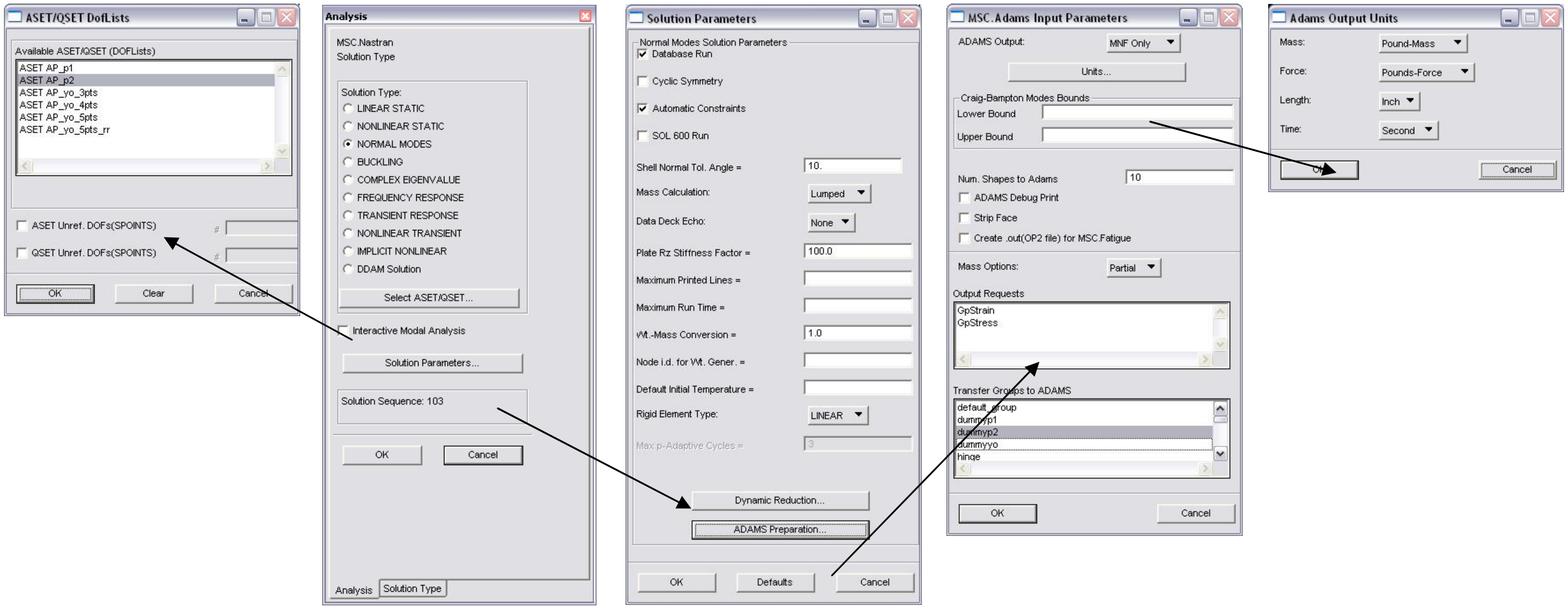


NASTRAN – ADAMS Interface

- **Numbers of fixed-boundary normal modes to consider**

  The number this normal modes can be easily selected in the PATRAN-ADAMS interface showed below.

  Usually the selection of 10 fixed-boundary normal modes is enough

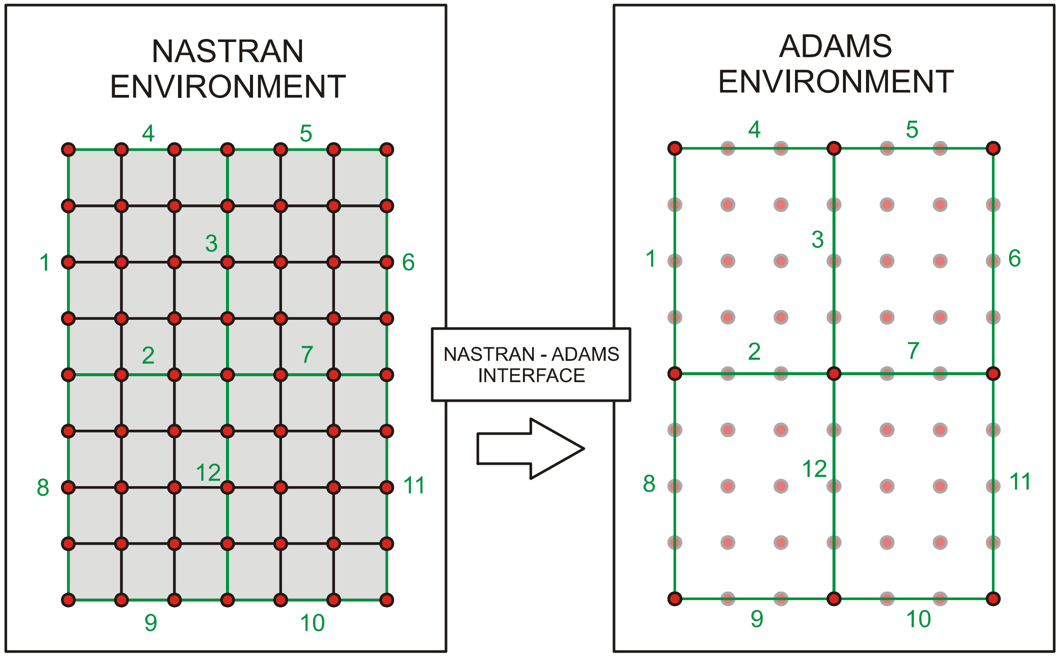


PLOTEL element

- **Generation of PLOTEL elements grid**

  ADAMS doesn't need the FE model elements. It uses only their grid to generate the graphical representation of the flexible body (MNF file).

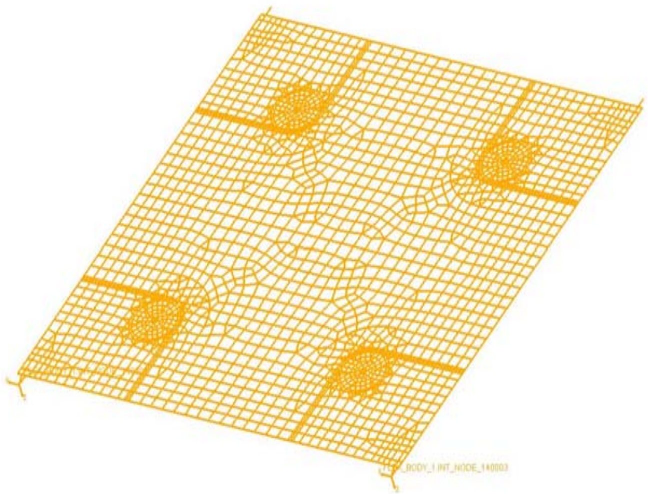
  For this reason we can create a grid of dummy elements (PLOTEL) to generate a gross and easier to handle grid



PLOTEL element

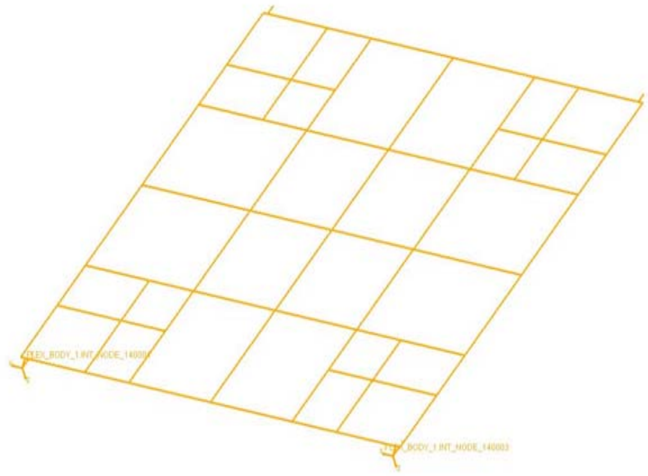
At the end we obtain the following result

NORMAL MNF



Element Faces	2476
MNF File size	2537 KB

REDUCED MNF



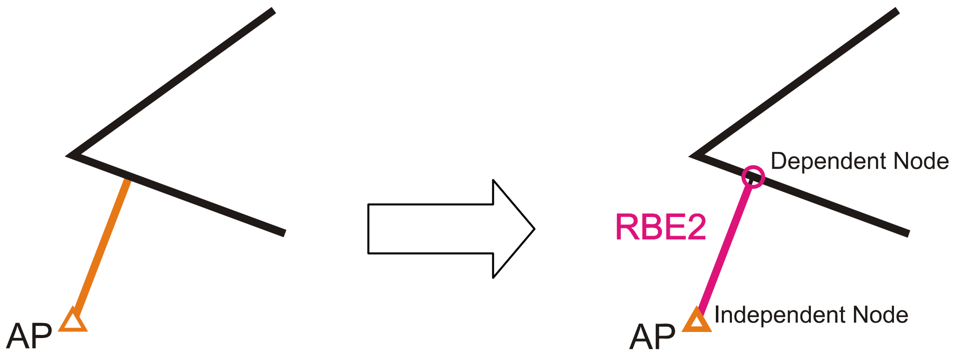
Element Faces	80
MNF File size	72 KB

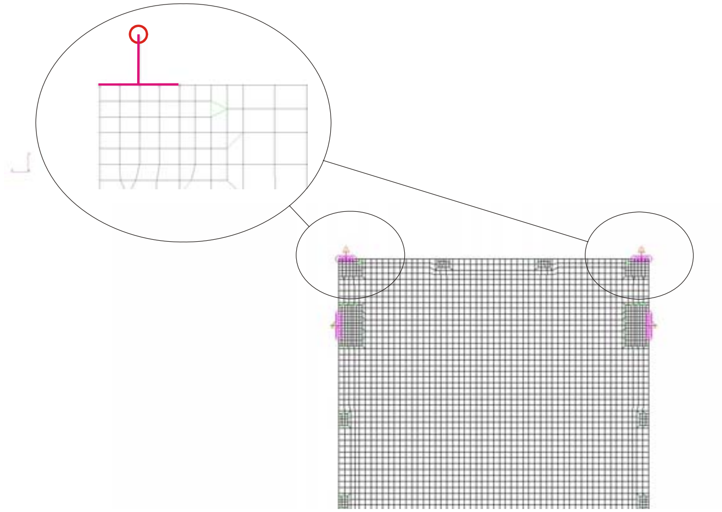
The Flexible model

Flexible Model

- Different kinds of Flexible Models

For each part of the solar array we have to generate an MNF file in NASTRAN
Using RBE2 element we can generate some rigid area
in the Flexible part.
So we can generate 2 kinds of Flexible model

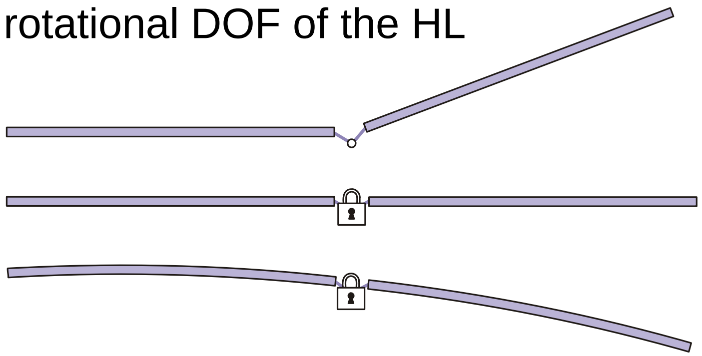




Full & Semi – Flexible model

Full-Flexible Model

- The structure and the hinges are flexible
- Hinge stiffness = inside its FEM representation (BEAM elm)
- The latching is obtained fixing the rotational DOF of the HL



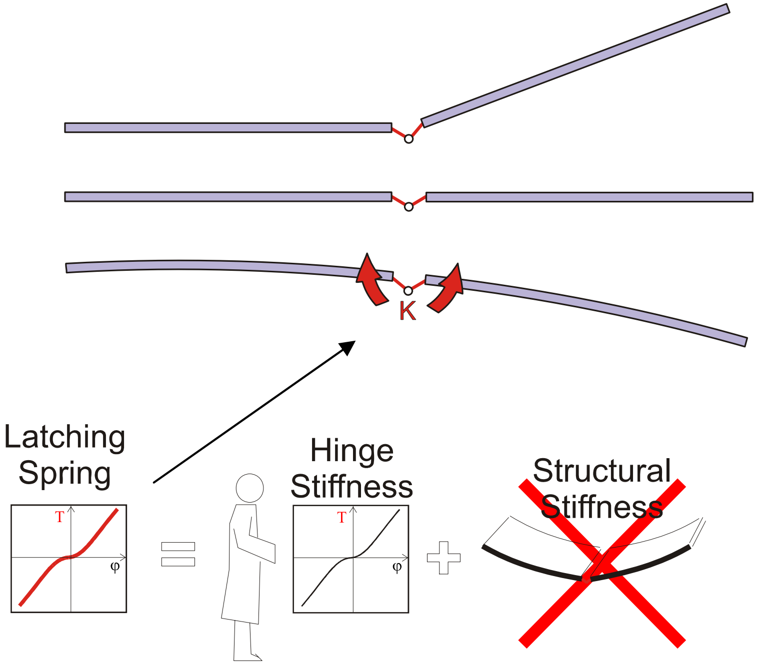
```
deact/motion,ID=5
deact/motion,ID=4

integrator/GSTIF, HMAX=0.001
sim/dyn,end=4.2,steps=42
activ/sensor,ID=2
integrator/GSTIF, HMAX=0.001
sim/dyn,dur=1,steps=400
deact/sensor,ID=2

activ/motion,ID=4
activ/motion,ID=5
motion/4,velocity,func=0.0
motion/5,velocity,func=0.0
```

Semi-Flexible Model

- The structure of the part is flexible and the hinges are rigid (RBE2 elm)
- Hinge stiffness = experimental data or equivalent stiffness



Adjustments of the Rigid Model

- **Adjustments of the Rigid Model**
  - ***Split of Forces and their relocation***

    The forces and torques in their real application points
  - ***Change of kind of joints***

    The spherical joints are changed with revolute e cylindrical joint

    (no more over constraint problems)
  - ***Modify of the ADAMS/solver script***

    New forces and joints ID to consider

    New element to consider (MOTION in full-flexible)

