

Accelerance Decoupling - Extracting SLS Free Modal Data from the Integrated Modal Test

Daniel Kaufman, NASA Goddard Space Flight Center
Joel Sills, NASA Johnson Space Center
Arya Majed, Applied Structural Dynamics, Inc.

Spacecraft and Launch Vehicles Dynamic Environments Workshop
June 26–28, 2018



Outline

- Objective
- Background
- Methodology
- Numerical Verification
- Findings



Objective

- Verify the Accelerance Decoupling (AD) approach by extracting the SLS free accelerance from the SLS + ML coupled accelerance



Background

- NASA desires direct extraction of SLS free modal data from SLS + ML integrated modal test (IMT) for:
 - Flight controls applications
 - Verify SLS FEM correlation



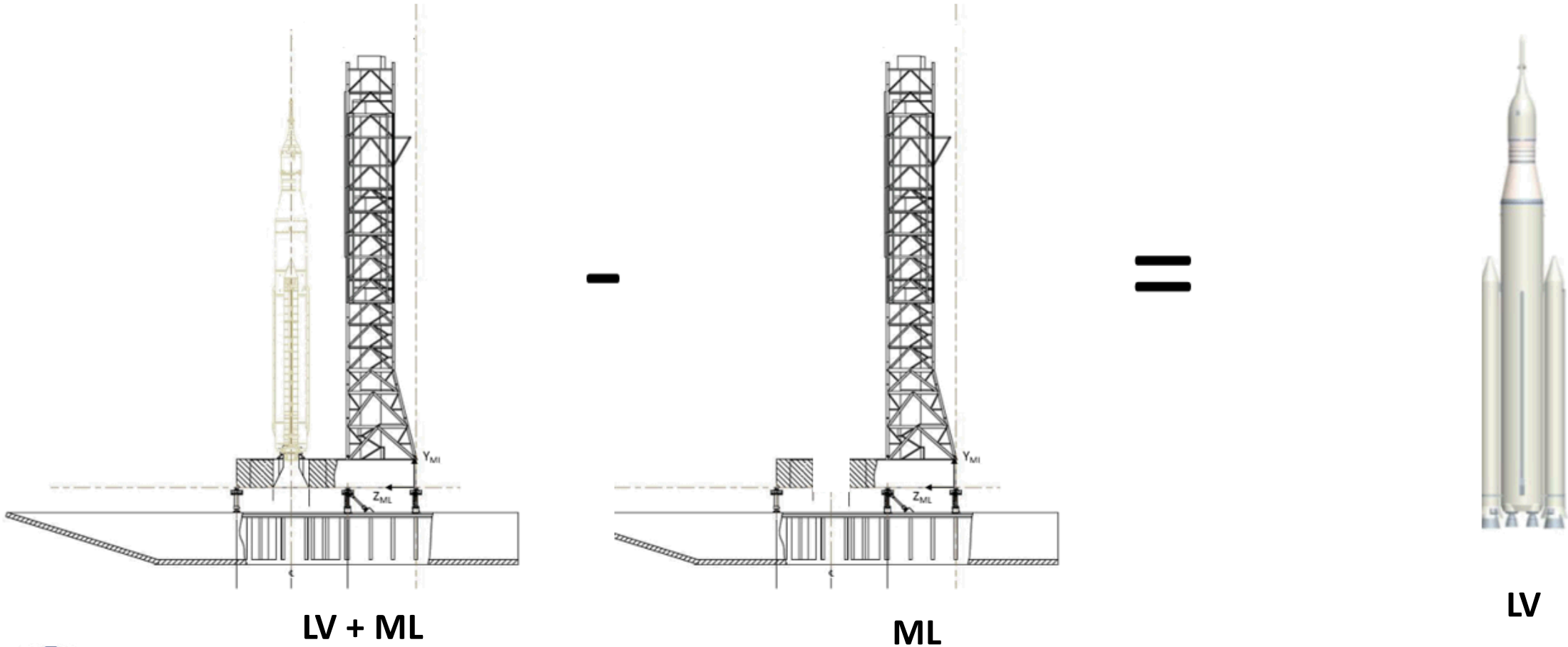
Method/Solution Requirements

- Method able to decouple (i.e., remove) ML influence from the integrated modal test (IMT) data resulting in SLS free modal data
- As much as possible, driven by measured data limiting the use of FEM to fill “gaps”
- Computationally robust – be able to compute with “real-world” data



Accelerance Decoupling (AD)

