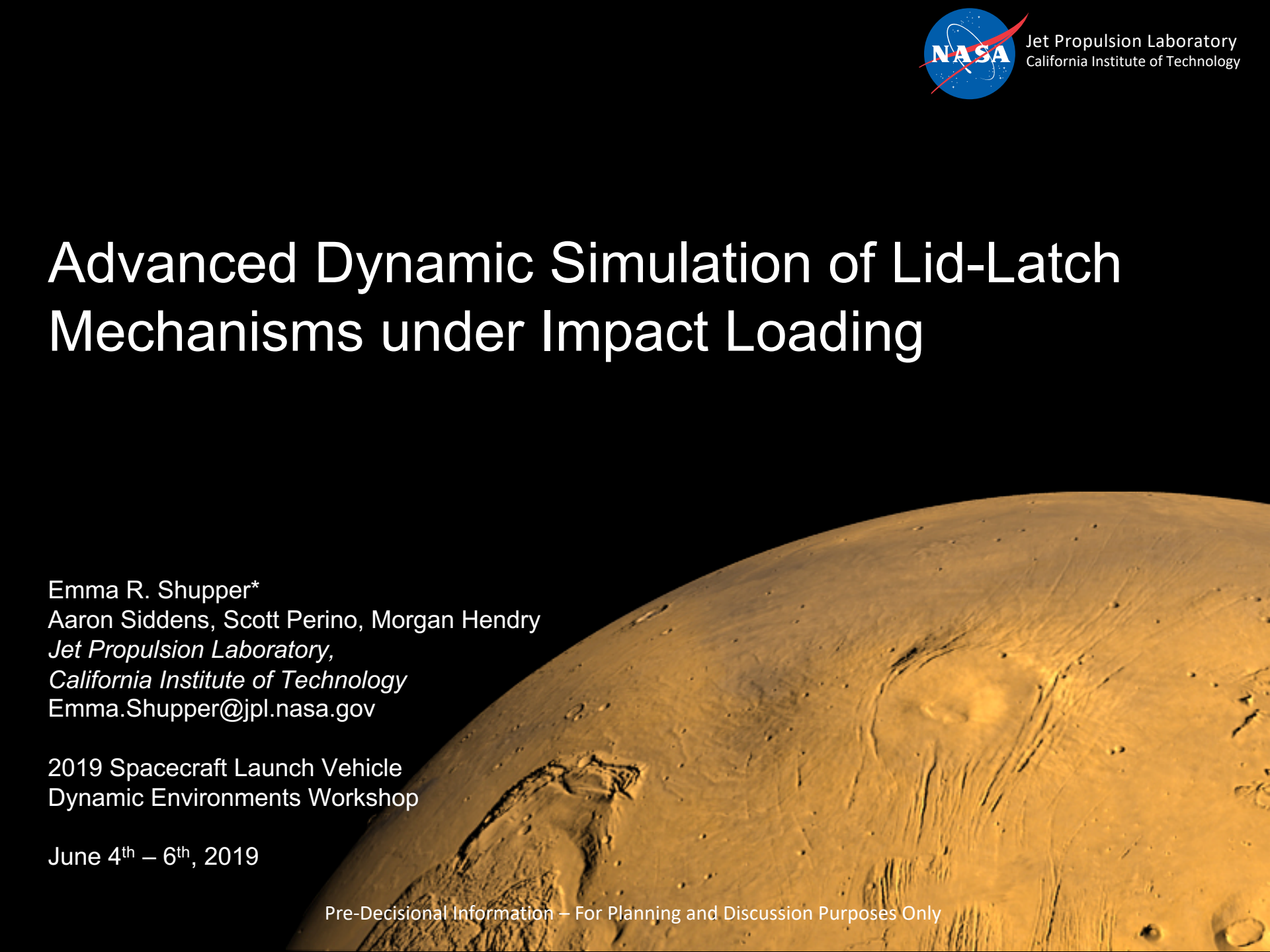

Advanced Dynamic Simulation of Lid-Latch Mechanisms under Impact Loading

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2019 Spacecraft Launch Vehicle
Dynamic Environments Workshop

June 4th – 6th, 2019

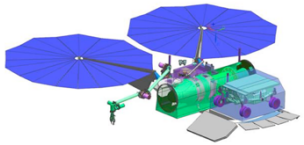
Outline

- Notional Mars Sample Return (MSR) Campaign Architecture Overview
- MSR Earth Entry Vehicle (EEV) Concept Overview
- MSR Containment Assurance Scheme
  - Assembly procedure
  - Key interfaces and interfaces under study
  - Load environment and implementation
- Analysis Methodology in LS-DYNA
  - LS-DYNA Analysis Examples
    - Single pawl studies
    - Piece-Part Studies of Secondary Containment Vessel (SCV)
    - Progress towards integrated, system-level model

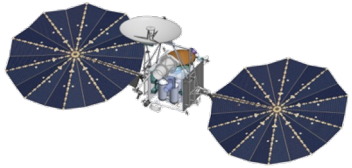
Notional Mars Sample Return (MSR) Campaign Overview

Flight

Sample Caching Rover (Mars 2020)



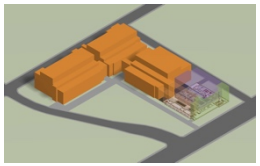
Sample Retrieval Lander



Earth Return Orbiter

Launch from Earth/Land on Mars → Select Samples → Acquire/Cache Samples → Retrieve/Package Samples on Mars → Launch Samples to Mars Orbit → Capture and Isolate Sample Container → Return to Earth → Land on Earth

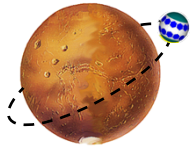
Ground



Mars Returned Sample Handling

Retrieve/Quarantine and Preserve Samples on Earth → Assess Hazards → Sample Science

