NONLINEAR DYNAMIC ANALYSES OF STS-1 FORWARD RCS OXIDIZER TANK STRUCTURAL FAILURE

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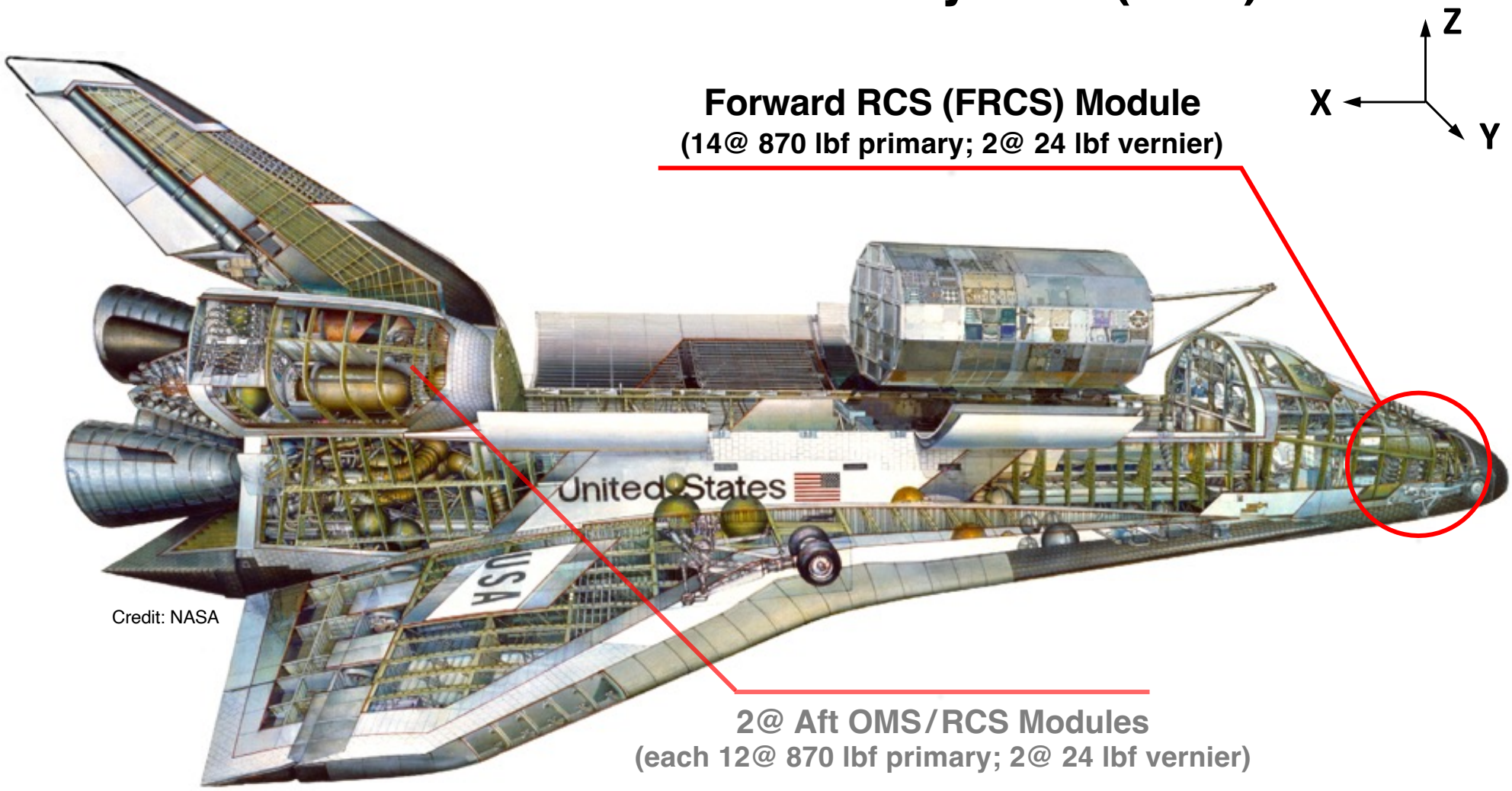
Nonlinear Dynamic Analyses of STS-1 Forward RCS Oxidizer Tank Structural Failure

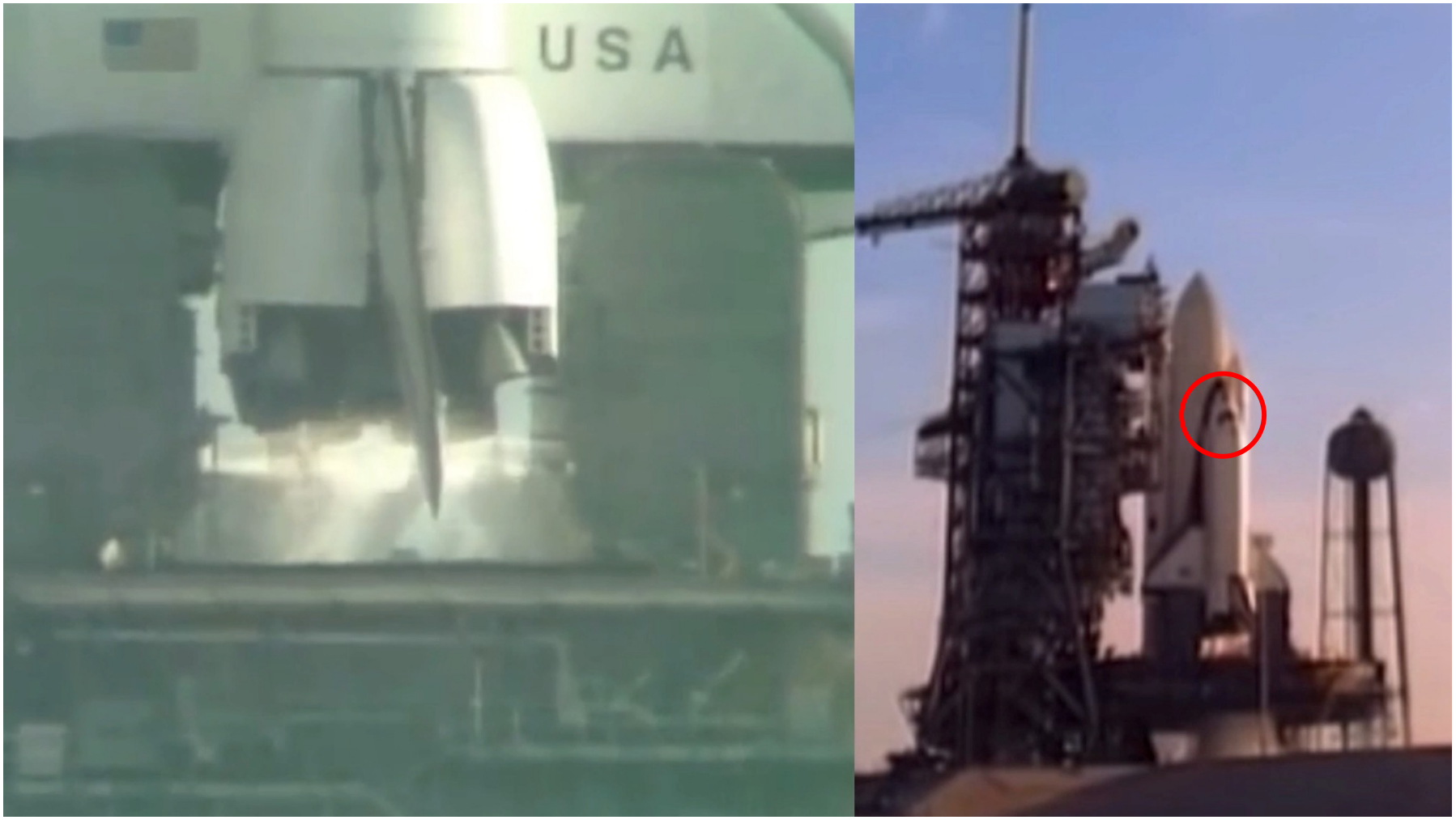
- Introduction
- STS-1 liftoff and IOP-induced loads
- FRCS module and oxidizer tank subsystem
- Linear static and bifurcation buckling
- Nonlinear static analyses
- Nonlinear dynamic analyses
- Concluding remarks

Orbiter Reaction Control System (RCS)



Credit: NASA

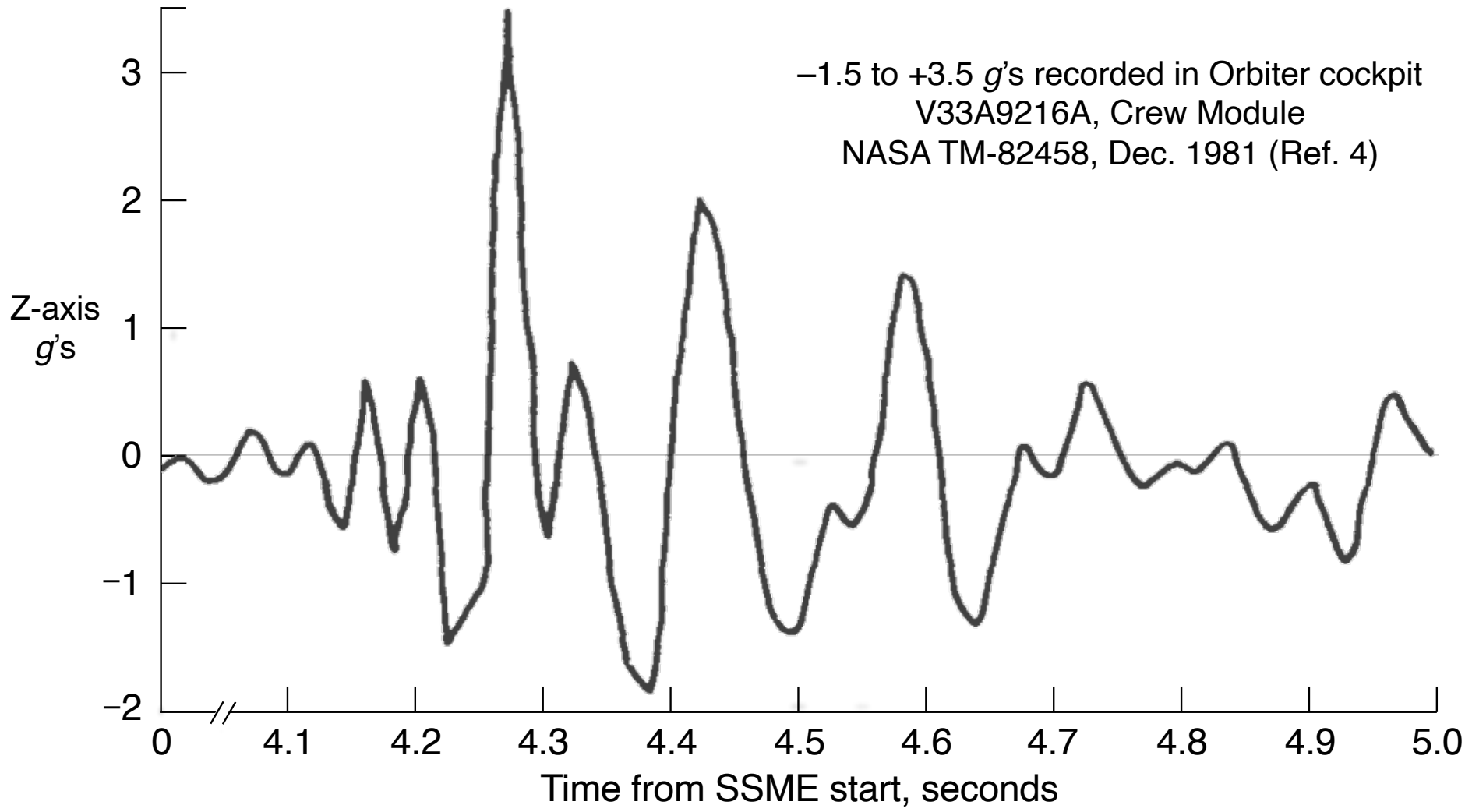
April 12, 1981 - Liftoff!