    Reduced integration step to set = for taking into account high frequency effects

ADAMS/solver script

RIGID

First deployment

```
! Insert ACF commands here:
deact/sforce,ID=19
deact/sensor,ID=2
sim/dyn,end=4.2,steps=42
```

Latching

```
activ/sensor,ID=2
sim/dyn,dur=1,steps=400
deact/sensor,ID=2
activ/sforce,ID=19
friction/6,FRICTION_TORQUE_PRELOAD=0.0
friction/10,FRICTION_TORQUE_PRELOAD=0.0
```

End deployment

```
sim/dyn, dur=2, steps=800
stop
```

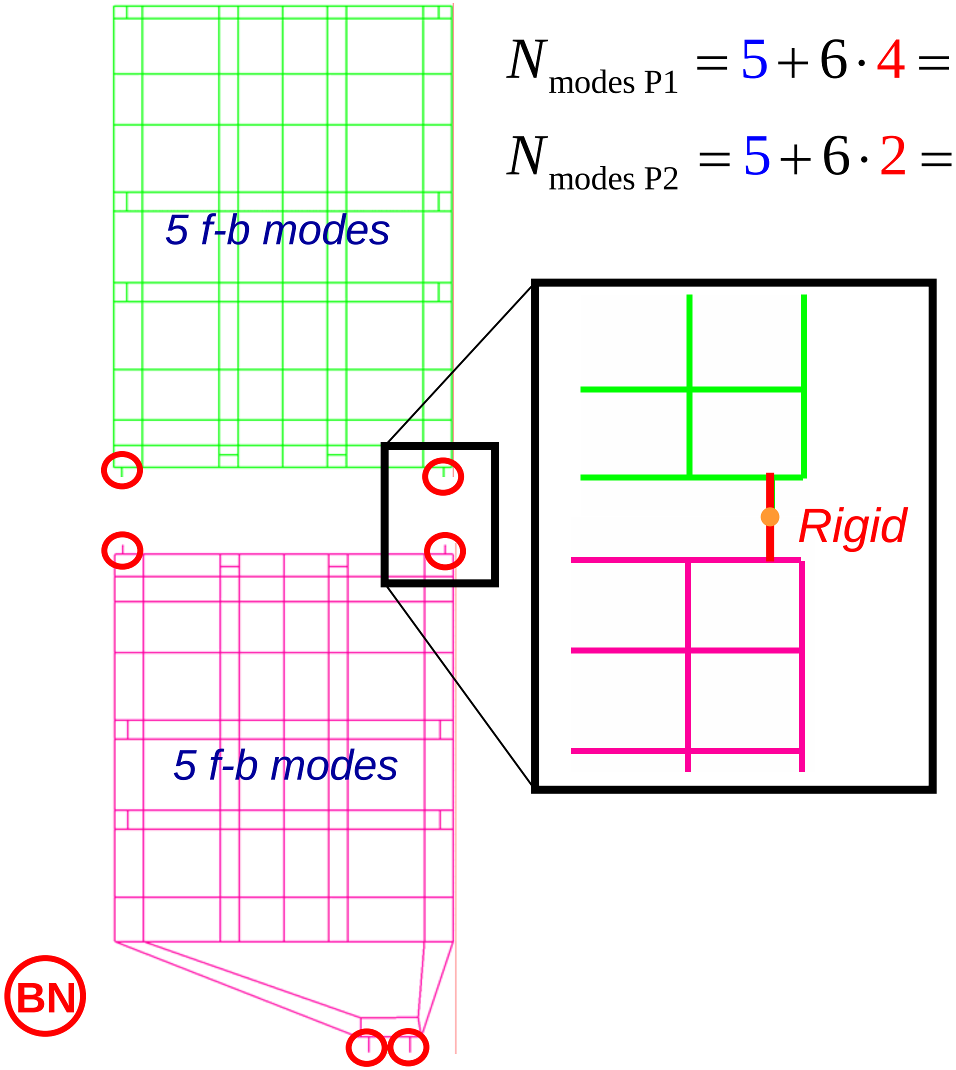
SEMI-FLEXIBLE

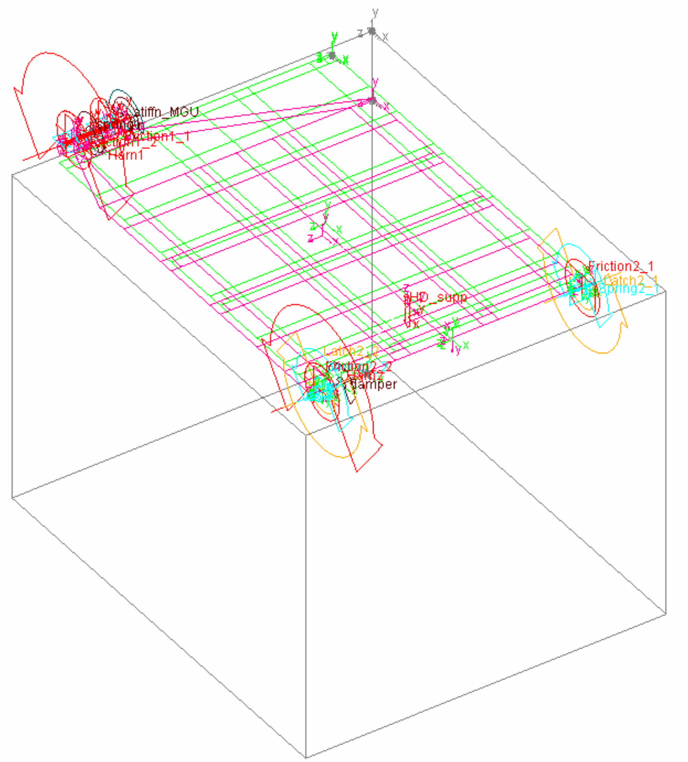
```
! Insert ACF commands here:
deact/sforce,ID=35
deact/sforce,ID=36
deact/sensor,ID=2
integrator/GSTIF, HMAX=0.001
sim/dyn,end=4.2,steps=42
activ/sensor,ID=2
integrator/GSTIF, HMAX=0.001
sim/dyn,dur=1,steps=400
deact/sensor,ID=2
activ/sforce,ID=35
activ/sforce,ID=36
friction/3,FRICTION_TORQUE_PRELOAD=0.0
friction/4,FRICTION_TORQUE_PRELOAD=0.0
integrator/GSTIF, HMAX=0.001
sim/dyn, dur=2, steps=800
stop
```

BEPI COLOMBO MPO s/a Semi-flex model

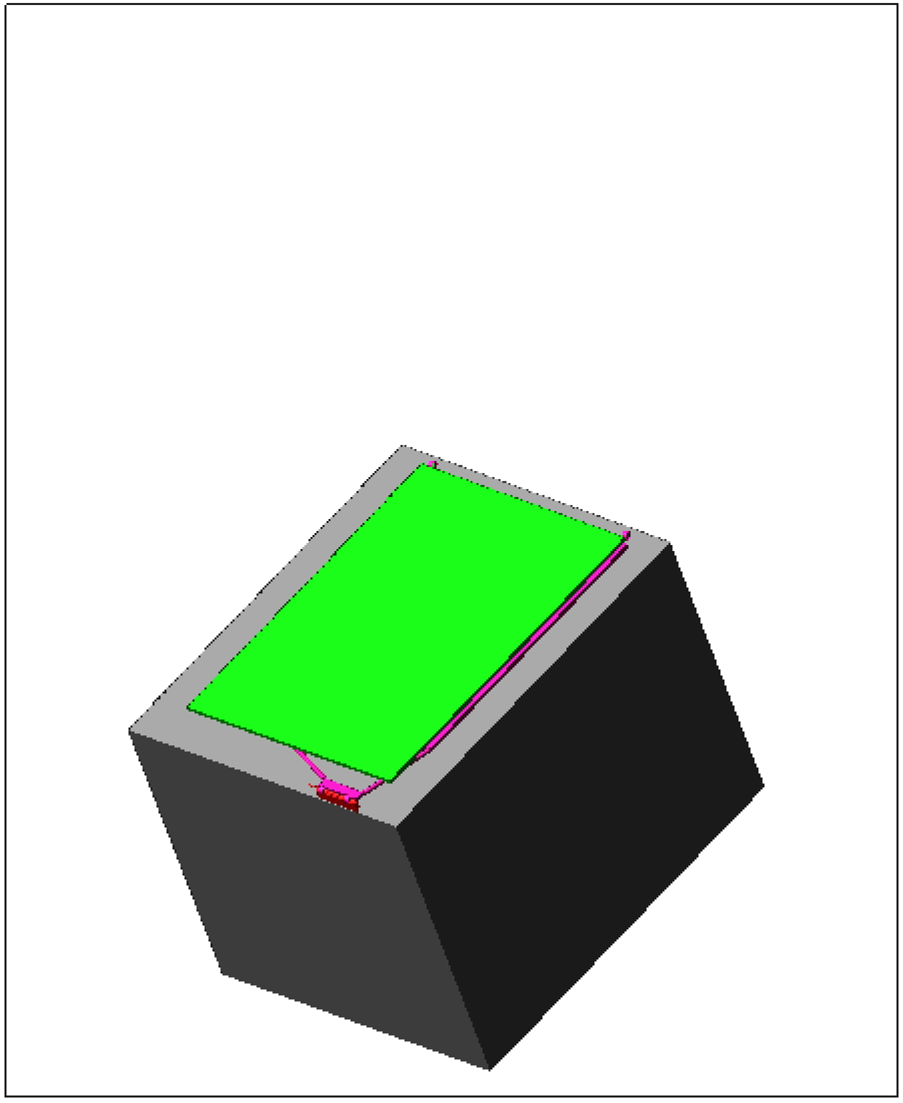
$$N_{\text{modes P1}} = 5 + 6 \cdot 4 = 29 \xrightarrow{-6 \text{ r-b modes}} N_{\text{FLEX modes P1}} = 23$$

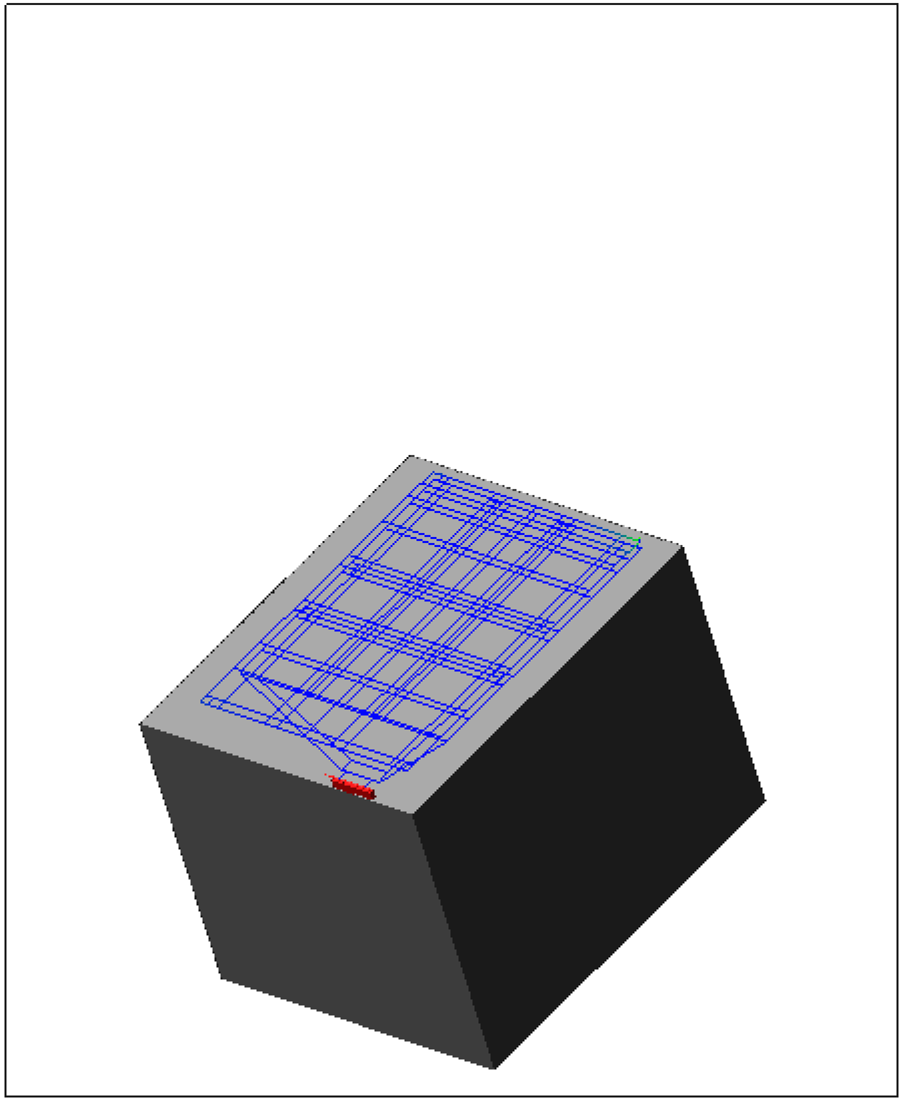
$$N_{\text{modes P2}} = 5 + 6 \cdot 2 = 17 \xrightarrow{-6 \text{ r-b modes}} N_{\text{FLEX modes P2}} = 11$$