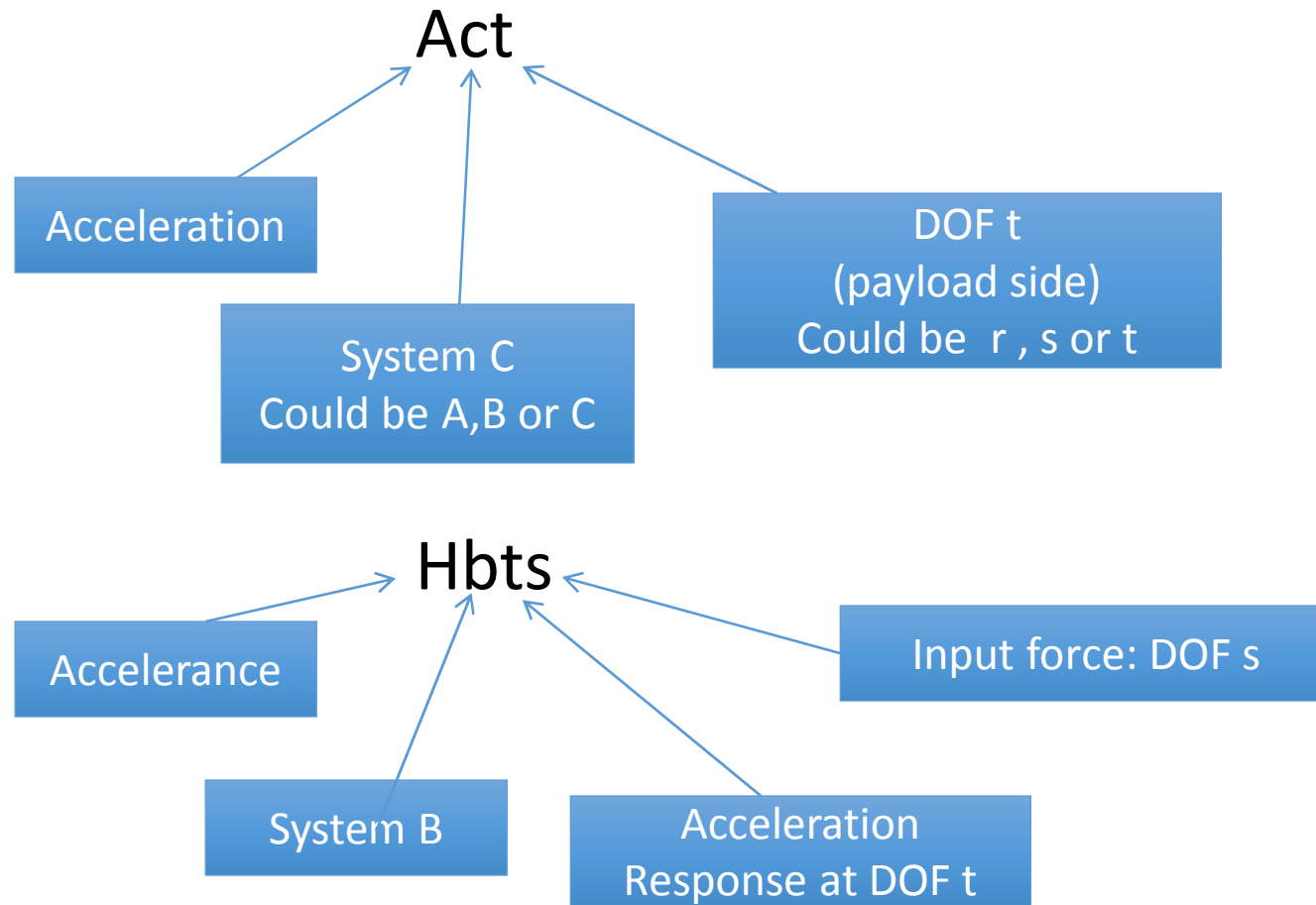
“In a Nutshell”



Methodology (Brief)



Notation



Notation

C: coupled system (A+B)

