Capturing Nonlinear Effects within Transient Coupled Loads Analysis

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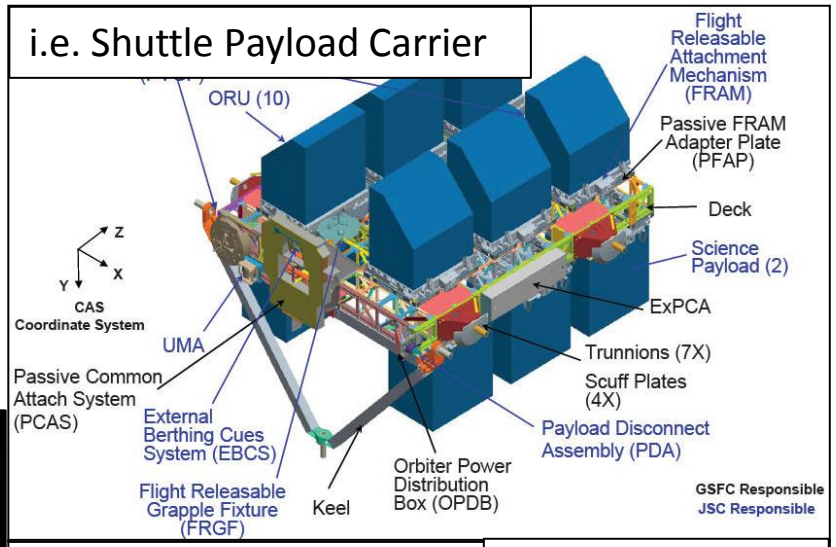
Motivation: Why do we need this?

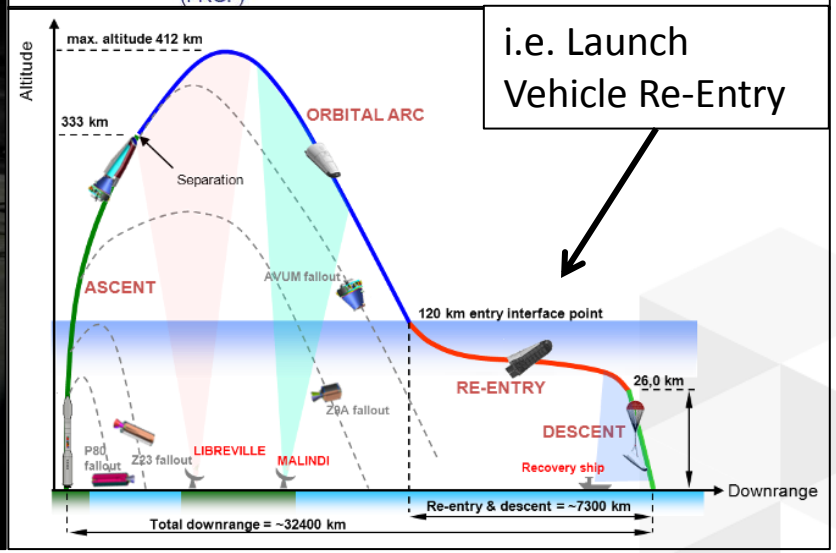
The ability to model local nonlinearities is often required for transient coupled loads analysis

i.e. Air-Drop

i.e. Shuttle Payload Carrier



i.e. Launch Vehicle Re-Entry



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Motivation: Options for Simulations capable of local nonlinearities

1. Write a special purpose program to simulate response
   - Henkel-Mar formulation, or standard integrators
2. Use a general purpose nonlinear solution
   - Abaqus, ANSYS, Nastran SOL 129/601, etc.
3. Use a standard linear Nastran solution with NOLINi cards to represent local nonlinearity
   - Much faster and simpler than other options
   - Limited to simple non-linear behavior such as gaps
     - No plasticity, large deformation, etc.

Method Presented

Methods and Implementation

Use NASTRAN's NOLIN functionality to apply forces resulting in non-linear behavior - $\boldsymbol{F_{n+1} = f(x_n, \dot{x}_n)}$

Method #1 (Direct)

- Reduce model to DOF associated with non-linear forces via Superelements

Method #2 (Modal)

- Modal Reduction
- Create EPOINTs
- Transfer functions

Keys to Implementation

- Small time steps
- Reduce model to small DOF

Methods and Implementation

Use NASTRAN's NOLIN functionality to apply forces resulting in non-linear behavior - $\boldsymbol{F_{n+1} = f(x_n, \dot{x}_n)}$