Sample Tube on Mars Surface



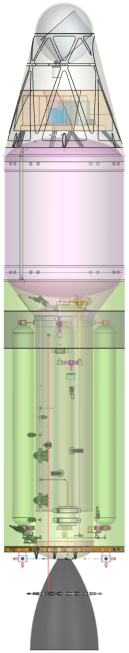
Orbiting Sample (OS) in Mars Orbit

Orbiting Sample (OS) on Earth

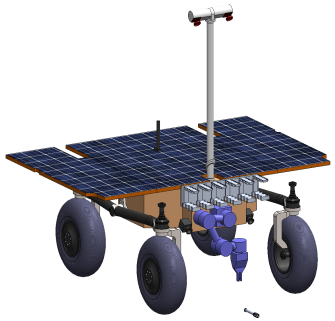
Sample Science

Notional MSR Key Elements of Interest

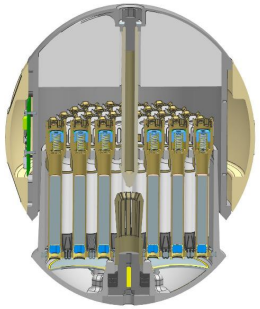
Sample Retrieval Lander



Mars Ascent Vehicle

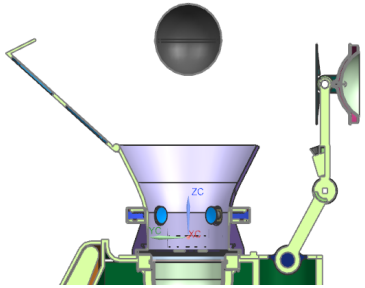


Sample Fetch Rover

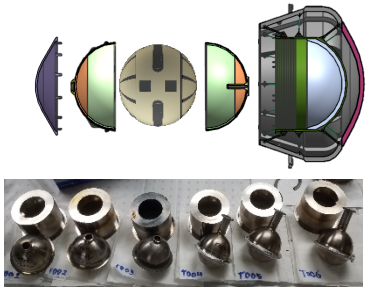


Orbiting Sample (OS) Container

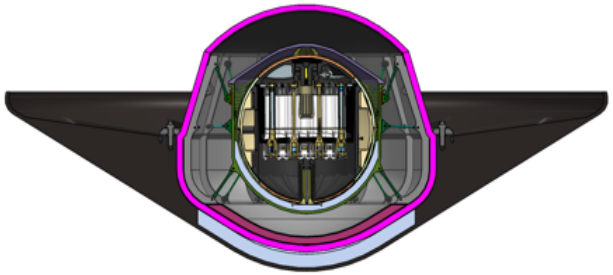
Earth Return Orbiter



Rendezvous and Capture

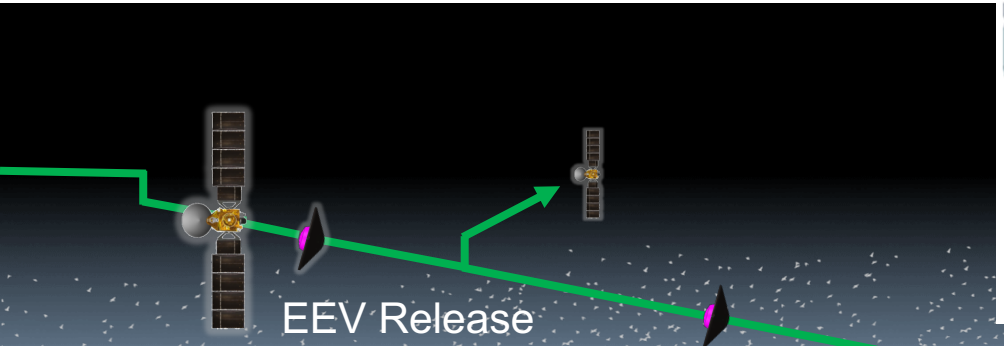


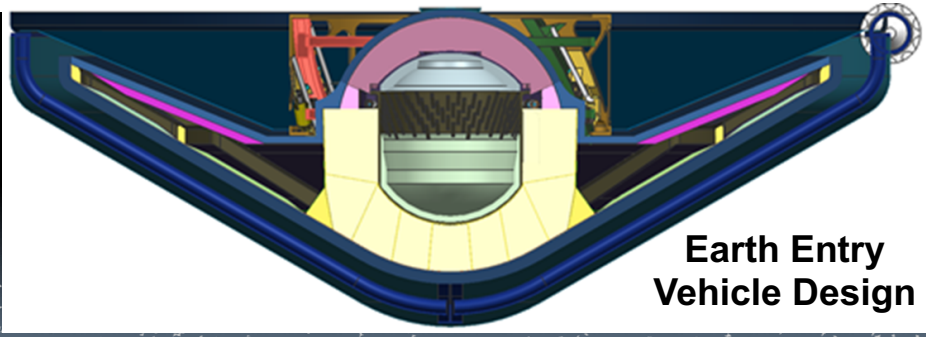
Containment Assurance



Earth Entry Vehicle

MSR Earth Entry Vehicle (EEV) Concept Overview





Atmospheric entry

Descent

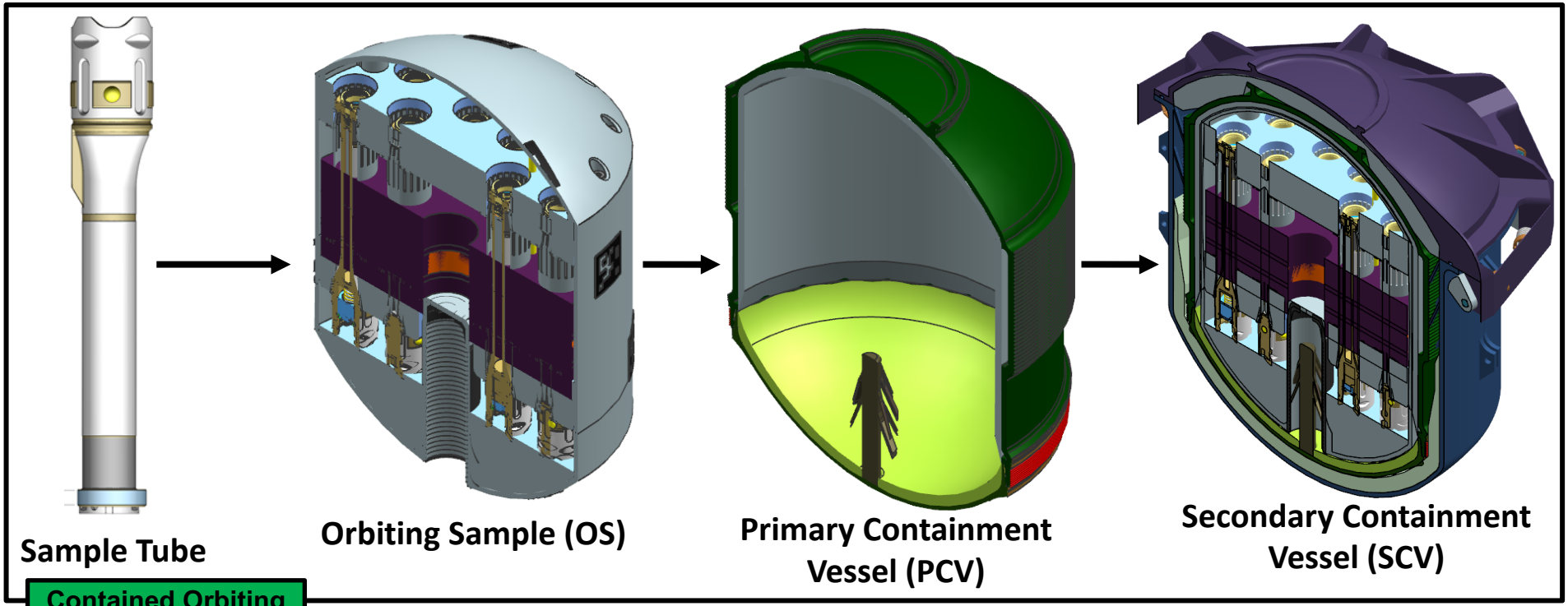
- MSR EEV is a ***passive*** entry system to safely return Martian samples to the surface of Earth
- A key design driver is ensuring robust and reliable containment assurance to meet planetary protection requirements
  - **Primary purpose is impact response mitigation of the payload**
  - Achieved primarily through design with **high energy absorbing materials** and implementation of **low-backlash/motion-limiting mechanisms** at key interfaces

Impact landing

Outside Landing Zone

Landing Zone

MSR Contained Orbiting Sample (C-OS)

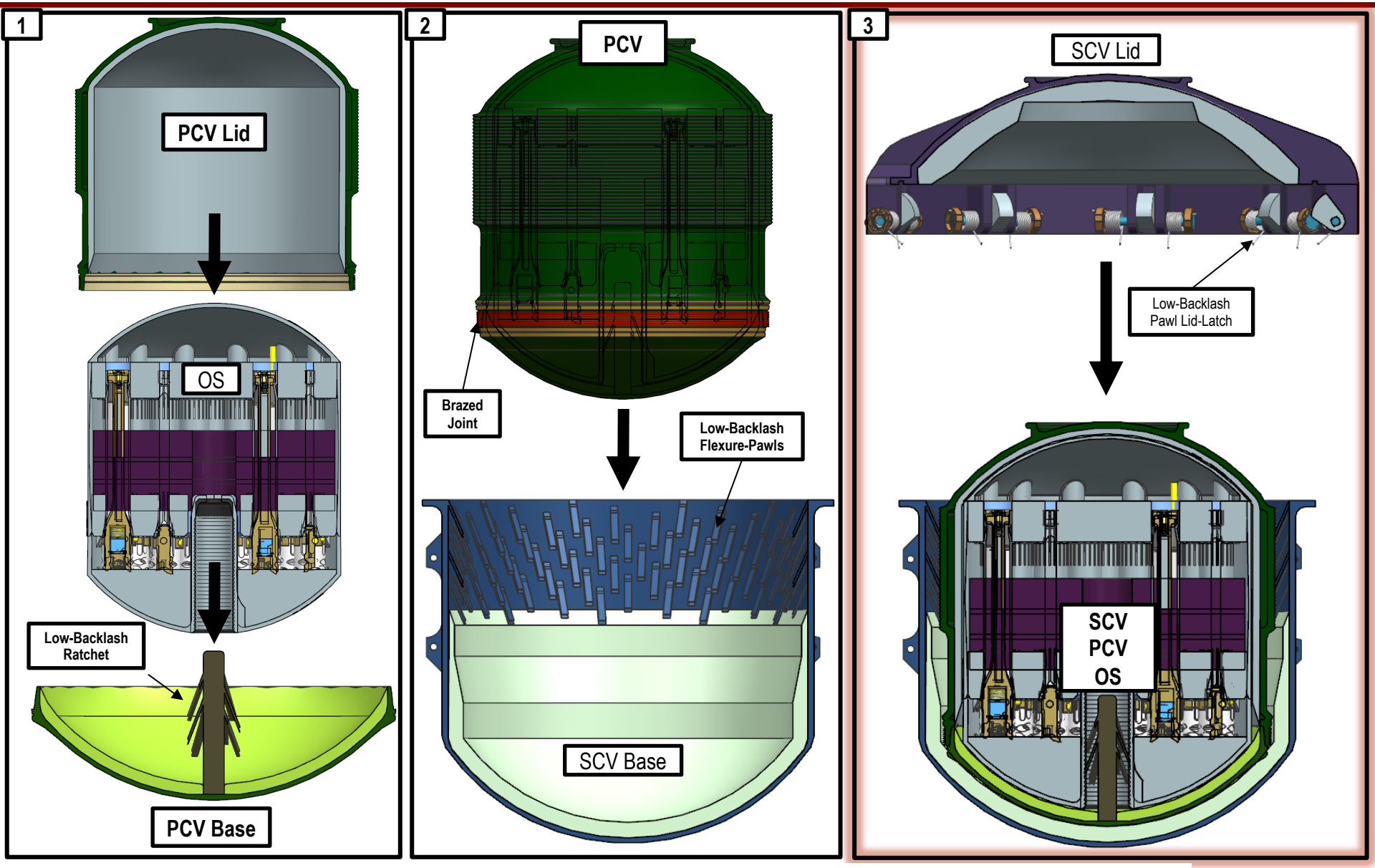


Contained Orbiting Sample (C-OS)

The Contained-OS is composed of: the (1) Orbiting Sample (OS), the (2) Primary Containment Vessel (PCV), and (3) Secondary Containment Vessel (SCV)

The **goal of the C-OS** is to provide returned samples with a "**redundant, fail-safe containment" methodology** able to survive Earth entry, descent, and impact landing - EEV required to provide majority of impact response mitigation during landing

Contained-OS Assembly Procedure



Interface Currently under Study

- Containment <u>not assured</u> when PCV and SCV:
  - Suffer overt structural failure (e.g. container cracks)
  - Gap/fail their seals
    - Due to deflection of the lid and/or base
    - Due to failure of the latch/closure system
- Believe that Containment Assurance currently **driven by failure of the latch system for SCV**

<u>Concern 1</u>

Quasi-static loading during in-orbit robotic assembly

<u>Response 1</u>

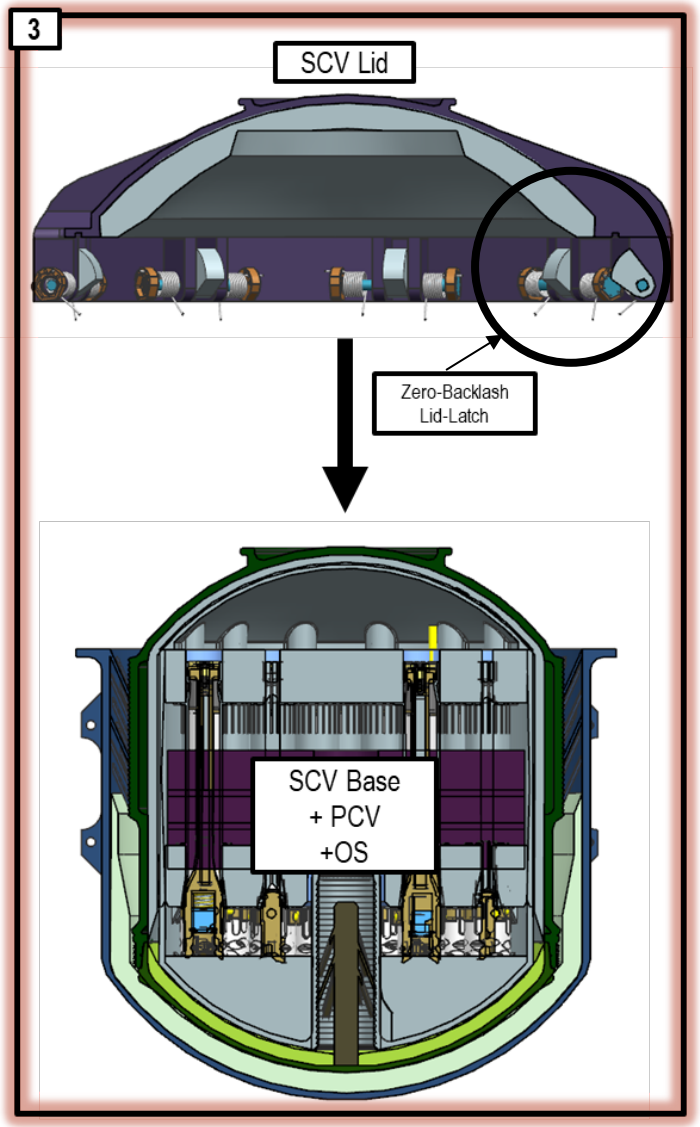
- Characterize performance of lid latches during C-OS assembly
- Minimize insertion loads
- Ensure robustness against off-nominal assembly environments

