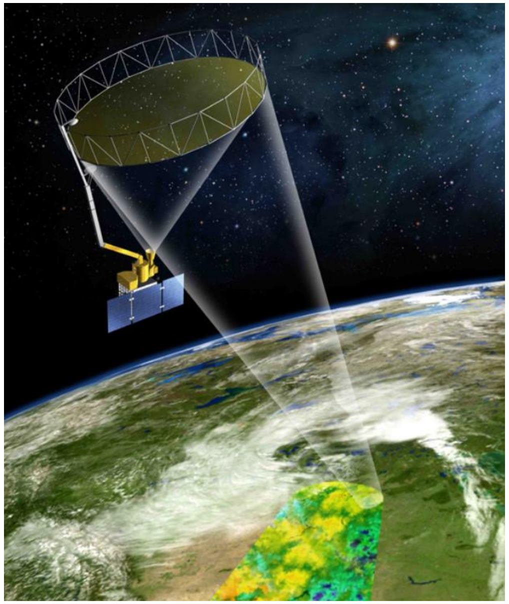
Jet Propulsion Laboratory
California Institute of Technology

Structural Analysis Methodology for Space Deployable Structures using Multi-Body Dynamic Solver

Authors: Farzin Montazersadgh
Mehran Mobrem, PhD

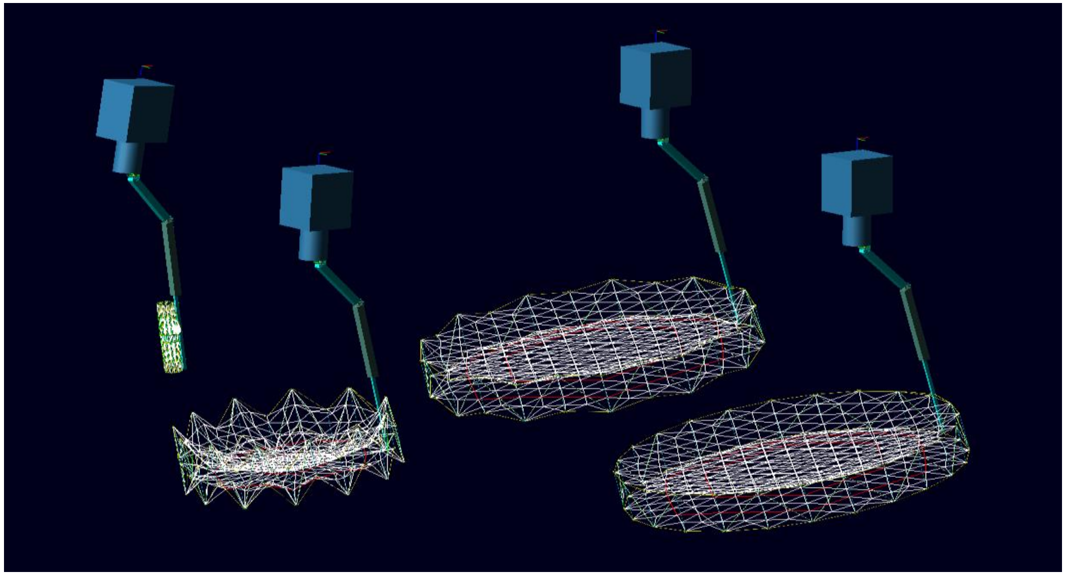
Introduction and Background

- Computational models are a common way to predict structural behavior and internal loads in different components of deployable structures for space application
- Modeling very complex deployable structures requires confirmation that small subsystems from within the large assembly can be modeled properly.
- **Such building block approach should highlight the strengths and shortcomings of the software on very specific problems.**
- In following benchmark problems, a simple subsystem of deployable structures has been separated and studied. In some cases, there are multiple ways of modeling the same physical problem with different methods, even within one software package.
- These benchmark problems were analyzed using multi-body dynamics and nonlinear finite element (FE) solvers.



Multi-Body Dynamics Solver

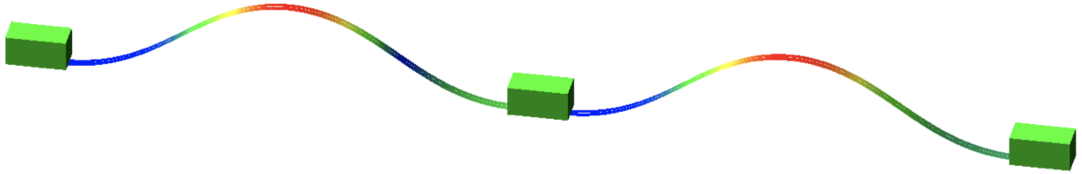
- ADAMS multi-body dynamics solver (MBD solver) is selected for these studies
  - It has been widely used for large motion deployable structures
  - Include limited finite element capabilities
  - A stiff integrator called "GSTIFF" is selected to handle the solutions efficiently
    - The formulation chosen to carry current studies is SI2 (Stabilized-Index Two)
    - Note that SI2 is an implicit numerical solver