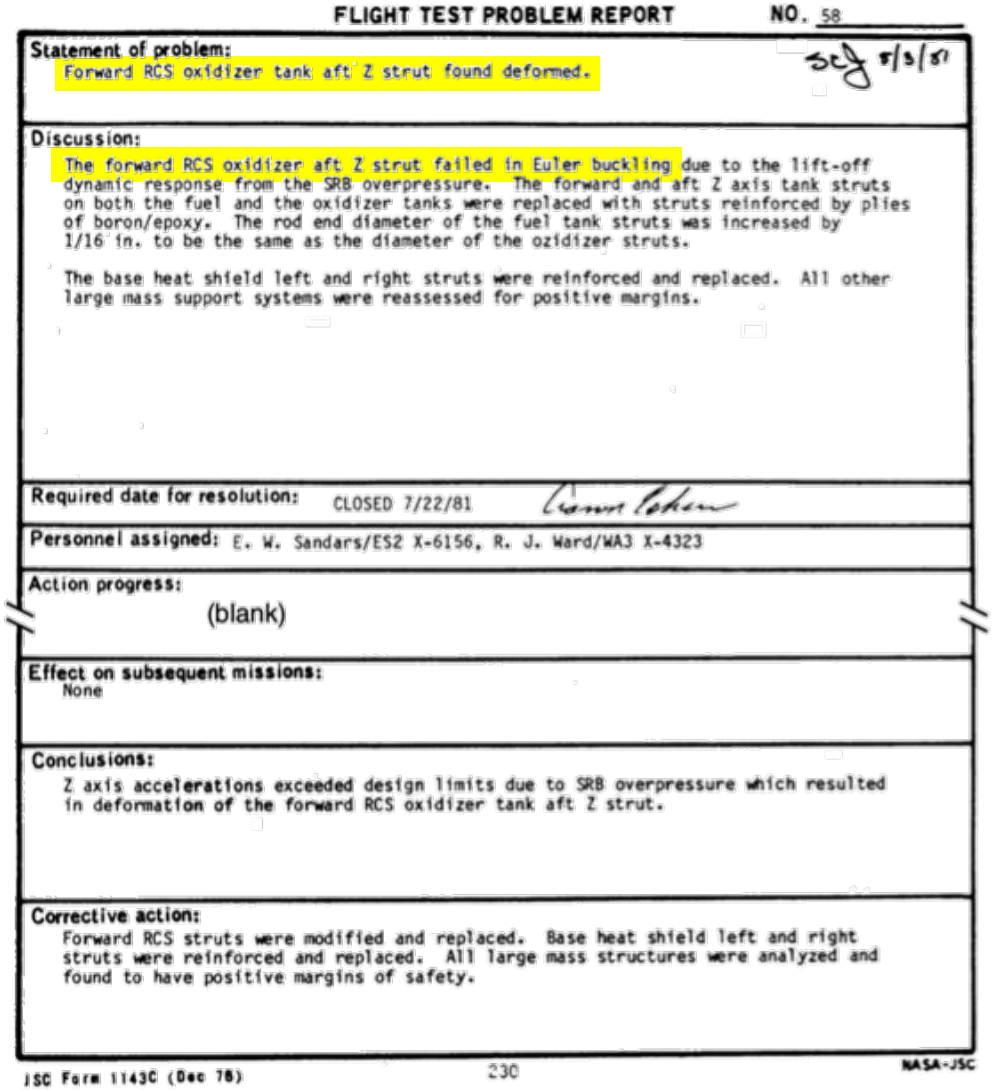
LC-39A Perimeter Camera Views

Credit: NASA/JSC

Reported Liftoff Z-Axis Accelerations



Orbiter Post-Flight Inspection



FLIGHT TEST PROBLEM REPORT NO. 58

Statement of problem:
Forward RCS oxidizer tank aft Z strut found deformed.

Discussion:
The forward RCS oxidizer aft Z strut failed in Euler buckling due to the lift-off dynamic response from the SRB overpressure. The forward and aft Z axis tank struts on both the fuel and the oxidizer tanks were replaced with struts reinforced by plies of boron/epoxy. The rod end diameter of the fuel tank struts was increased by 1/16 in. to be the same as the diameter of the ozidizer struts.

The base heat shield left and right struts were reinforced and replaced. All other large mass support systems were reassessed for positive margins.

Required date for resolution: CLOSED 7/22/81

Personnel assigned: E. W. Sandars/ES2 X-6156, R. J. Ward/WA3 X-4323

Action progress:
(blank)

Effect on subsequent missions:
None

Conclusions:
Z axis accelerations exceeded design limits due to SRB overpressure which resulted in deformation of the forward RCS oxidizer tank aft Z strut.

Corrective action:
Forward RCS struts were modified and replaced. Base heat shield left and right struts were reinforced and replaced. All large mass structures were analyzed and found to have positive margins of safety.

JSC Form 1143C (Dec 78) 230 NASA-JSC

STS-1 Orbiter Final Mission Report, JSC-17378, Aug. 1981 (Ref. 1)

In-Flight Anomaly STS-1-V-58 (IFA V-58)

"Forward RCS oxidizer tank aft Z strut found deformed."

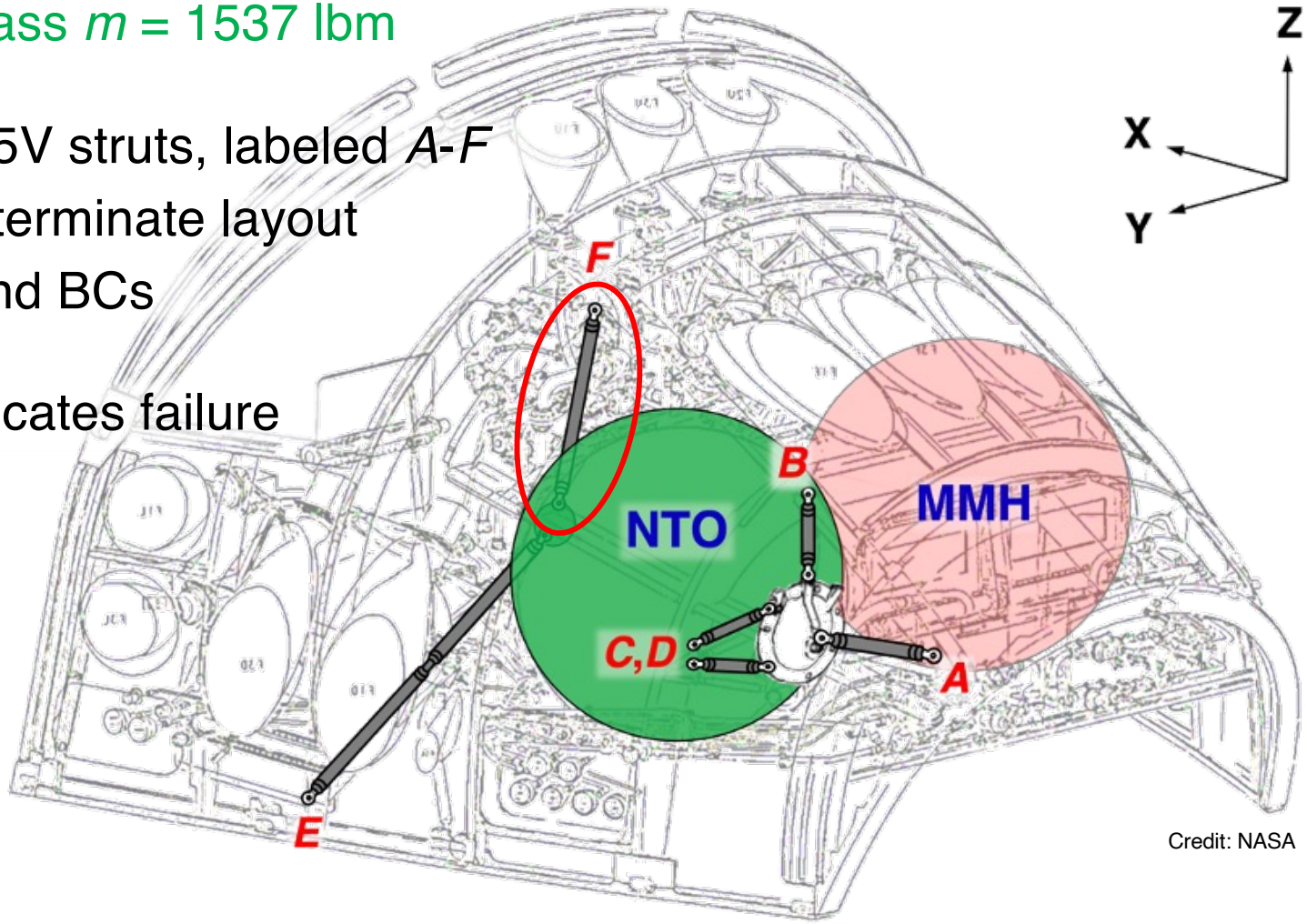
"The … strut failed in Euler buckling due the lift-off dynamic response from the SRB overpressure."

FRCS Oxidizer Tank Subsystem

NTO tank mass m = 1537 lbm

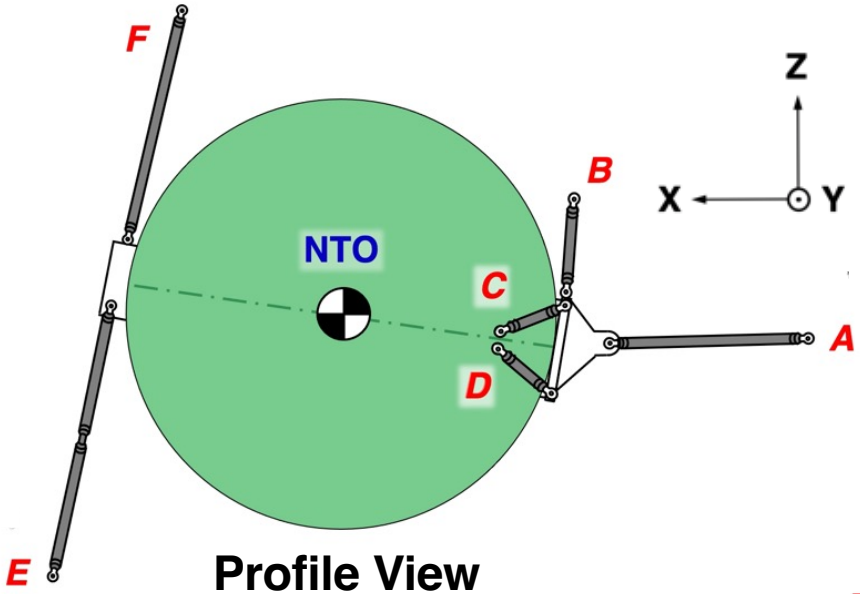
Six Ti-3Al-2.5V struts, labeled *A*-*F*
Statically determinate layout
All pinned-end BCs

IFA V-58 indicates failure
of Strut *F*

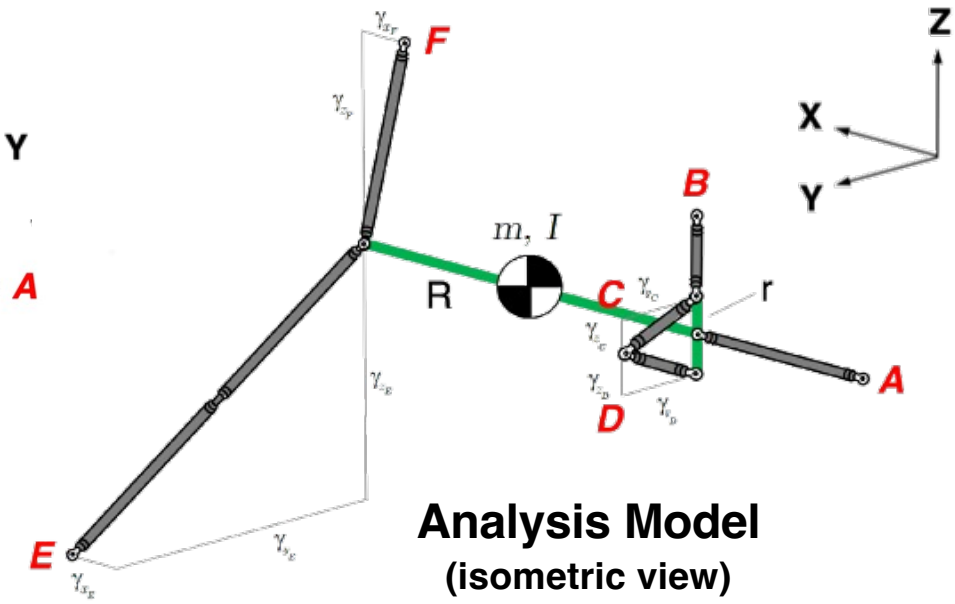


Credit: NASA

NTO Tank Subsystem Model



Profile View
(starboard inboard)



Analysis Model
(isometric view)