<u>Concern 2</u>

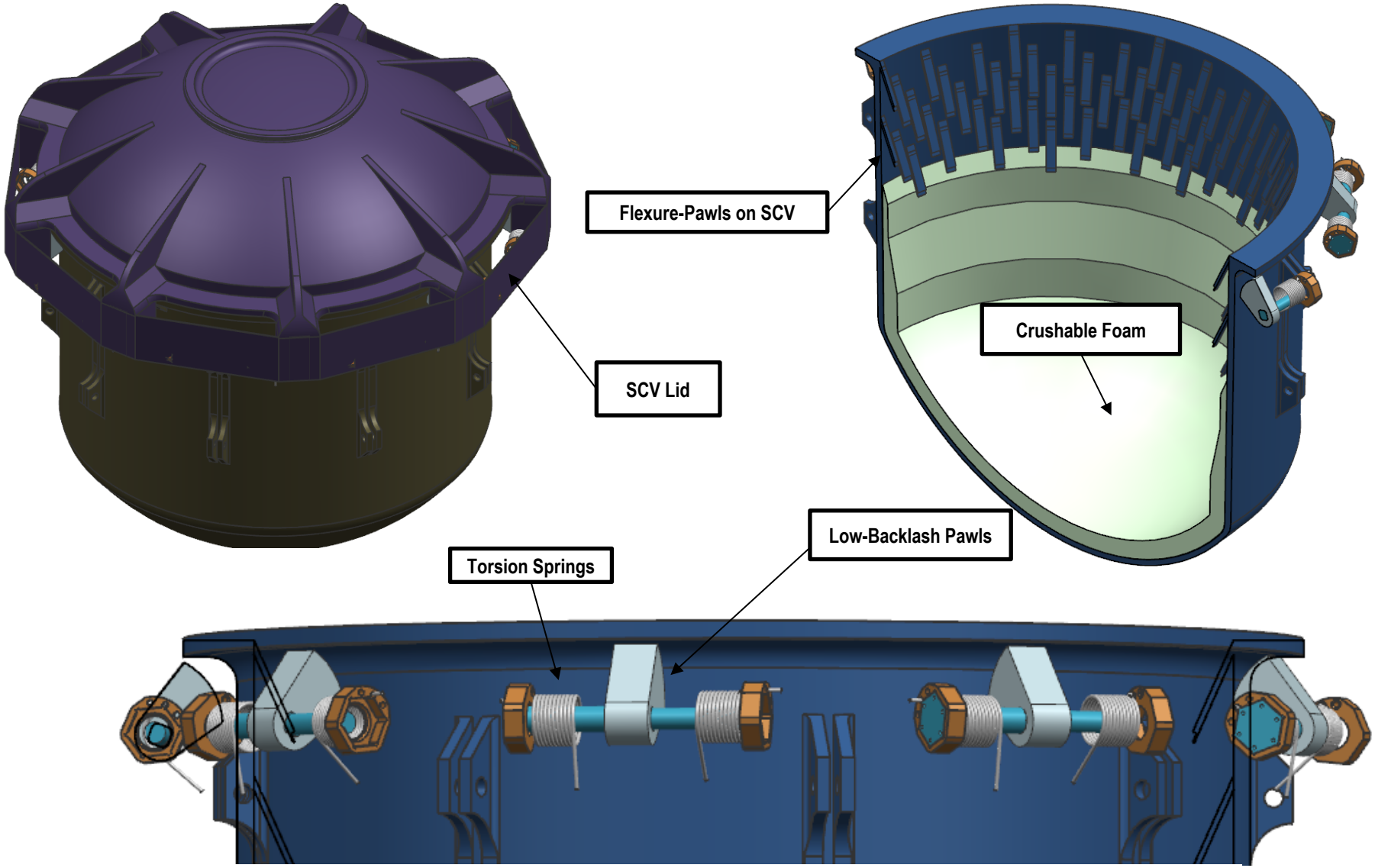
Dynamic loading during Earth re-entry and impact landing

Response 2

- Characterize performance of lid latches during dynamic impact event
- Ensure positive structural margins
- Ensure no gapping at lid and latch interface

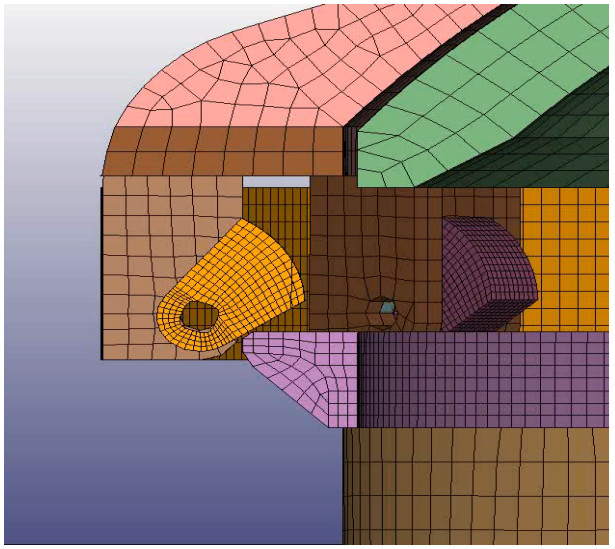


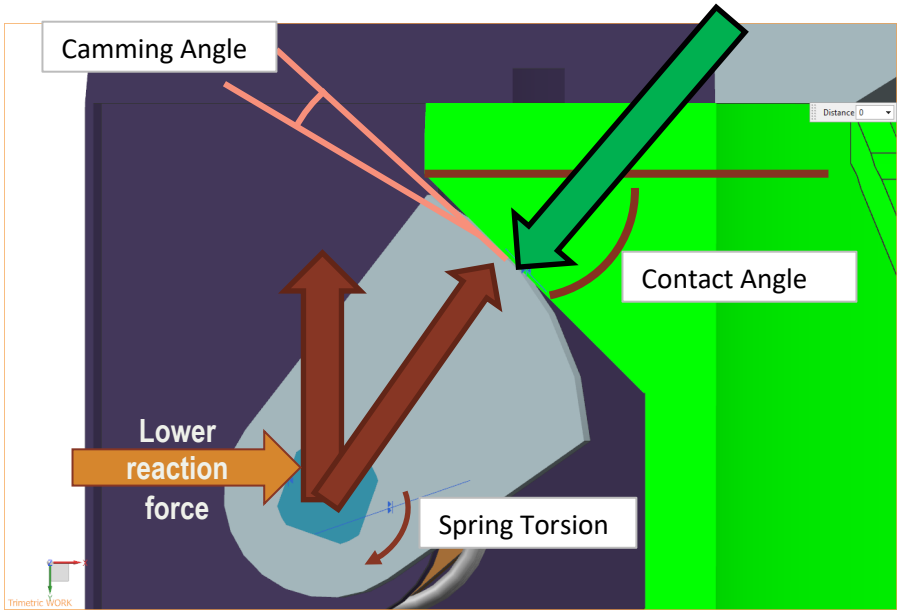
SCV Lid Latch Interface Details



SCV Pawl Lid-Latch Design

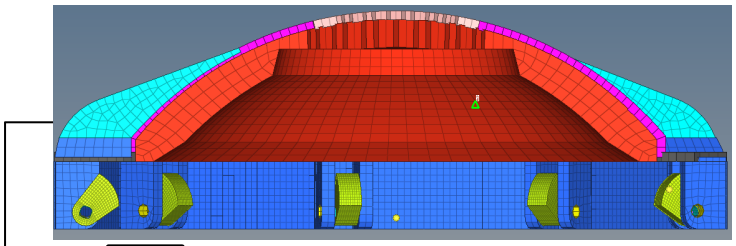
- Lid-latch is based off of a low-backlash pawl design
  - Used on MSL Remote Sensing Mast and SMAP Solar Array
- The logarithmic cam profile - prevents backlash in an impact event
  - Entry/impact forces will push lid closed, resulting in increased latch engagement
  - Torsional springs help to drive engagement
- Latch requires (very low) friction to remain engaged
- Radial forces must be reacted - overhang surface to reduce both reaction loads and contact stresses
- Success in quasi-static environment – not yet characterized in impact environment





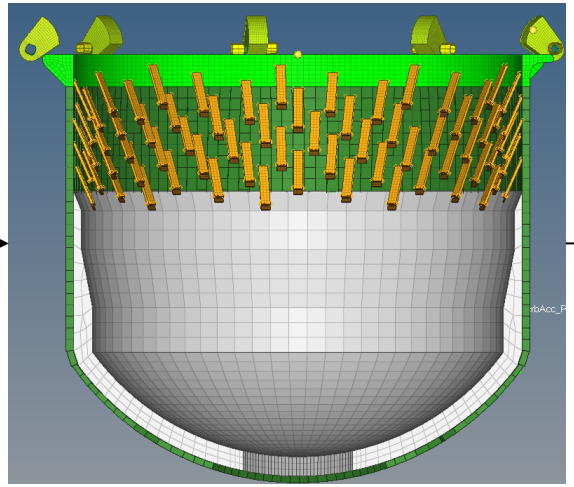
C-OS Model Overview

- Primary driver of Contained-OS design is **assurance of sample containment**
- All key mechanisms and interfaces must be able to structurally withstand peak dynamic load environments, while maintaining proper seal engagement at lids of containment vessels
- **Properly assessing the Contained-OS in a dynamic load environment is critical to achieving a viable design**