ADAMS Simulation of SMAP Reflector: Stowed, Bloom, Crenellation, Full

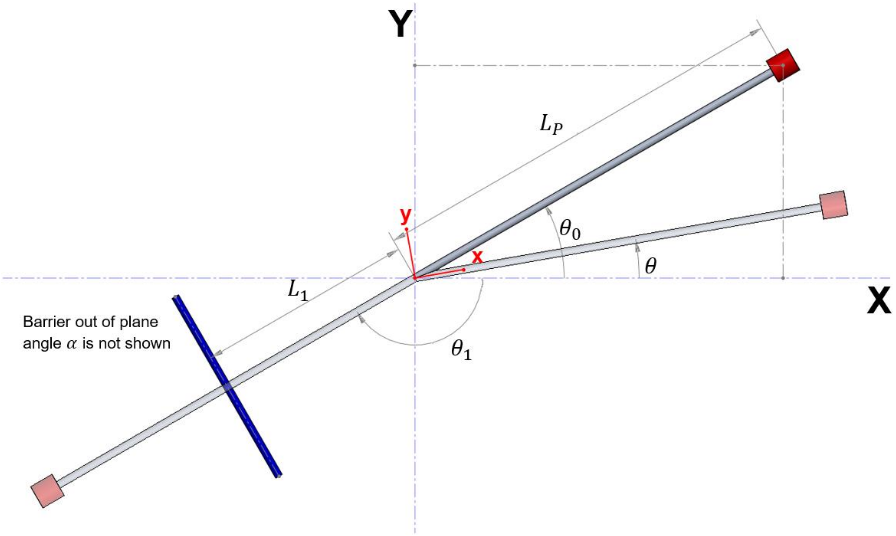
Modeling Flexible Bodies in ADAMS

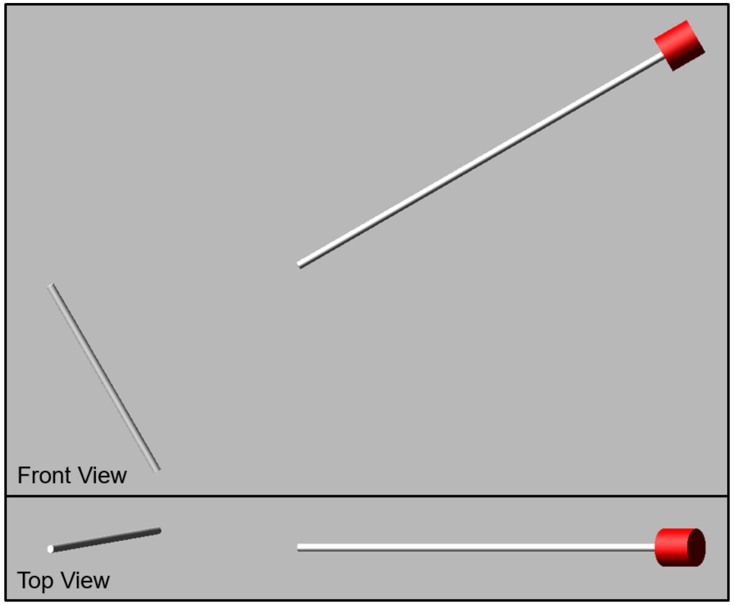
- Unlike FE solvers MBD solver does not have specific element types available, but in order to model flexible bodies, there are a few options:
  - ***Discrete Links:*** the beam-like structures are discretized into many parts that are connected through forces.
  - ***Flexible Bodies:*** the FE mesh is generated in an FE package and solved outside MBD solver and then imported as a Modal Neutral File (MNF). The MNF includes node locations and connectivity, nodal mass and inertia, mode shapes, and generalized mass and stiffness for mode shapes. The model setup and parameterization is also challenging when using this method.
  - ***FE_Part:*** the FE_Part is MBD solver’s native modeling object for beam-like structures. The major advantages of using this method compared to the other two methods mentioned above are: model preparation and parameterization are much easier and geometric nonlinearity is also supported.



Pendulum and Barrier

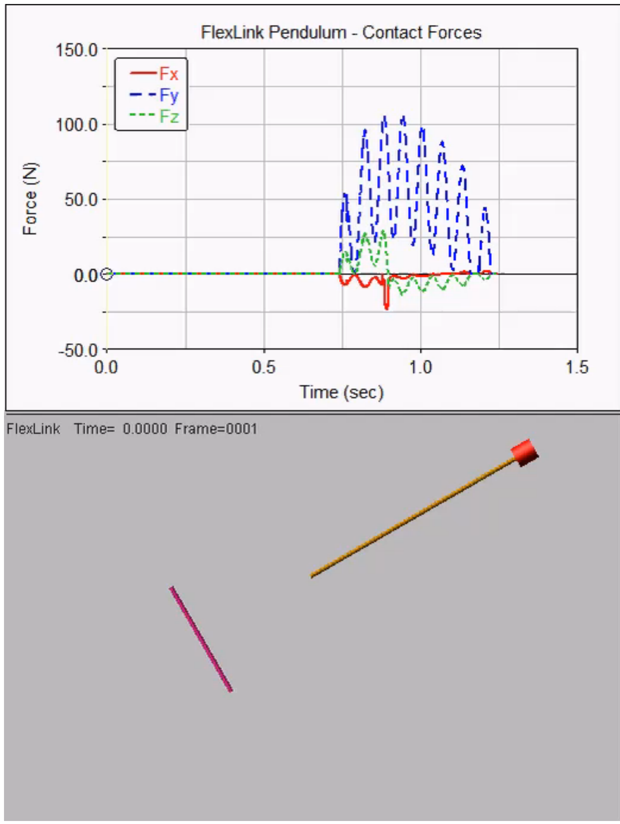
- Motivation for this problem:
  - Evaluate the nonlinear FE capabilities for large rigid body motion in addition to elastic deformation
  - Evaluate behavior during contact between different parts