Set-up Example and Visualize NASTRAN's NOLIN Functionality

Superelements

Keys to Implementation

- Small time steps
- Reduce model to small DOF

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Example Model Set-up

General Attributes: Steel Rod, 0.5” diameter

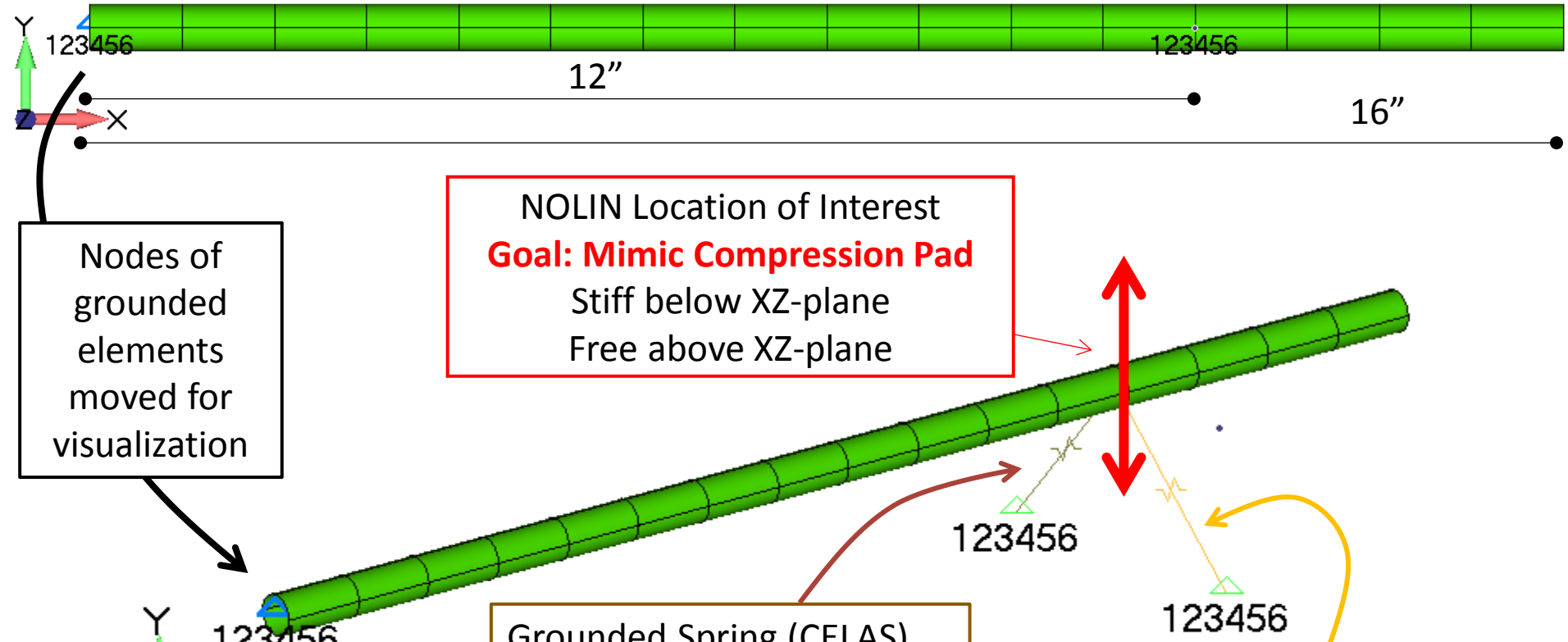

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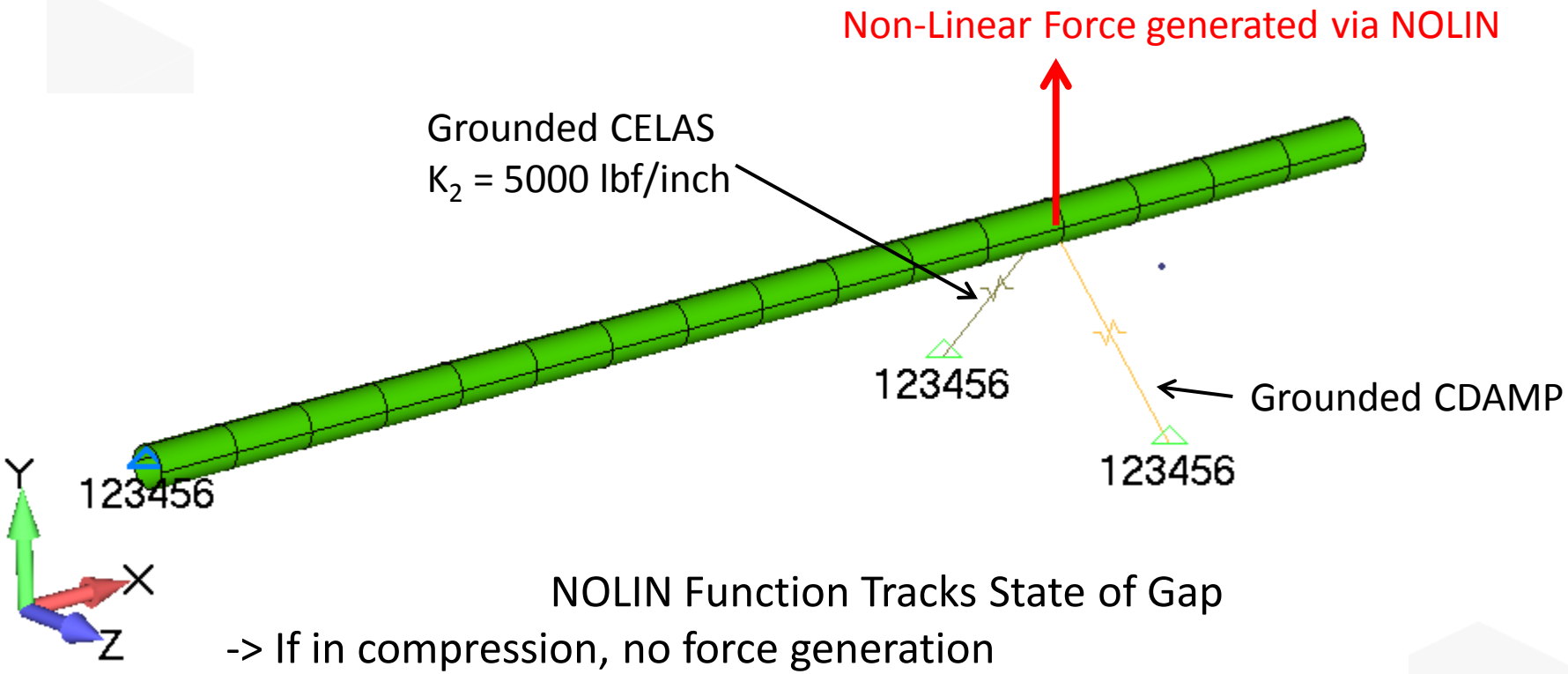
Illustration of NOLIN NASTRAN Capability



NOLIN Function Tracks State of Gap

-> If in compression, no force generation

-> If in tension, **force equal and opposite force of CELAS generated**

NOLIN FEM contains implementation

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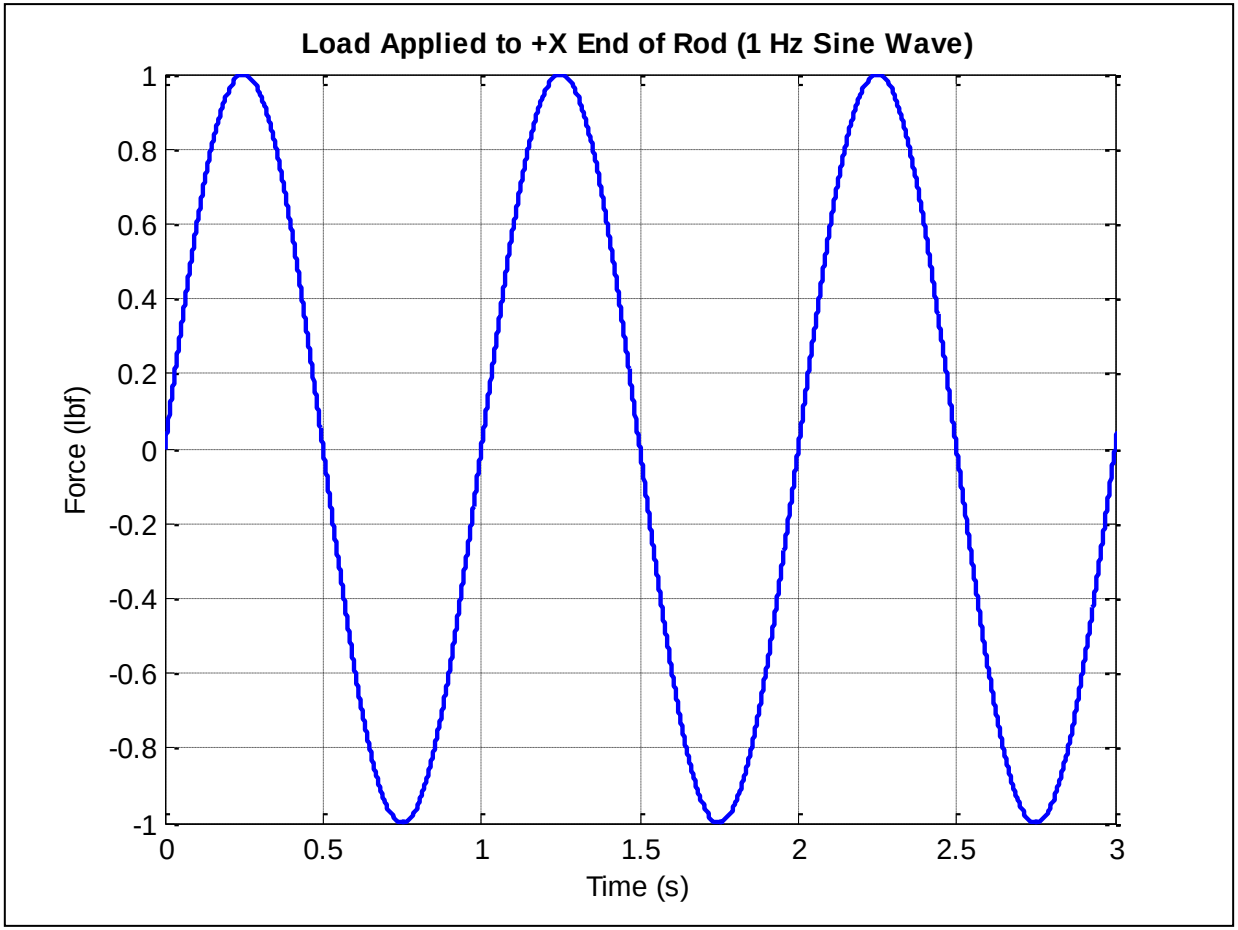
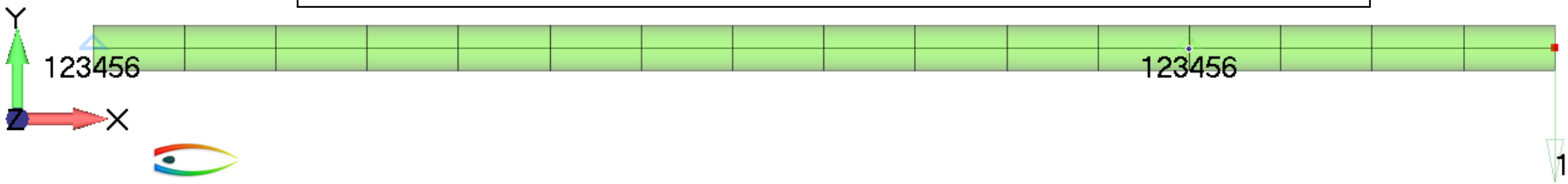
Loading Applied to +X End of Rod