A: LV with internal dofs R

B: MBT with internal dofs T

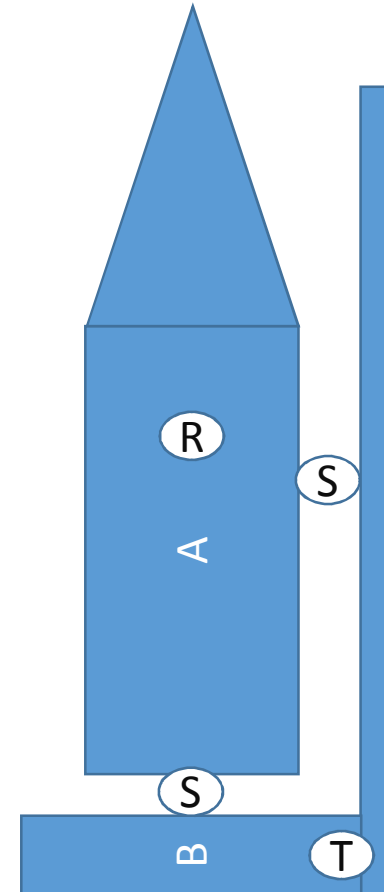
S: connecting dofs

H: accelerance [g/lb]

W: Impedance [lb/g]

F: [lb], A: [g]

During the test forces are applied at some of the R dofs and accelerations measured at the R and S dofs



Methodology

Fundamental Receptance Coupling (RC) equation for two substructures:

$$\begin{bmatrix} H_{crr} & H_{crs} & H_{crt} \\ H_{csr} & H_{css} & H_{cst} \\ H_{ctr} & H_{cts} & H_{ctt} \end{bmatrix} = \begin{bmatrix} H_{arr} & H_{ars} & 0 \\ H_{asr} & H_{ass} & 0 \\ 0 & 0 & H_{btt} \end{bmatrix} - \begin{bmatrix} H_{ars} \\ H_{ass} \\ -H_{bts} \end{bmatrix} [H_{ass} + H_{bss}]^{-1} \begin{bmatrix} H_{ars} \\ H_{ass} \\ -H_{bts} \end{bmatrix}^T \quad (1)$$



Methodology – AD Core and Auxiliary Eqns

From (1), we can derive the AD “core” equation

$$H_{arf} = H_{crf} + \underbrace{H_{ars}}_{\text{Requires "auxiliary eqns" from coupled system}} (H_{ass} + H_{bss})^{-1} \underbrace{H_{asf}}_{\text{Requires "auxiliary eqns" from coupled system}} \quad (2)$$

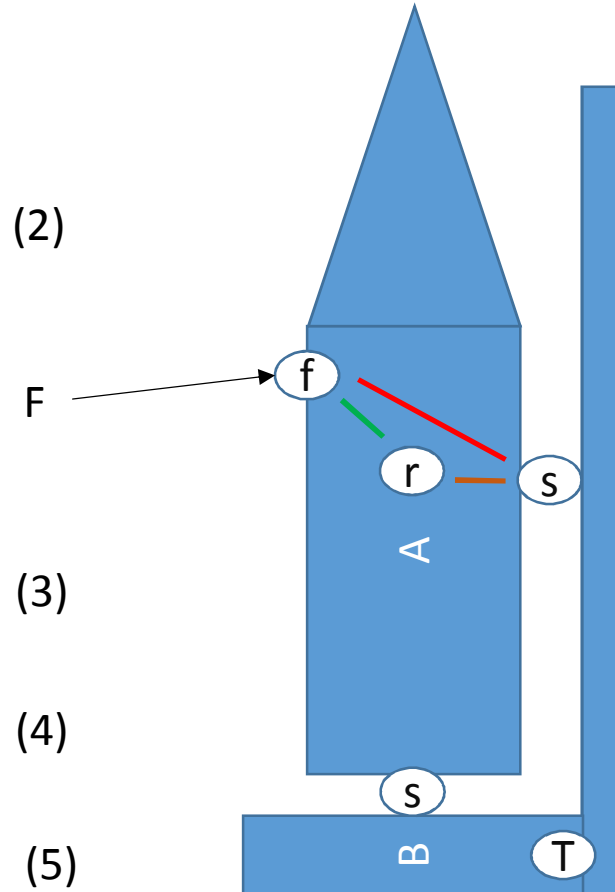
Requires “auxiliary eqns” from coupled system

Auxiliary equations:

$$H_{ars} = [I_{ss} - (H_{ass} + H_{bss})^{-1} H_{ass}]^{-1} H_{crs} \quad (3)$$

$$H_{asf} = [I_{ss} - H_{ass} (H_{ass} + H_{bss})^{-1}]^{-1} H_{csf} \quad (4)$$

$$H_{css}^{-1} = (H_{ass}^{-1} + H_{bss}^{-1}) \quad (5)$$



SLS Free Accelerance (Benchmark for AD Verification)