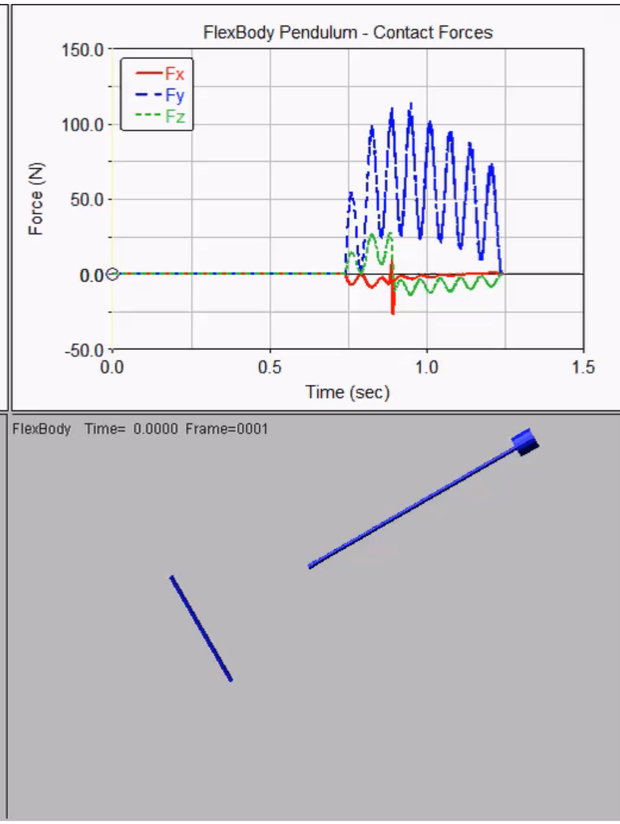


Different Modeling Methods in ADAMS

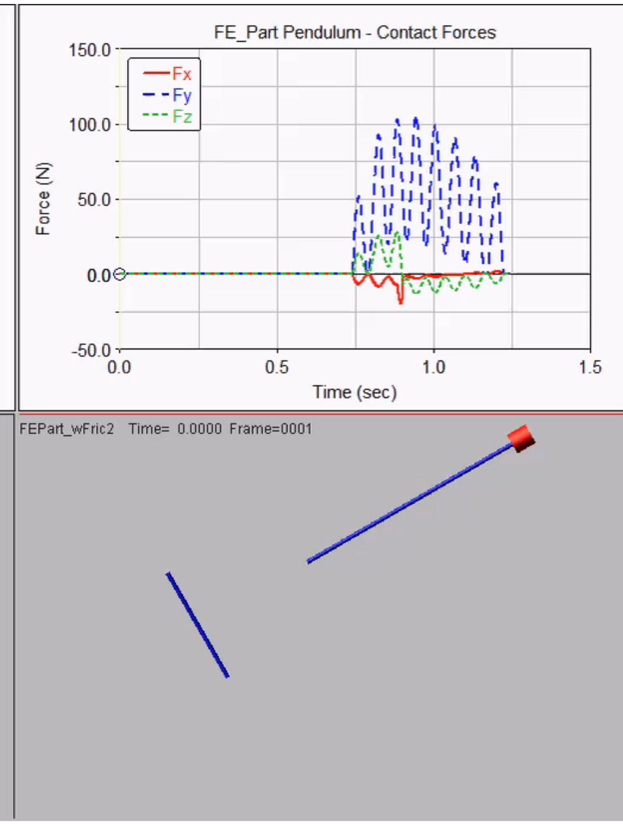
Discrete Links



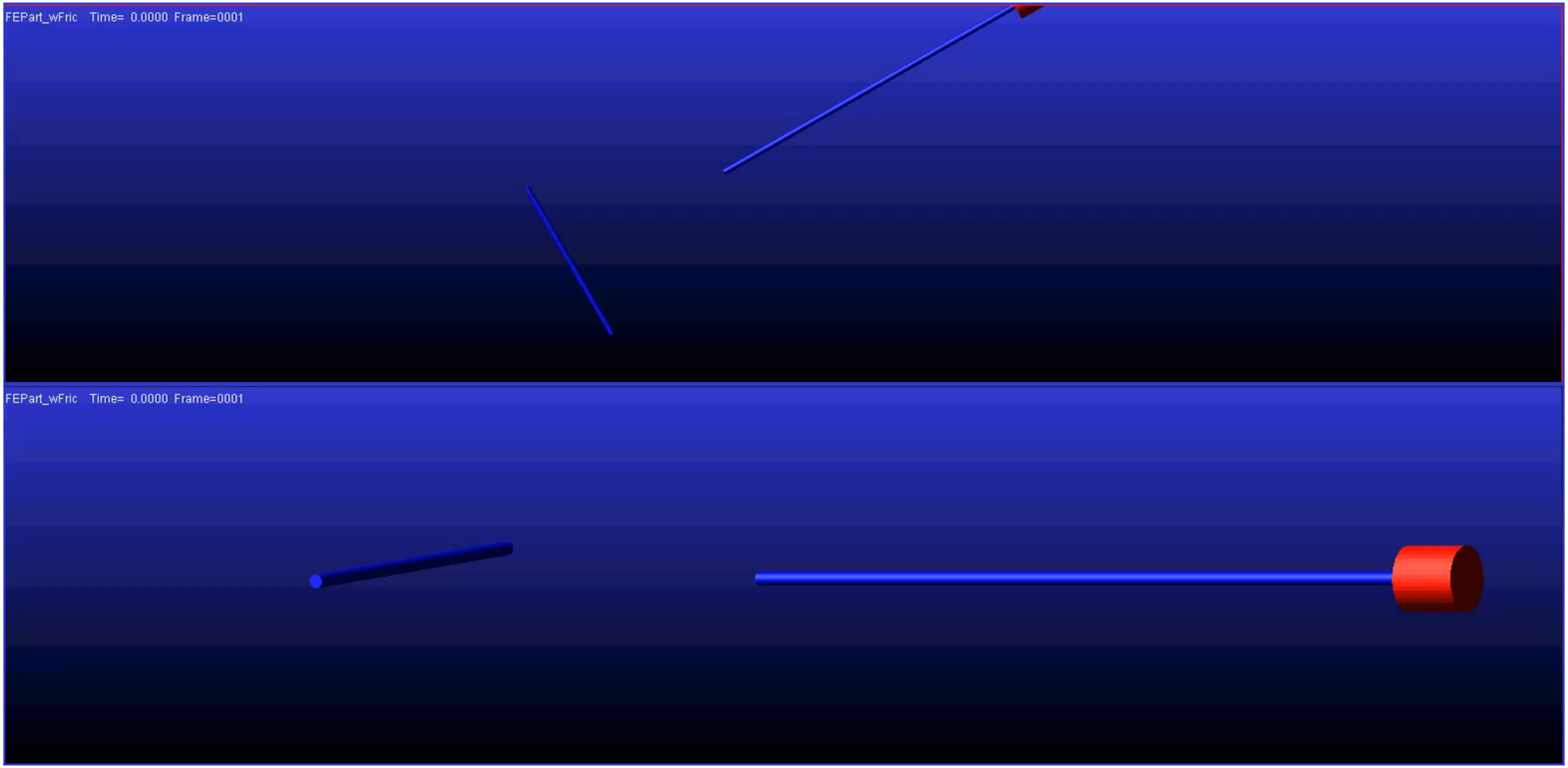
Flexible Bodies



FE_Part



FE_Part Pendulum Animation



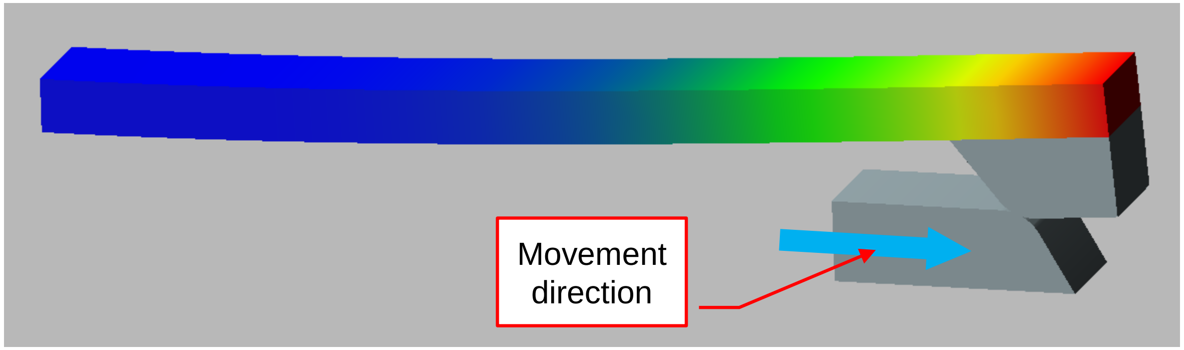
Pendulum and Barrier Results

- **Discrete links:** The most time-consuming model setup was related to the discrete link method but rigid body to rigid body contact is handled very efficiently in the MBD solver
- **Flexbody:** The advantage of this method is the ability to bring in a complex part (not just beam shape) into ADAMS by using the FE mesh.