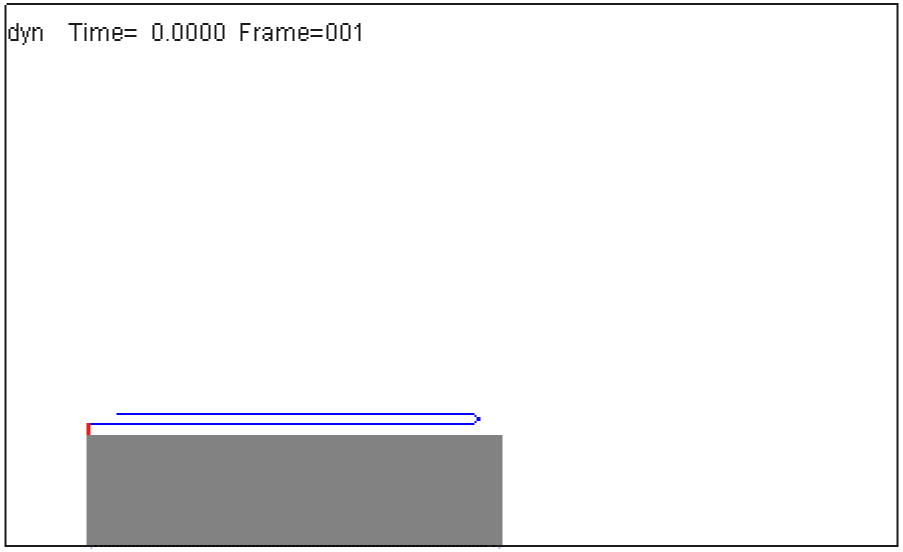


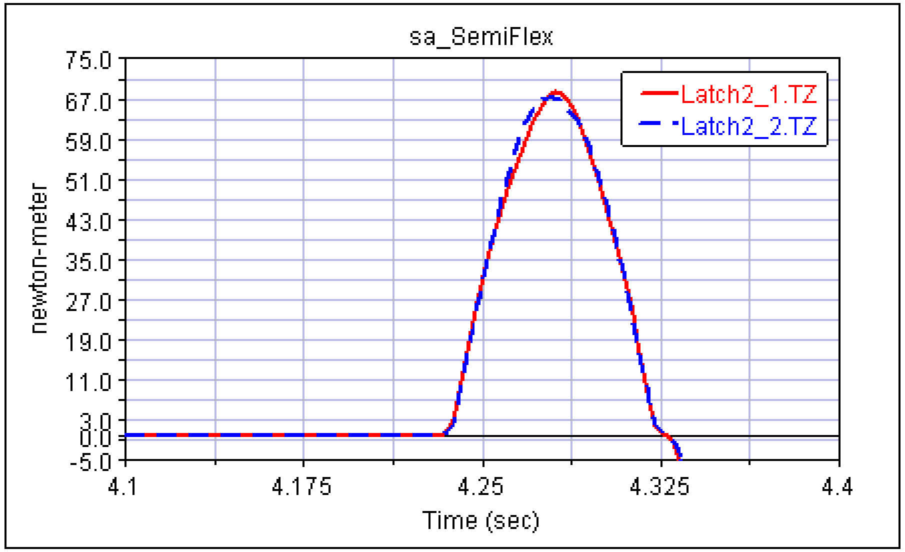
Rigid vs Semi-Flex deployment

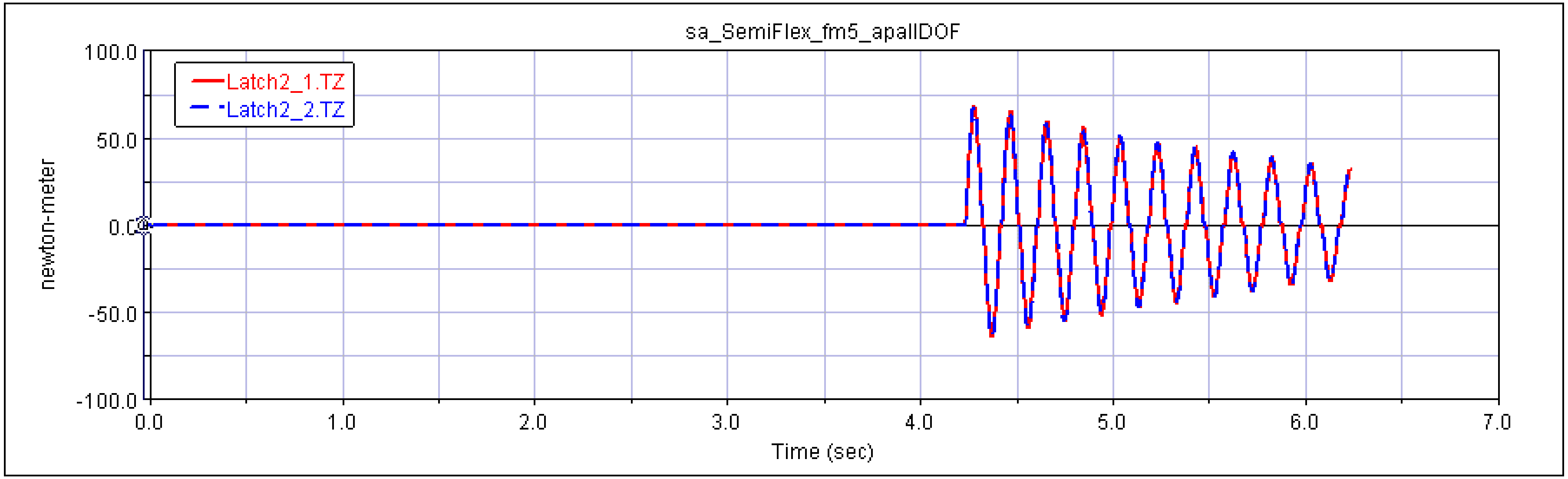




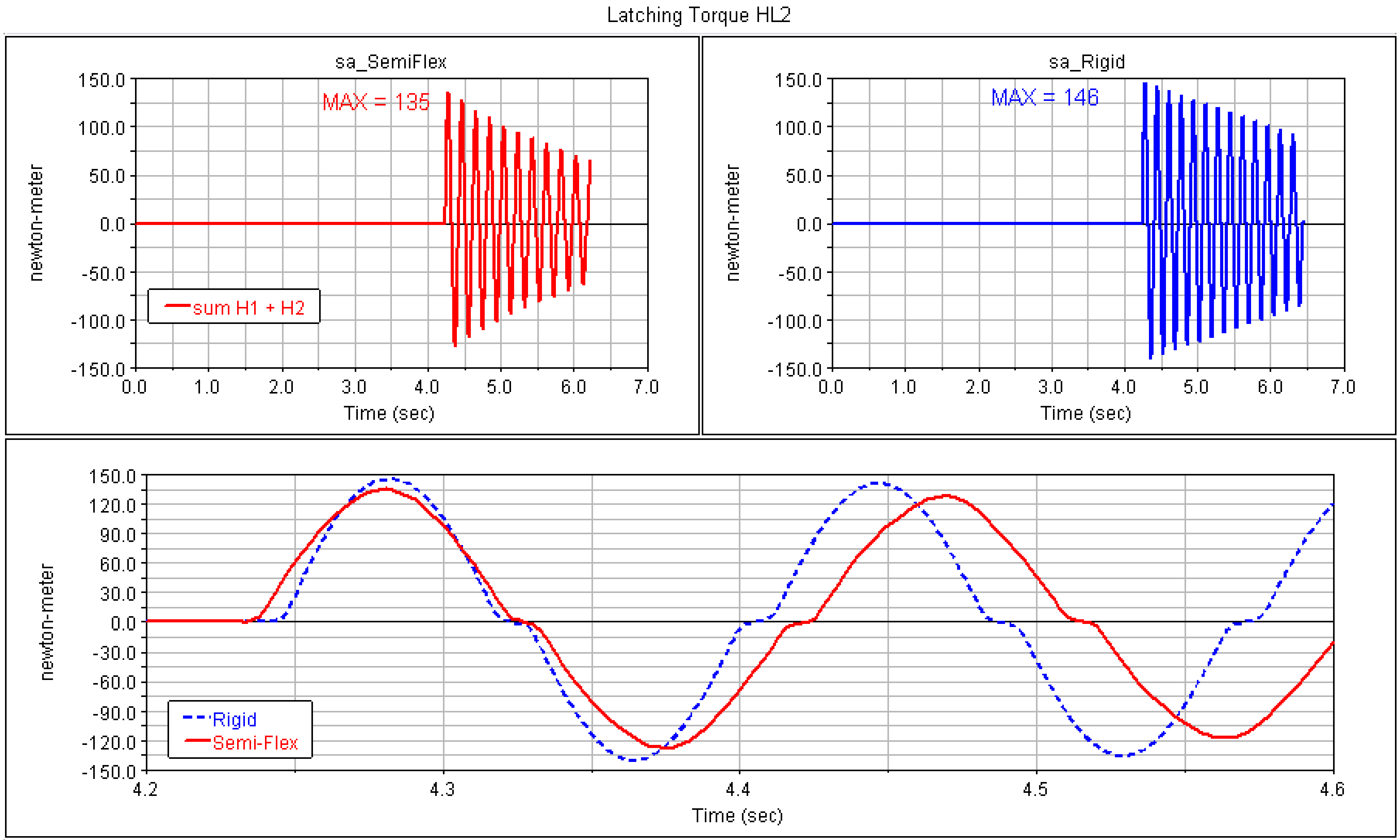
Latching Torque on HL2



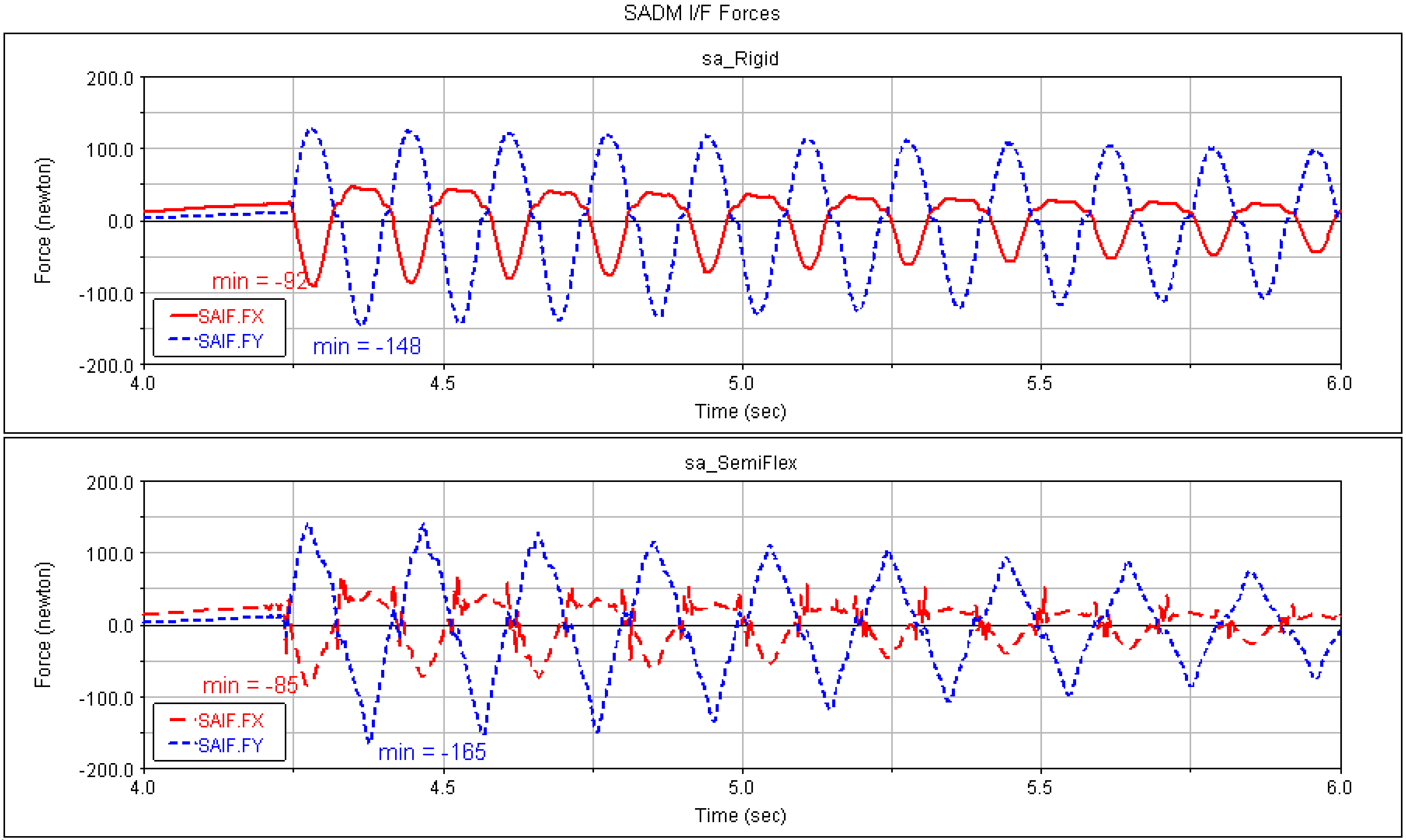




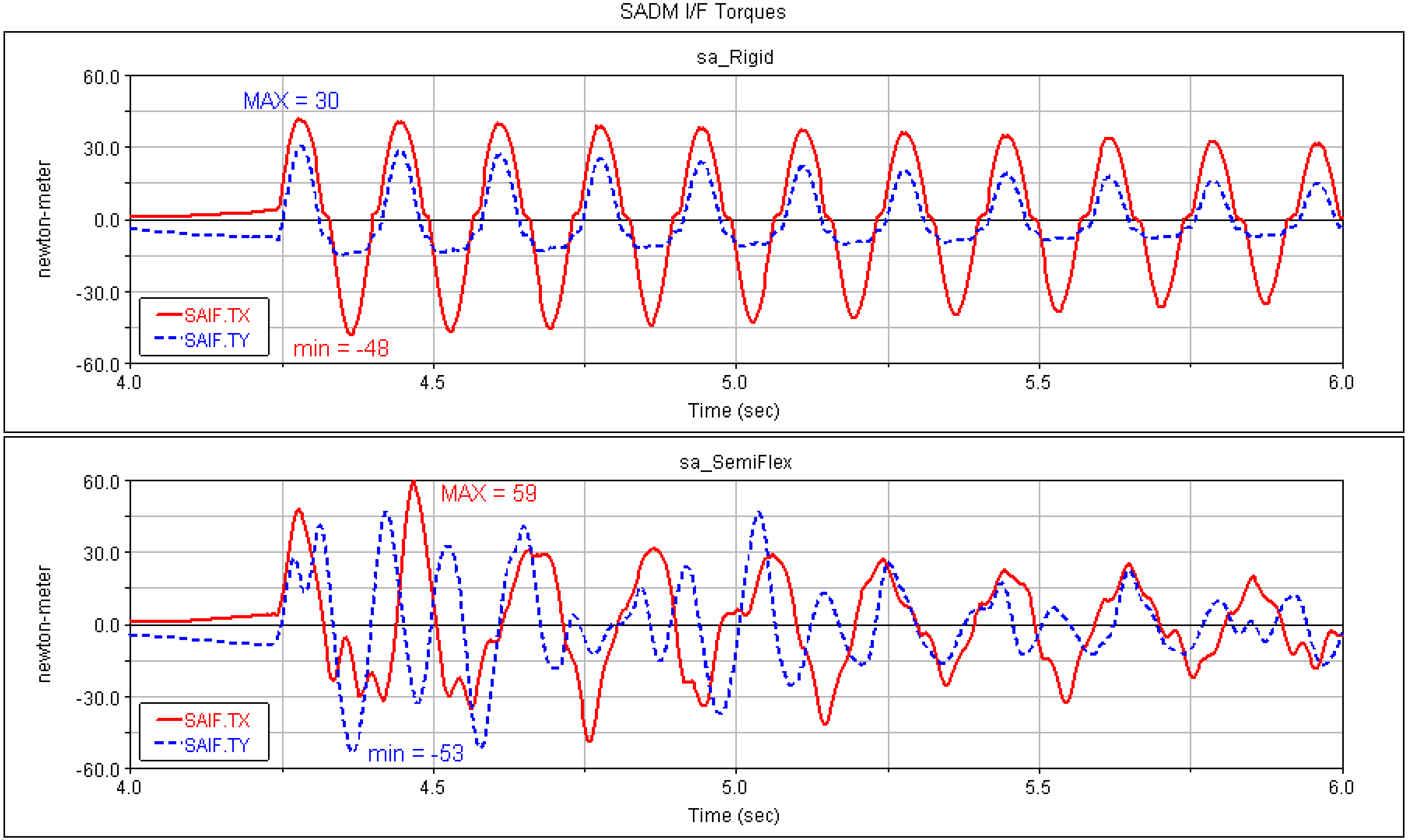
Semi-Flex vs Rigid Latching Torque



Rigid vs Semi-Flex SADM I/F Forces



Rigid vs Semi-Flex SADM I/F Torques

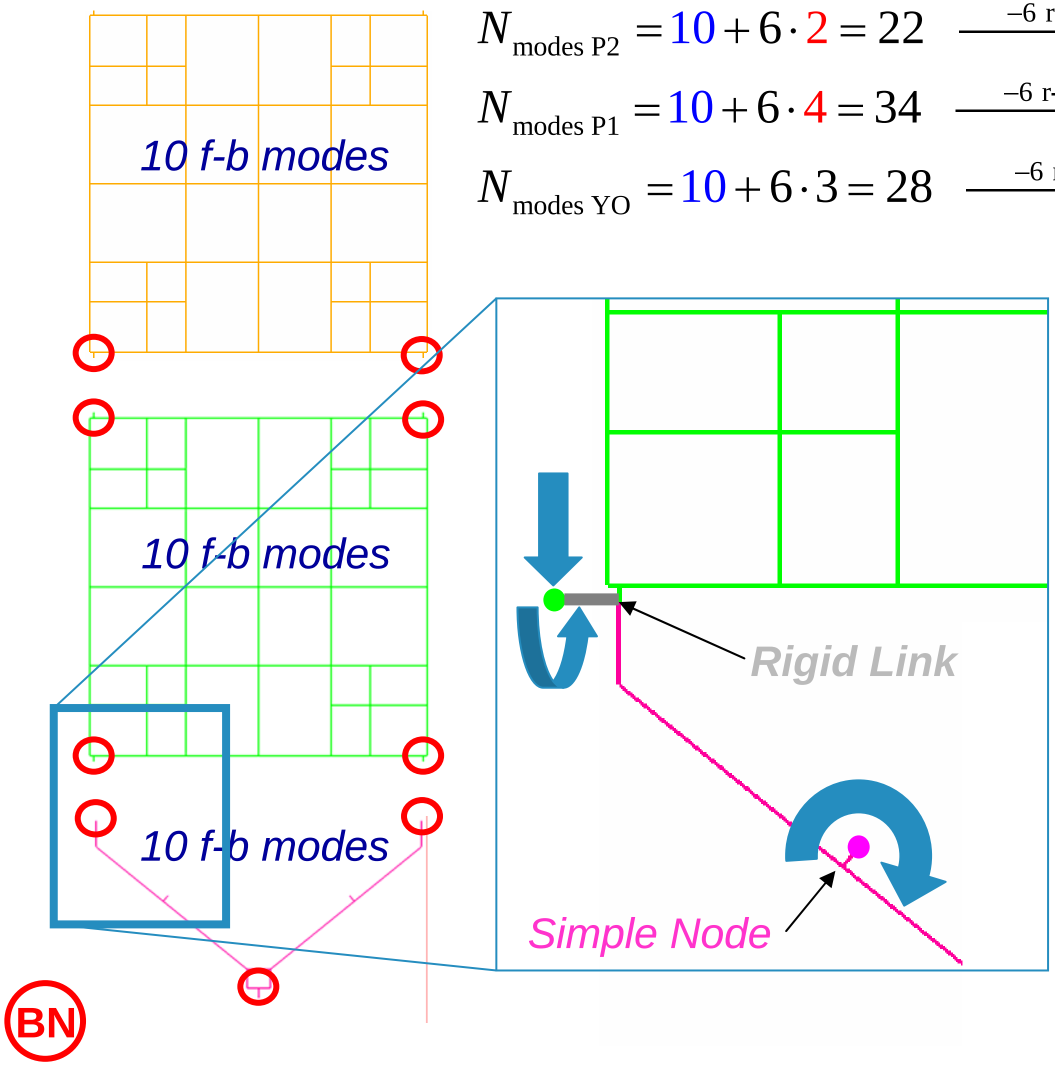