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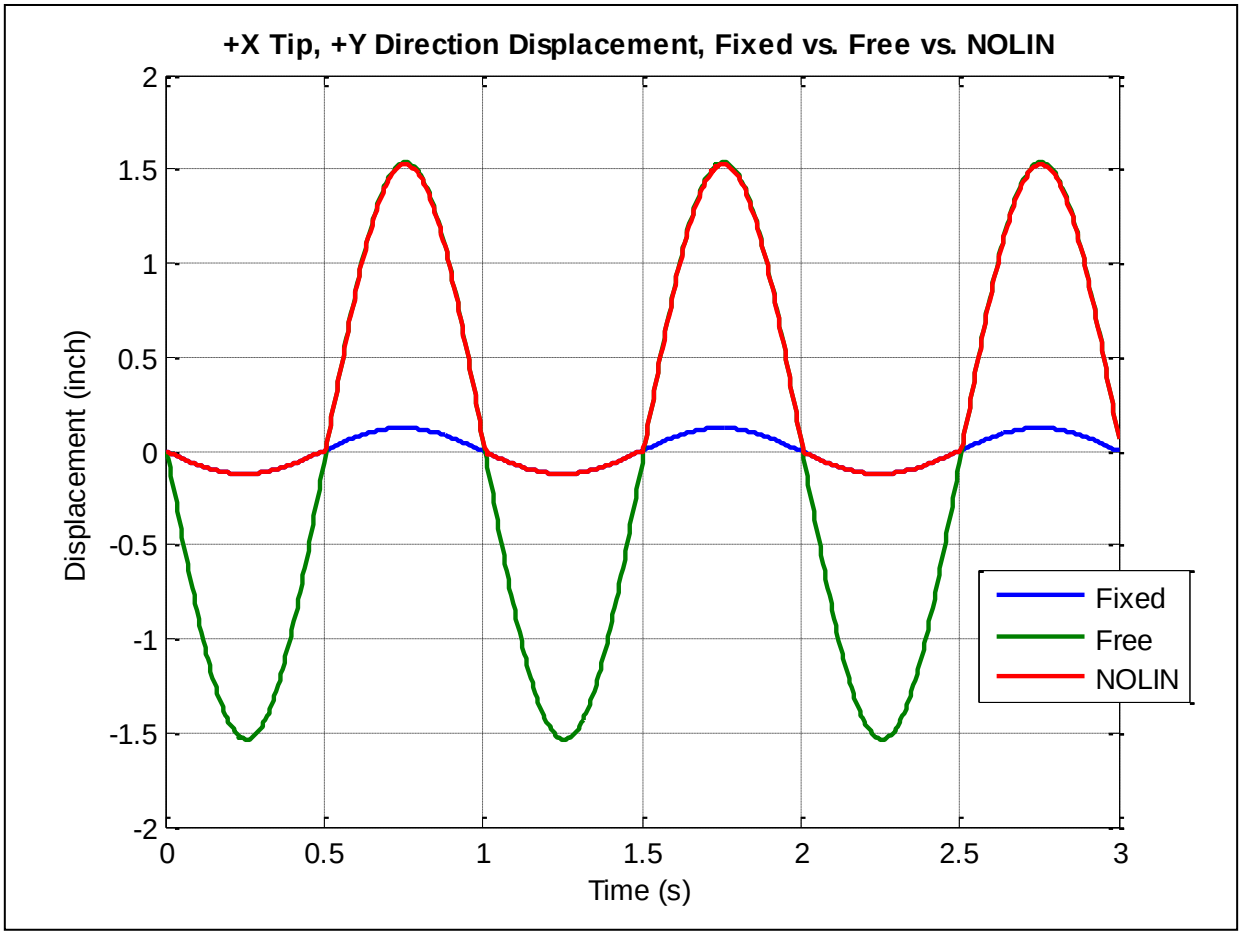
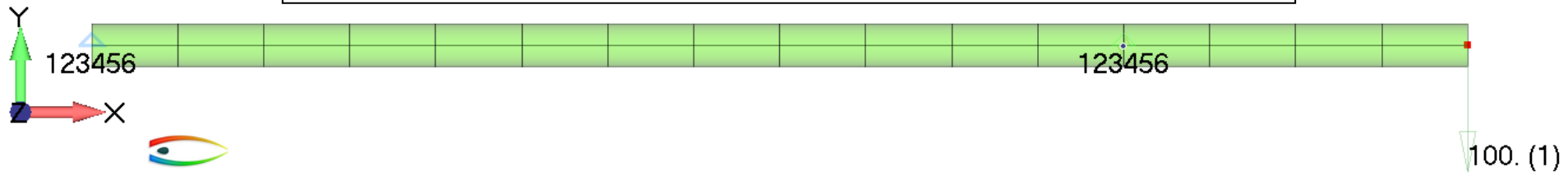
Comparison of +Y Tip Displacements: Fixed vs. Free vs. NOLIN





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Methods and Implementation

Use NA… SUN functionality to apply forces resulting in… havior - $F_{n+1} = f(x_n, \dot{x}_n)$

Walk through Direct Method

Method #1 (Direct)

- Reduce model to DOF associated with non-linear forces via Superelements

Keys to Implementation

- Small time steps
- Reduce model to small DOF

Method #2 (Modal)

- Modal Re…
- Create EPOINTs
- Transfer functions

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How was Non-Linearity capability implemented in the Direct Method?


```
SESET,100,101,THRU,112
SESET,100,114,THRU,117
SPOINT,1001,THRU,1100
SEQSET1,100,0,1001,THRU,1100
CELAS2    9999001   5000.       113         2
CDAMP2    9999002      1.       113         2
TABLED1       999
              -1.       0.       0.       0.      10.      10.     ENDT
NOLIN1        100      113         2   5000.      113         2      999
$------><--02--><--03--><--04--><--05--><--06--><--07--><--08-->
```

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NOLIN1        100      113        2  5000.      113        2      999
$------><--02--><--03--><--04--><--05--><--06--><--07--><--08-->
```

Step 1: Define Superelement

Note 1: All grids except 113 – which is grid at NOLIN location – pulled into superelement

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-04--><--05--><--06--><--07--><--08-->
```

Step 1: Define Superelement
Note 1: All grids except 113 – which is grid at NOLIN location – pulled into superelement