- **FE_Part:** In comparison to the other two methods, FE_Part model setup and modification is much easier. The shortcoming of FE_Part at the moment is that it can't be saved as a deformed component

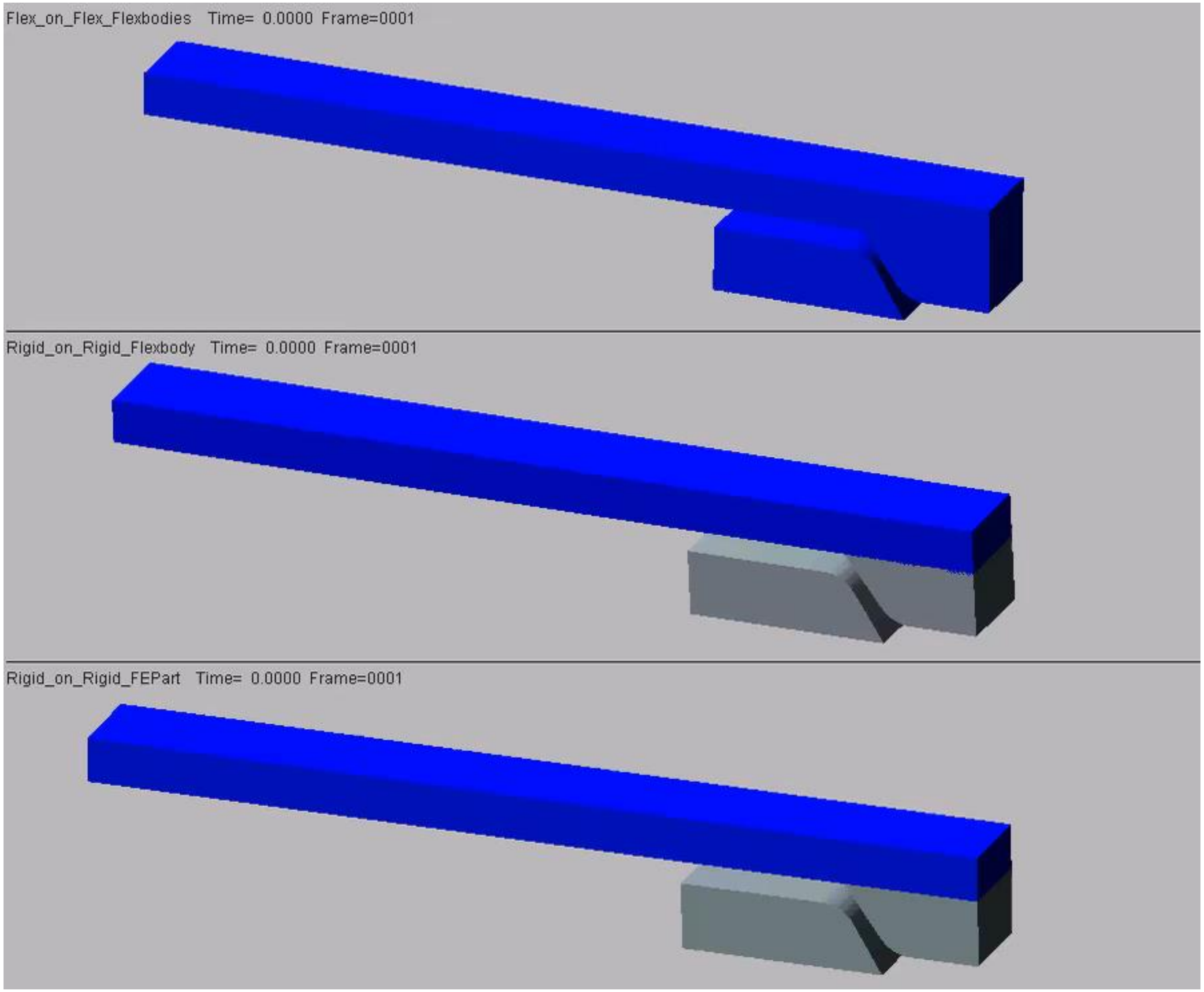
	MBD Solver			Closed-Form Solution [3]
Element Type	Flexlink	Flexbody	FE_Part	Beam Theory
Max rotation after contact (deg)	23.89	24.16	24.66	24.55
First Contact Force Peak [N]	57.1	57.6	54.1	62.4
Max Contact Force [N]	109.4	114.6	107.2	
CPU Time	5 min	1 hour, 36 min	15 min	
Number of CPU cores	8	8	1 CPU	
Solver Type	GSTIFF, SI2	GSTIFF, SI2	GSTIFF, SI2	
Number of elements	83 Parts	9508 solid elements	83 beams	
Notes	Rigid parts are connected through forces	Reduced FE model, 78 modes for each part	1 CPU core limitation	