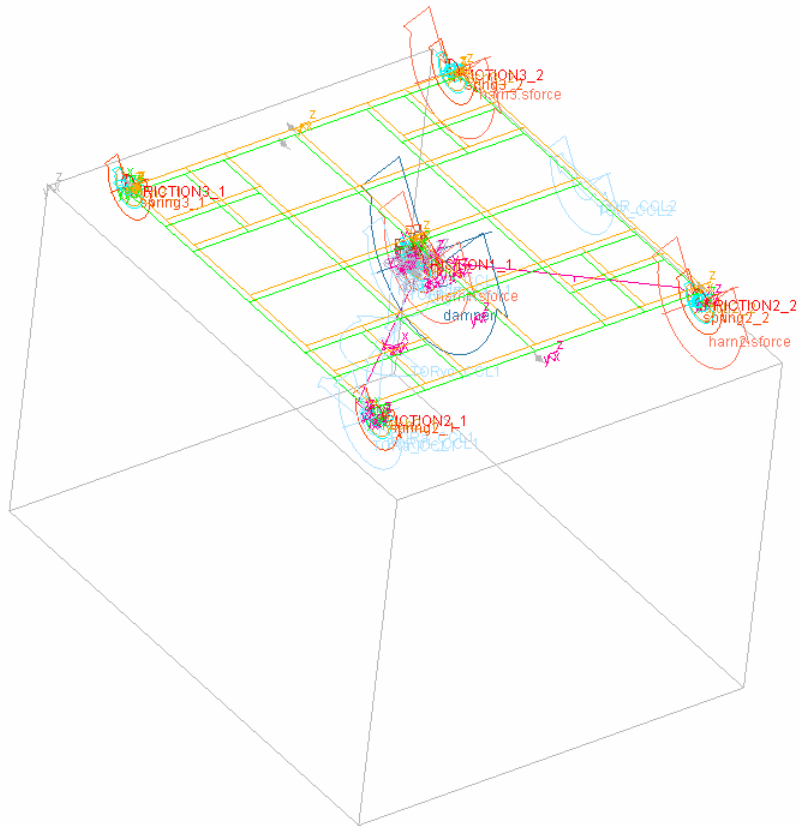
AMOS-3 s/a Full-flex model

$$N_{\text{modes P2}} = 10 + 6 \cdot 2 = 22 \xrightarrow{-6\text{ r-b modes}} N_{\text{FLEX modes P2}} = 16$$

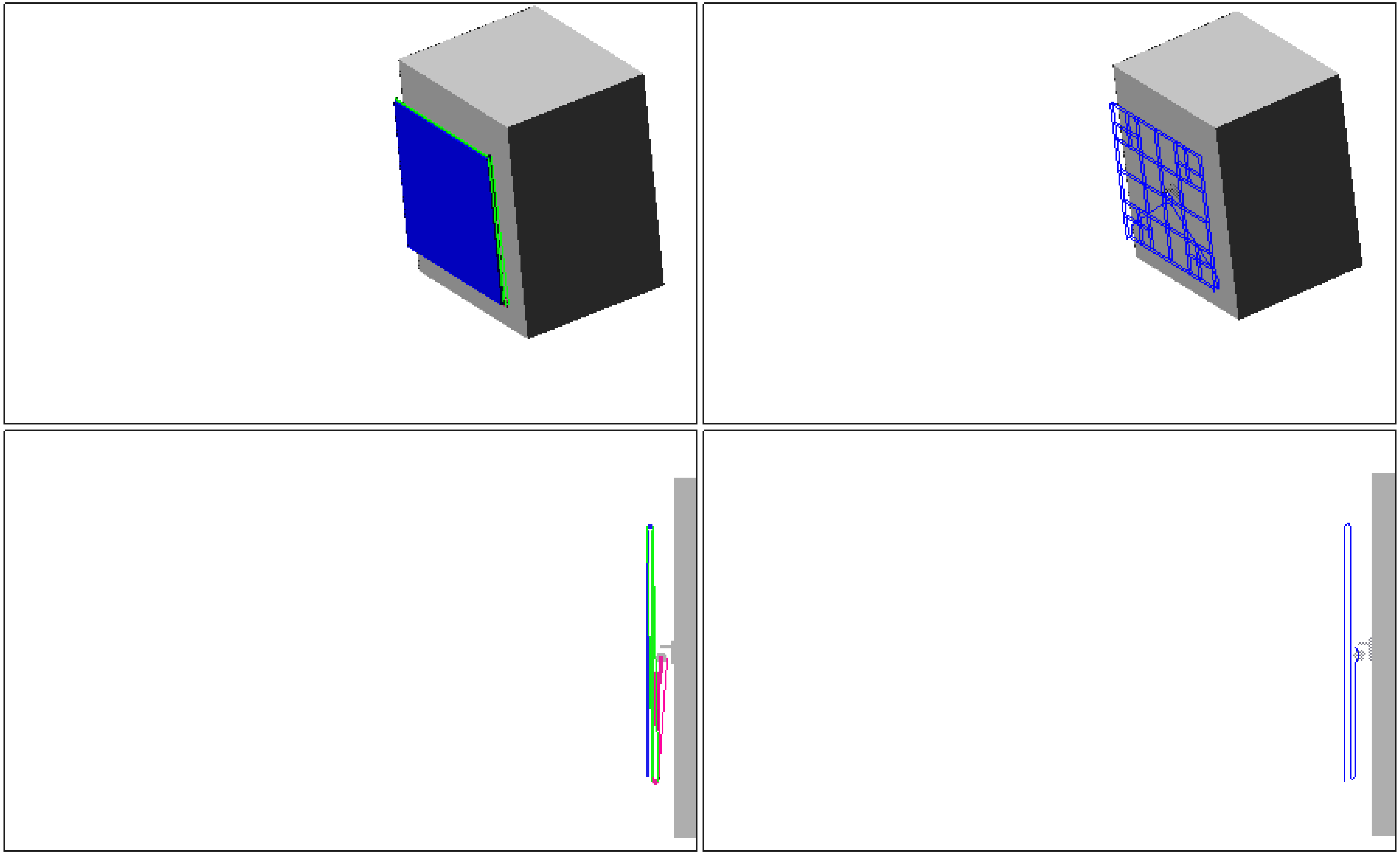
$$N_{\text{modes P1}} = 10 + 6 \cdot 4 = 34 \xrightarrow{-6\text{ r-b modes}} N_{\text{FLEX modes P1}} = 28$$

$$N_{\text{modes YO}} = 10 + 6 \cdot 3 = 28 \xrightarrow{-6\text{ r-b modes}} N_{\text{FLEX modes YO}} = 22$$