Step 2: Use NOLIN to determine force $F_{n+1} = f(x_{n\,(gap)})$

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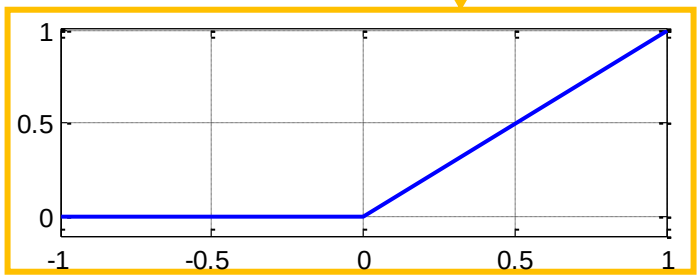
TABLED1       999
              -1.       0.          0.         0.        10.       10.       ENDT
NOLIN1        100      113           2      5000.       113         2        999
-04--><--05--><--06--><--07--><--08-->
```

Step 1: Define Superelement
Note 1: All grids except 113 – which is grid at NOLIN location – pulled into superelement

Note 4: NOLIN Reference
Slope = 0 in "compression"
Slope = 1 in "tension"

Step 2: Use NOLIN to determine force $F_{n+1} = f(x_{n\,(gap)})$

Note 3: NOLIN Slope equal to spring constant



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Methods and Implementation

Use NASTRAN's NOLIN fu… pply forces resulting in non-li… $F_{n+1} = f(x_n, \dot{x}_n)$

Walk through Modal Method

Method #2 (Modal)

- Modal Reduction
- Create EPOINTs
- Transfer functions

…duce model to DOF associated with non-linear forces via Superelements

Keys to Implementation

- Small time steps
- Reduce model to small DOF

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How was Non-Linearity capability implemented in the Modal Method?


```
$------><--02--><--03--><--04--><--05--><--06--><--07--><--08-->
EPOINT   1000002
EPOINT   1000003
CELAS2   9999001  5000.      113       2
CDAMP2   9999002     1.      113       2
TF           100     113        2      1.
         1000002       0     -1.
TF           100 1000003        0      1.
             113       2     -1.
TF           100 1000002        0      1.
TABLED1      999
             -1.      0.       0.      0.     10.     10.     ENDT
NOLIN1       100 1000002        0  5000. 1000003        0      999
$------><--02--><--03--><--04--><--05--><--06--><--07--><--08-->
```

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EPOINT    1000002
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CELAS2    9999001  5000.      113        2
CDAMP2    9999002     1.      113        2
TF            100      113        2      1.
              1000002        0     -1.
TF            100 1000003        0      1.
                  113        2     -1.
TF            100 1000002        0      1.
TABLED1       999
              -1.       0.       0.       0.      10.      10.     ENDT
NOLIN1        100 1000002        0  5000. 1000003        0      999
$------><--02--><--03--><--04--><--05--><--06--><--07--><--08-->
```

Step 1: Create 2 EPOINTs

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How was Non-Linearity capability implemented in the Modal Method?


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TF            100      113         2       1.
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TF            100  1000003         0       1.
              113        2      -1.
TF            100  1000002         0       1.
TABLED1       999
              -1.       0.        0.        0.       10.       10.     ENDT
NOLIN1        100  1000002         0   5000.  1000003         0      999
$------><--02--><--03--><--04--><--05--><--06--><--07--><--08-->
```

Step 1: Create 2 EPOINTs

Step 2: Set-up EPOINTs
Equate “Gap” to one EPOINT
Equate Force output from NOLIN to other EPOINT

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How was Non-Linearity capability implemented in the Modal Method?


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TF            100      113         2       1.
          1000002        0        -1.
TF            100  1000003         0       1.
              113        2        -1.
TF            100  1000002         0       1.
TABLED1       999
              -1.       0.        0.        0.       10.       10.      ENDT
NOLIN1        100  1000002         0   5000.  1000003         0       999
        --03--><--04--><--05--><--06--><--07--><--08-->
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Step 1: Create 2 EPOINTs

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Step 3: Use NOLIN to determine force
$F_{n+1} = f(x_{n\,(gap)})$

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CDAMP2    9999002       1.       113         2
TF              100      113         2       1.
          1000002        0        -1.
TF              100 1000003         0       1.
                113        2        -1.
TF              100 1000002         0       1.
TABLED1         999
                -1.       0.        0.       0.       10.       10.       ENDT
NOLIN1          100 1000002         0    5000. 1000003         0         999
```

```
--03--><--04--><--05-->
```

Step 1: Create 2 EPOINTs

Note 1: NOLIN Slope equal to spring constant

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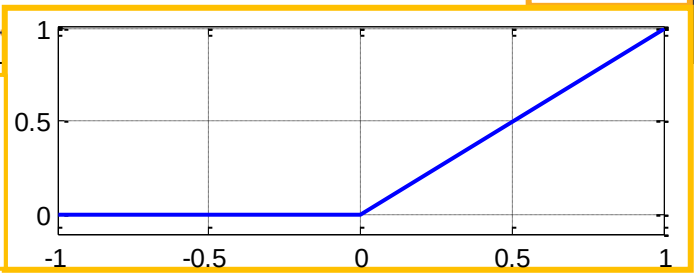

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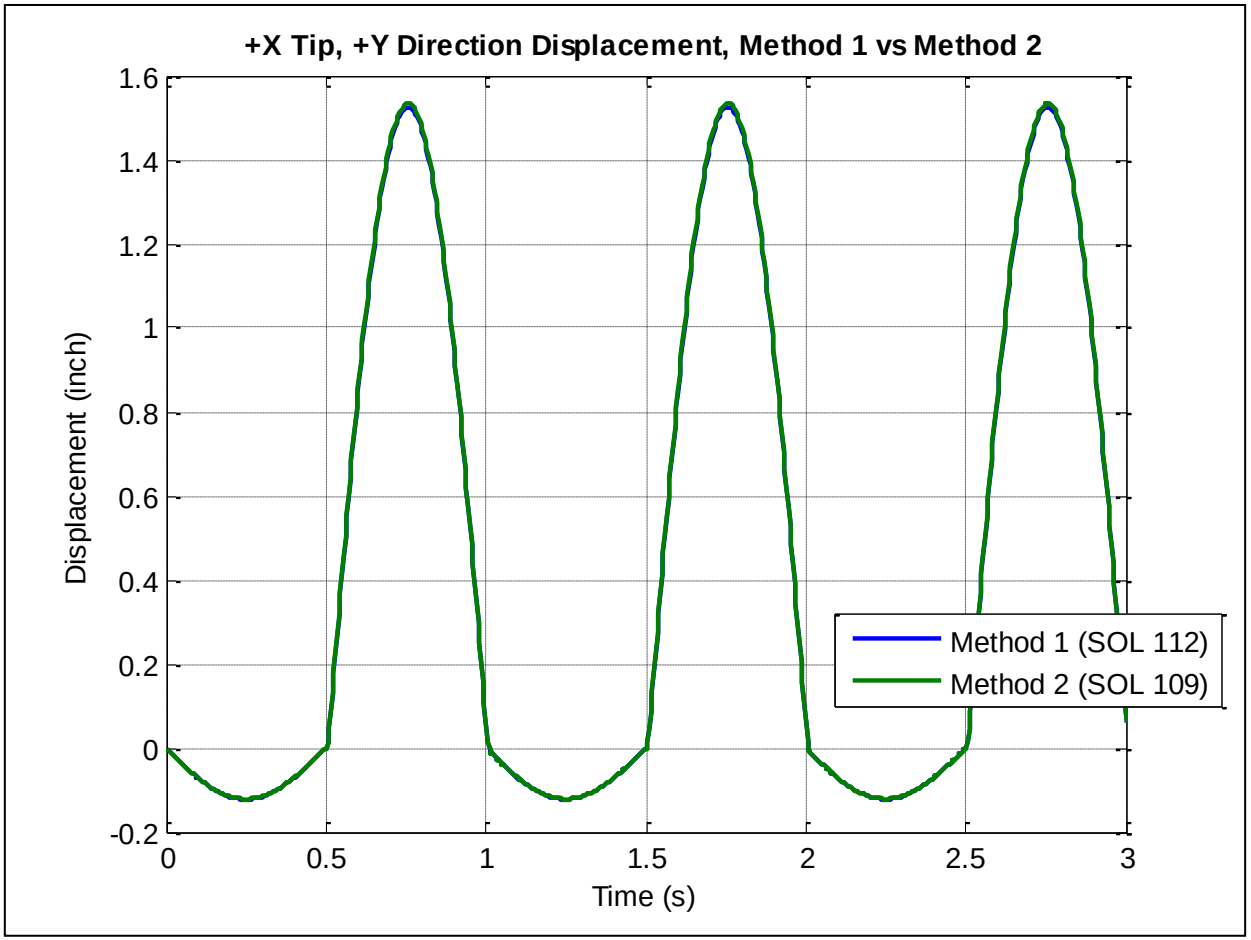
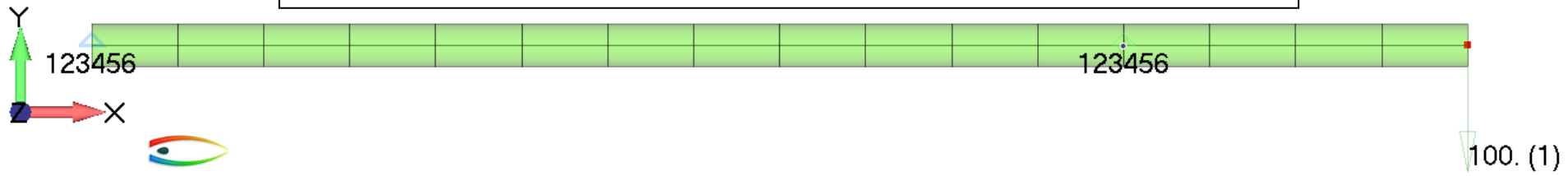
Comparison of +Y Tip Displacements: Method 1 (Modal) vs. Method 2 (Direct)