Flexure Bump

- Motivation for this problem:
  - Evaluate large motion between two parts in FE solver
  - Characterize semi stiff contact
- A common one-way irreversible sliding and locking mechanism used in deployable structures is a ratchet/detent setup.

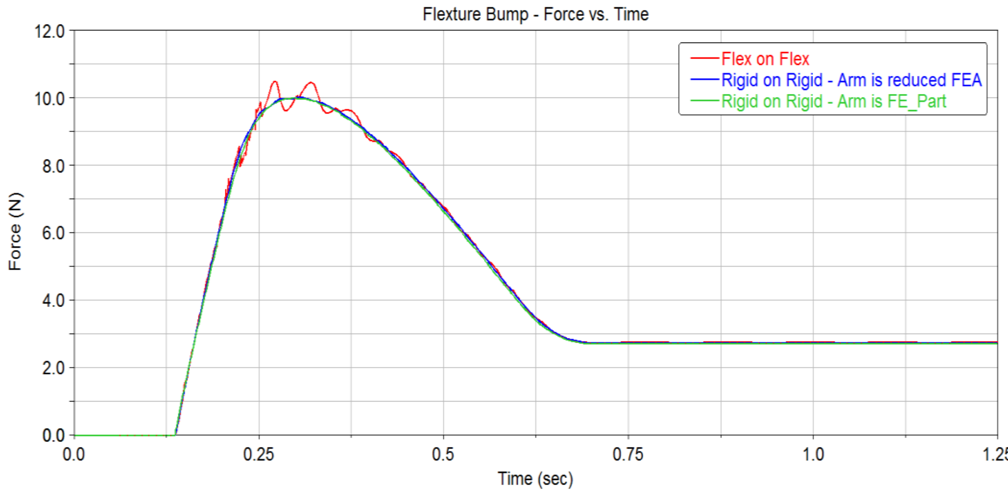


Different Modeling Methods in ADAMS



Flexure Bump Results

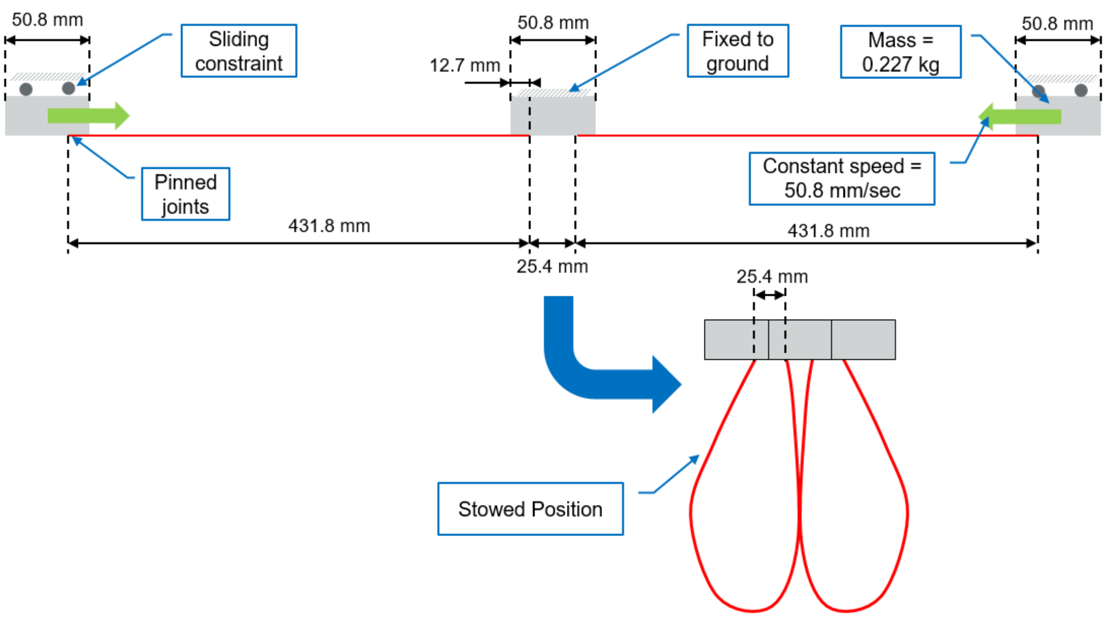
- The high frequency oscillation in flex on flex case is due to FE elements faceting
- ADAMS is a lot more efficient in solving rigid to rigid contact compared to flex on flex or flex on rigid



Bump v=4 mm/sec	MBD Solver		
Case Description	Element Type	Bump Fx [N]	Run Time
Both flexure and bump are flexible	Solids (reduced FEA)	10.5	3 hours 50 mins
Flexure is flexible bump is rigid	Solids (reduced FEA)	10.1	2 hours 4 mins
Flexure arm is flexible, flexure tip and bump are rigid	Solids (reduced FEA)	10.0	Under 2 mins
Flexure arm is flexible, flexure tip and bump are rigid	Beams (FE_Part)	10.0	Under 2 mins
Bump v=40 mm/sec			
Flexure arm is flexible, flexure tip and bump are rigid	Beams (FE_Part)	10.5	Under 2 mins