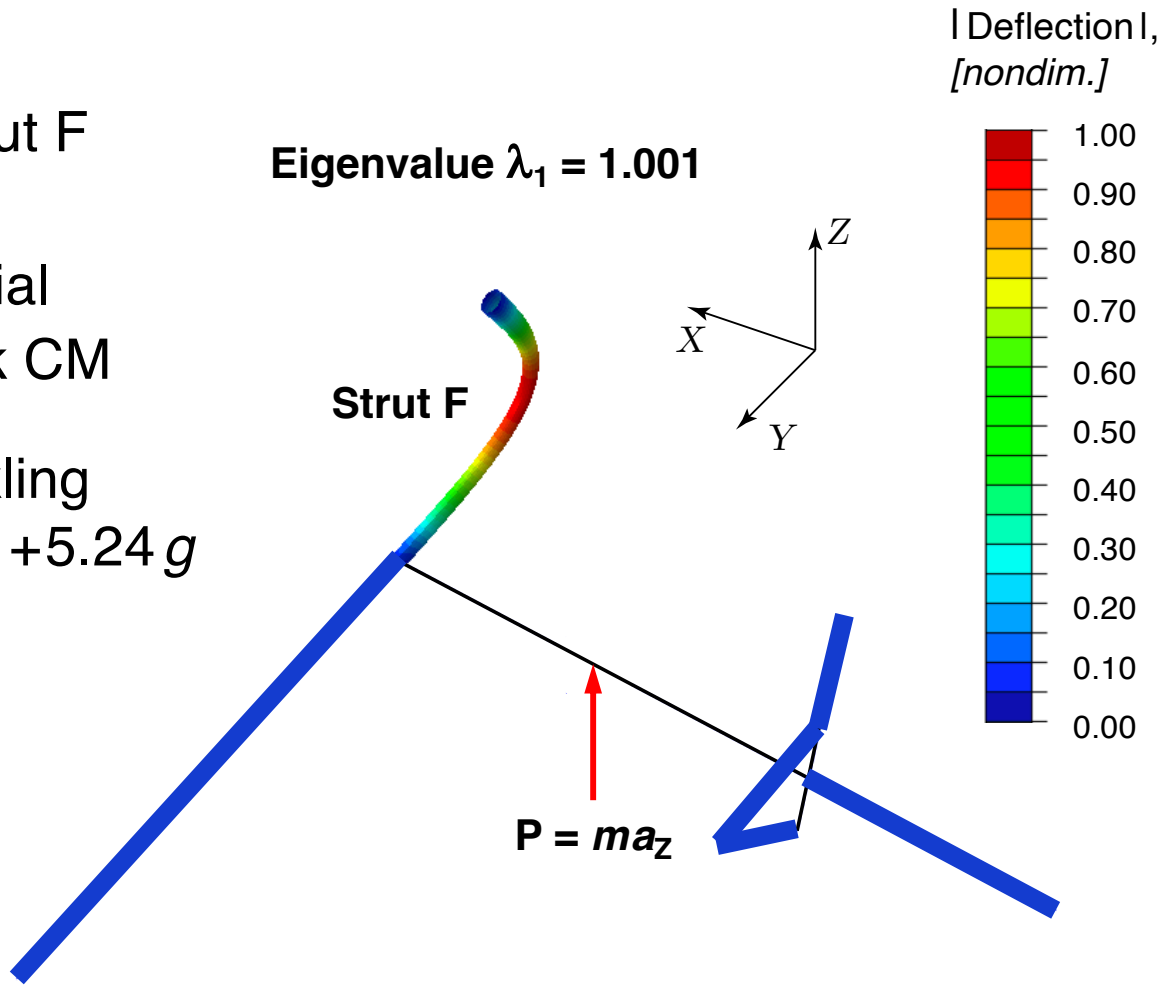
- Rigid tank and FRCS module structures
- Statically determinate => Solve equilibrium for individual strut forces P_i, i = A, … F
- Calculate $P_F = -m a_Z / (2\gamma_{Z_F})$ = Euler P^{cr}

Linear Static and Buckling Analyses

Analysis assumptions
- Tube of plate elt's for Strut F
- Beam elt's for Struts A-E
- Linear Ti-3Al-2.5V material
- Constant Z-accel. at tank CM

Calculate Strut F Euler buckling
$P_F^{cr} = -4142$ lbf from $a_Z = +5.24\,g$ applied at tank CM

FE results validate prior closed-form analyses (Ref. 2)



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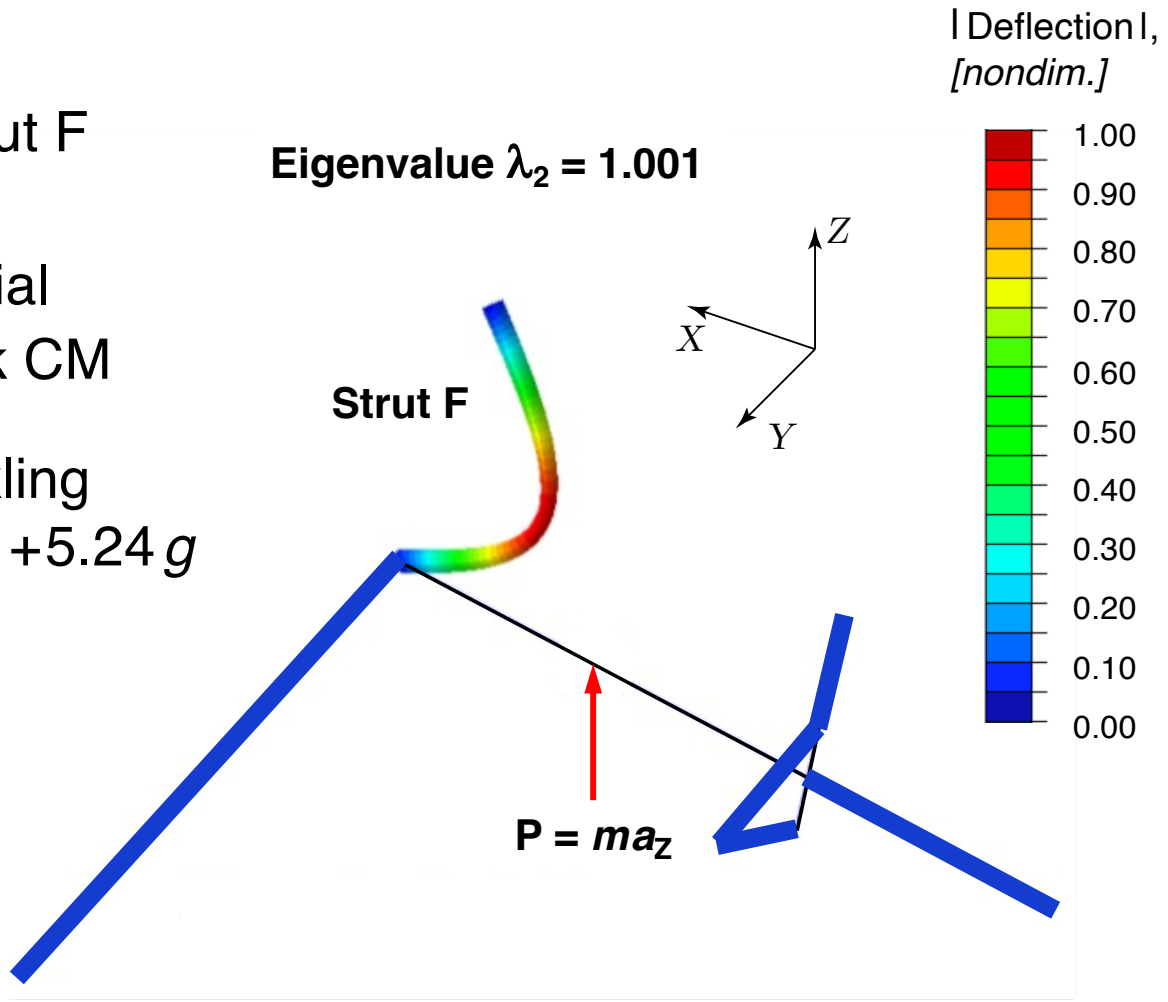
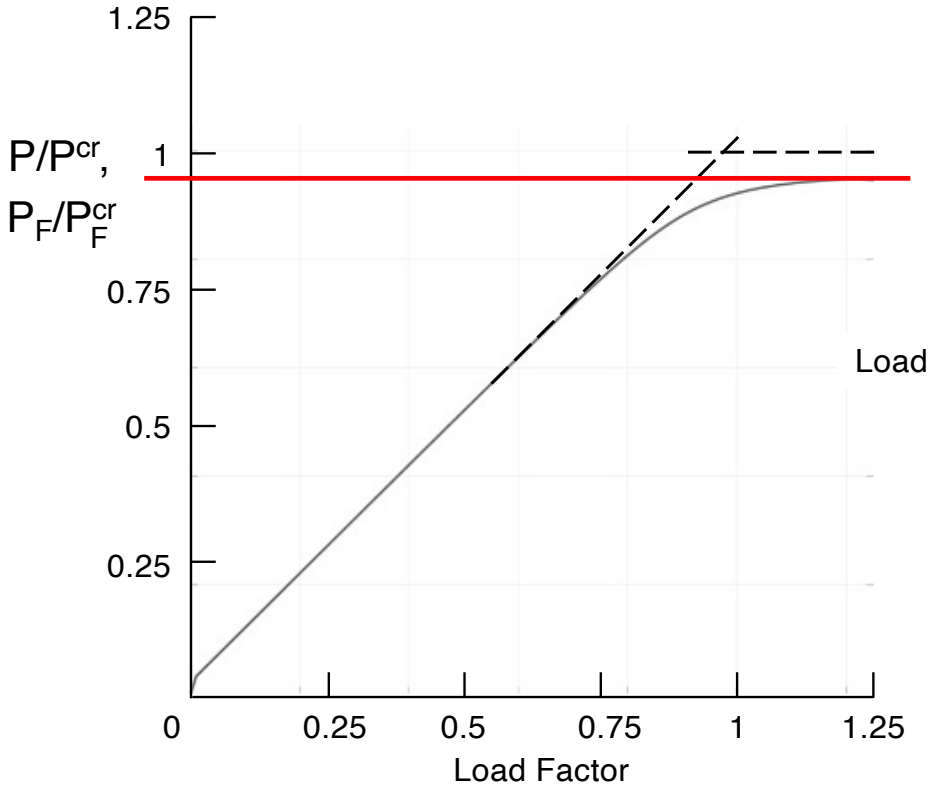
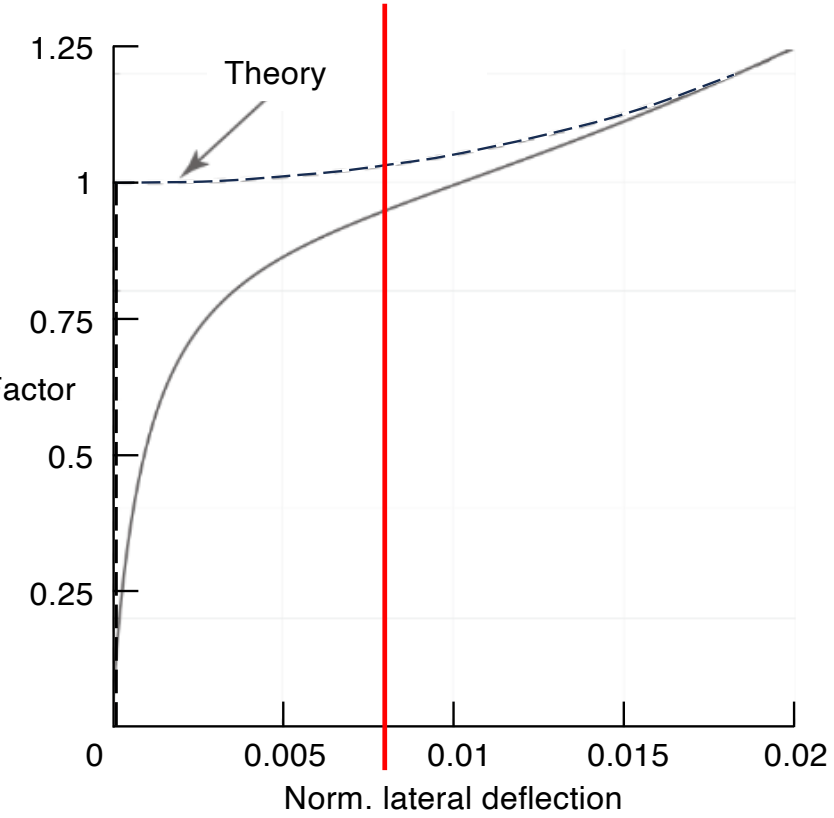


Geometrically Nonlinear Analysis

Performed to assess NTO tank support structure postbuckling

- Applied max Z-displ. from linear buckling $m^* a_Z$ at tank CM
- Elastic-perfectly plastic material, $\sigma_{cy} = -105$ klbf/in^2