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Modal Reduction (Method 1) vs Superelement/Direct Solution (Method 2)

Modal Reduction

Pros

- Ability to remove rigid body motion

Cons

- Necessary to use Transfer Functions and EPOINTs for NOLINi

Superelement/Direct

Pros

- NOLINi can use nodal input directly
  - Much simpler input

Cons

- Cannot remove rigid body motion
- Requires some understanding of superelements

Methods and Implementation

Use NASTRAN's NOLIN functionality to apply forces resulting in non-linear behavior - $F_{n+1} = f(x_n, \dot{x}_n)$

Method #1 (Direct)

Method #2 (Modal)

Look at Keys to Implementation and Best Practices

Superelements

Keys to Implementation

- Small time steps
- Reduce model to small DOF

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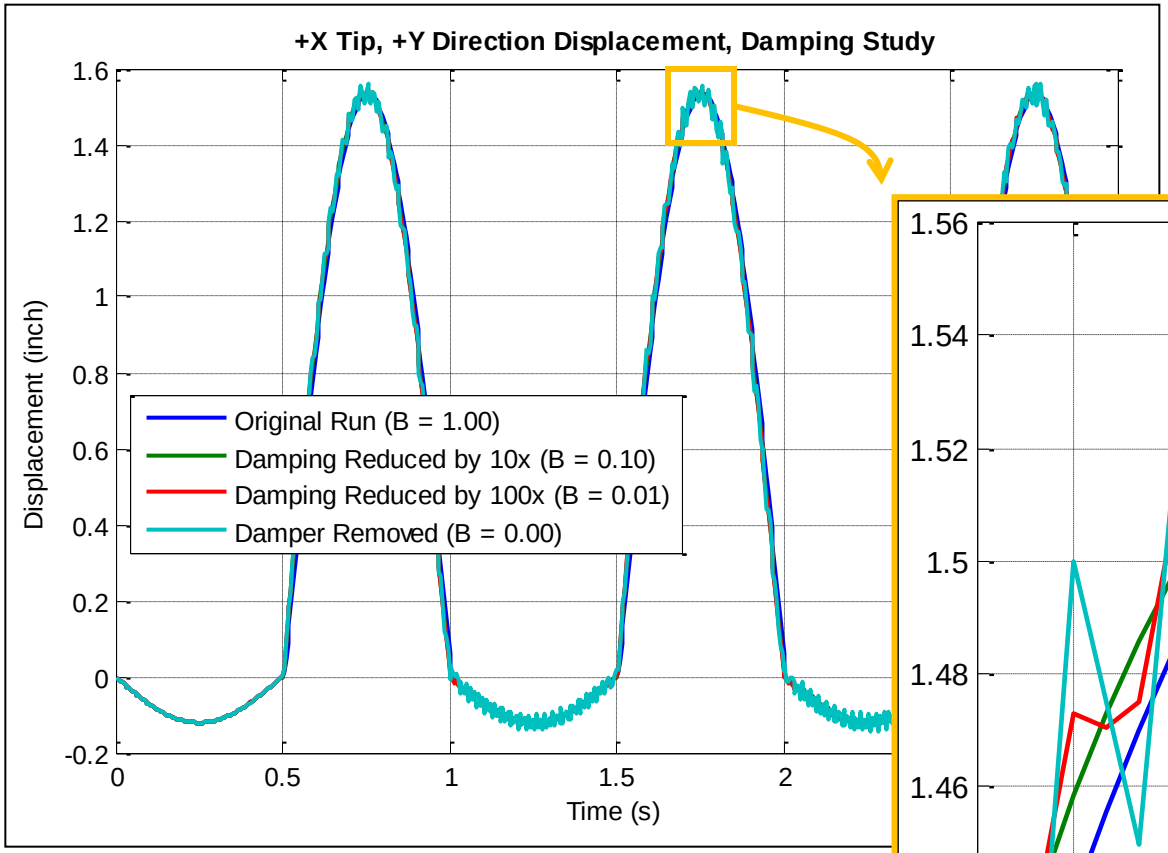
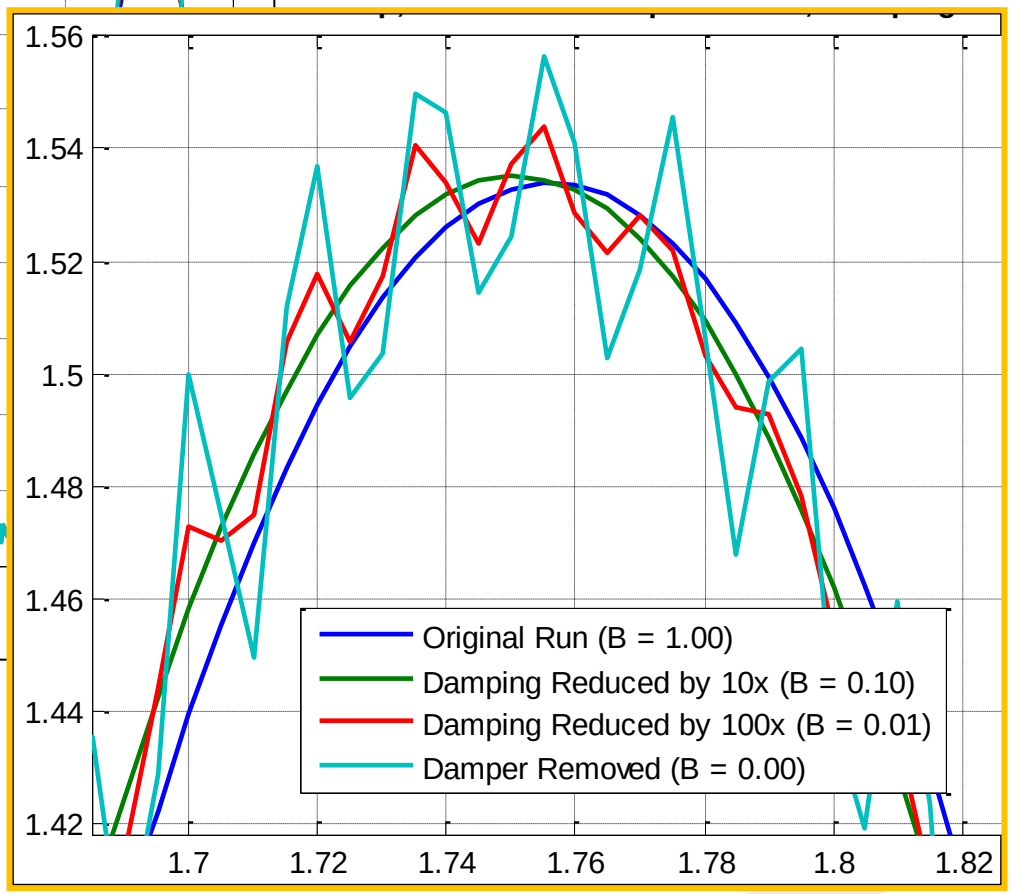
Why the damper element?