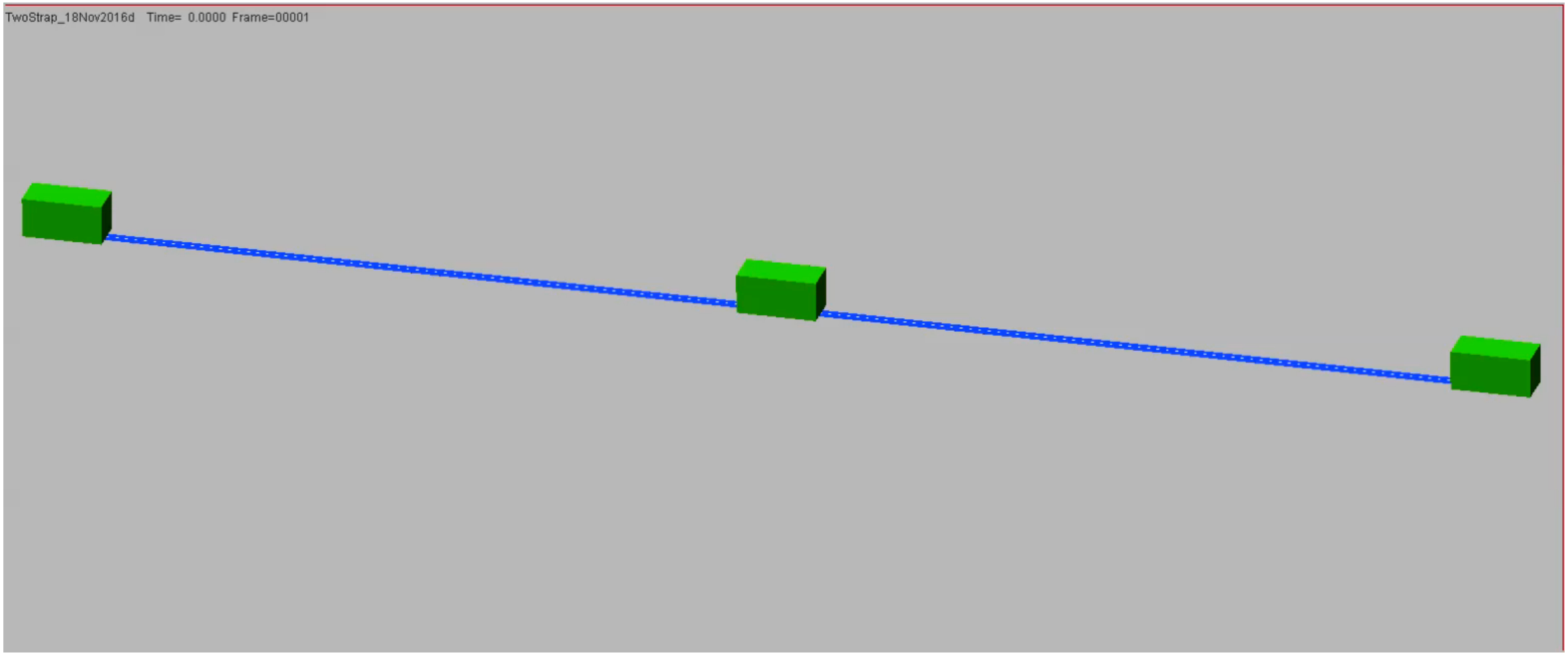
Two Strap Setup

- Motivation for this problem:
  - Evaluate highly flexible parts with large displacements and contact
  - Establish stored strain energy
- There are many types of deployable mechanisms made of thin wall flexible structures, for example a network of straps making the structural surface of reflector mesh antenna



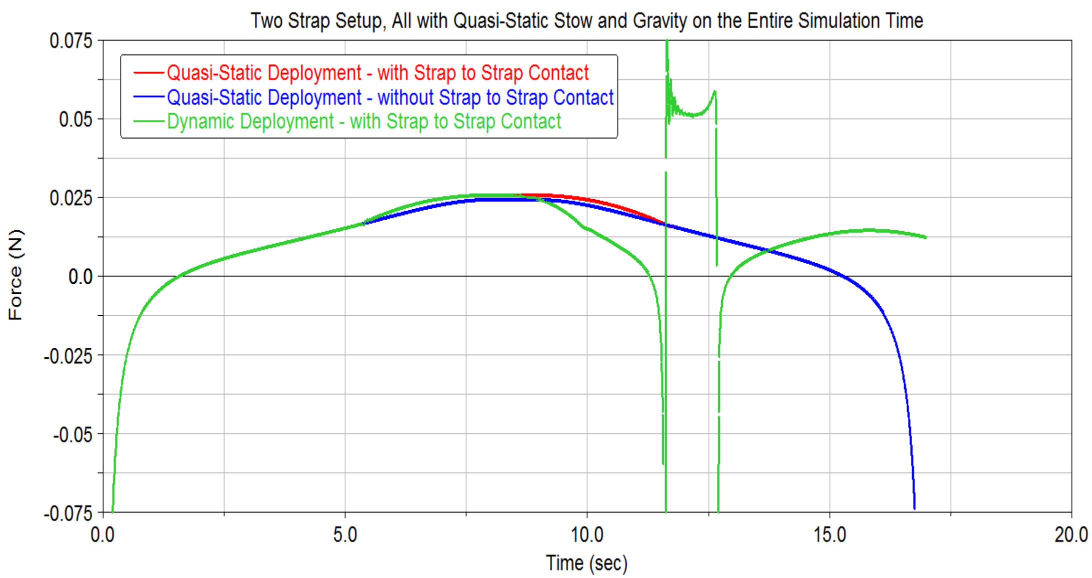
Two Strap Animation

Quasi-static stowing and dynamic release without gravity



Two Strap Results

- In this example the straps are not constrained from both sides, therefore, the max force does not change significantly when the contact is not included. If there are more straps in a more confined space, the contact will affect the stowing/deploying force more significantly.
- Introducing contact is important to capture forces properly and can be used to detect snags
- Further improvement in contact formulation is required for solver efficiency