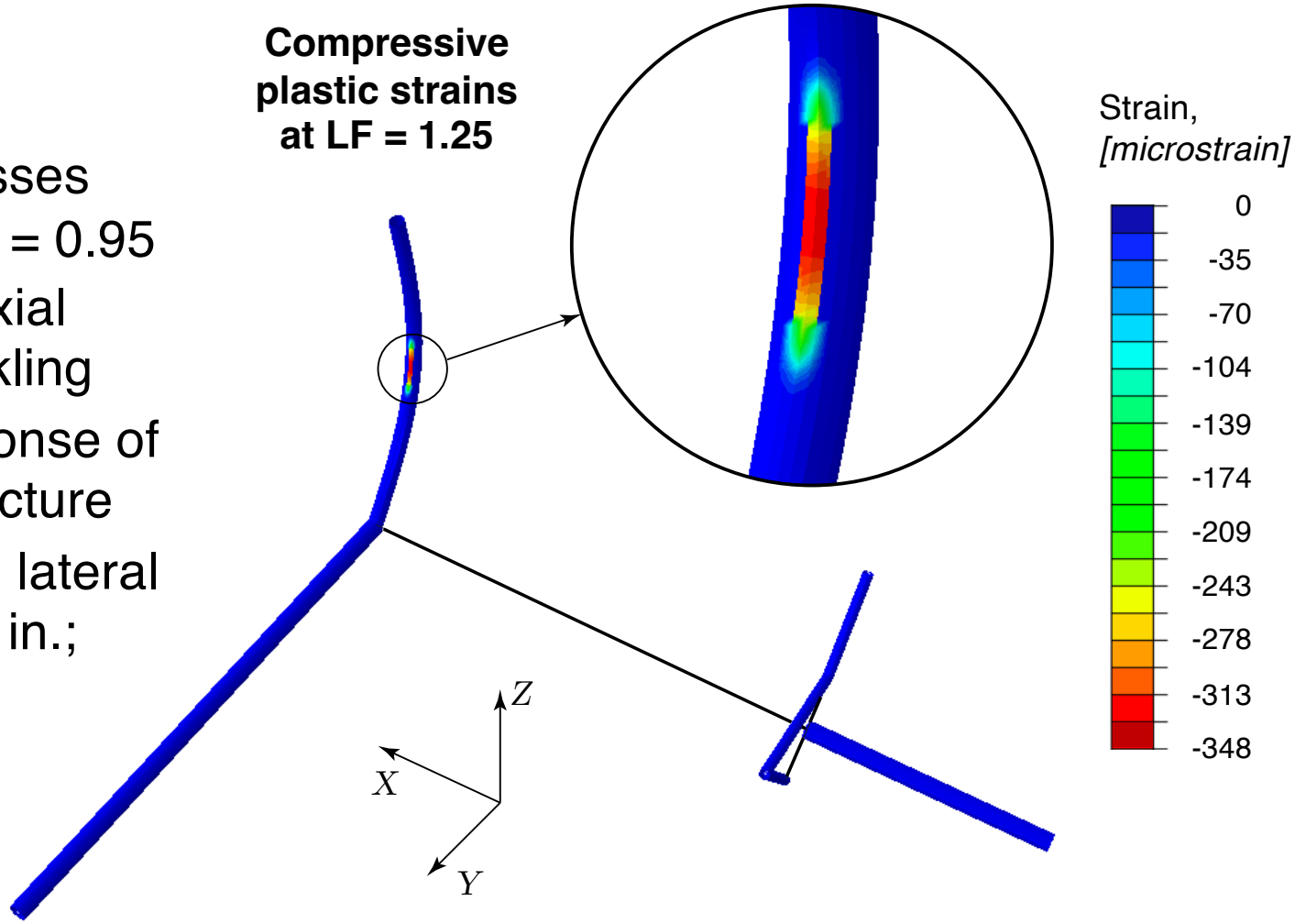




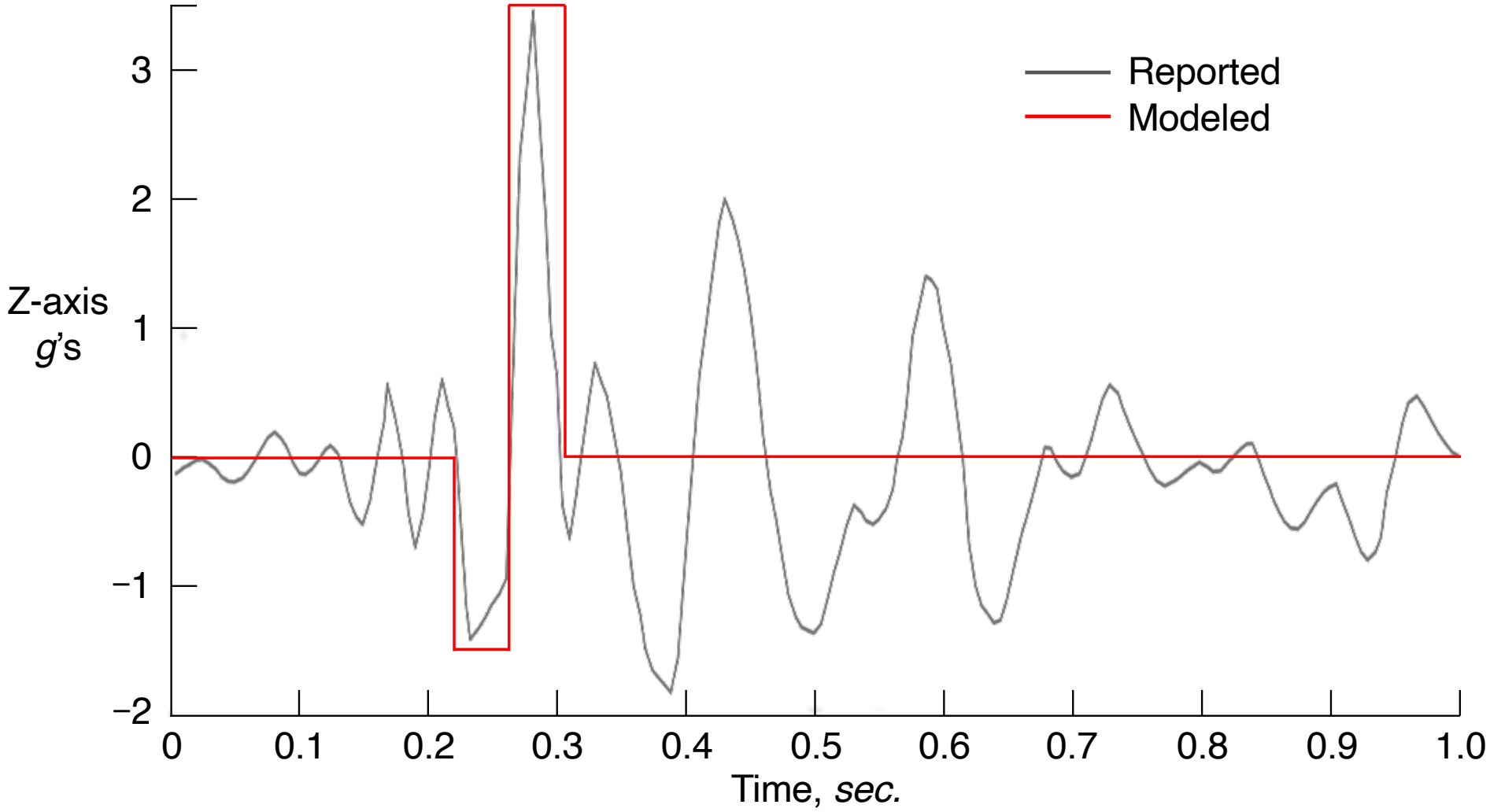
Geometrically Nonlinear Analysis (2)

Analysis results

- Plastic yield stresses reached ~ $P_F/P_F^{cr} = 0.95$
- Loss of Strut F axial stiffness at buckling
- Mechanism response of tank support structure
- Strut F maximum lateral deflection = 0.52 in.; Λ/L = 2 percent