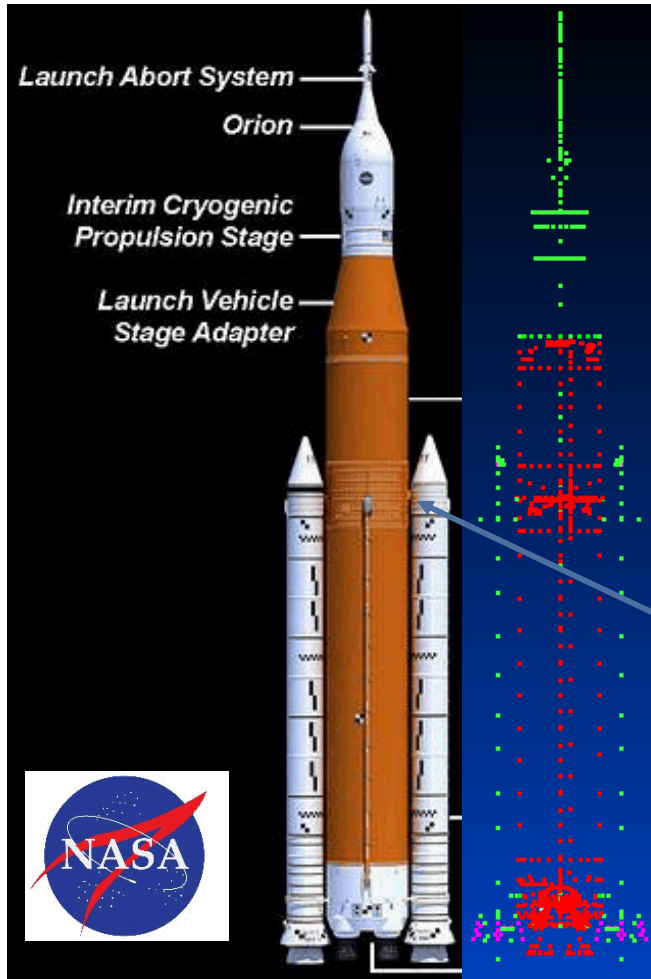


Task

- Compute SLS free accelerance as benchmark to gage accuracy of AD extracted SLS free accelerance
- Compare to SLS + ML coupled accelerance to see the effect of ML



NASA Space Launch System (SLS) CLA Model

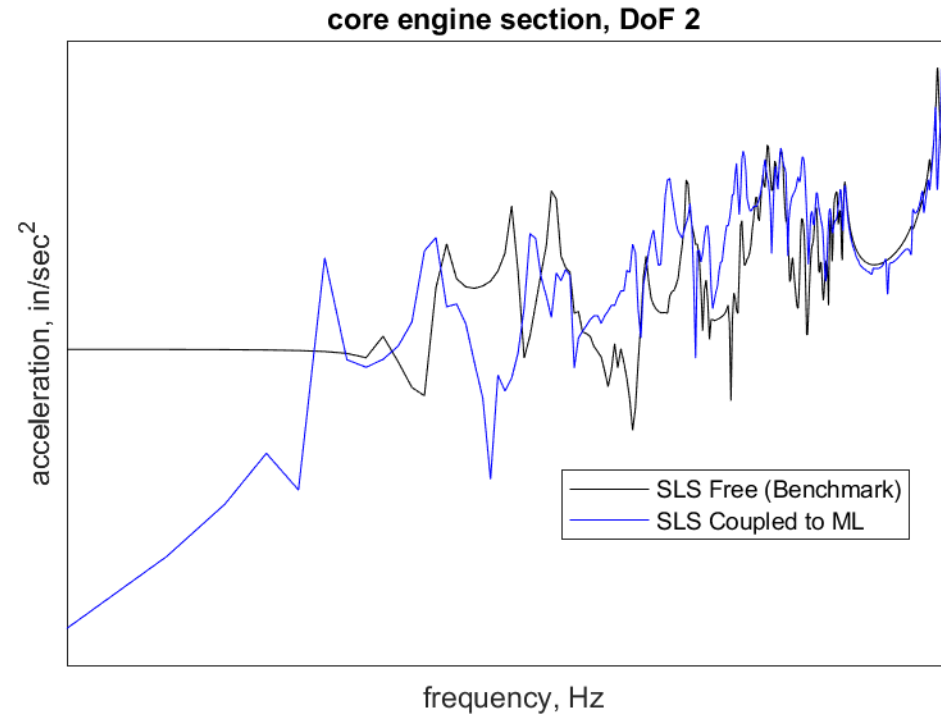


- Integrated SLS is an over-constrained Hurty/Craig-Bampton (HCB) dynamic math model (DMM) with ~11,000 DoFs
- Retained nodes include
 - *Centerlines*
 - *Actuators/Gimbals*
 - *Many Others*
- For this problem, input loads at Core Stage Forward Attach (CS FA)
 - $F_x=F_y=F_z = 100 \text{ lbs (0.1 - 50 Hz)}$