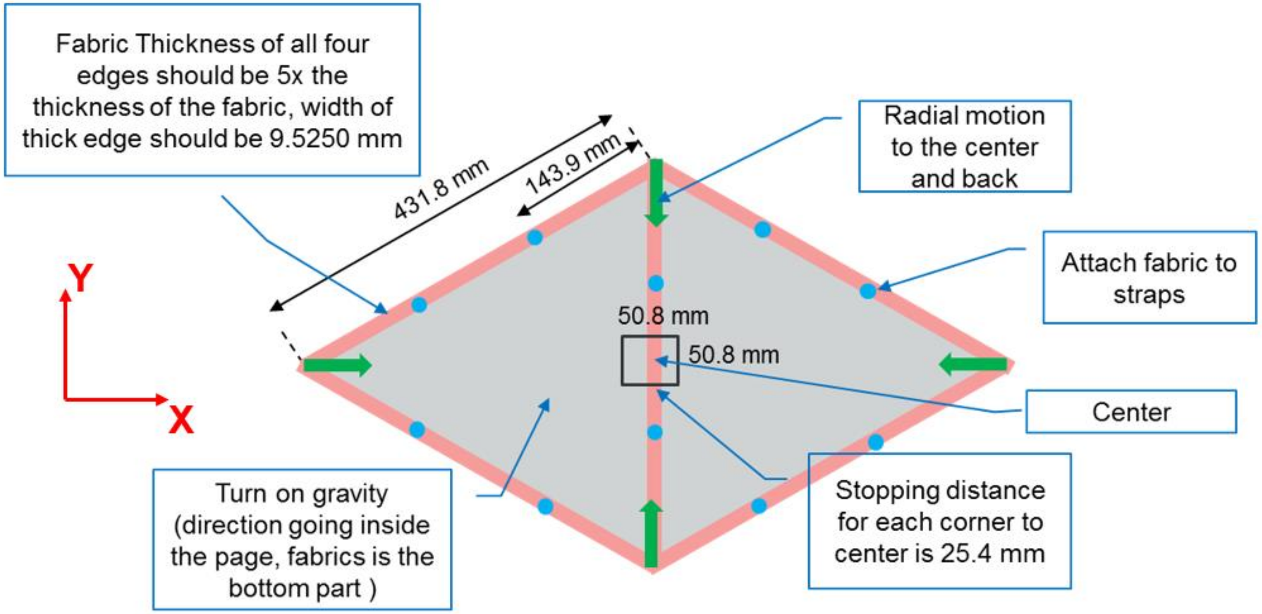


	MBD Solver		
Case Description	Gravity	Stowed Force[1] [N]	Run Time (t= 18 sec)
Quasi-Static both Stow and Deployment (with contact)	Yes	0.0257	9 min 24 sec
Quasi-Static both Stow and Deployment (without contact)	Yes	0.0243	1 min 18 sec
Quasi-Static Stow, Dynamic Deployment (with contact)	Yes	0.0257	7 min 25 sec
Quasi-Static Stow, Dynamic Deployment (with contact)	Only for Stowing	0.0257	8 min 4 sec