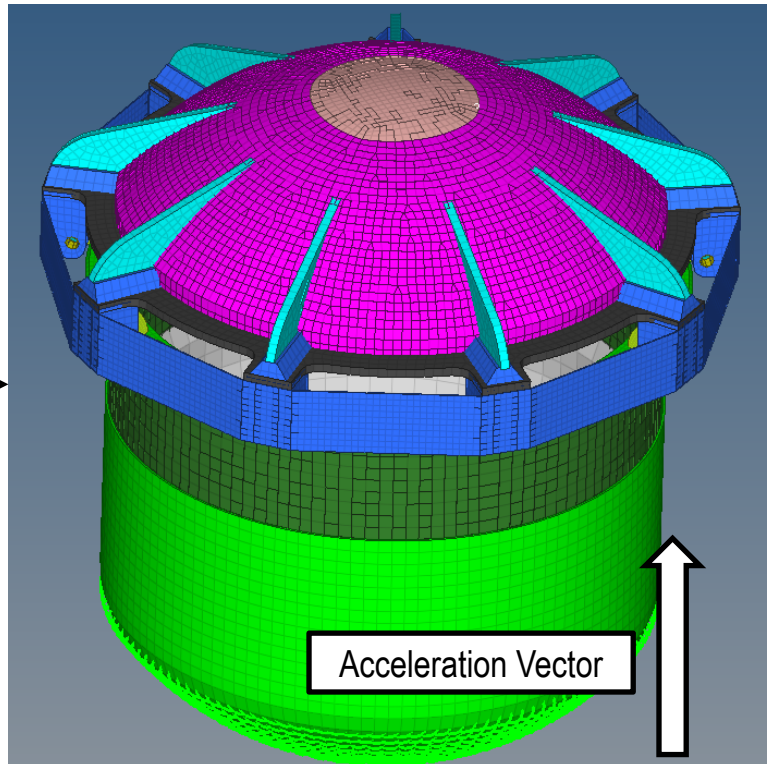
1

Lid inserted onto SCV base to assess **feasibility of assembly**



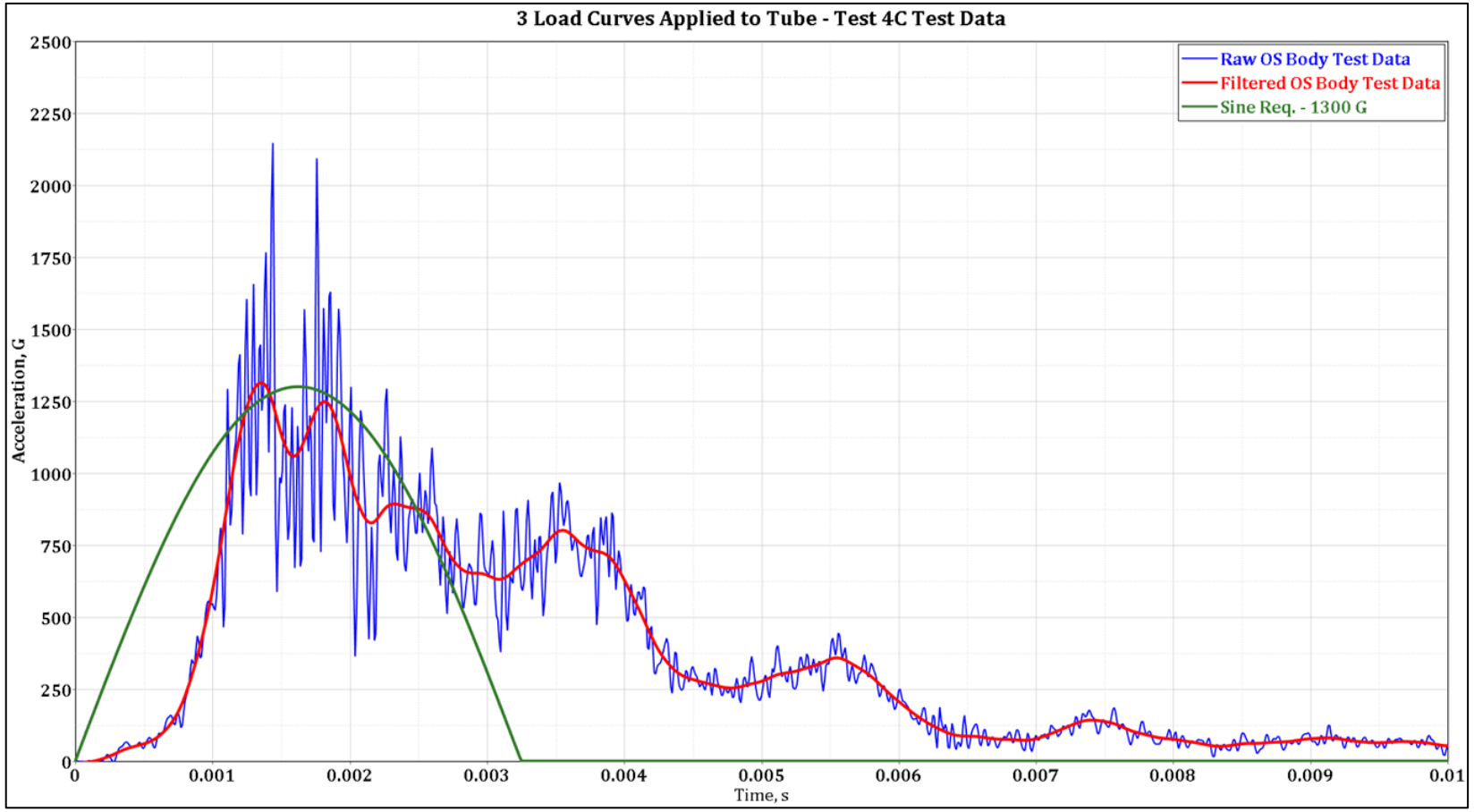
2

Impact environment imposed to asses **impact survivability of lid latch**

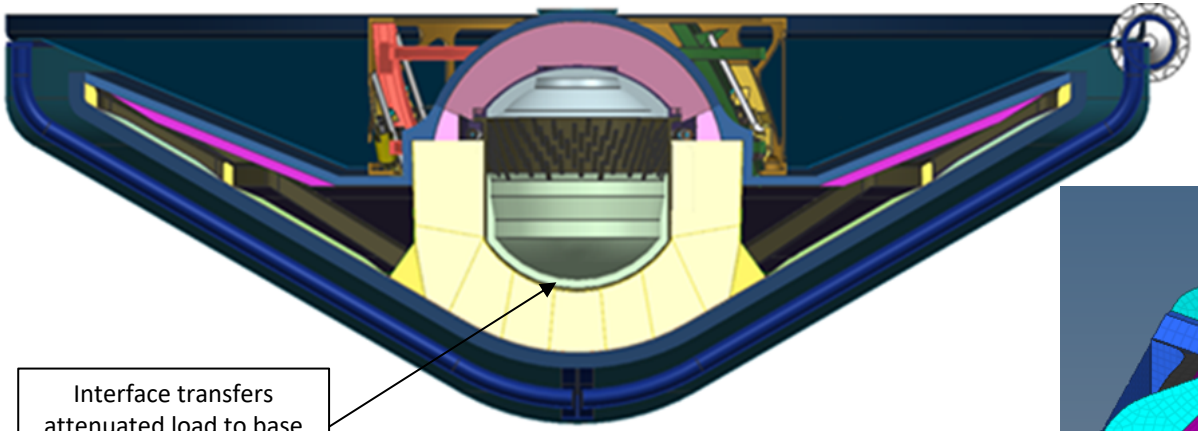


Earth-Impact Dynamic Load Environment

- Drop-tests were performed to determine the dynamic response at the C-OS during impact
- In initial simulations, the measured acceleration curves are used to approximate the load environment at the C-OS sub-assembly level
- In future simulations, full-scale system level models will be implemented in order to accurately capture load transfer from the EEV to the C-OS to the sample tubes

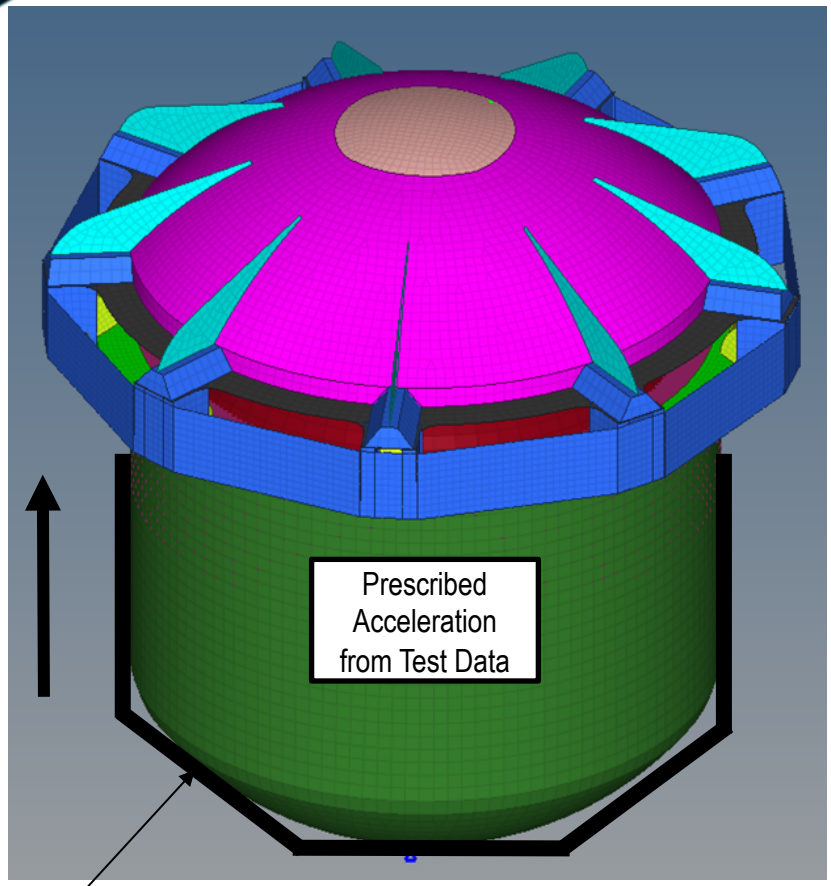


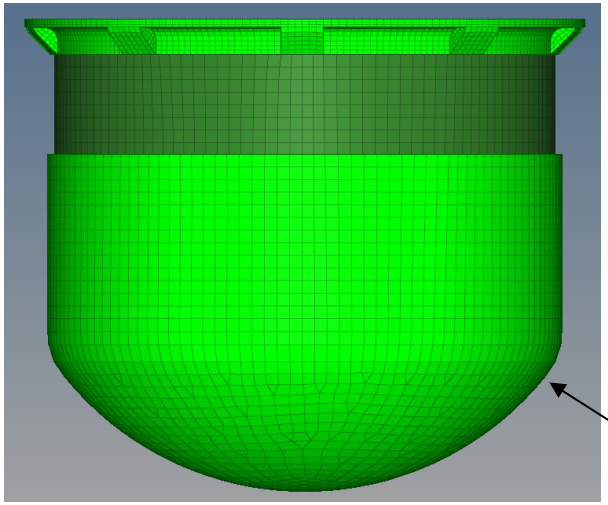
Idealization of Load Environment on C-OS



Interface transfers attenuated load to base of C-OS

1. Encase SCV in rigid shell
2. Prescribe boundary acceleration to rigid shell
3. Load transfer from rigid shell to SCV sub-structure





Dynamic Analysis Methodology in LS-DYNA

Goal #1
- Characterize performance of lid latch in assembly environment
- Quantify quasi-static load capacity of lid-latch system

Goal #2
- Characterize performance of lid latch during dynamic impact event
- Quantify robustness against contact gapping.