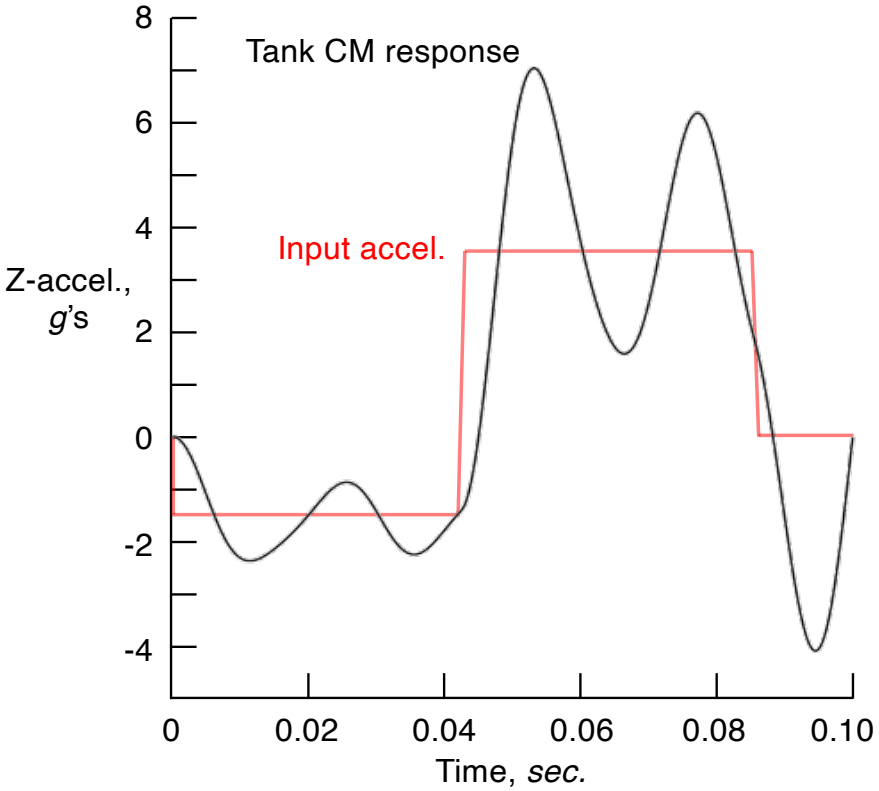


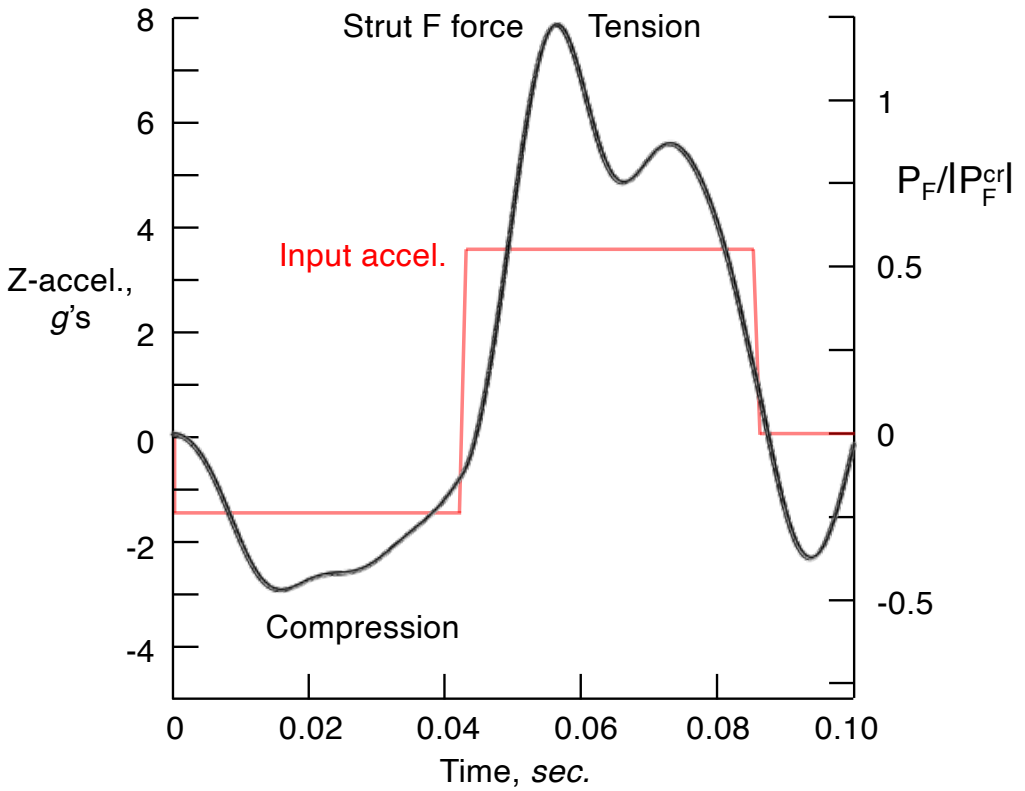
Nonlinear Dynamic Analysis – Step Input



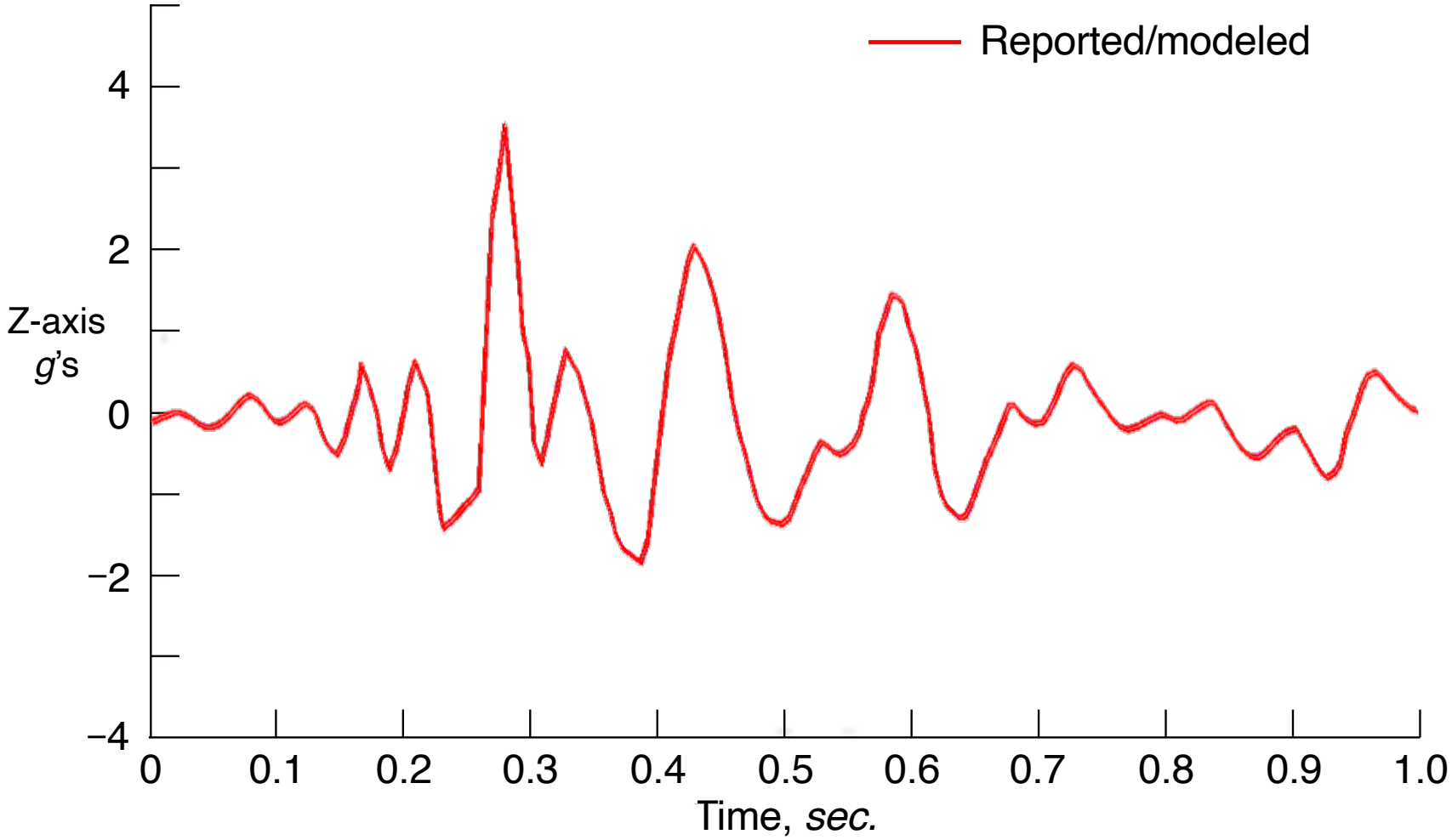
Analysis Results – Step Input

- Tank CM acceleration ranges from +7 to –4 *g*'s
- Normalized Strut F force ranges from –0.5 to +1.25 x $|P_F^{cr}|$
- Strut F compr. stress ~ 14 percent of plastic yield stress





Nonlinear Dynamic Analysis – Reported Input



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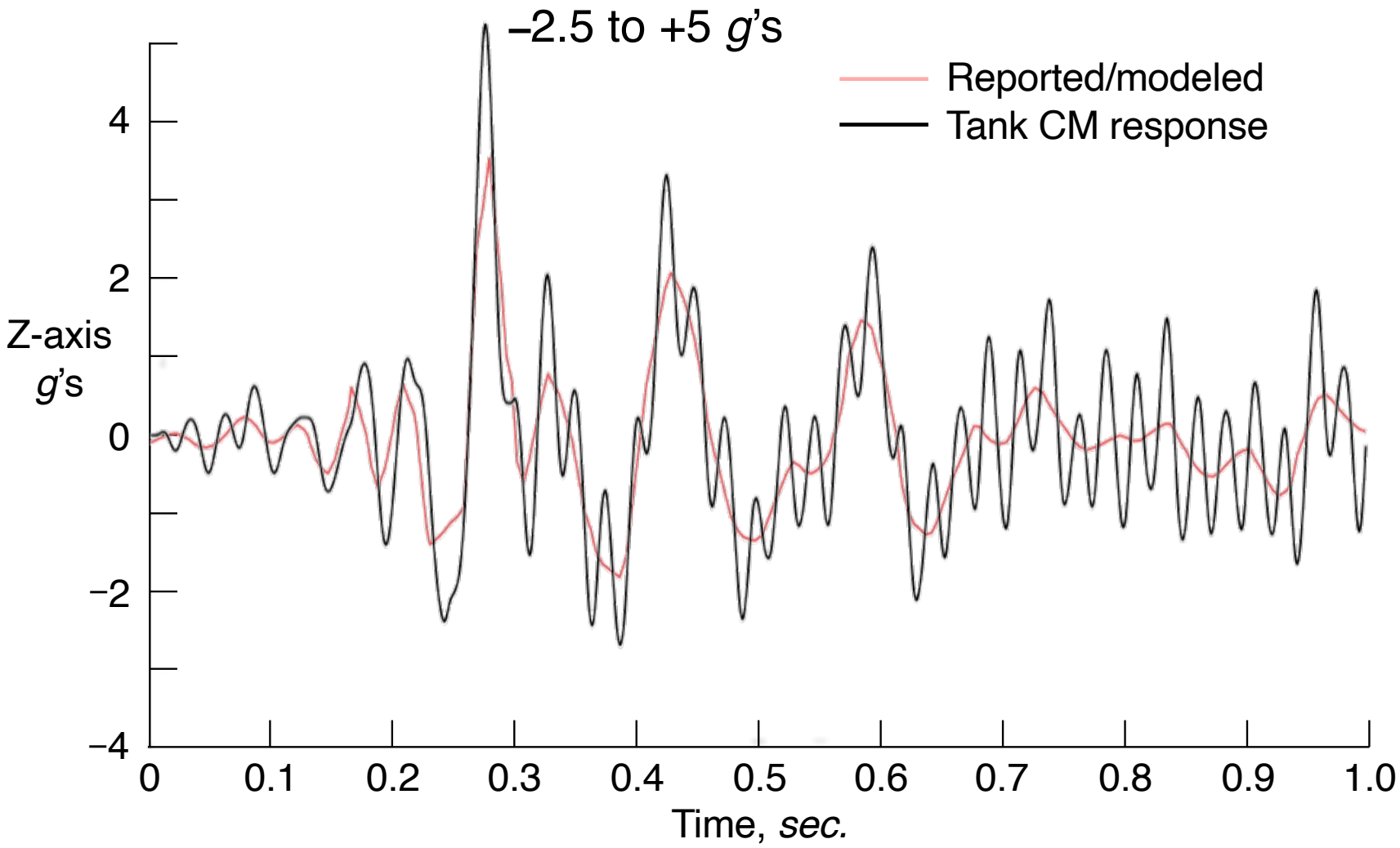
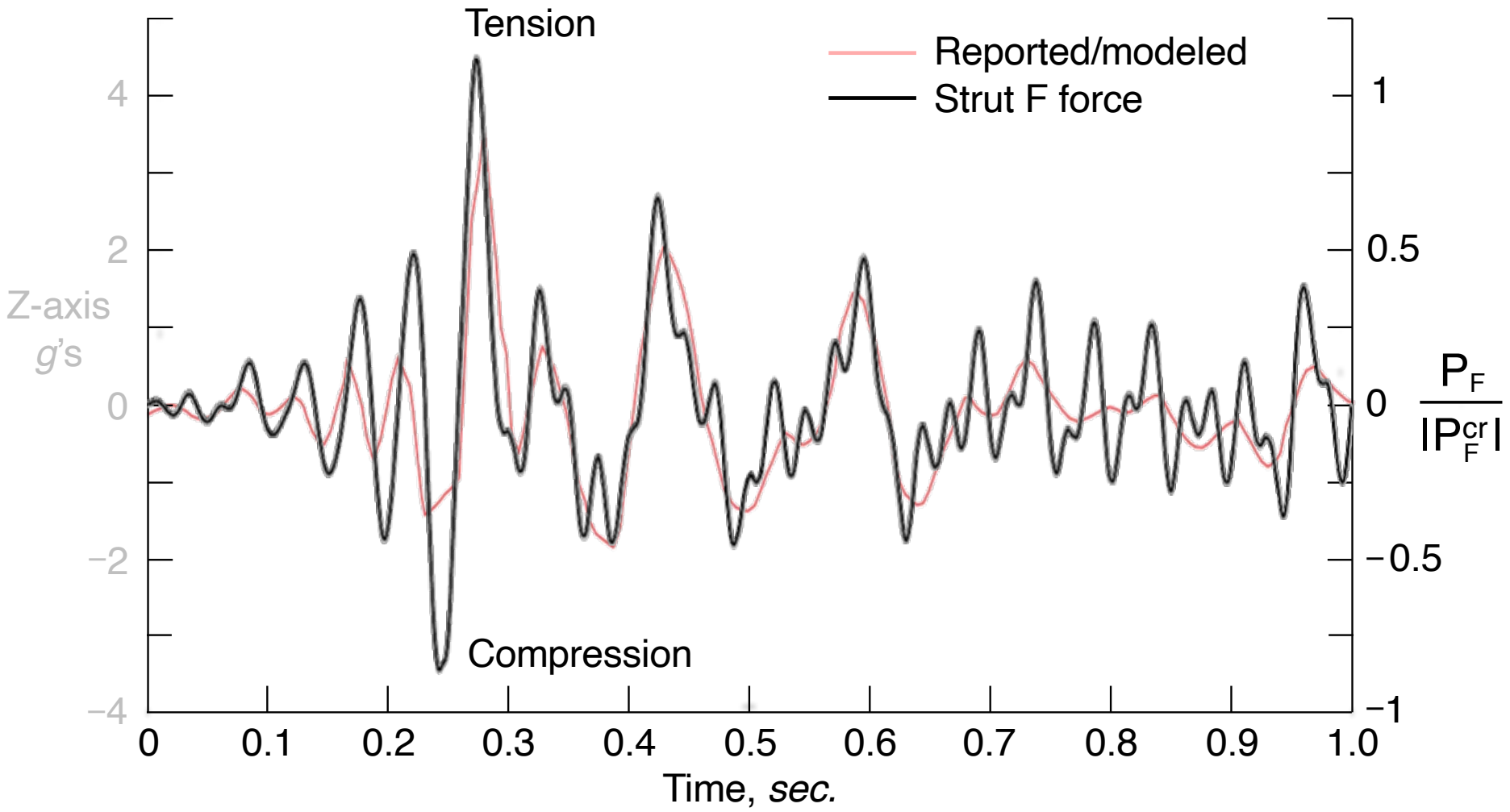
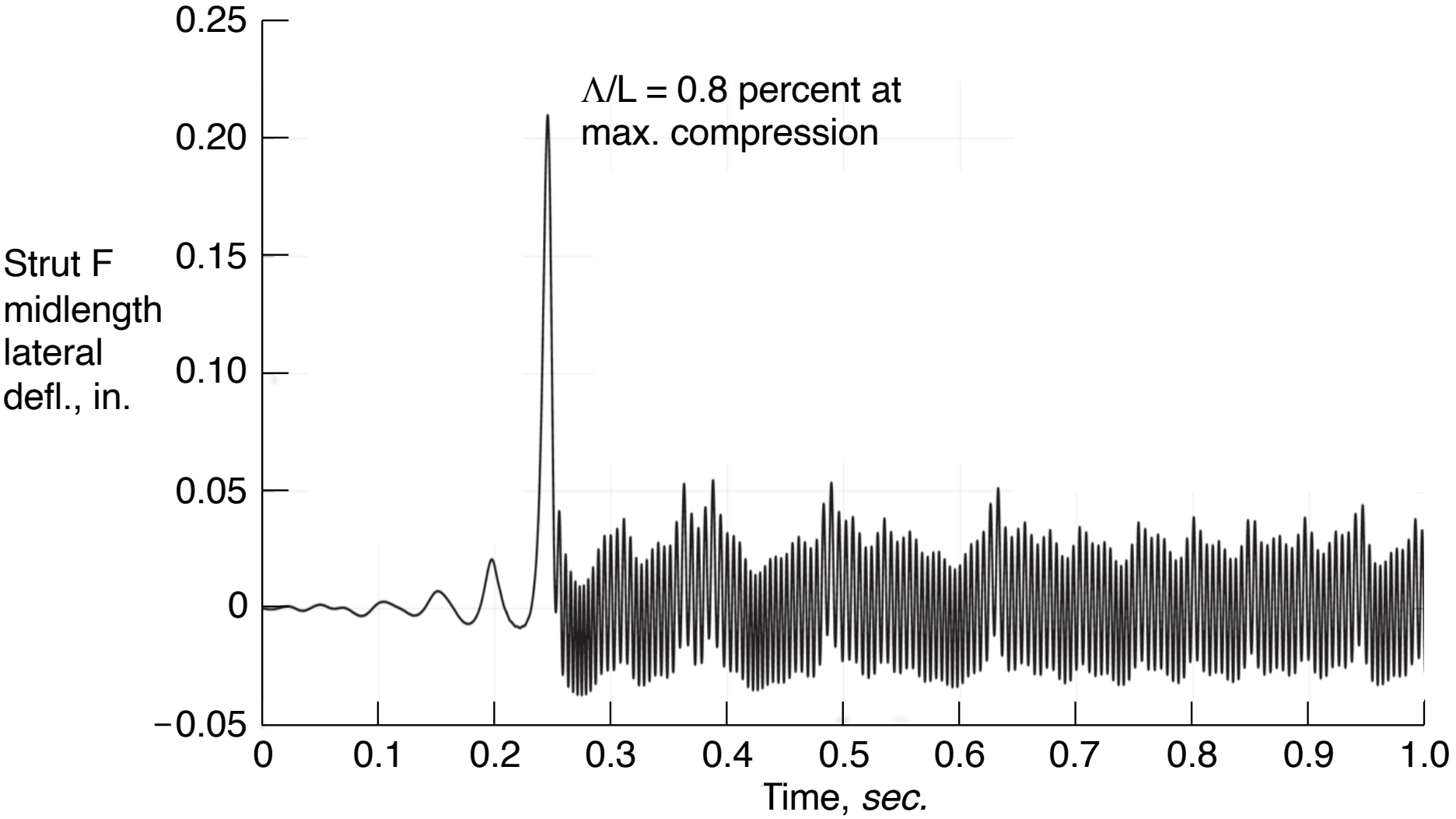