NOLIN Functionality:

$$F_{n+1} = f(x_n, \dot{x}_n)$$



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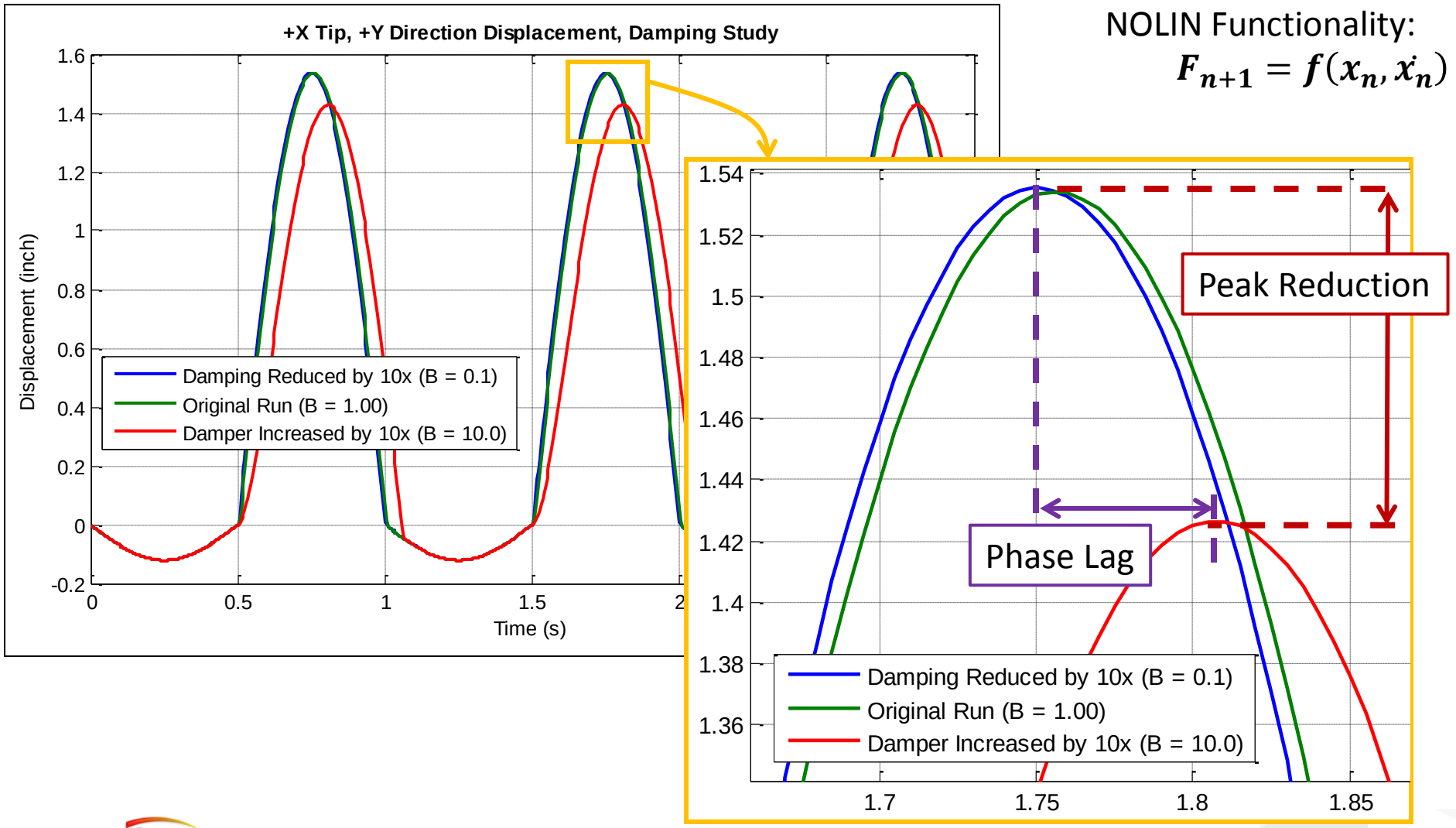
Be careful with damping - check effects

NOLIN Functionality:

$$F_{n+1} = f(x_n, \dot{x}_n)$$



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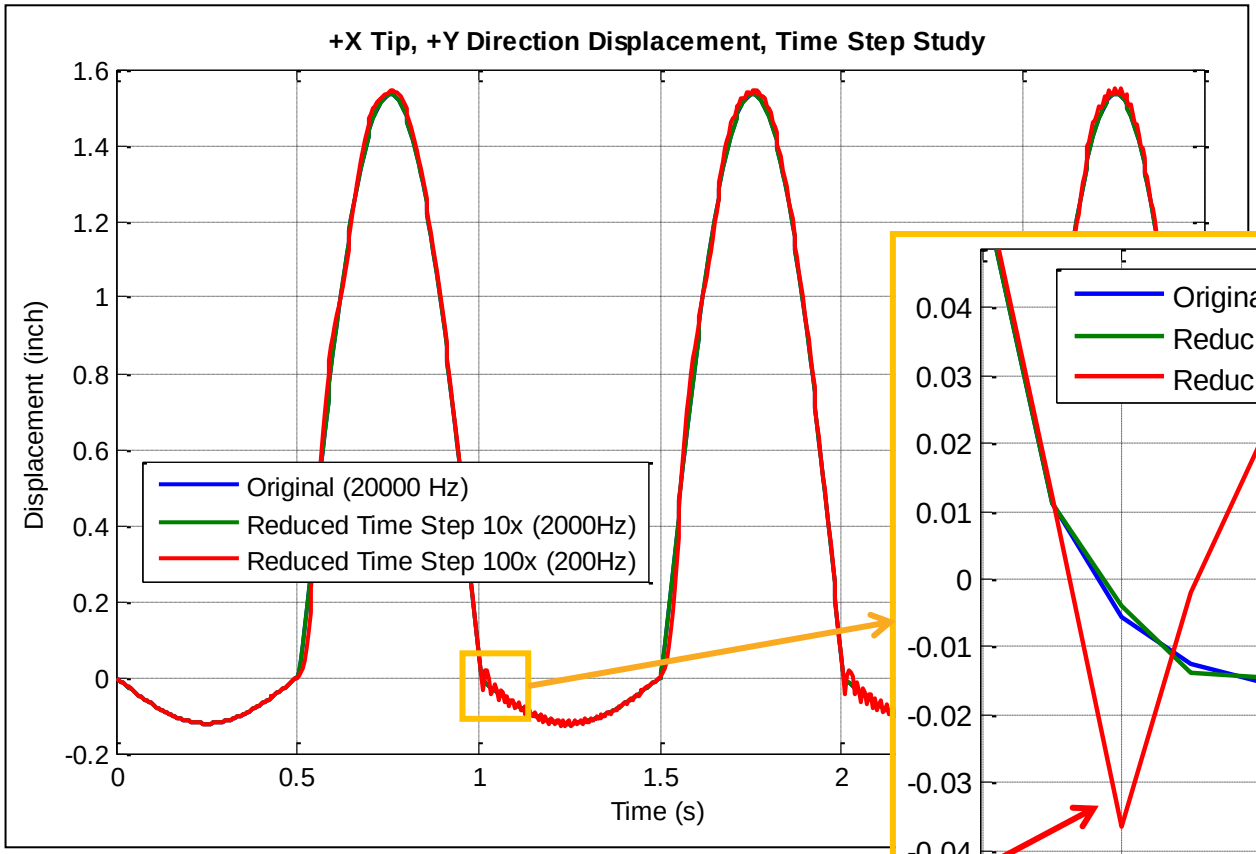
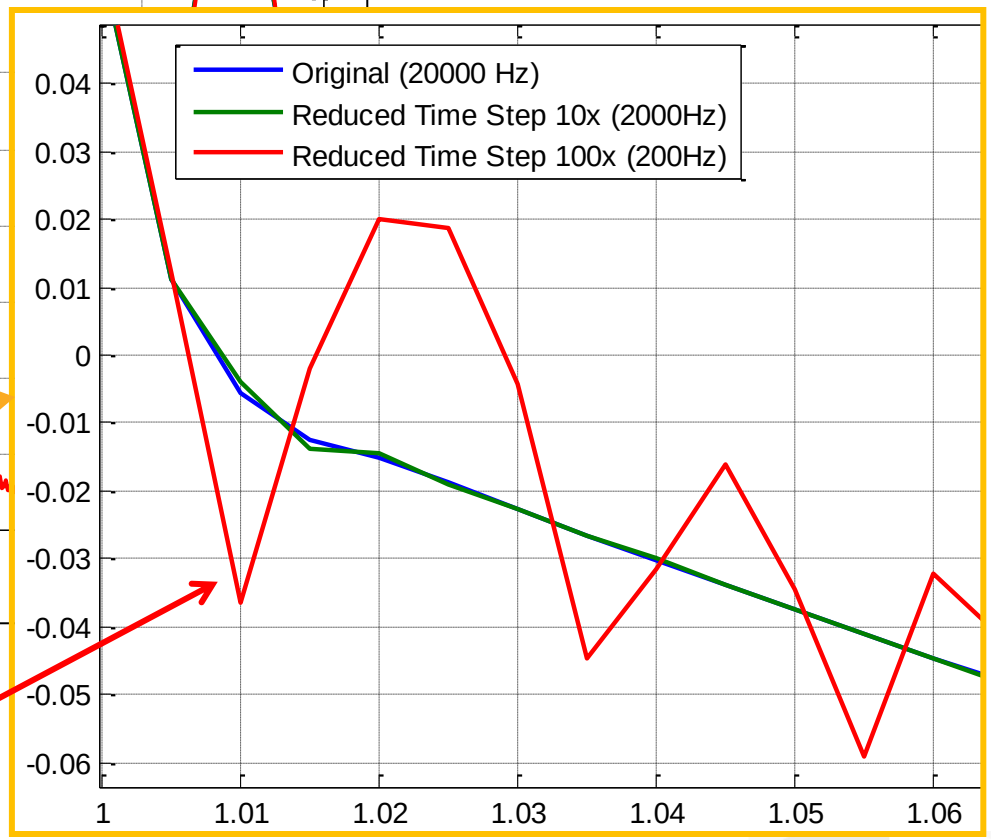
Why to be wary of time step

NOLIN Functionality:

$$F_{n+1} = f(x_n, \dot{x}_n)$$





Confirm noise is analytical and not mode of system
(example loading quasi-static)

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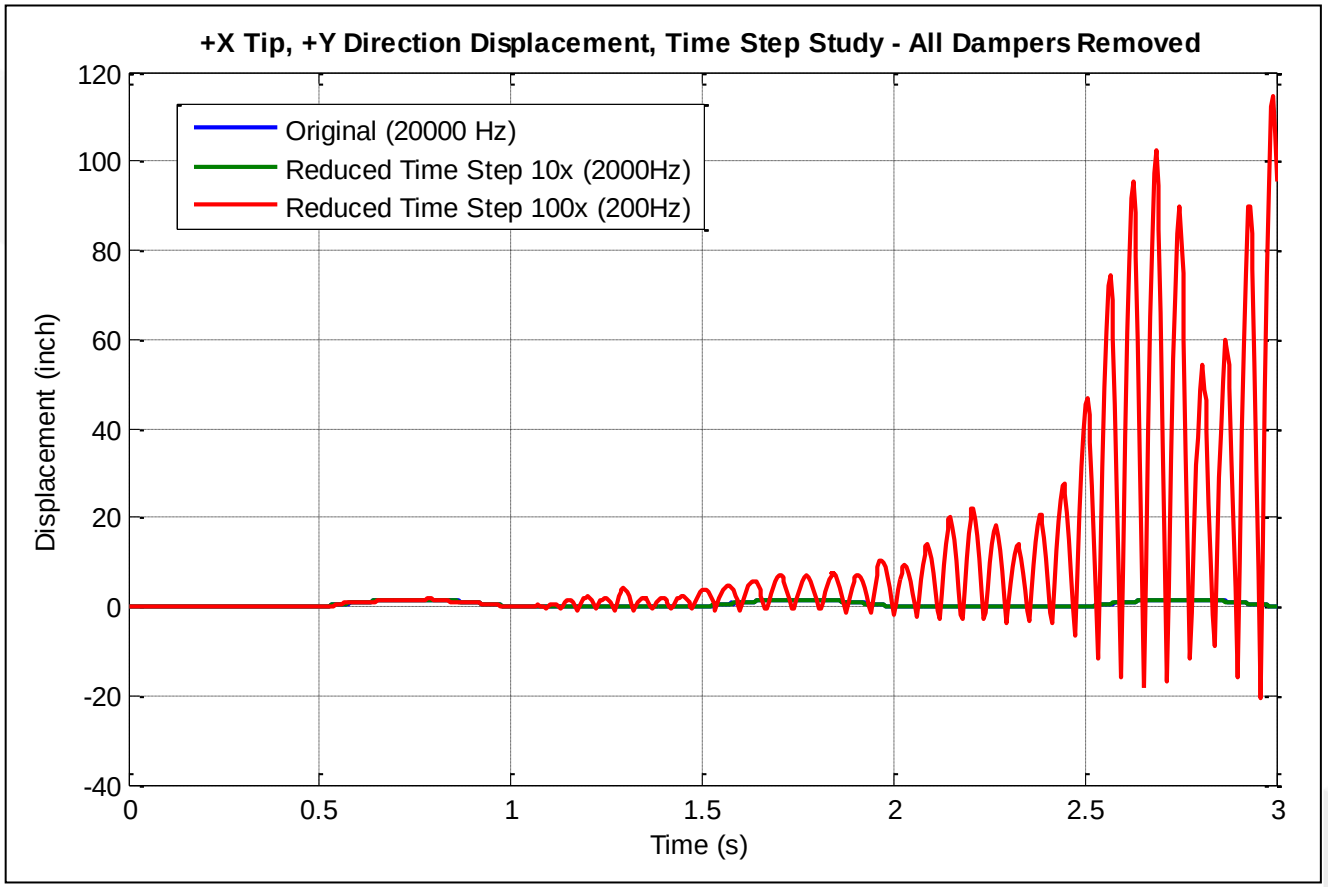
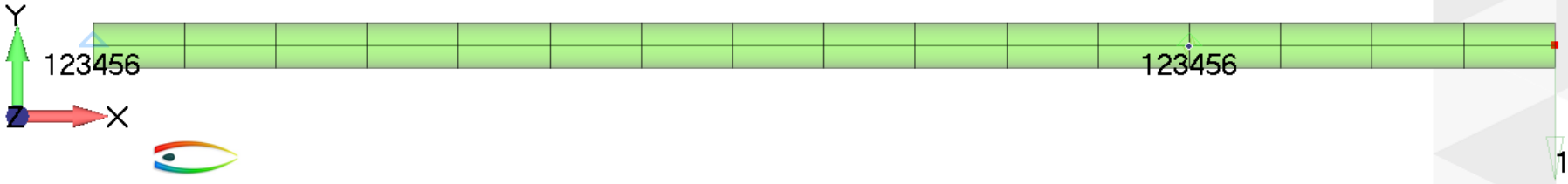
Things get even worse without dampers