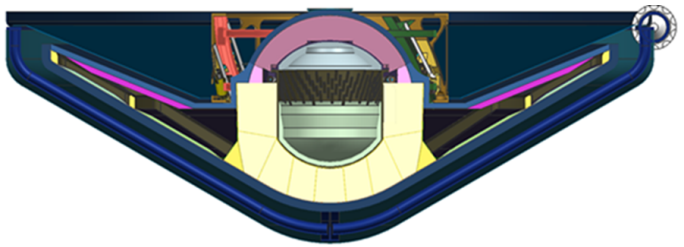
Understand Sensitivities of Isolated Latch to Design Parameters

Understand Sensitivities of SCV Sub-Assembly to Design Parameters

Understand Sensitivities of SCV Sub-Elements to Off-Nominal Assembly Conditions

Understand Structural Performance under Off-Nominal Impact Environments

Understand Load Capacity of SCV Latch



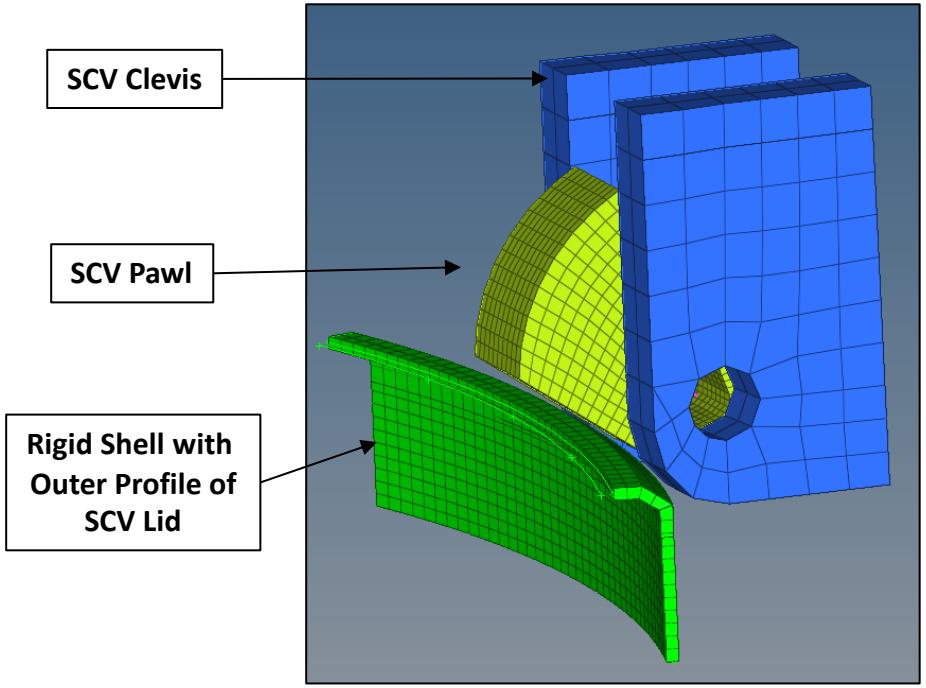
Final Goal
High-fidelity, system-level model of C-OS assembly and Earth impact landing with EEV to capture coupled load transfer.

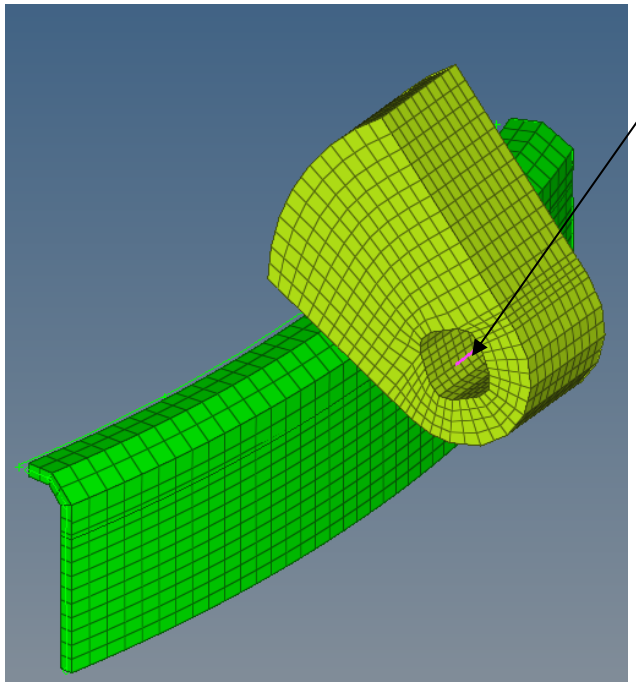
Single Pawl Characterization Studies

Goal: Characterize performance of pawl during assembly under varying spring stiffness and geometric conditions

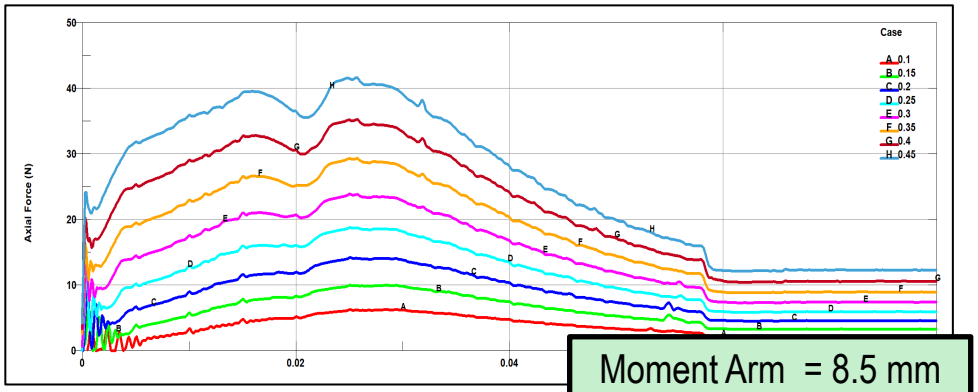
Method: Generate rigid-body, single-pawl model to define design space and to verify behavior of *CONSTRAINED_JOINT element in LS-DYNA

Assumptions: All components rigid, all rotational and in-plane translational DOFs constrained on shell, reduced density of pawl material (to attenuate unrealistic transient effects of pawls due to short simulation time)