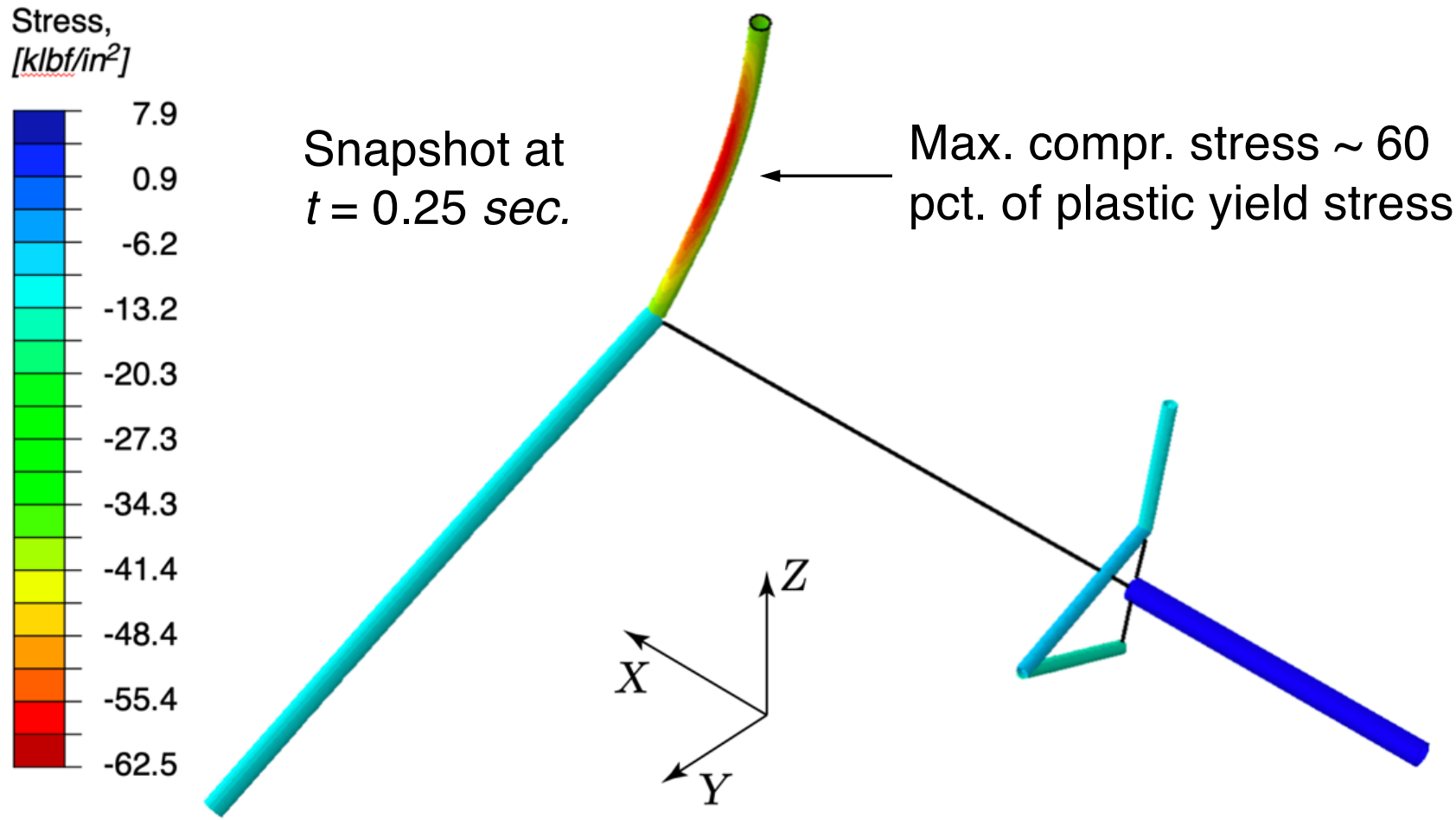
Analysis Results – Reported Input (2)



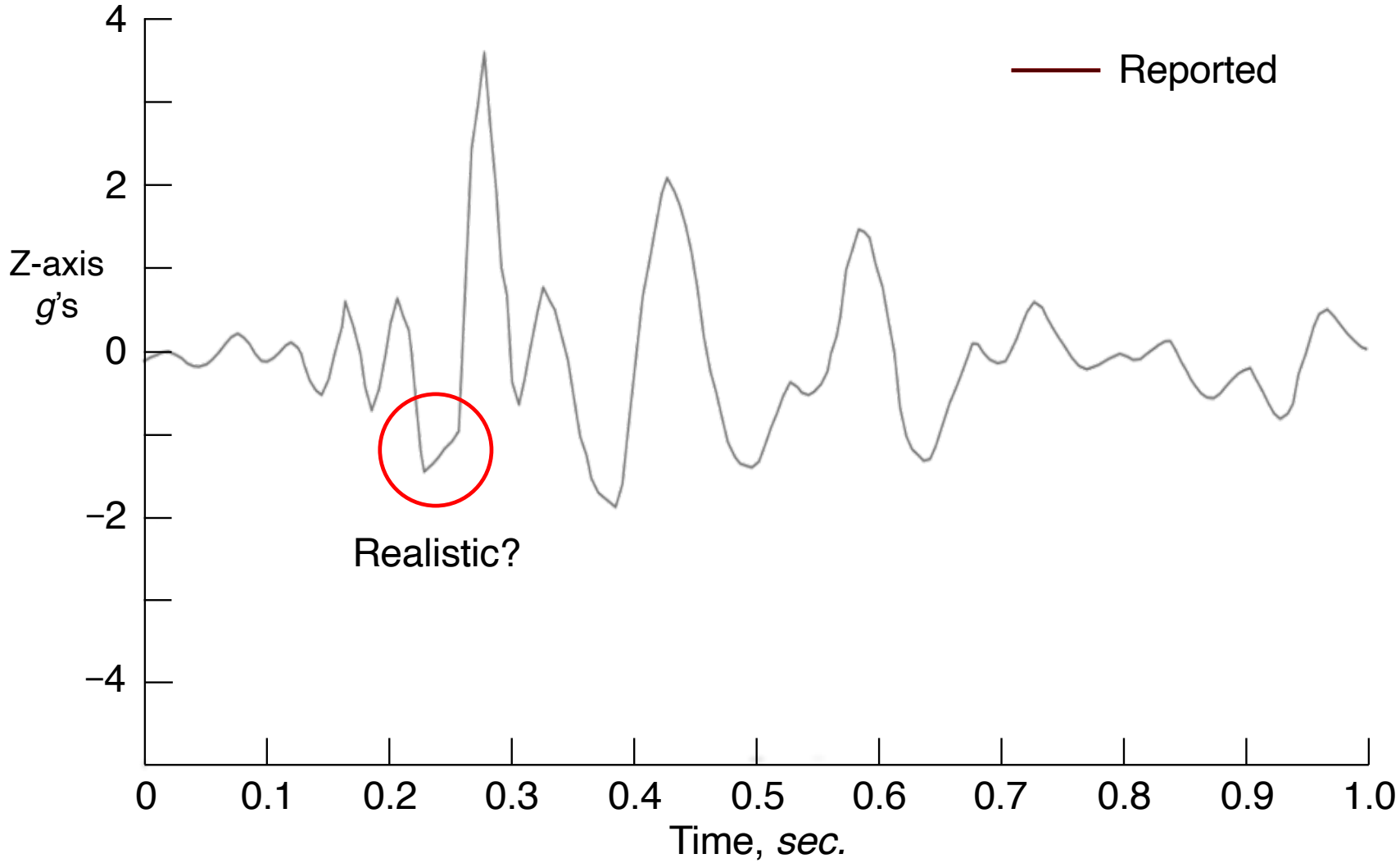
Analysis Results – Reported Input (3)



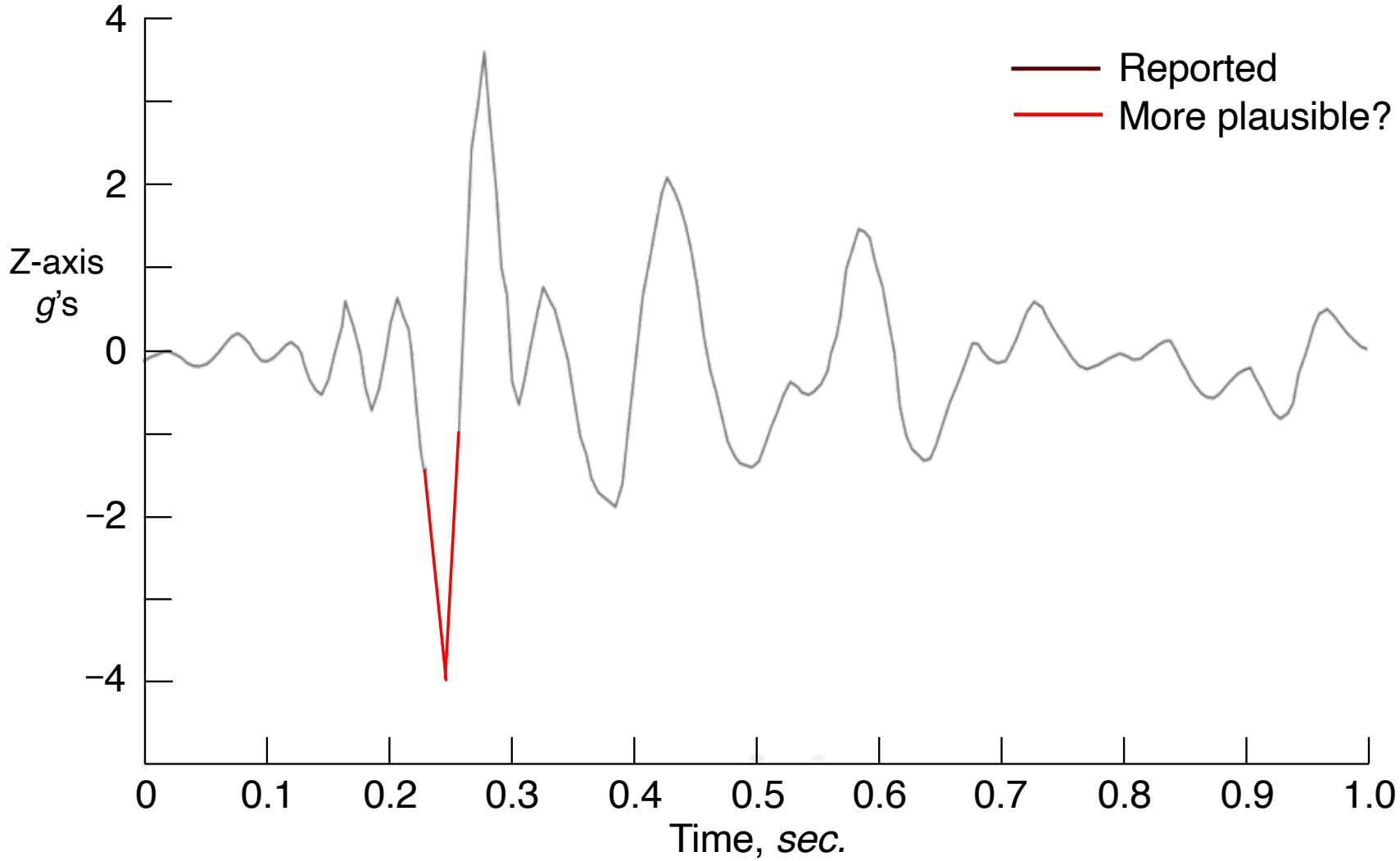
Analysis Results – Reported Input (4)