[1] Maximum force along the cart motion

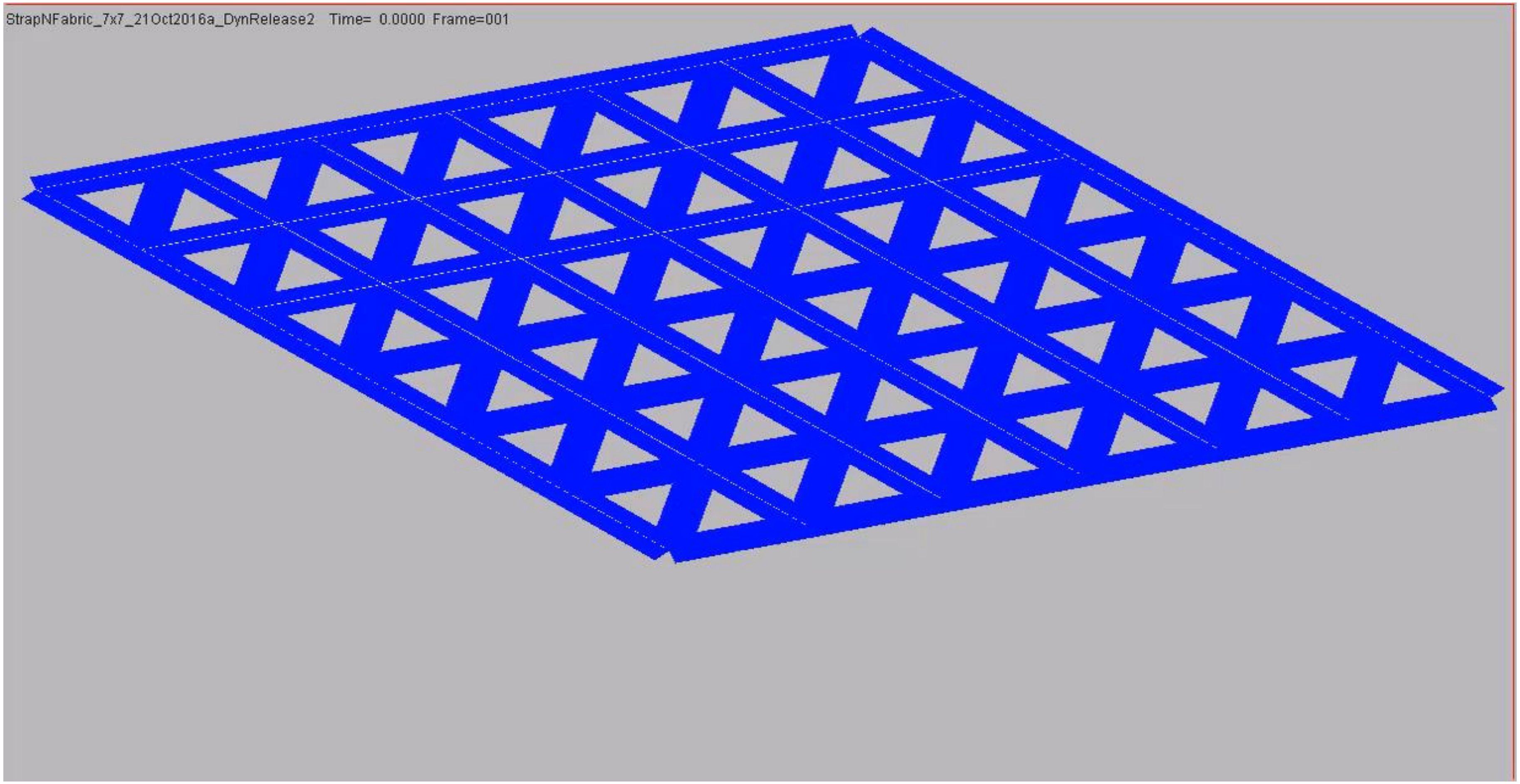
Straps and Fabric

- Motivation for this problem:
  - Evaluate highly flexible parts with large displacements and contact
  - Establish stored strain energy



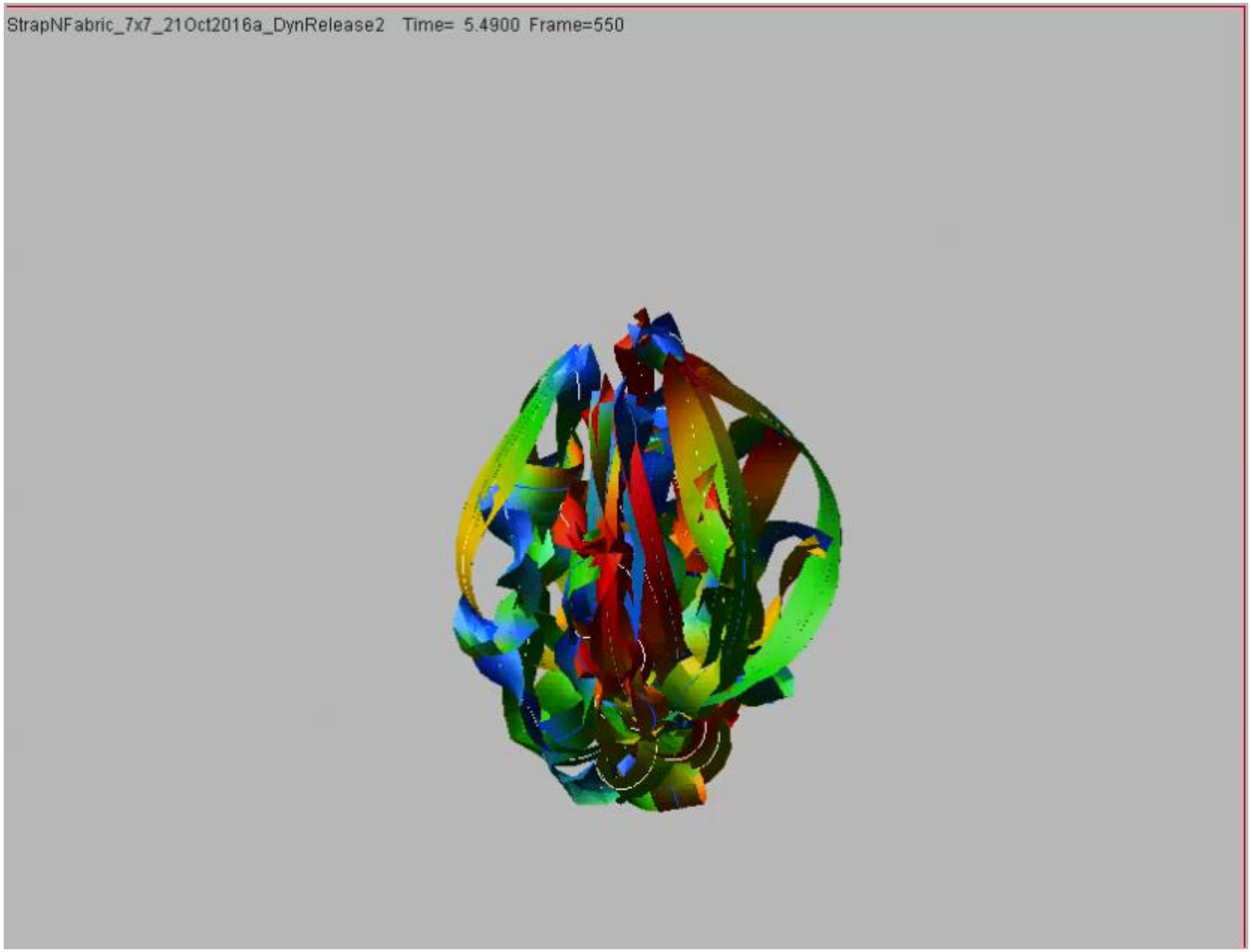
Straps and Fabric Animation – Stowing

Stowing with gravity present, without contact between parts



Straps and Fabric Animation – Dynamic Release

Stowing with gravity present, deploying ? gravity without contact between parts



Conclusions

- In the examined benchmark problems using MBD solver, optimizing solver settings for each model is important to keeping the run time low and manageable.
  - For example, in models where contact has been defined, turning off contact and taking larger time steps before contact happens could significantly lower the computation time. The contact force can then become activated with a distance or time sensor.
- Rigid to rigid contact solves much faster than other options, therefore, wherever possible, this contact algorithm is preferred.
  - Further improvement in FE_part contact formulation is needed to keep run times reasonable
- Constructing fabric with FE_Part and tying them together is not recommended since both model setup and run time showed to be not feasible even for a scaled down problem.
- If these subsystems are complicated and CPU-intensive, then it is recommended to build a detailed model and extract force/displacement functions based on subsystem results and then implement them as functions in the system level model.