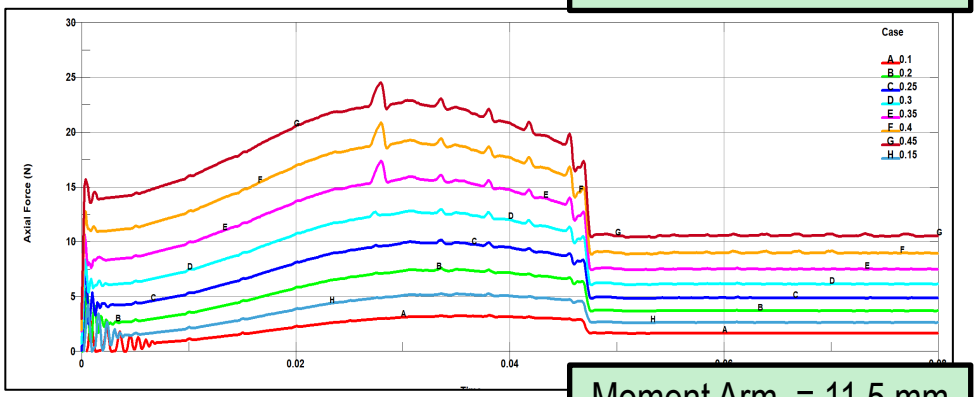




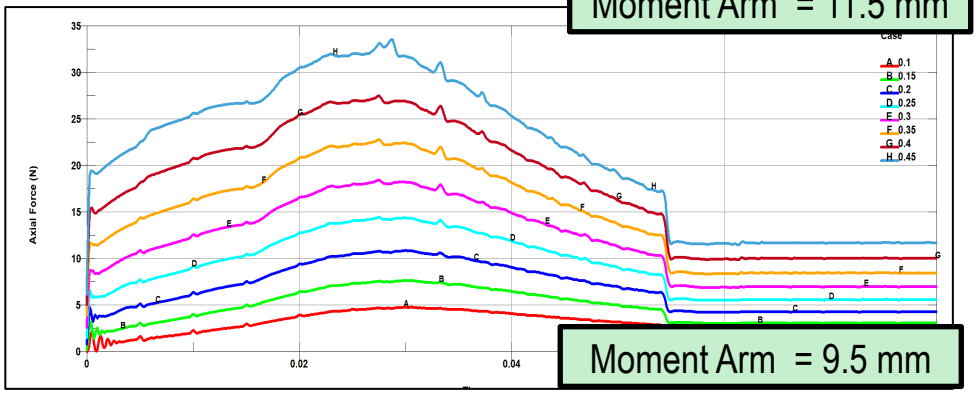
Axial Contact Force on Pawl



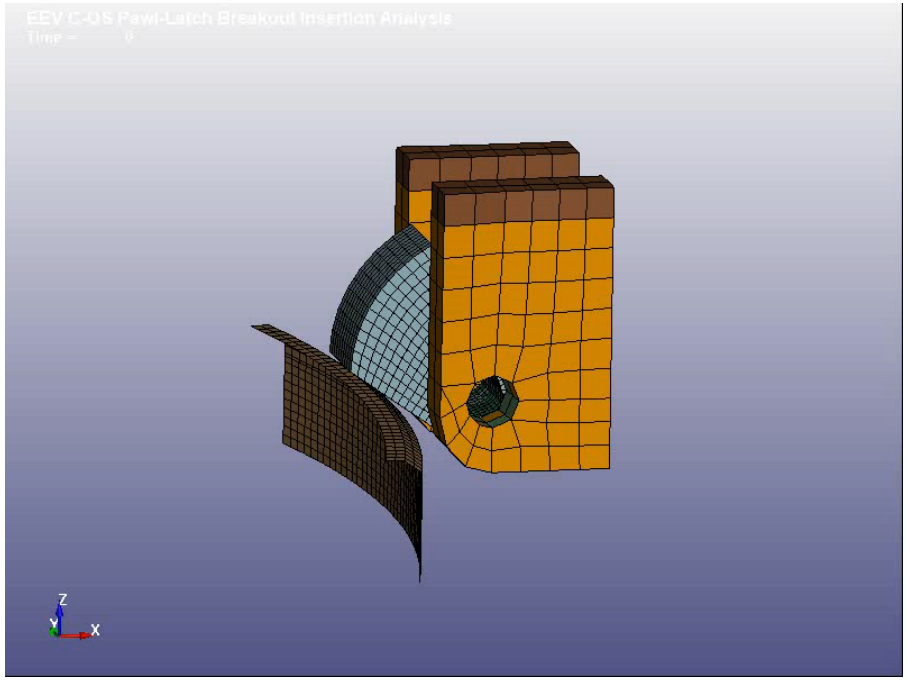
Moment Arm = 8.5 mm



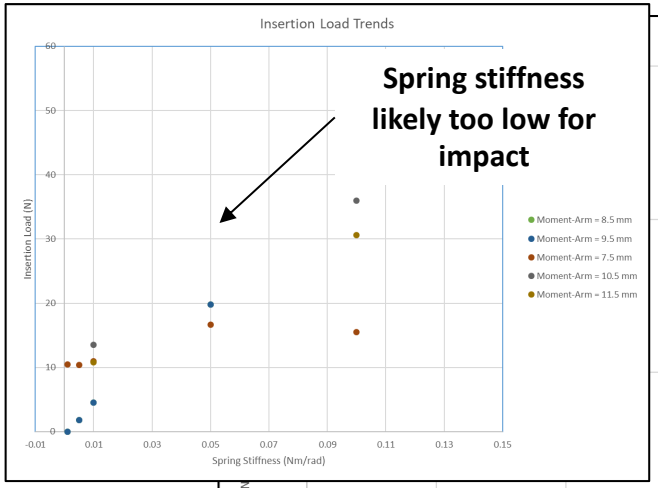
Moment Arm = 11.5 mm



Moment Arm = 9.5 mm



Initial Simulation-Based Design Space

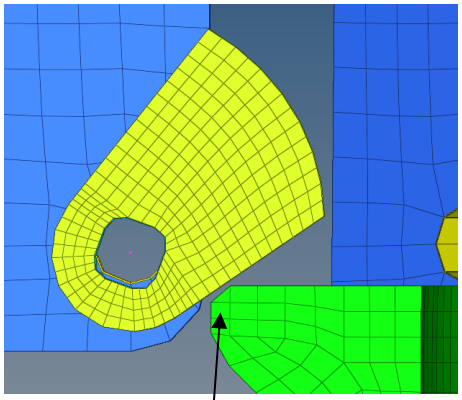


SCV Sub-Assembly Model

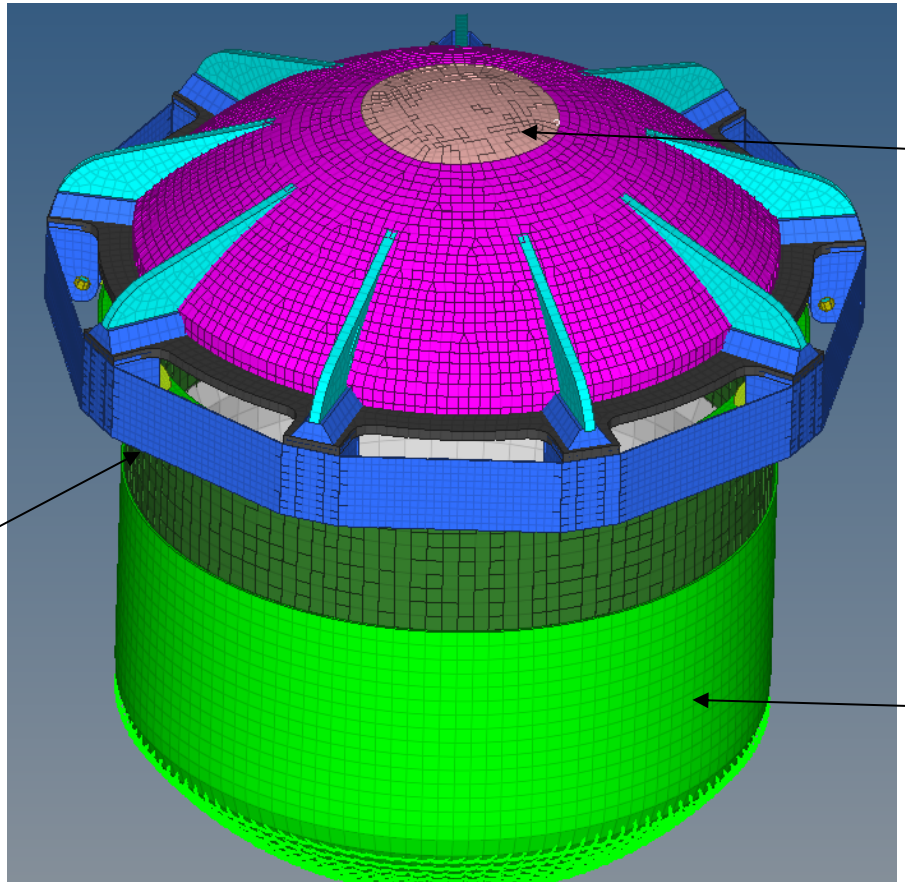
Goal: Characterize performance of SCV latch during SCV lid insertion, retention, and dynamic load environments

Method: Generate break-out model that includes isolated SCV hardware, pawls, and bonded foam – vary parameter space using Hyperstudy

Assumptions: Pawls rigid, chamfer added to lid, base nodes of SCV tied to rigid shell, foam tied to lid, no load contribution from seal and PCV rebound



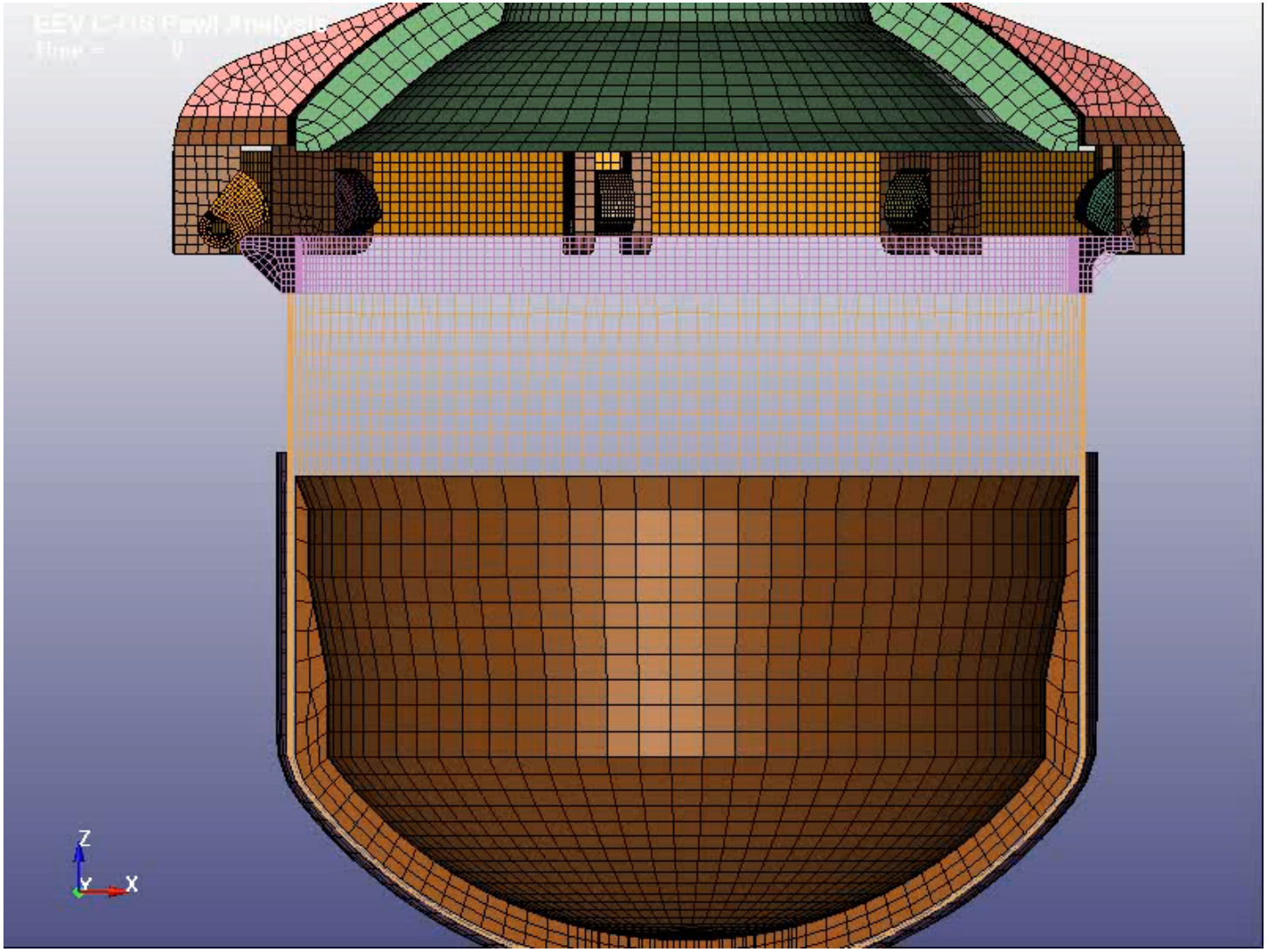
Chamfer added to lid



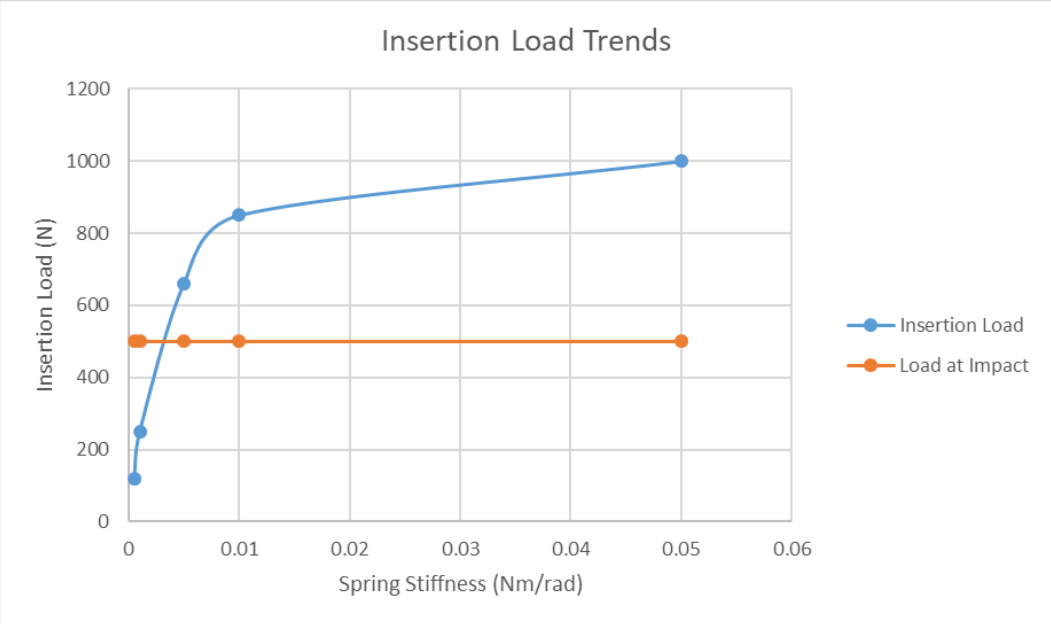
Rigid section for prescribed displacement