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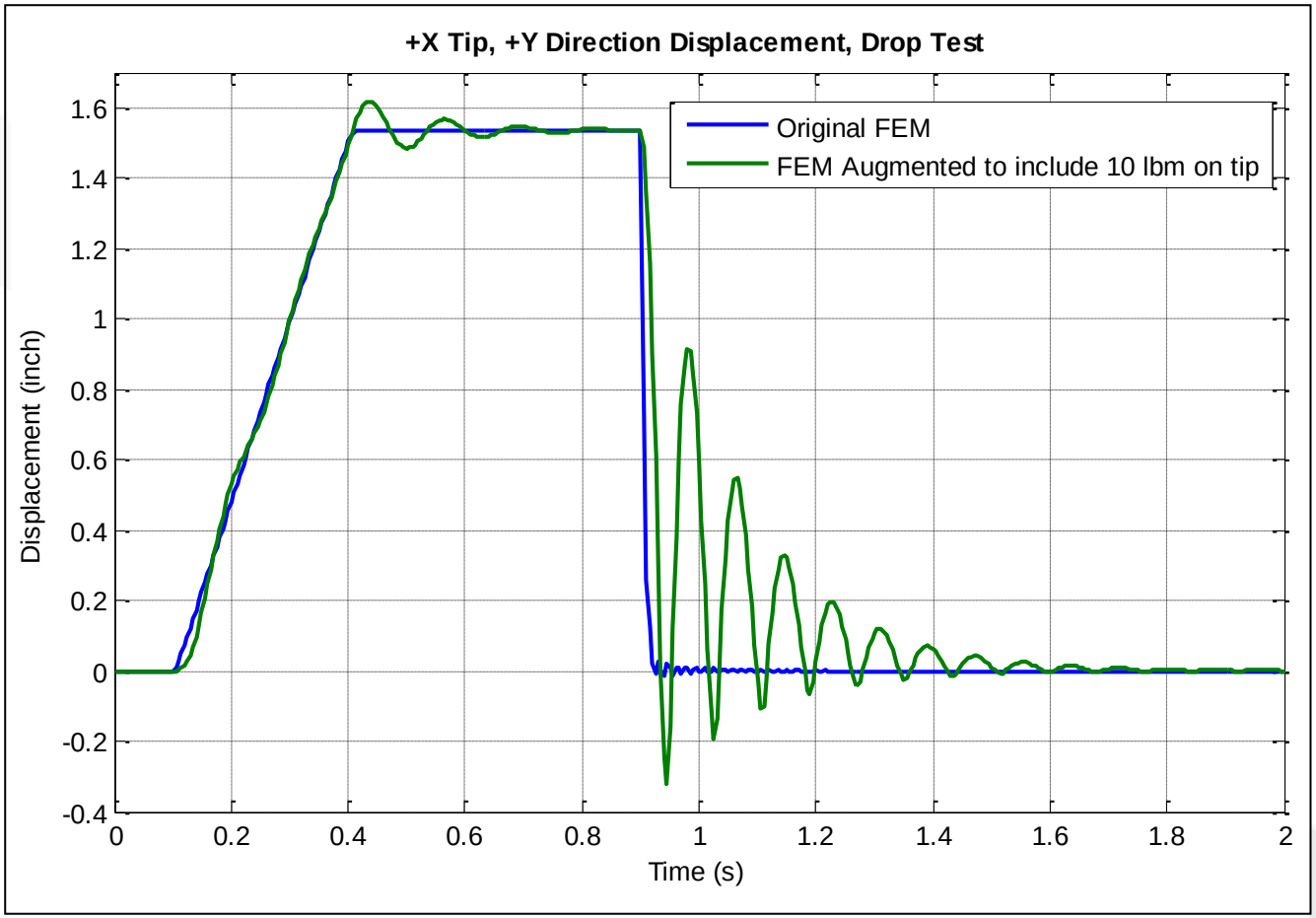
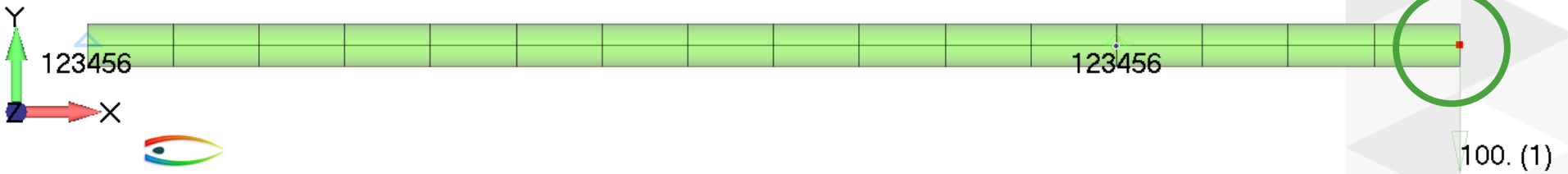
Practical Loading Example:

What happens when system is twanged?





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Wrap-up Summary

Capturing Nonlinear Effects in Transient Coupled Loads Analysis

Summary:

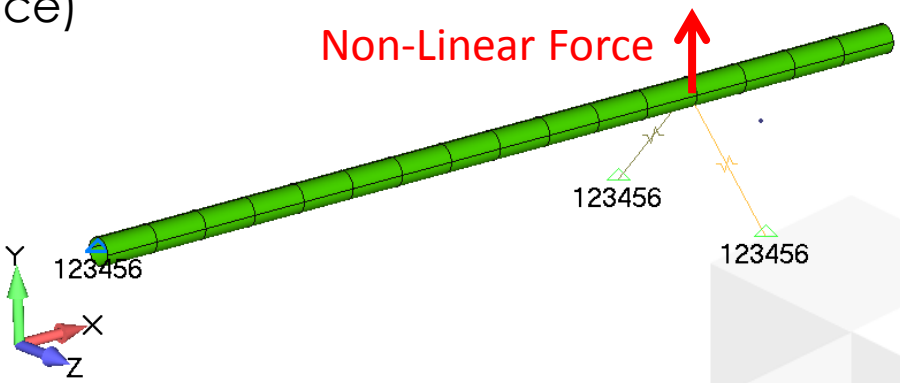
NASTRAN's NOLINi capabilities allow non-linear effects such as impact, separation and gapping to be represented in a Linear Modal or Direct Transient Coupled Loads Solution

Best Practices:

- Include spring and make nonlinear force equal and opposite to spring tension force
- Small viscous damper added to point of interest (check phase lag enforced)
- Small Time Steps (check convergence)

Application Examples:

- Drop impact
- Payload carriers with free-play
- Air Launch
- Vehicle Re-entry



SOL 112/NOLIN/TF/EPOINT Documentation:

- Feel free to ask for decks, Sam.Dyas@ata-e.com

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