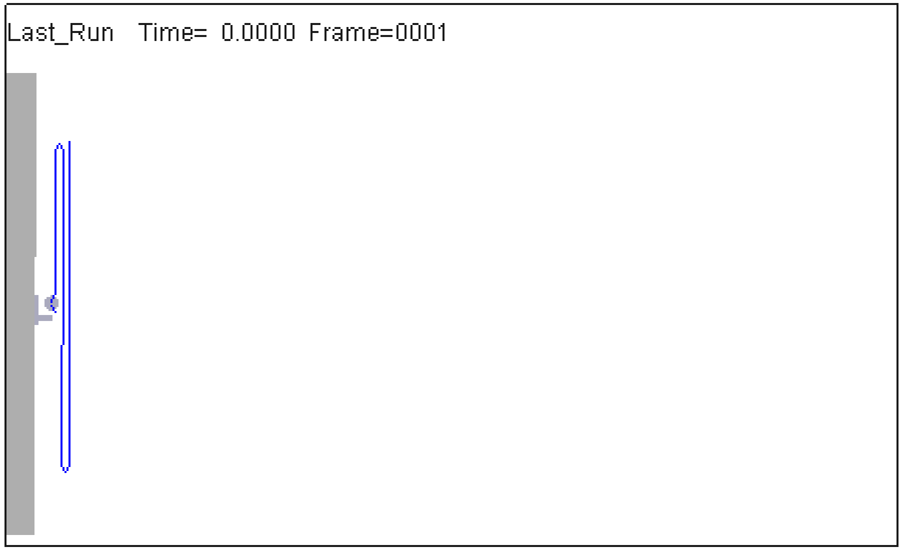


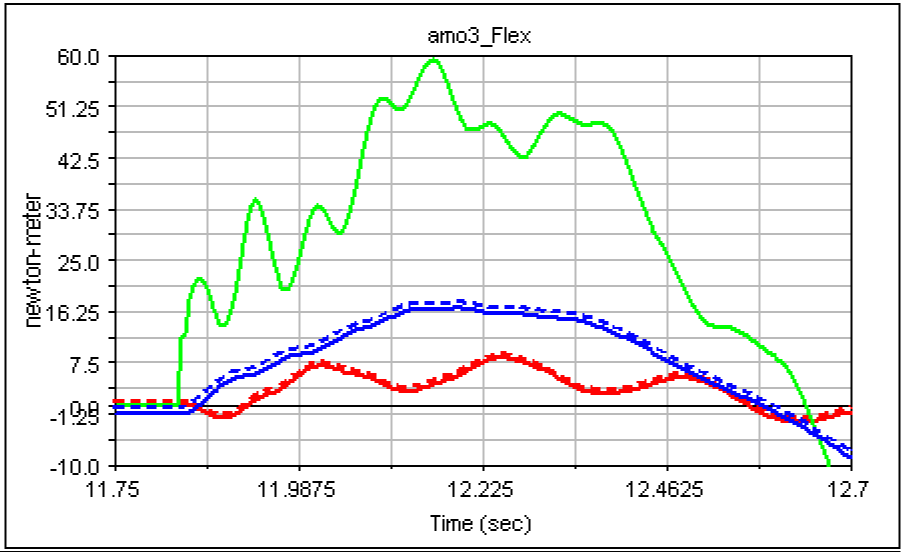


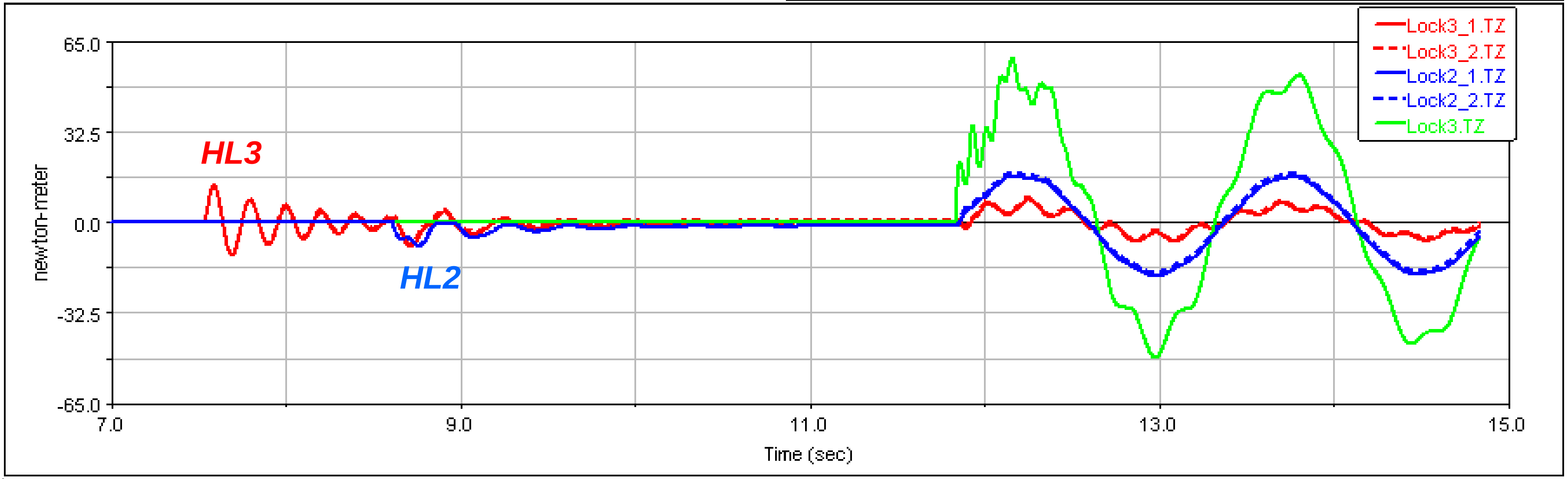
Rigid vs Full-Flex deployment



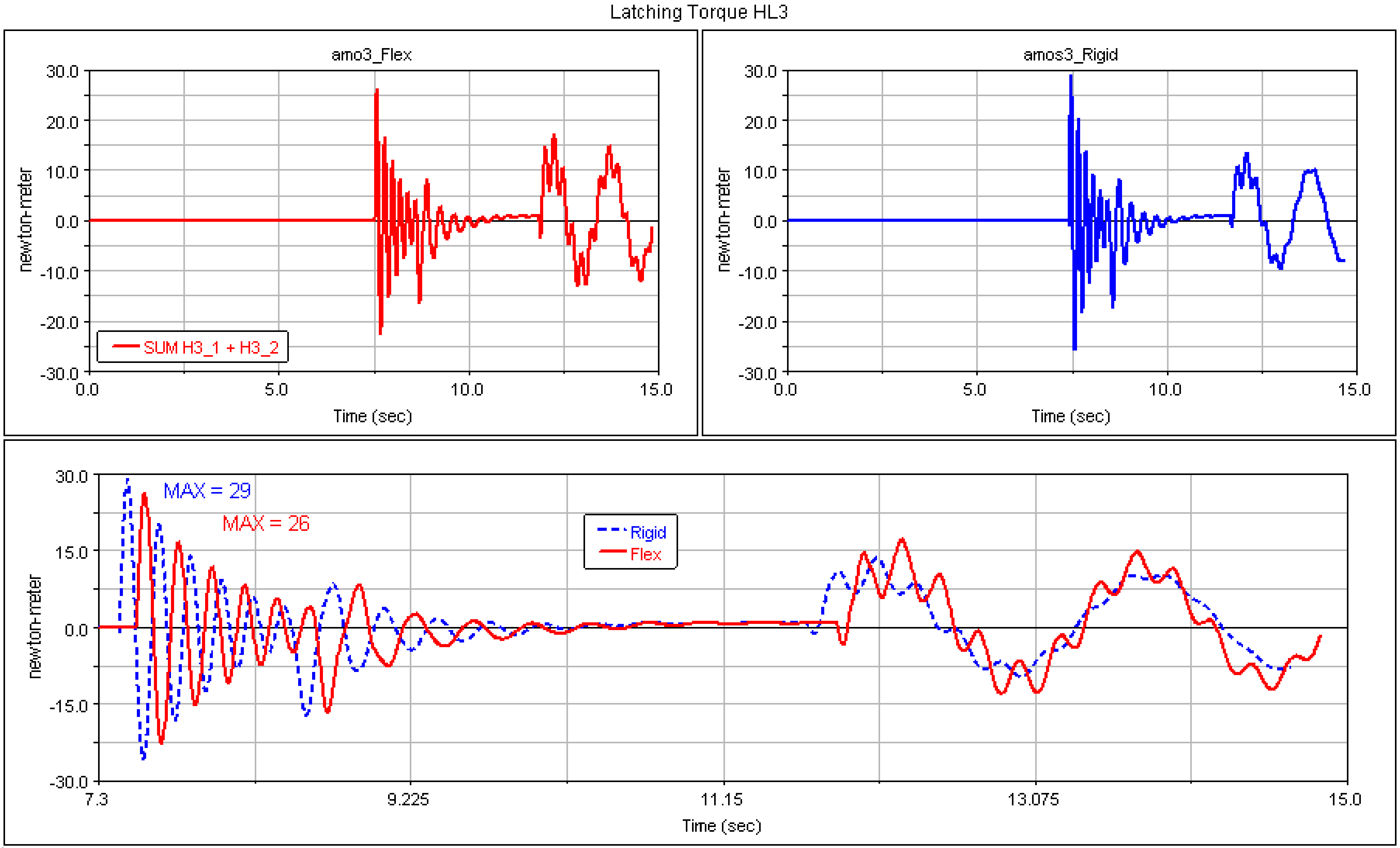
Latching Torques on HLs



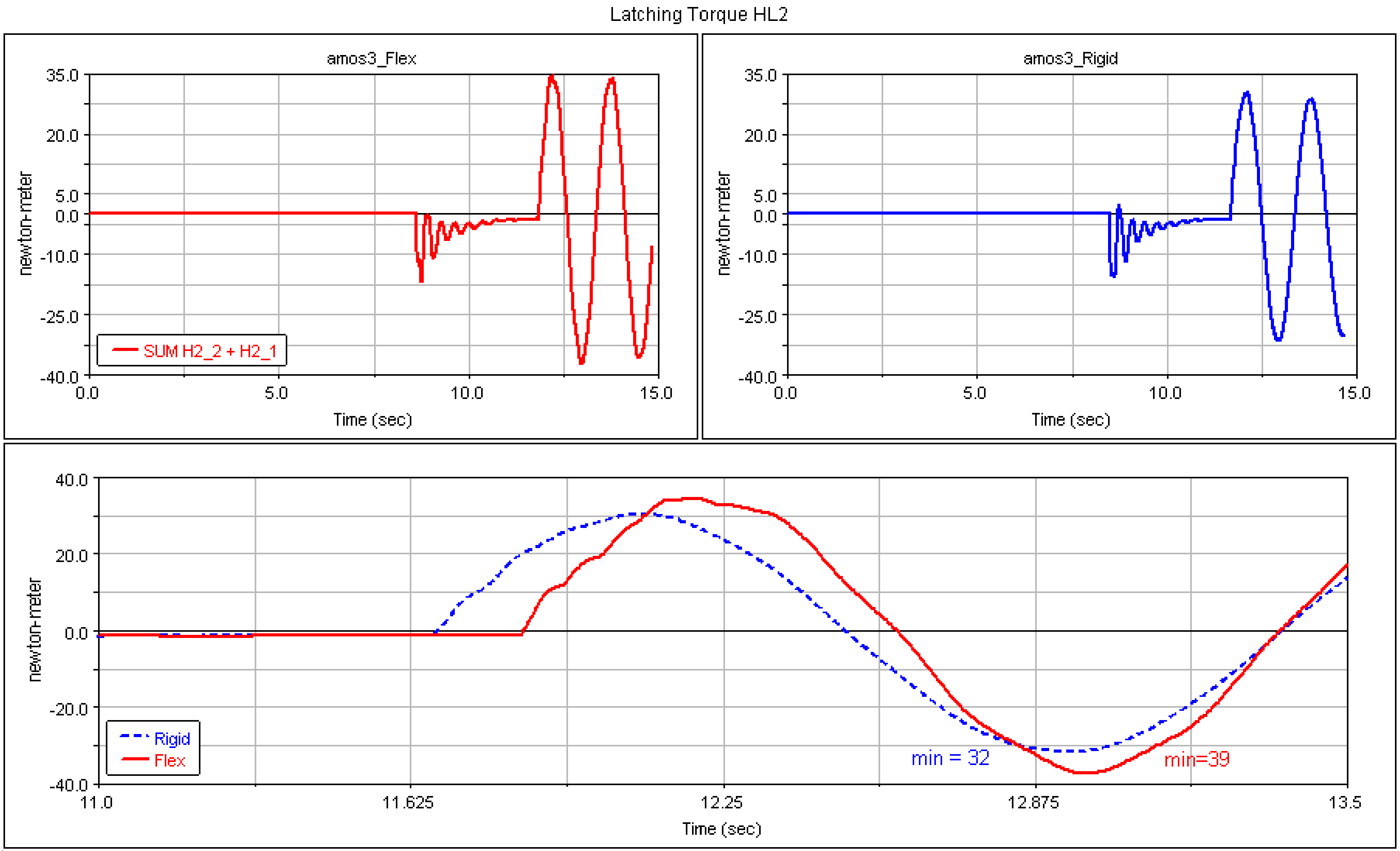




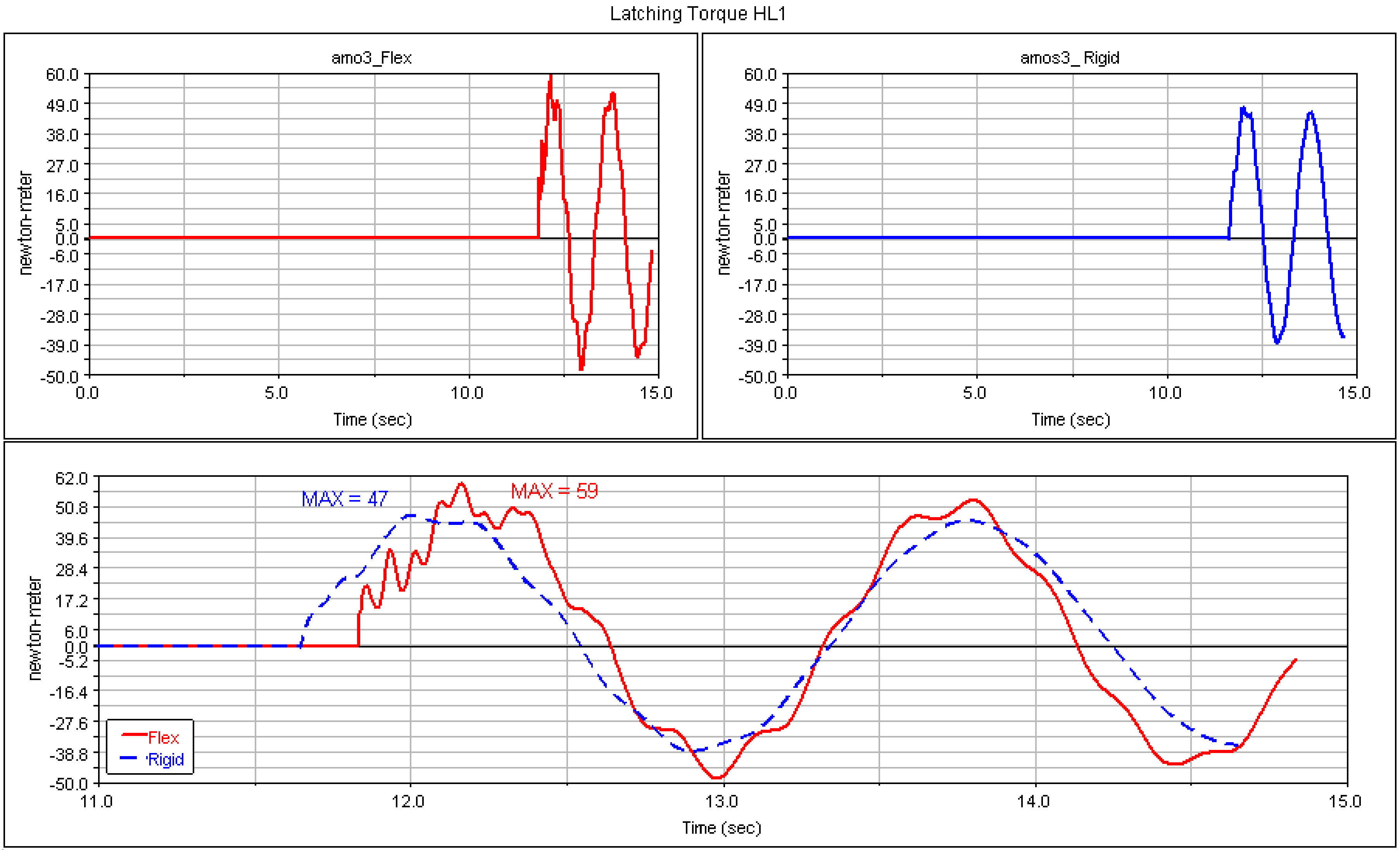
Latching Torques on HL3



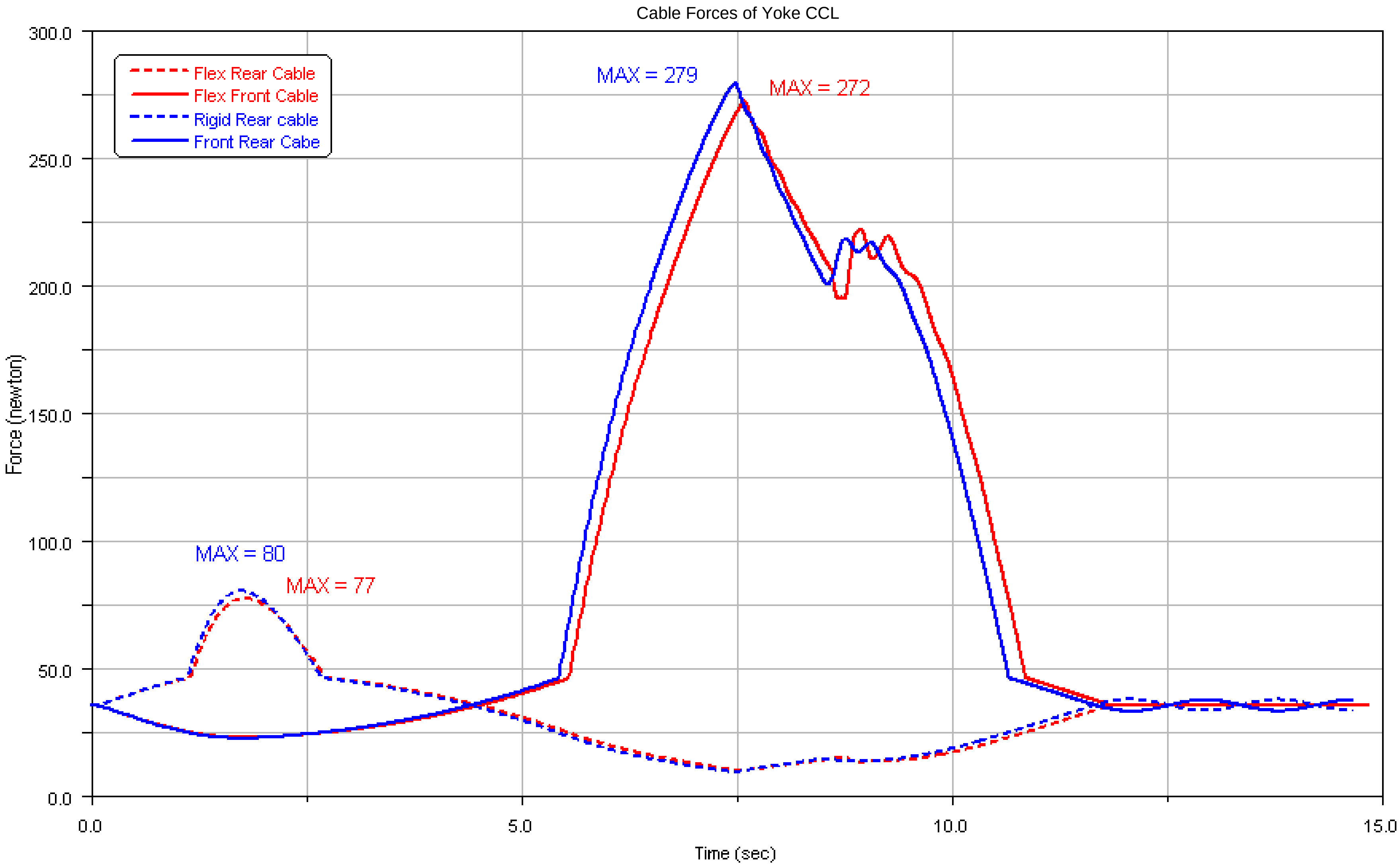
Latching Torques on HL2



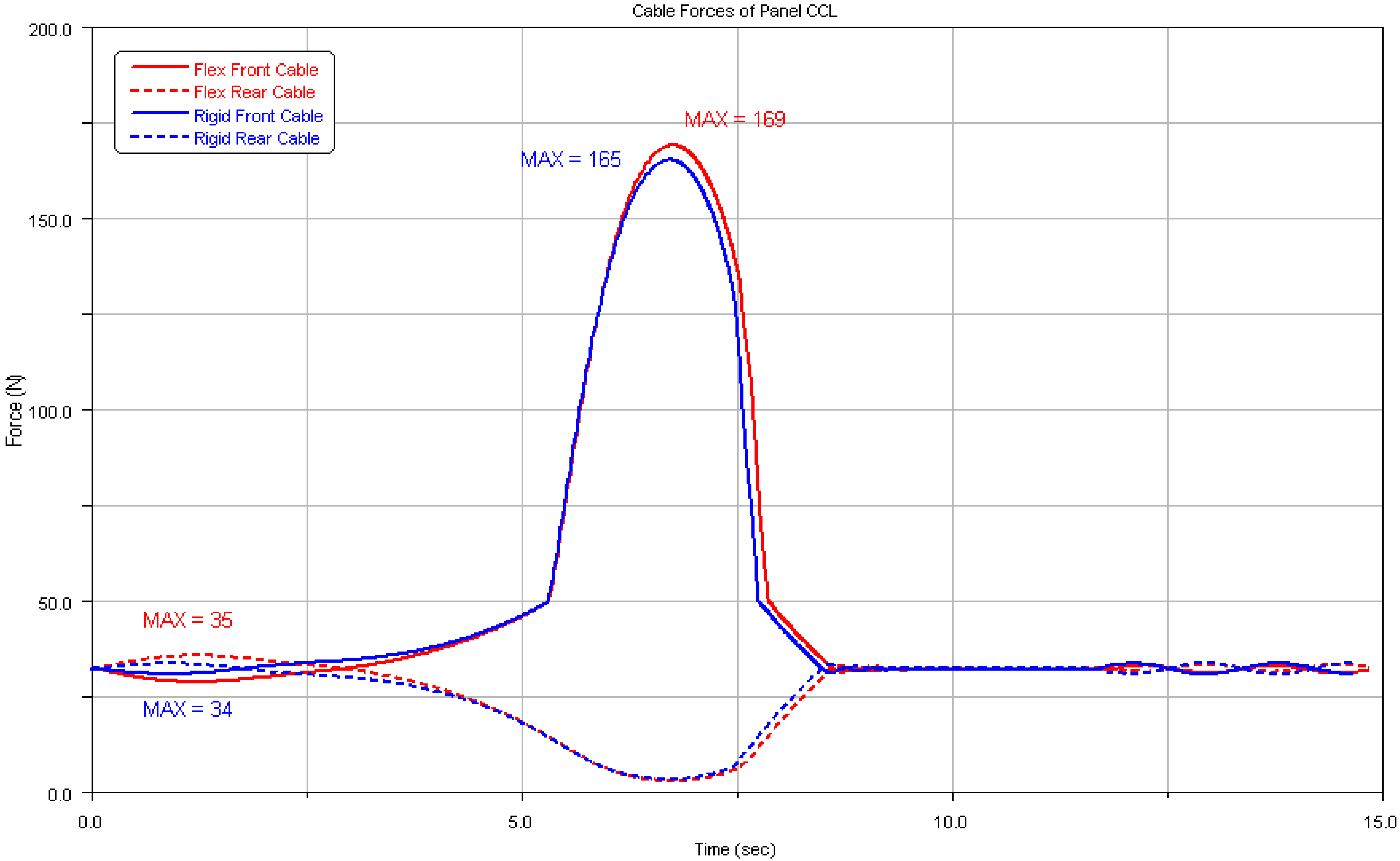
Latching Torques on HL1