Rigid shell to prescribe acceleration

Animation of Simplified System



Axial Insertion Loads at SCV Latch

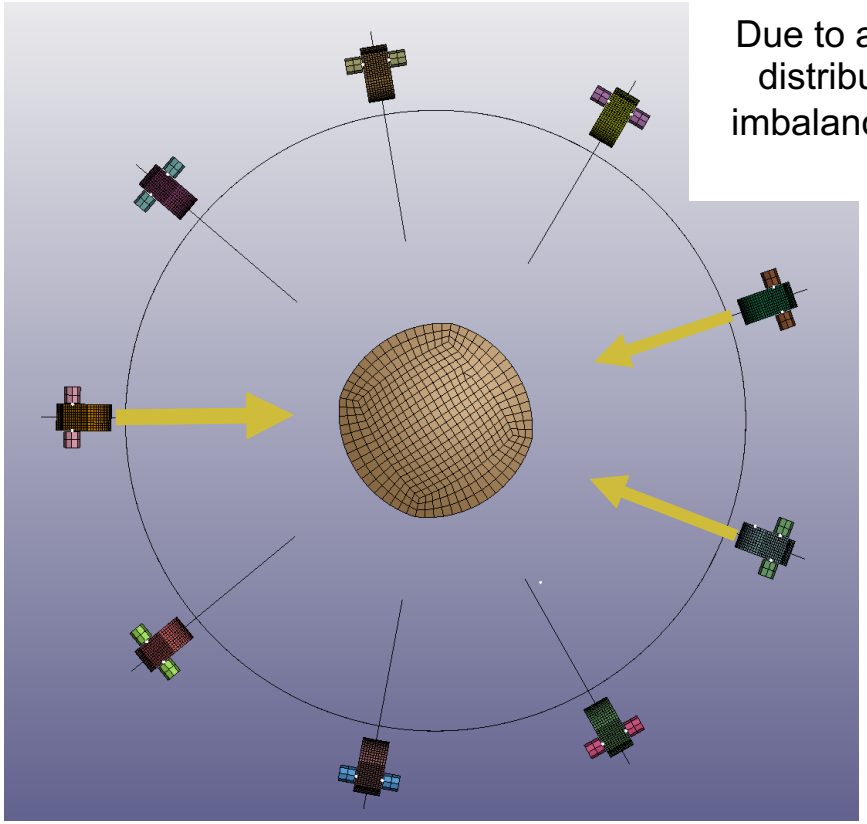


Insertion, Impact, and Extraction Loads

Stiffness (Nm/rad)	Insertion Load (N)	Load at Impact (N)
0.05	1000	500
0.01	850	500
0.005	660	500
0.001	250	500
0.0005	120	500

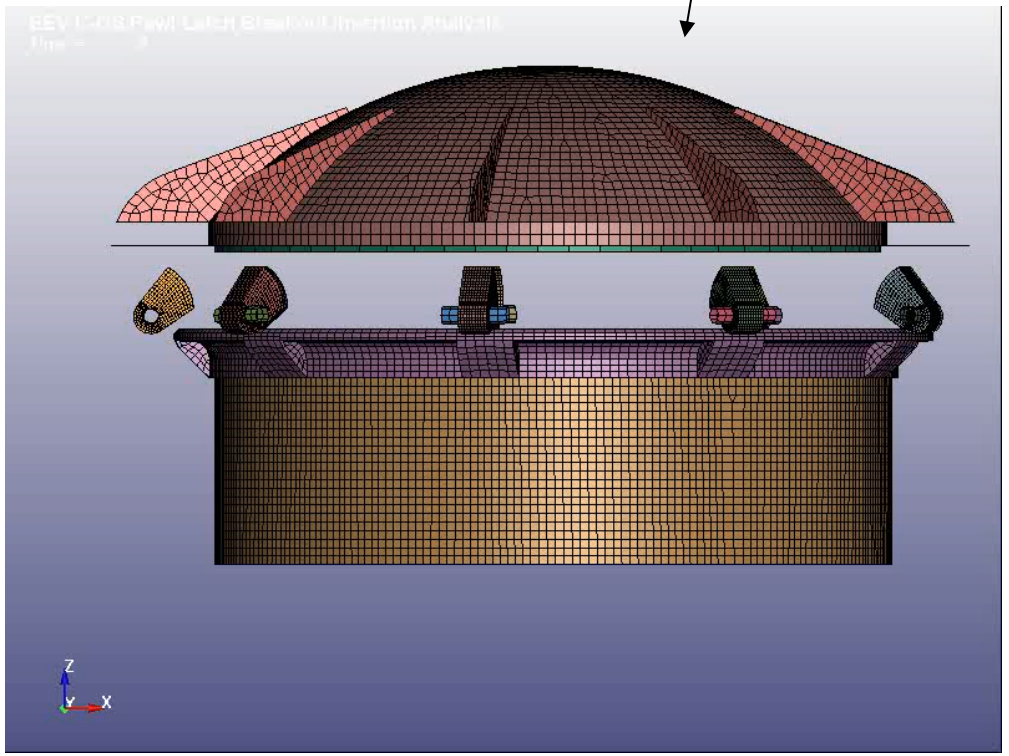
- As spring stiffness increases, insertion load increases
- Extraction loads are consistent over spring stiffness range –**material failure occurs prior to latch failure**
  - Material deflection that produces gapping at lid more likely failure mode than latch failure
- Contact force at lid interface remains non-zero during impact, preliminarily indicating that **no (global) gapping occurs during impact**
  - Local gapping could occur due to lid deflection

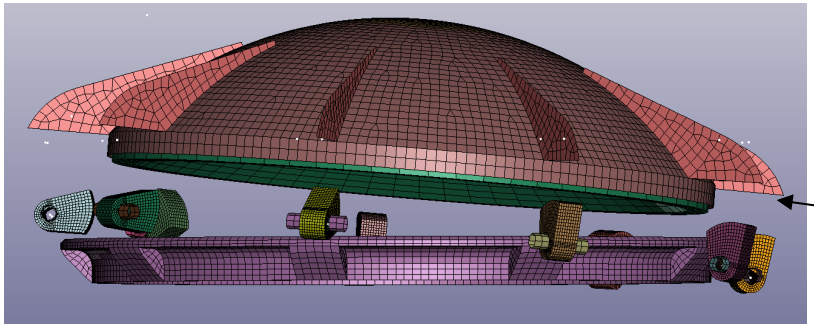
General Behavior of Lid Latch



Due to asymmetry in pawl distribution, lateral load imbalance occurs on initial insertion

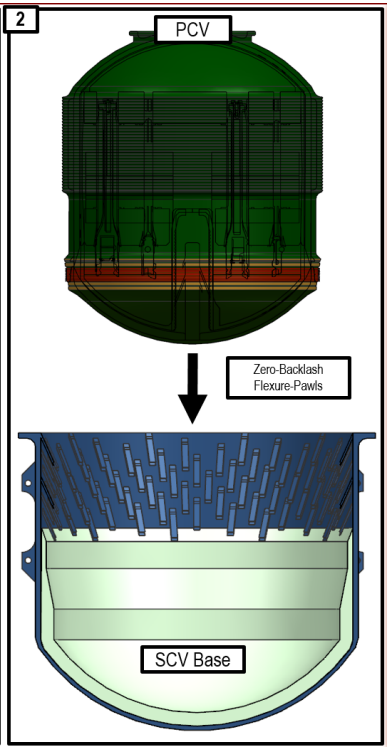
Mechanism allows for self-alignment in off-nominal case