Nonlinear Dynamic Analysis – Sinusoidal Input



Nonlinear Dynamic Analysis – Sinusoidal Input



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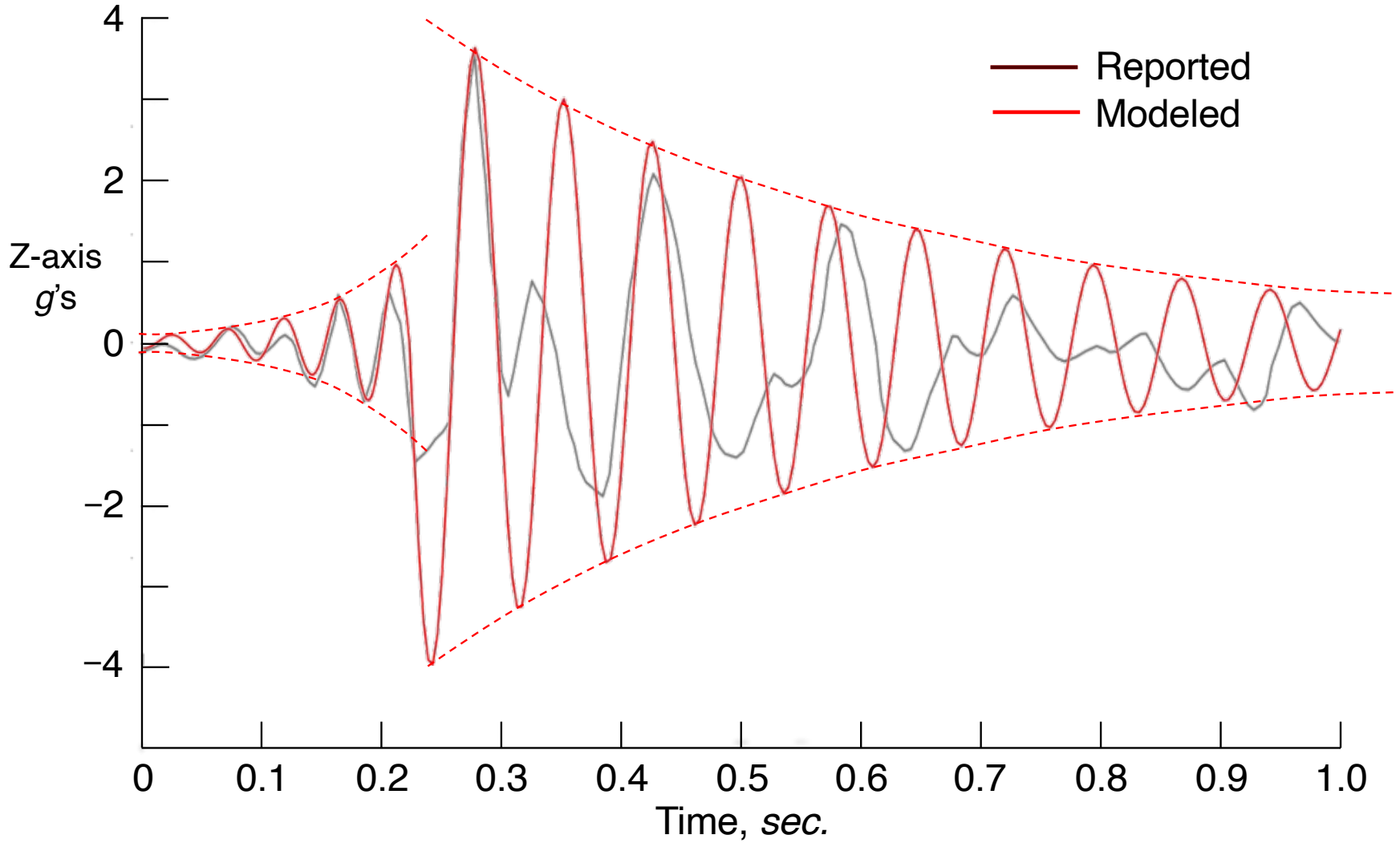

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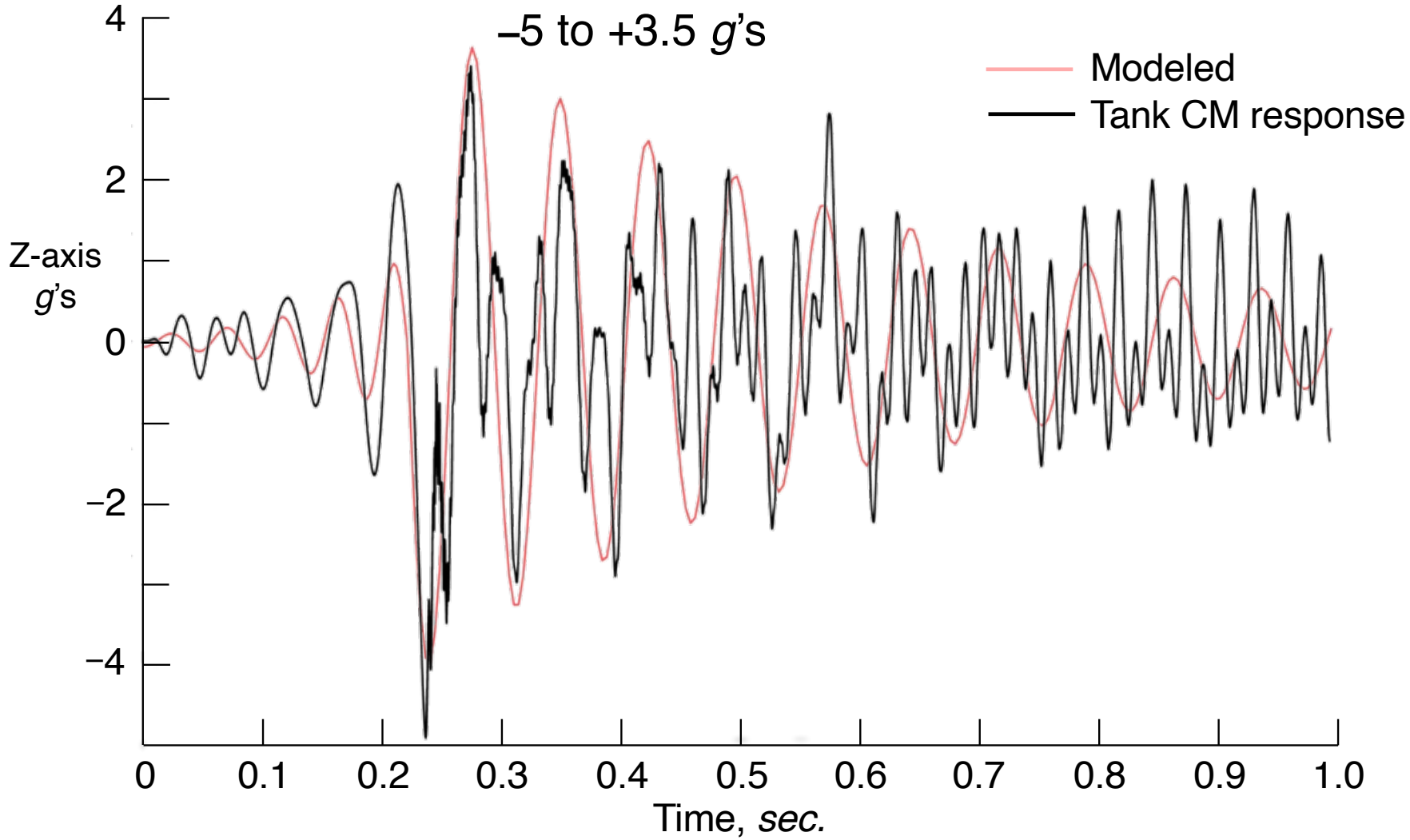

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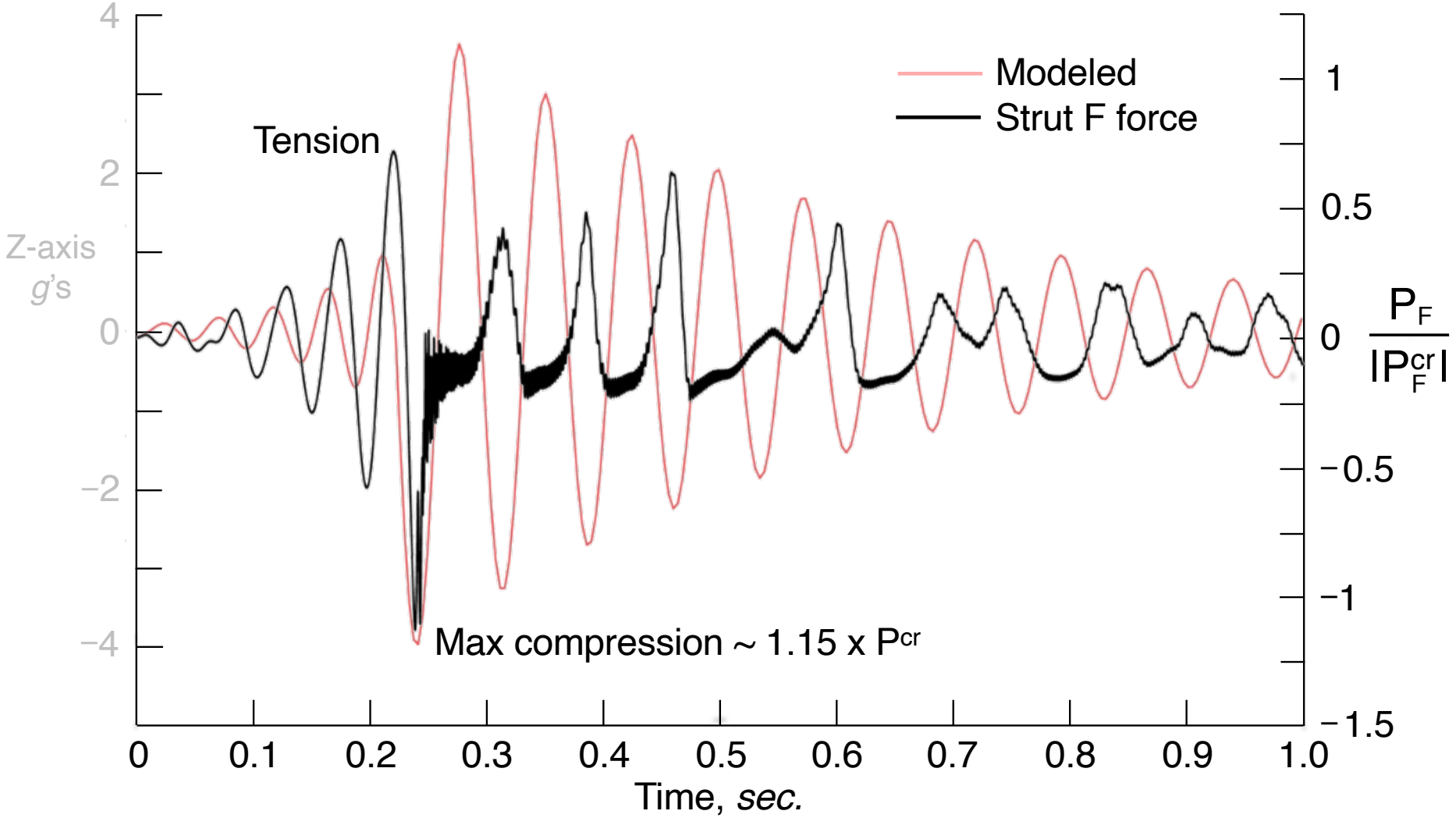

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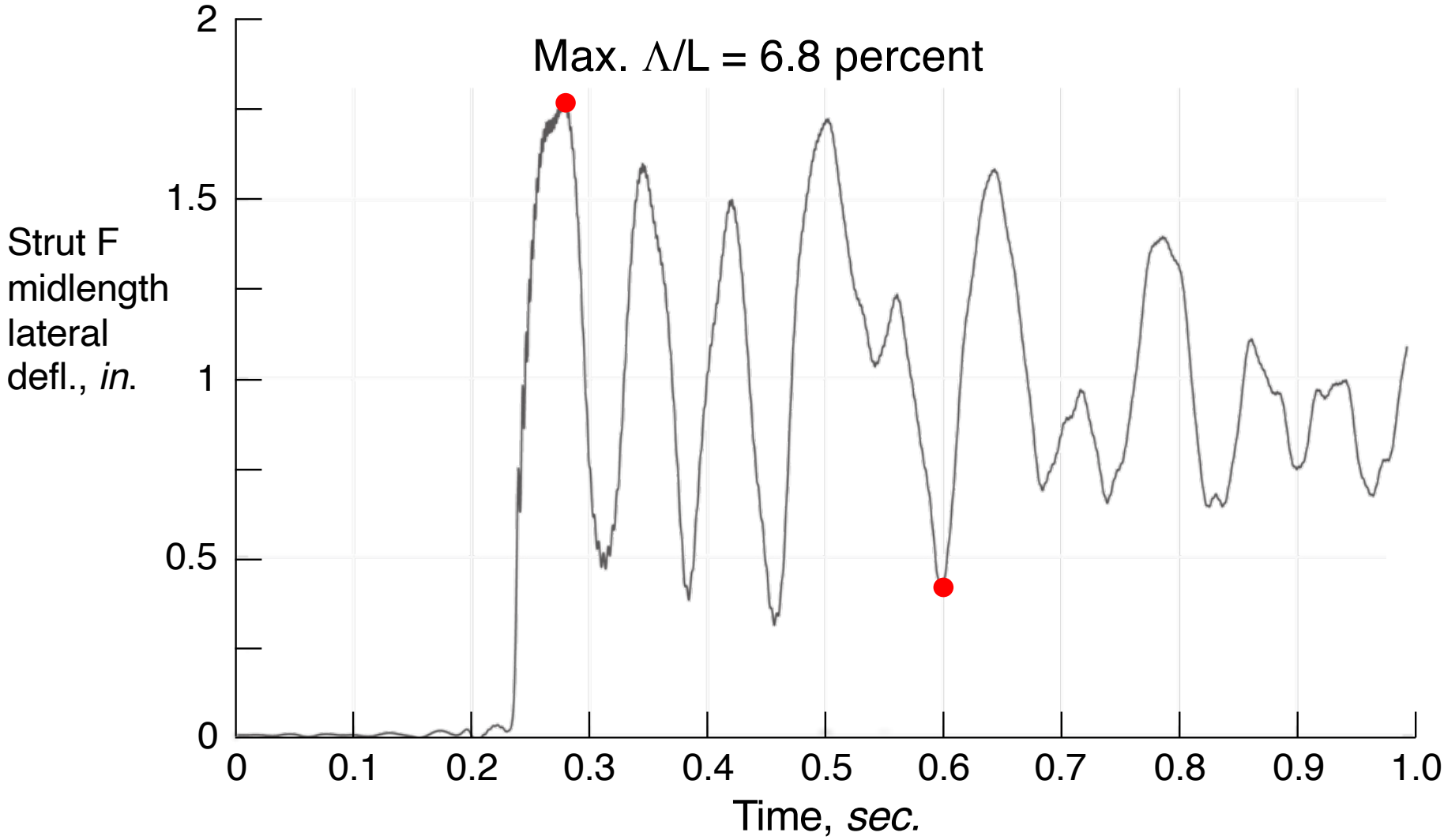