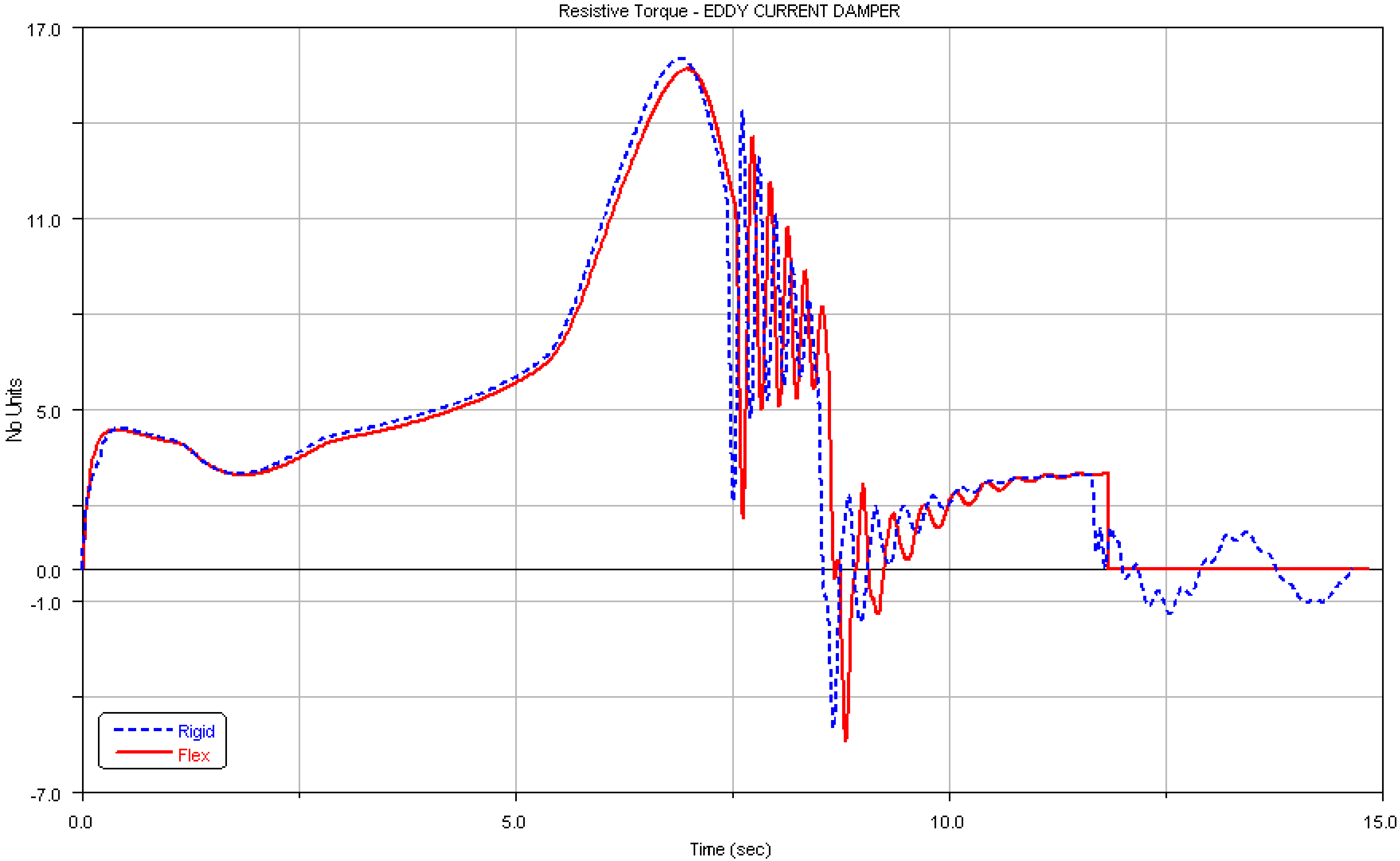
Cable Forces of Yoke CCL



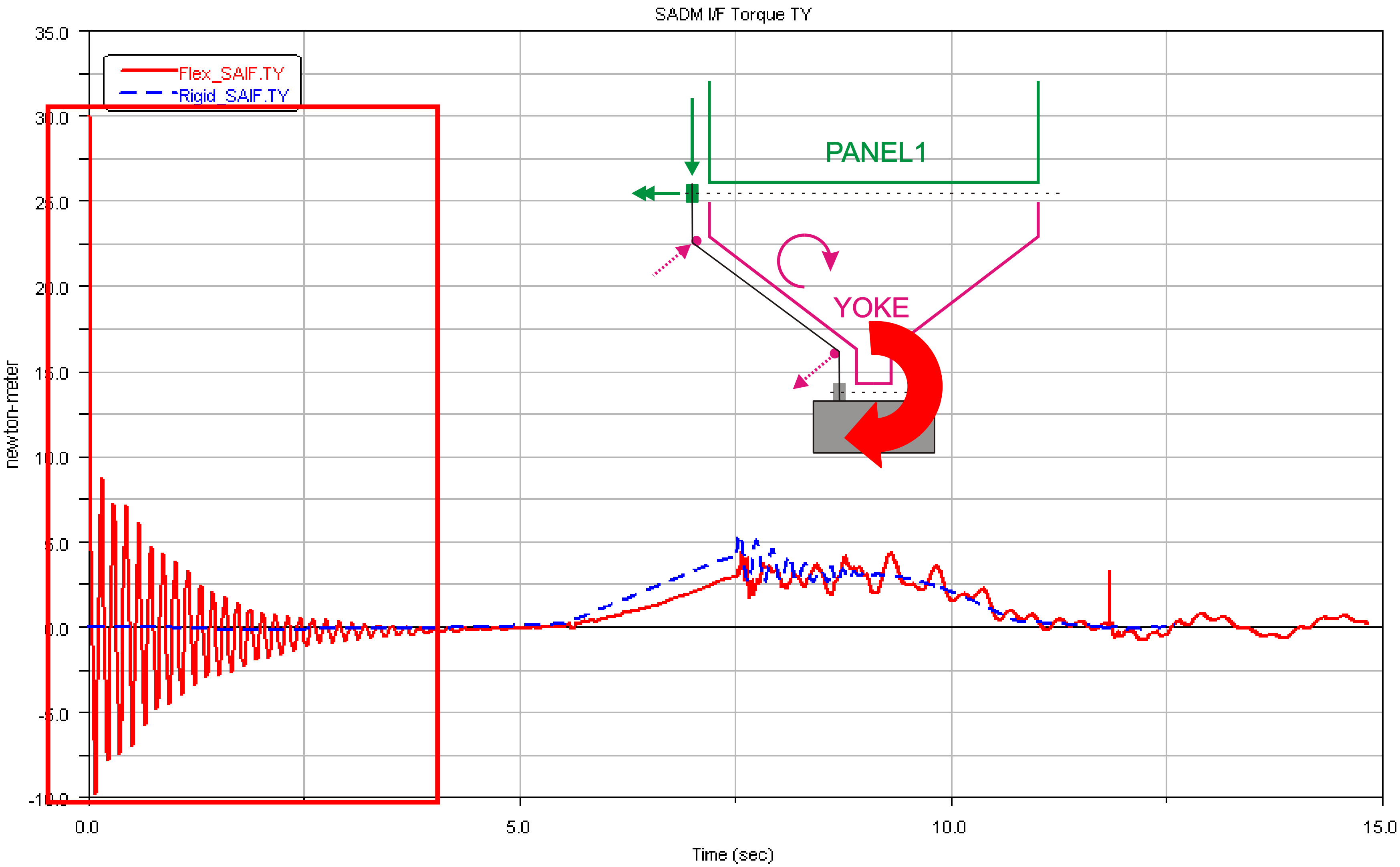
Cable Forces of Panel CCL



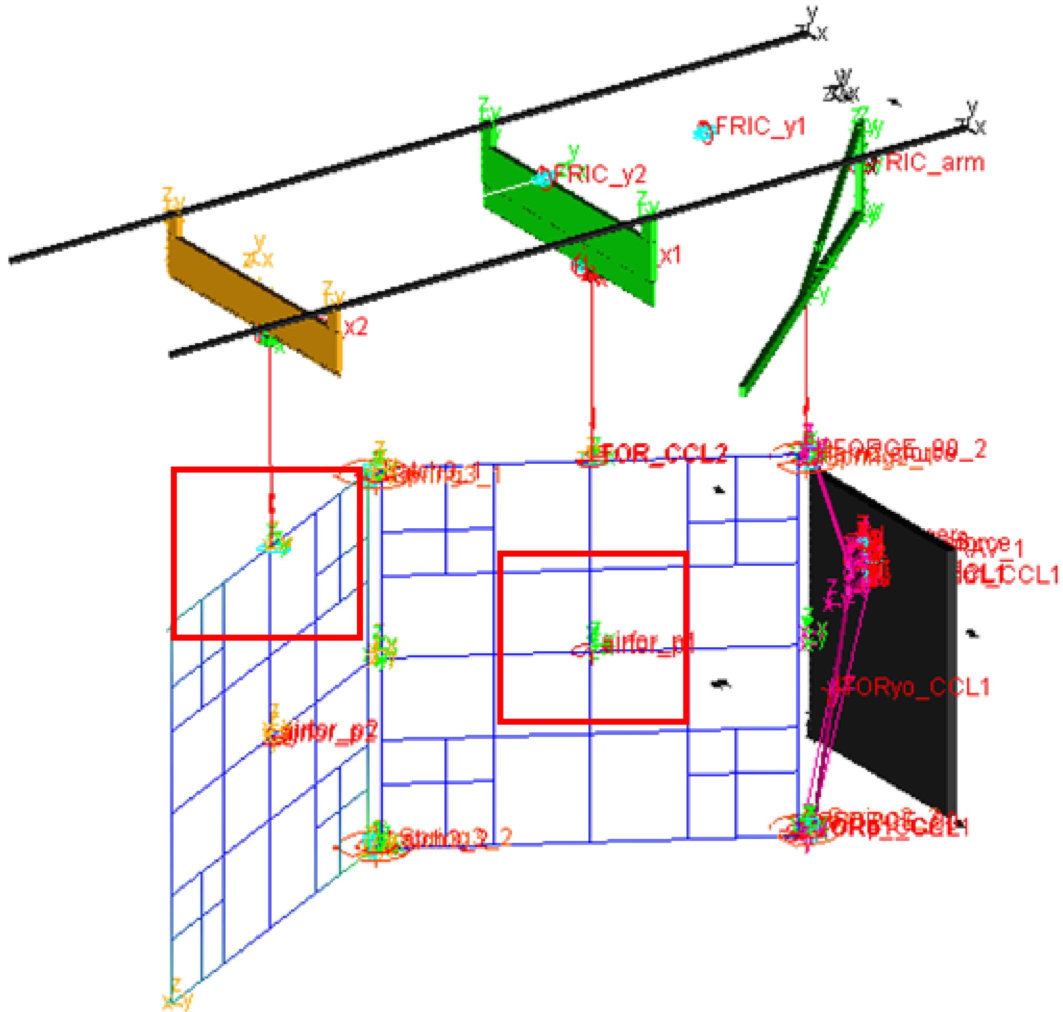
Resistive Torque – Eddy Current Damper



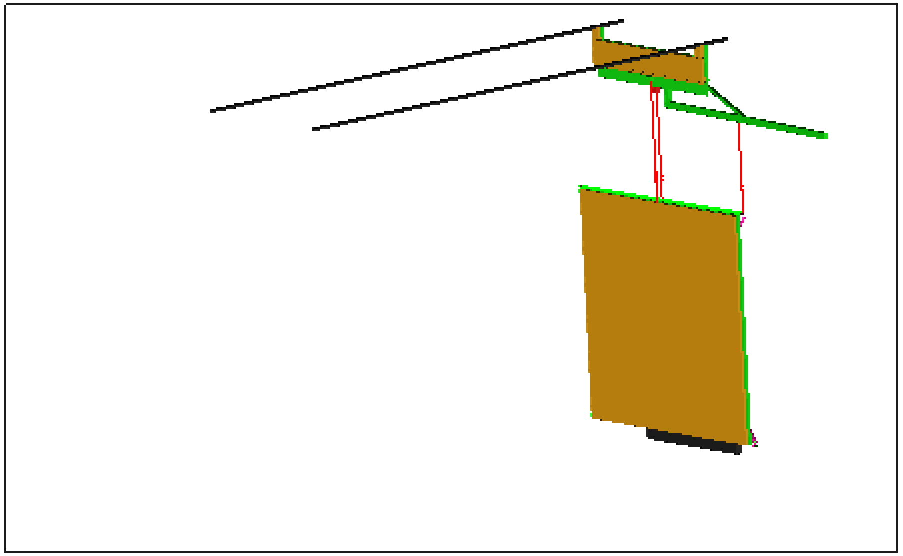
Rigid vs Semi-Flex SADM I/F Torques

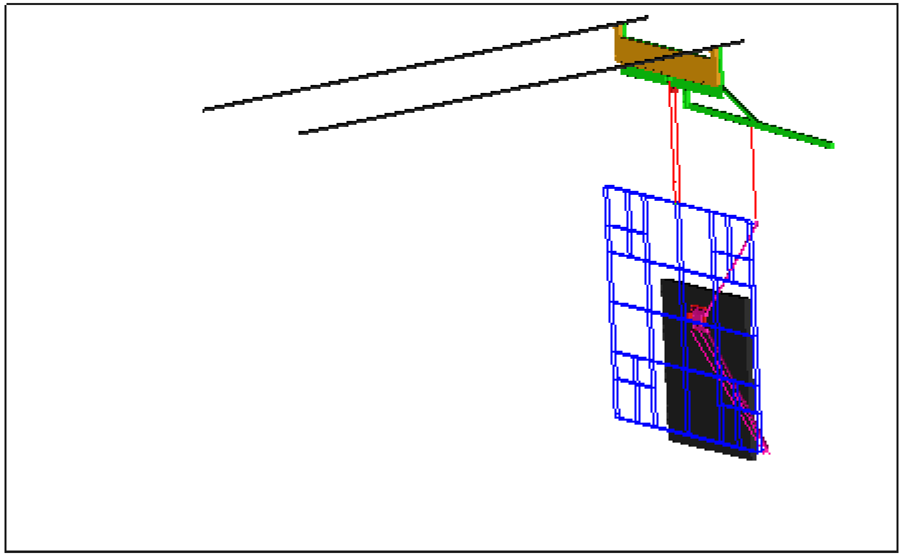


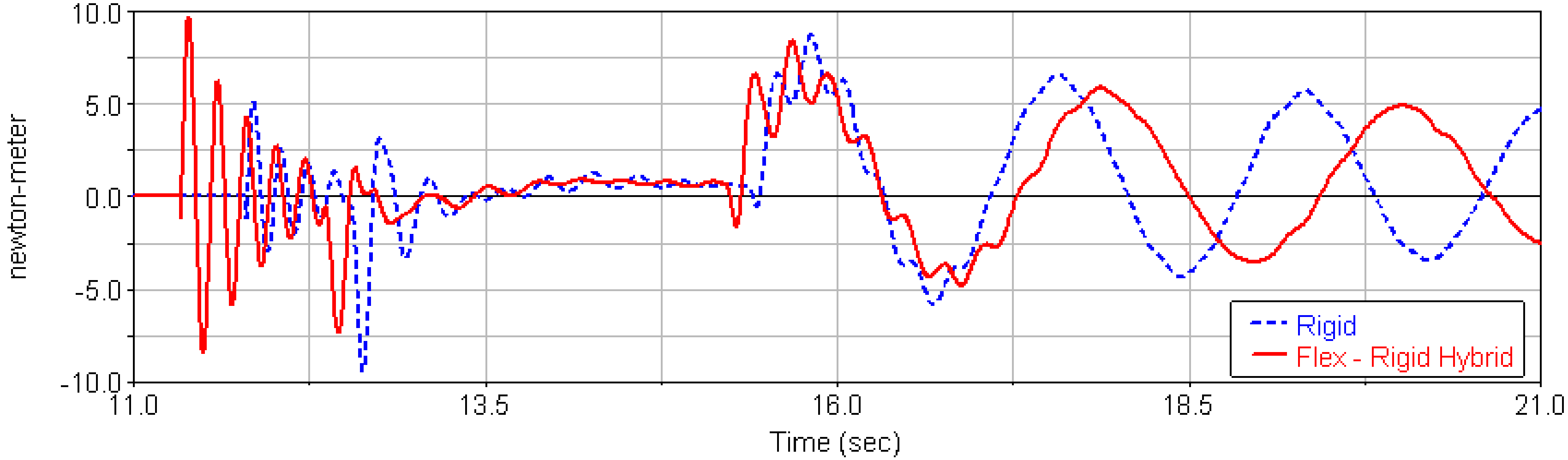
AMOS-3 On Ground Check



AMOS-3 On Ground Check 2



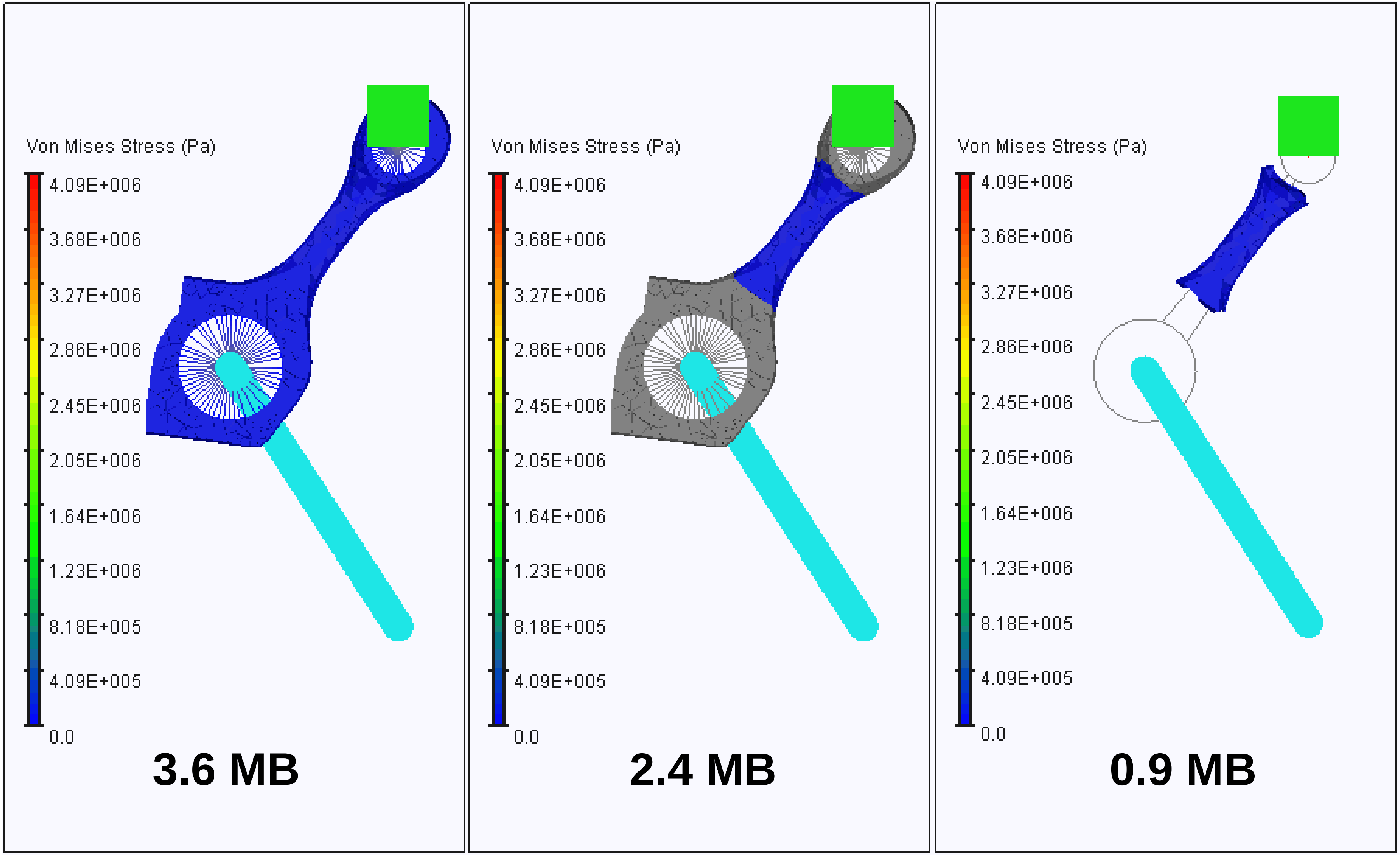