Reduced Dynamic Math Model (DMM)

ML not shown

Internal DoF Acceleration



SLS free acceleration vs coupled to ML shows measurable difference which the AD procedure must overcome in order to be a viable



Accelerance Decoupling

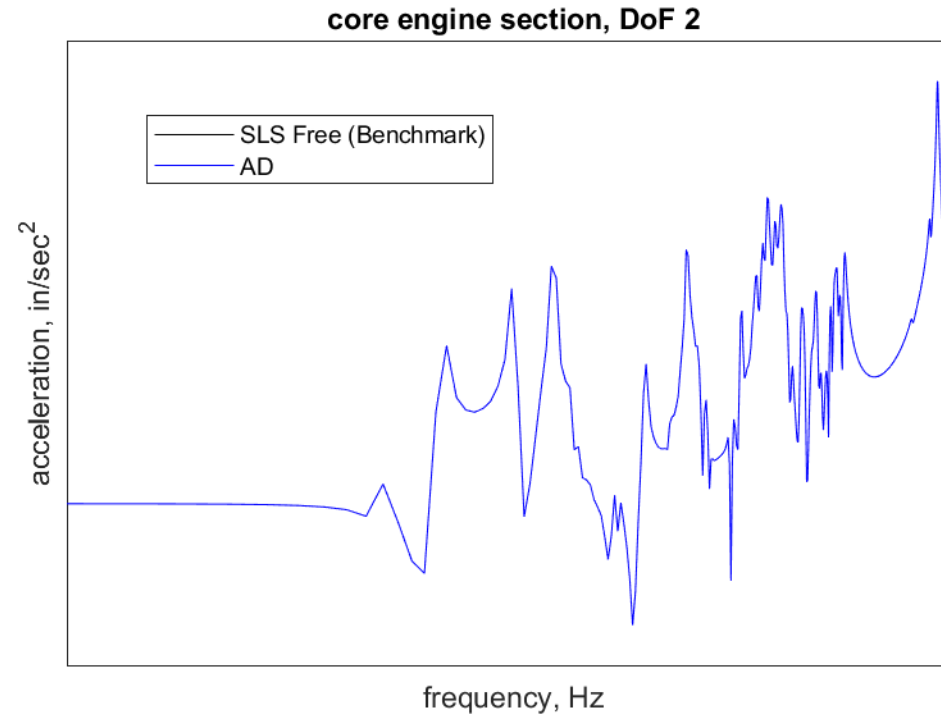


Task

- Utilize AD to extract SLS free acceleration from SLS + ML coupled acceleration
- Compare to benchmark



Internal DoF Acceleration



AD procedure was able to correctly “dissect” the SLS free acceleration from the coupled SLS + ML acceleration resulting in a near perfect numerical match to the benchmark