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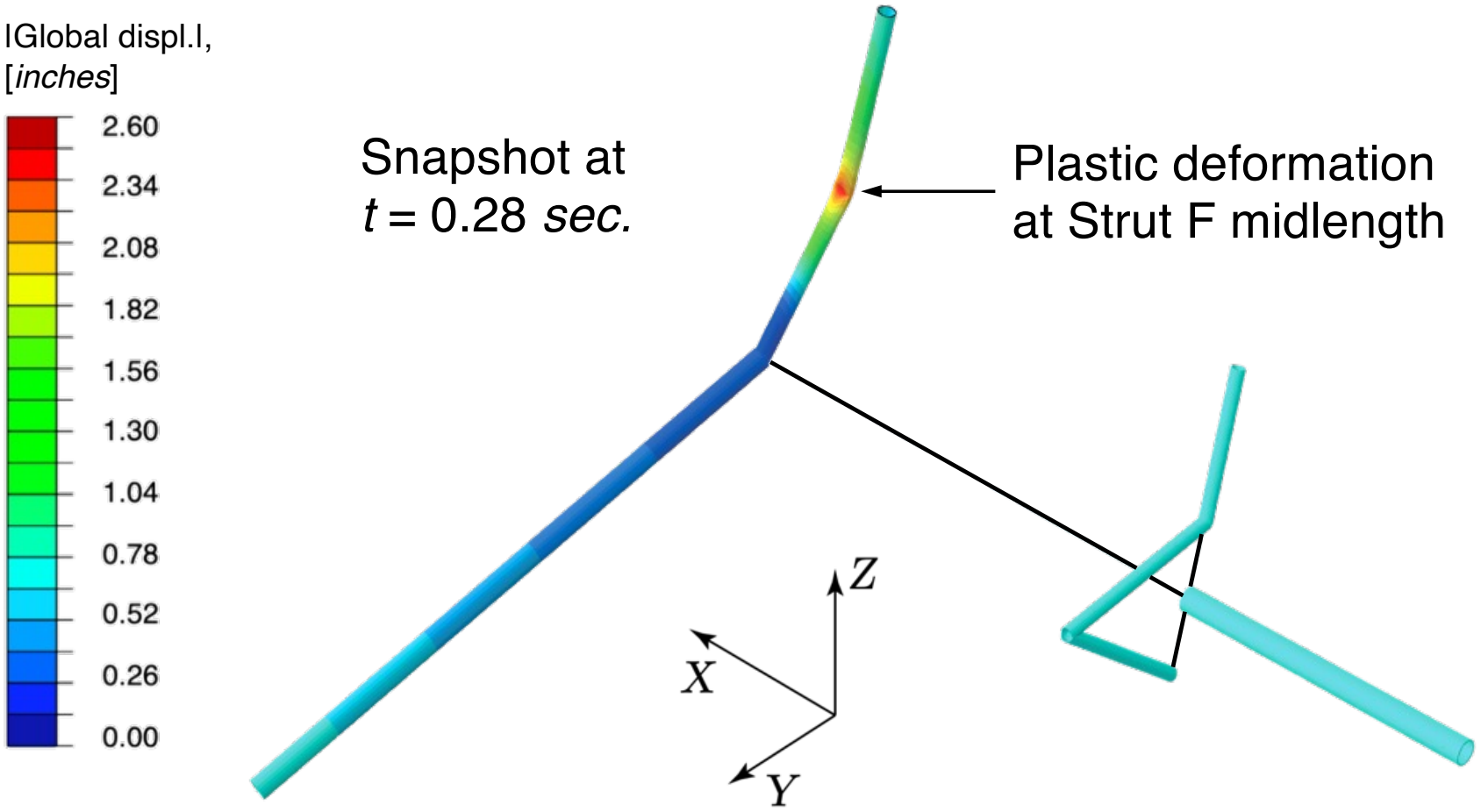
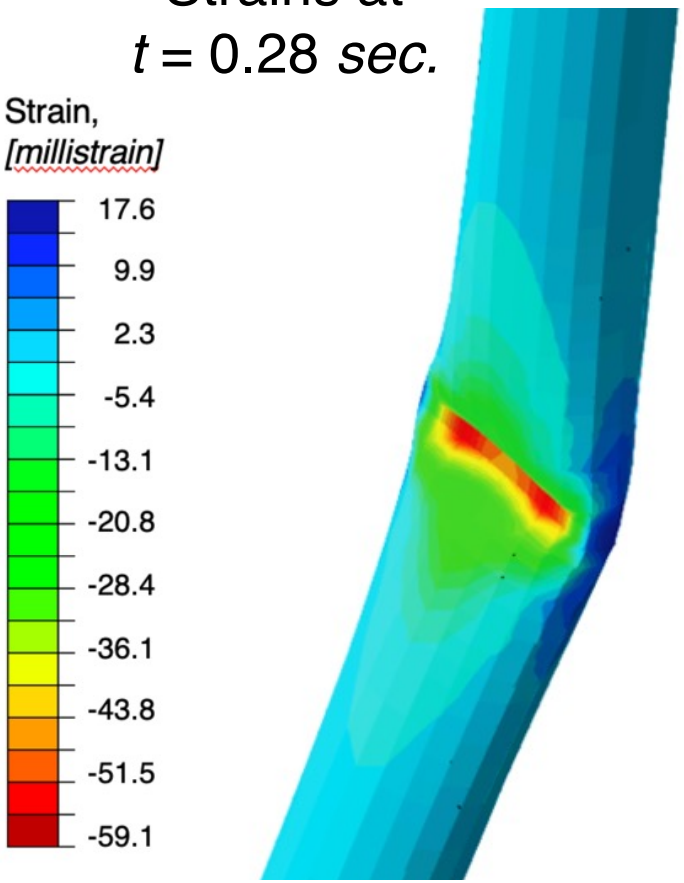


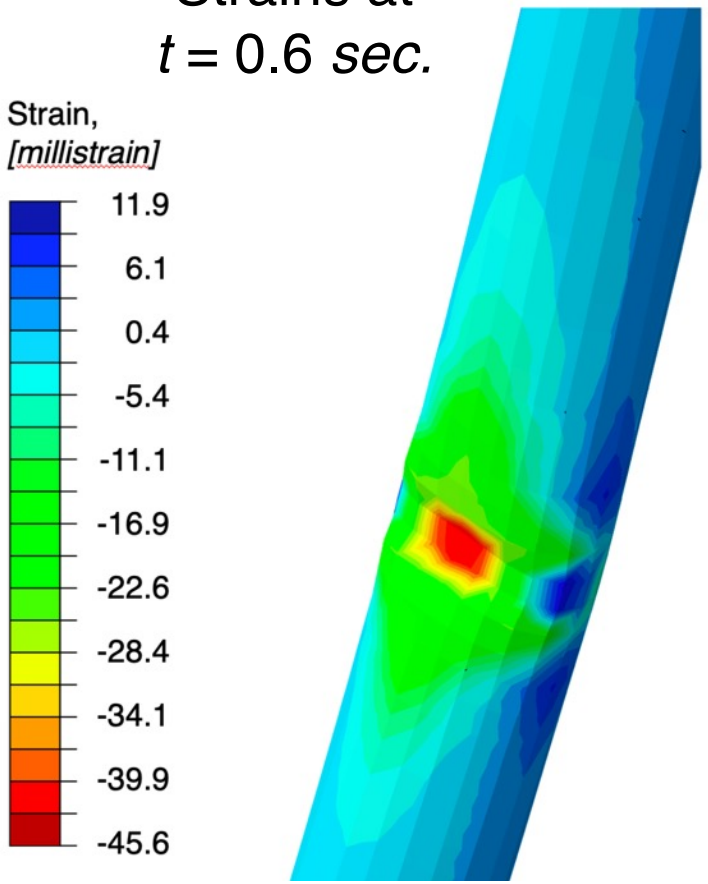
Analysis Results – Sinusoidal Input (5)

Strains at
$t = 0.28$ *sec.*



$\sigma_c \sim -125$ klbf/in^2

Strains at
$t = 0.6$ *sec.*



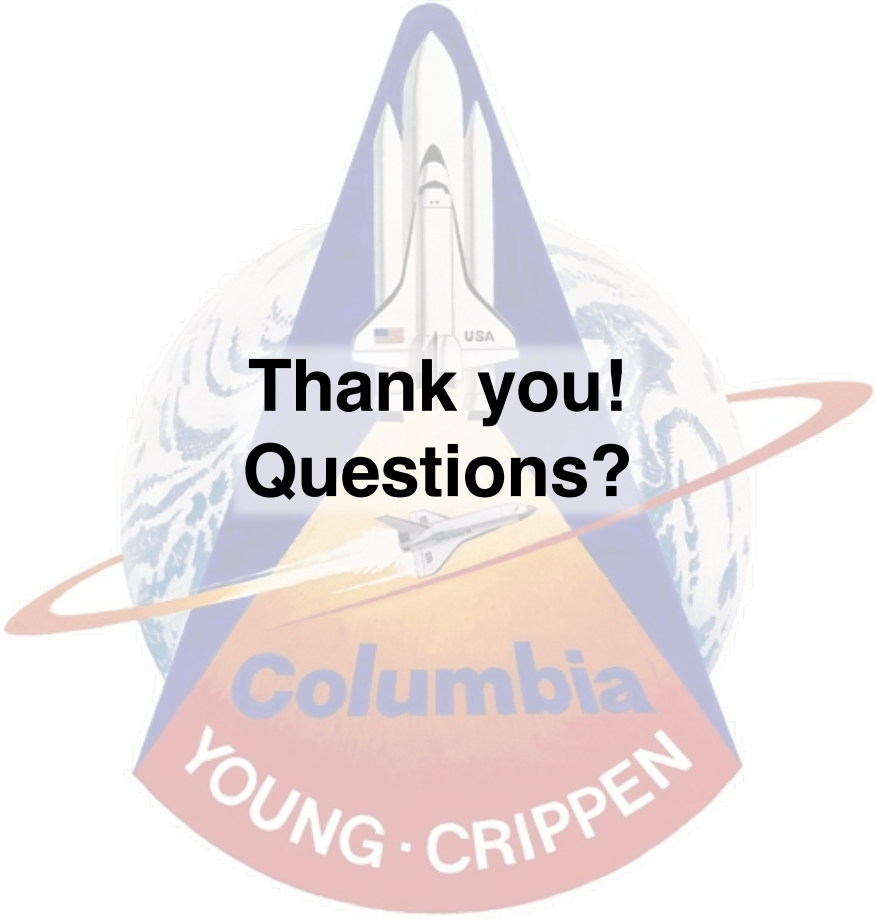
$\sigma_c \sim -115$ klbf/in^2

Concluding Remarks

- Forward RCS NTO Strut F damage found during STS-1 post-flight inspection
- Linear and geometrically nonlinear FE analyses of NTO support structure performed to estimate Euler buckling and structural response to static loads
- Nonlinear dynamic analyses of NTO support structure performed to assess structural response to applied dynamic loads
- Modeled plastic failure at Strut F midlength broadly replicates observed Strut F damage.
- Mitigations applied for STS-2 and all subsequent flights - no recurrence over next 30 years and 134 flights!

“*We Just Became Infinitely Smarter*”

Credit: NASA/JSC



Thank you!
Questions?