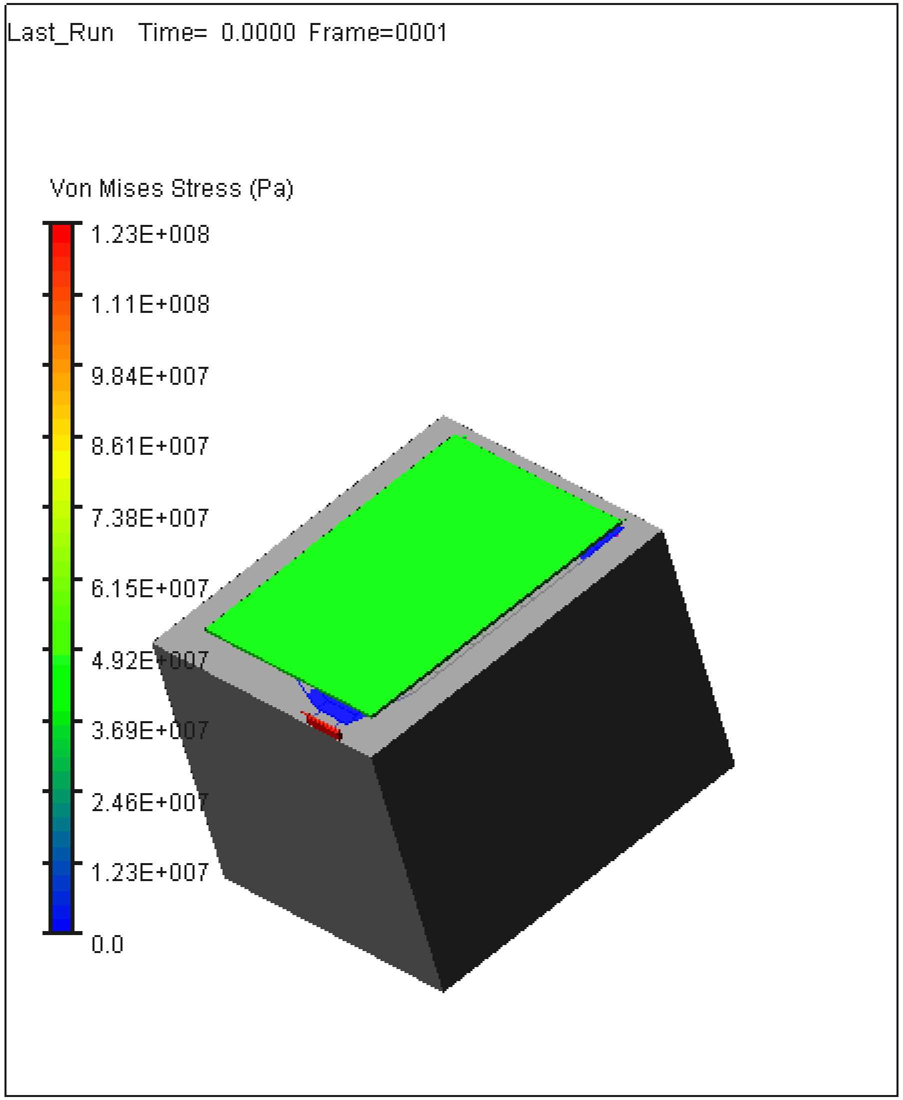
Stress & Strain in ADAMS environment

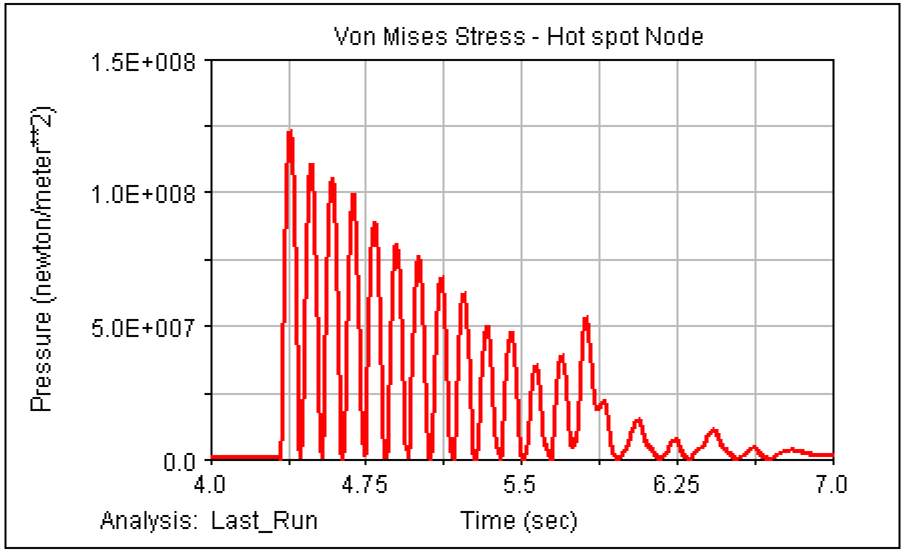
(ADAMS Durability Plugin)

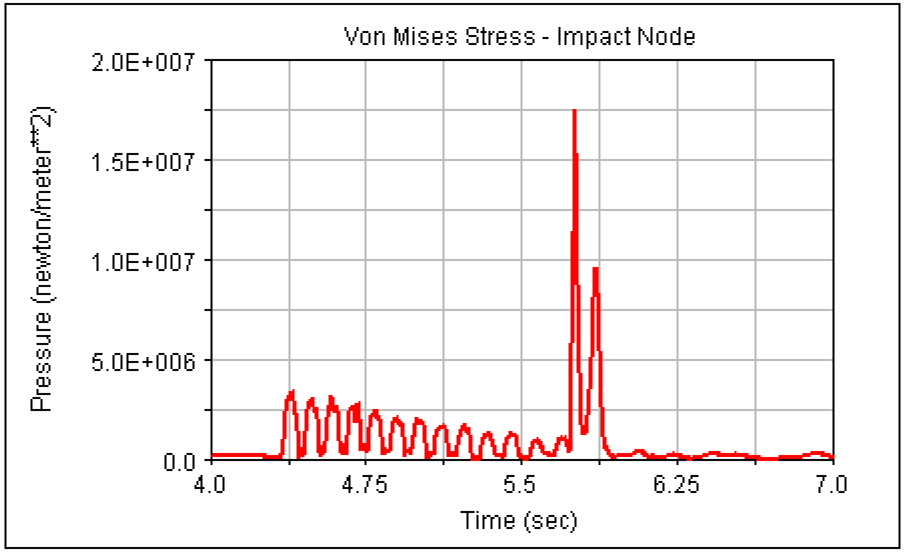
Stress & Strain in ADAMS environment



Deployment and Impact Von Mises Stress





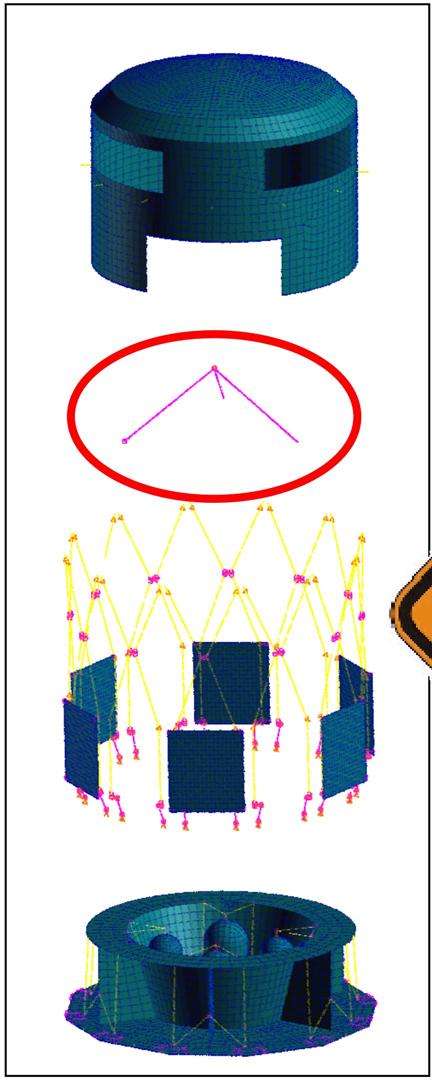


Vibration Analysis in ADAMS environment

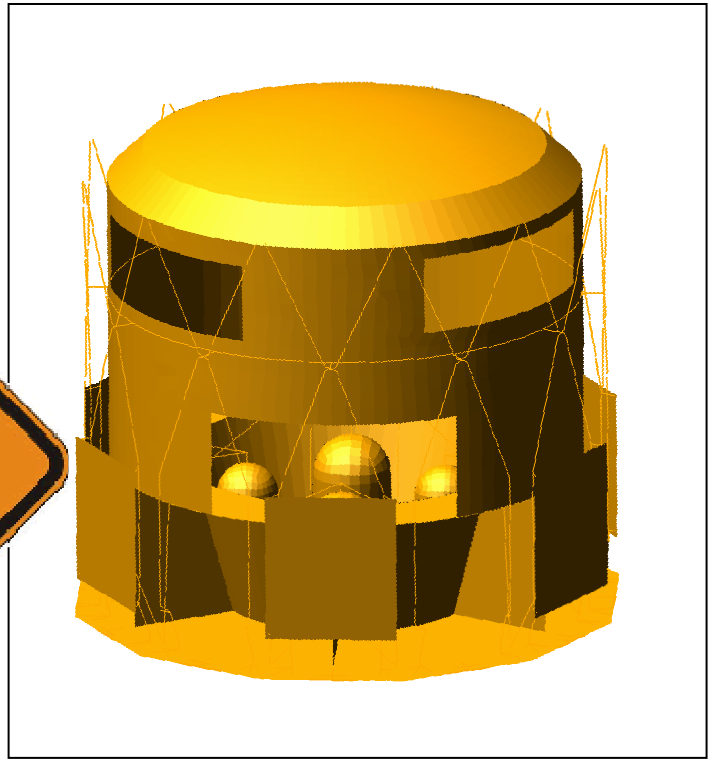
(ADAMS Vibration Plugin)

GAIA Flex - Model