AD Sensitivity ML Accelerance Perturbations



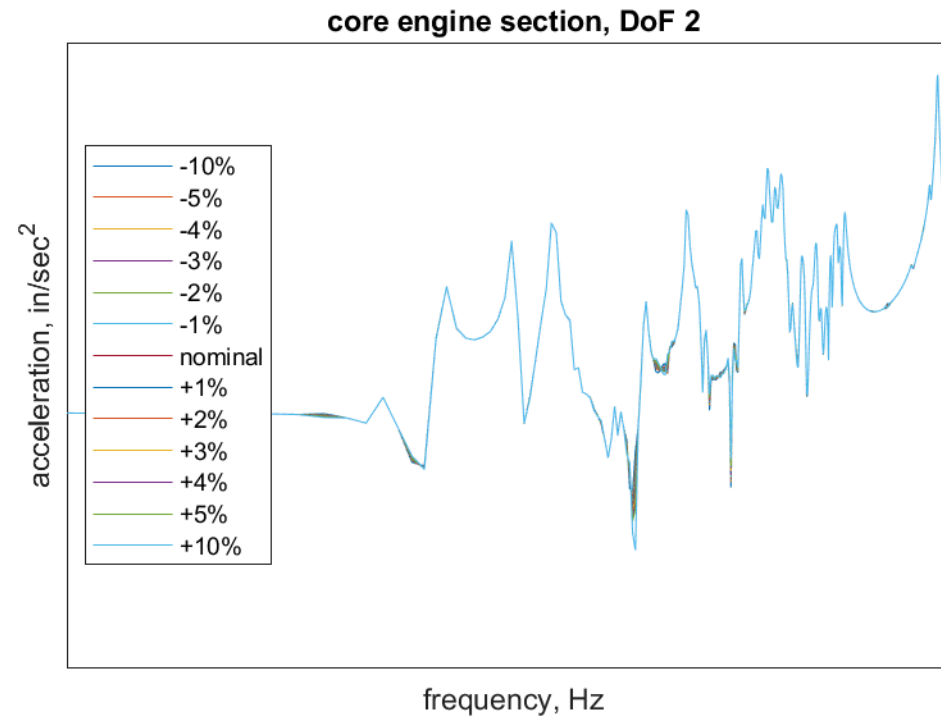
Tasks

- Assess AD computational sensitivity to perturbations of ML accelerance while keeping coupled SLS + ML accelerance unchanged
 - ML damping varied +/- 10% of nominal in 1% increments
 - +/- 5% of nominal in 1% increments (11 runs)
 - +/- 10% of nominal (2 runs)
- Compare to benchmark

*NASA Peer Review Required Task



Internal DoF Acceleration



Benchmark is nominal case

AD remains computationally robust under ML acceleration perturbations



AD Sensitivity

Rotational DoFs Stiction



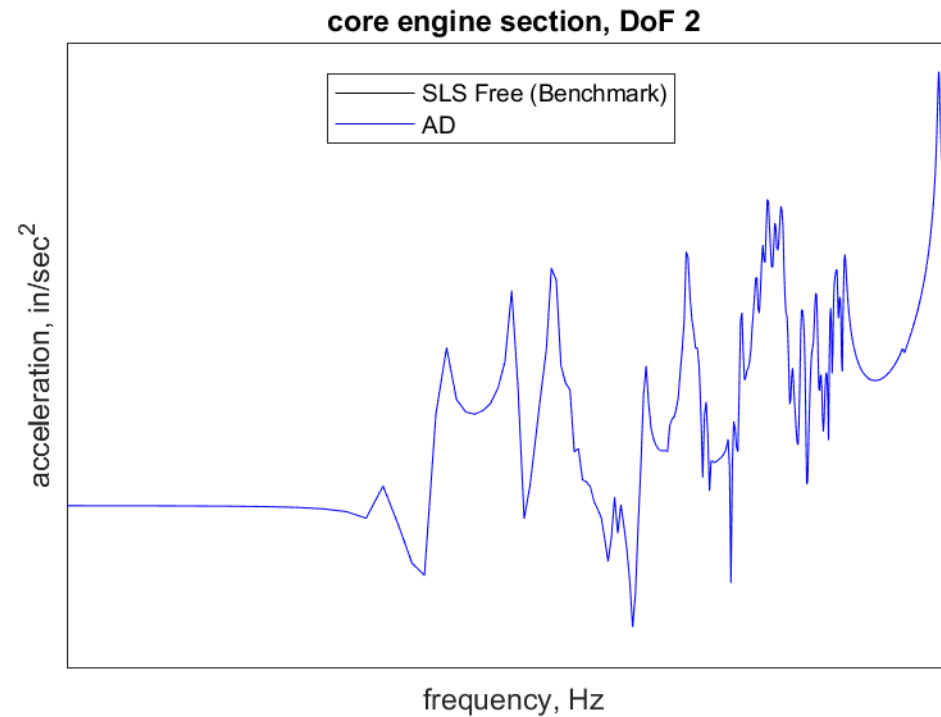
Tasks

- Assess AD sensitivity to VSP rotational DoFs stiction
- Compare back to benchmark

*NASA Peer Review Required Task



Internal DoF Acceleration



AD remains accurate under
VSP rotational DoFs stiction



Findings

- SLS free accelerance vs coupled to ML show measurable differences which AD must overcome in order to be a viable procedure
- AD procedure was able to correctly “dissect” the SLS free accelerance from the coupled SLS + ML accelerance resulting in a near perfect numerical match to the benchmark
- AD procedure remained robust under ML accelerance perturbations (NASA peer review requirement)
- AD procedure remained robust under VSP stiction (NASA peer review requirement)
- More work remains – effect of noise



Thank you