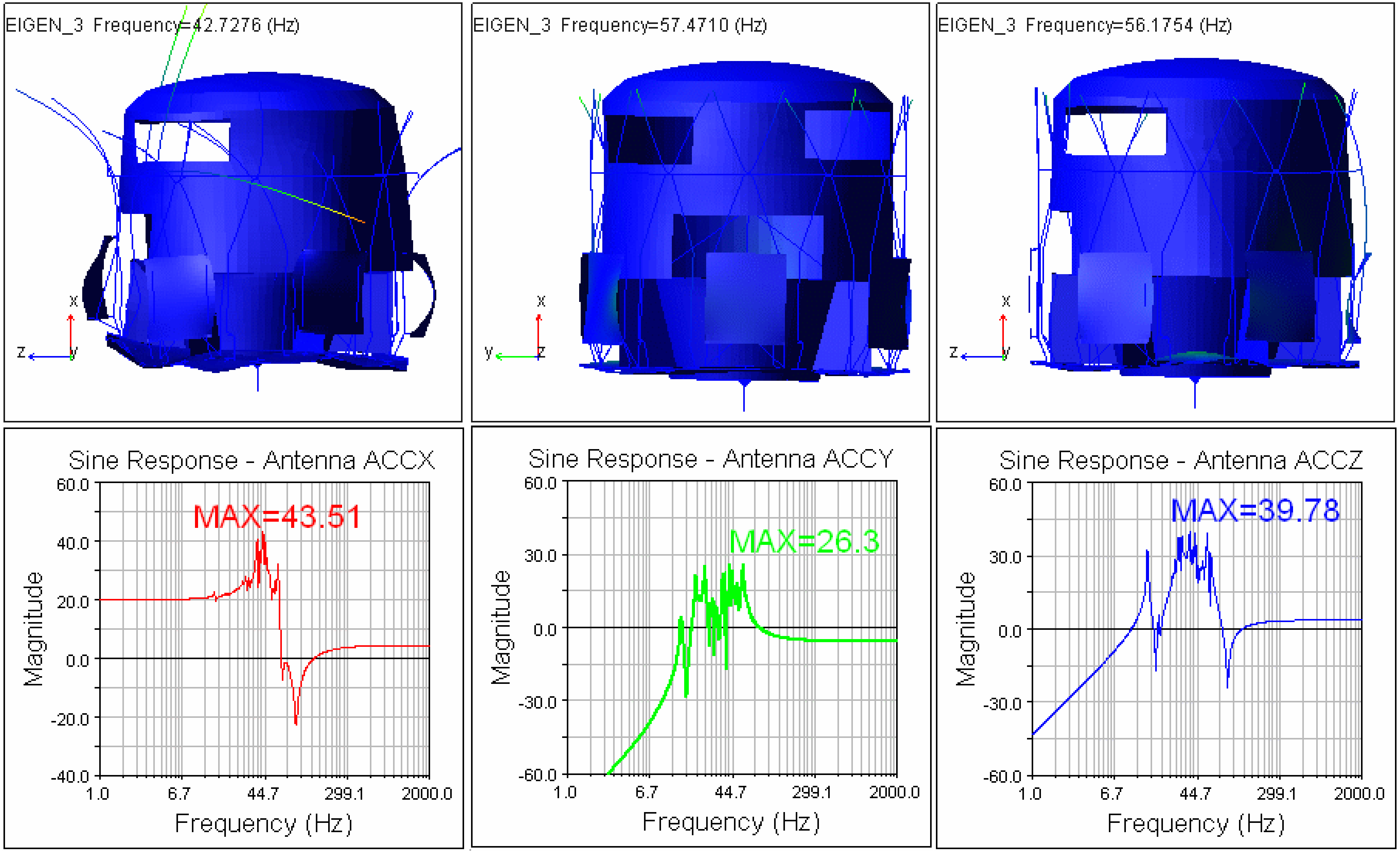
NASTRAN - environment



ADAMS - environment



Gaia - Sine Respose Analysis (2% c.d.)



Conclusions

Solar array application

- Latching shock = Good matching between Flex and Rigid Model
  - *No need of transient analysis in NASTRAN*

- High frequency effects = Relevant effects on reaction Forces and Torques
  - *To take in consideration to right evaluation of M.o.S. on SADM I/F*

Secondary applications

- Wide possibilities in Vibration Analysis