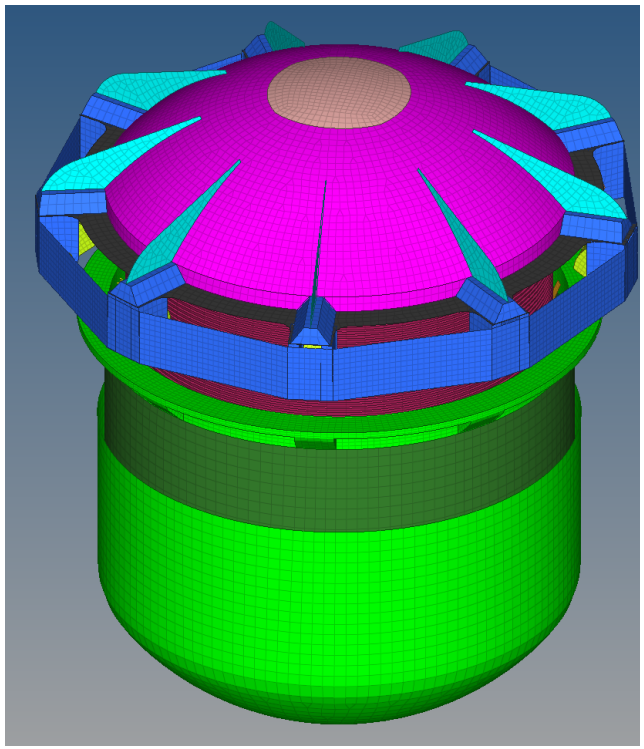


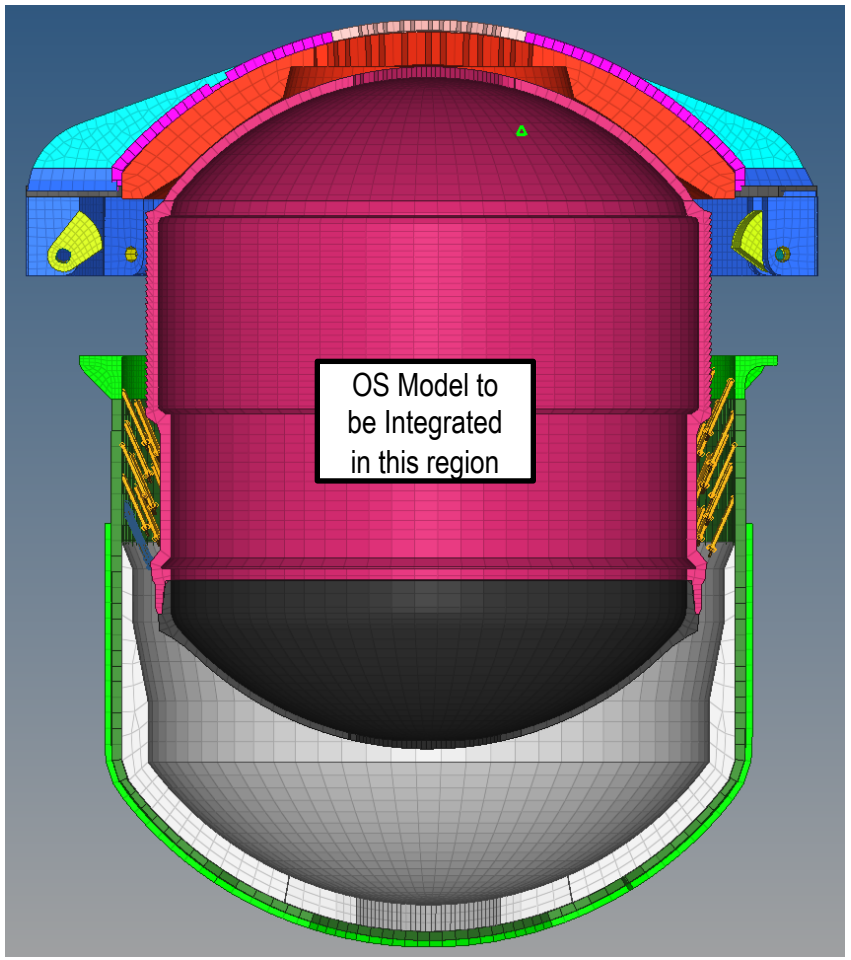


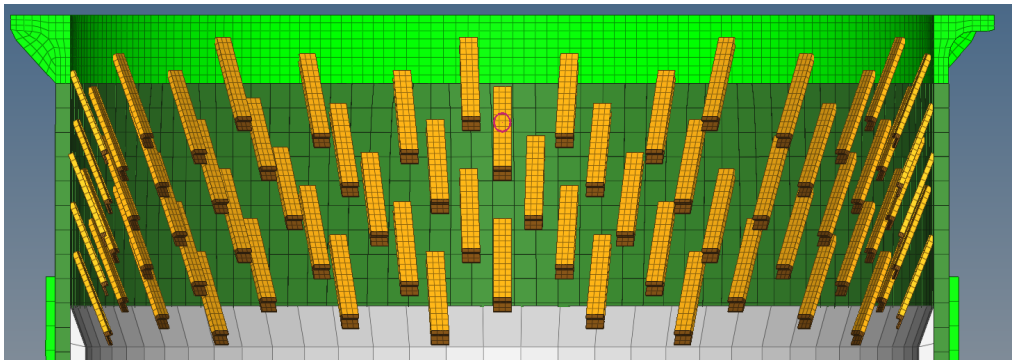
When rotational DOF constraints on lid removed during insertion, lateral load imbalance causes instability

SCV and PCV Assembly Model









Summary and Future Work

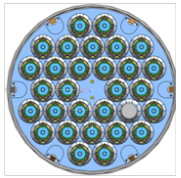
- Simulation and analysis and performance characterization of lid latch designs is currently underway – will be verified with testing
- In conjunction, simplified sub-system level models are being used for understanding behavior and sizing – will be verified with testing
- Sub-system level models and lid latch models will be integrated into a single C-OS system-level model to quantify coupled performance of mechanisms under impact
- C-OS system-level model will be integrated into EEV model to simulate entire Earth impact landing event
- Analysis will eventually be verified with an extensive test program that includes:
  - Material test campaign
  - PCV impact, SCV impact, PCV/OS impact, C-OS impact testing
  - Soft and hard EEV impact testing

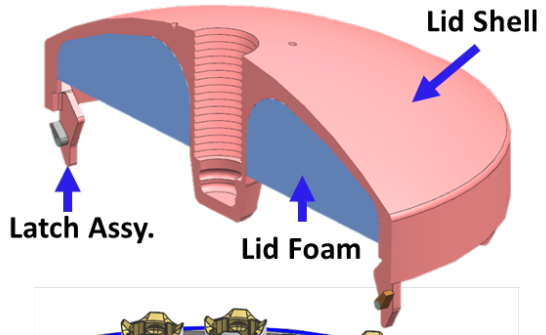
Back-Up: Path Forward to System-Level Model

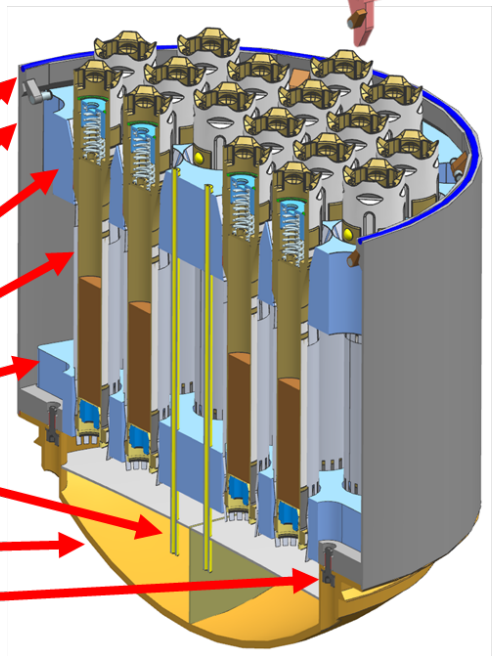
Non-Spherical OS Idealized FEM

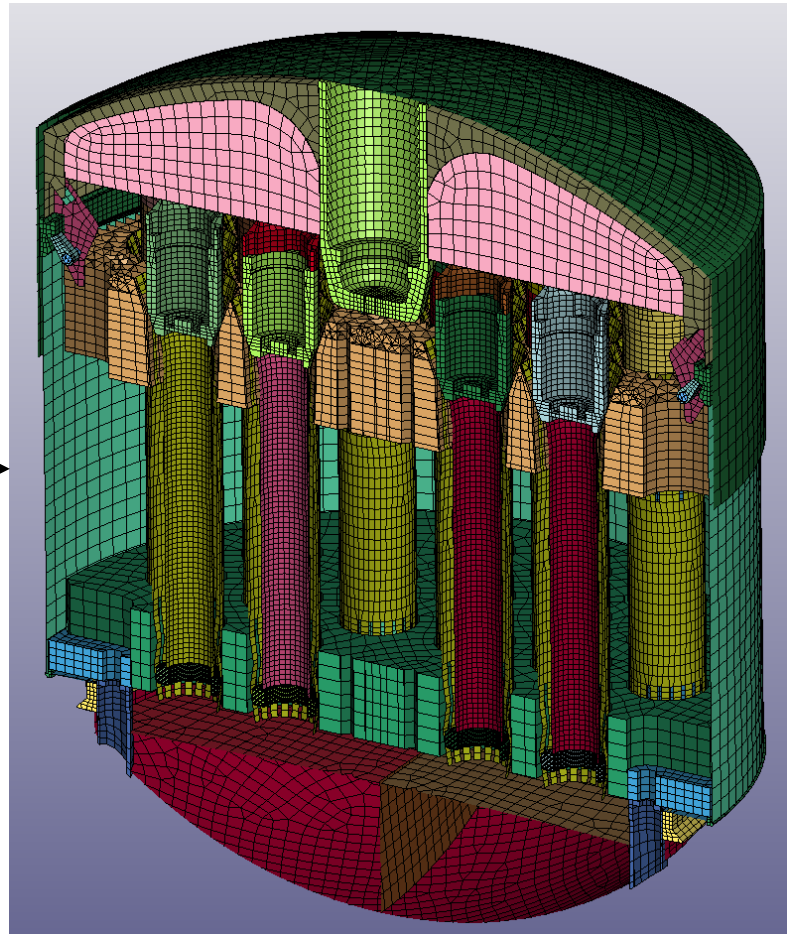
Idealized OS model used to verify positive structural margins for hardware sizing verification – all interfaces tied and no mechanisms explicitly modeled

Hex-Packing
- 31 Cells
- 30 Tubes
- 1 Valve Cell
- 6 Latch Areas

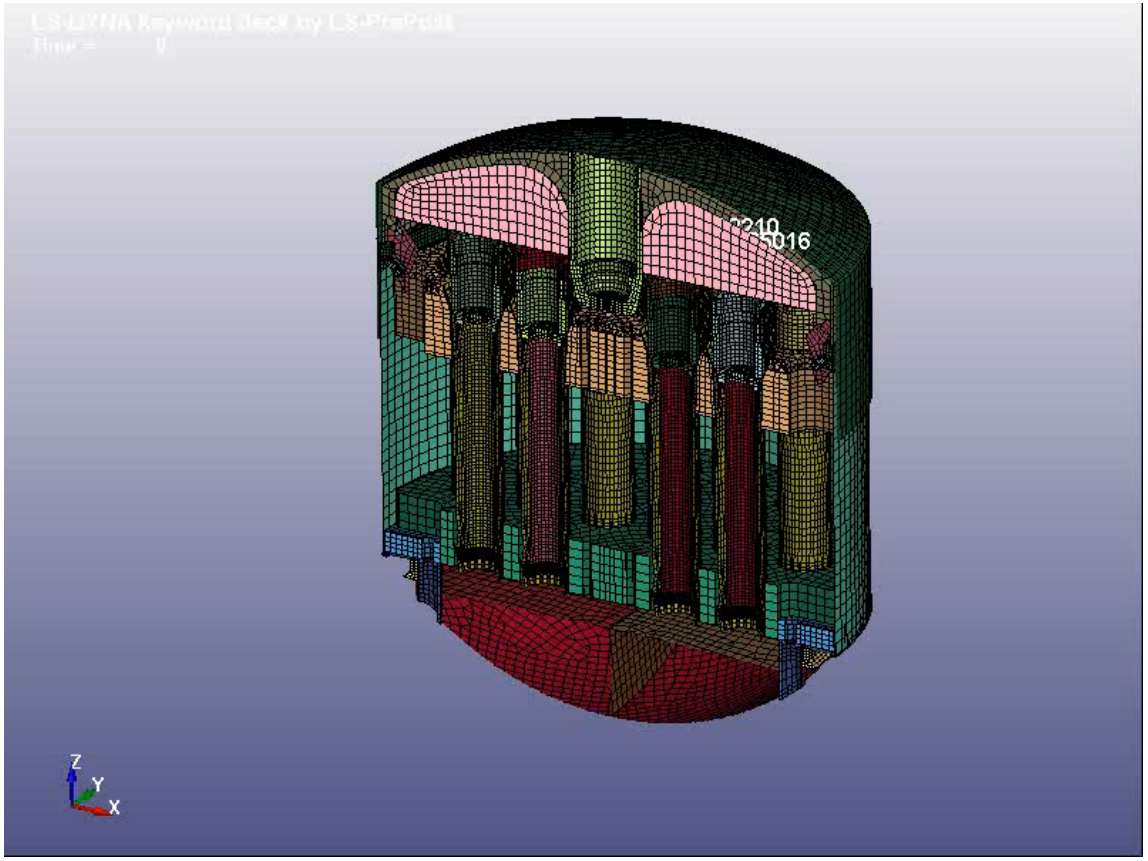


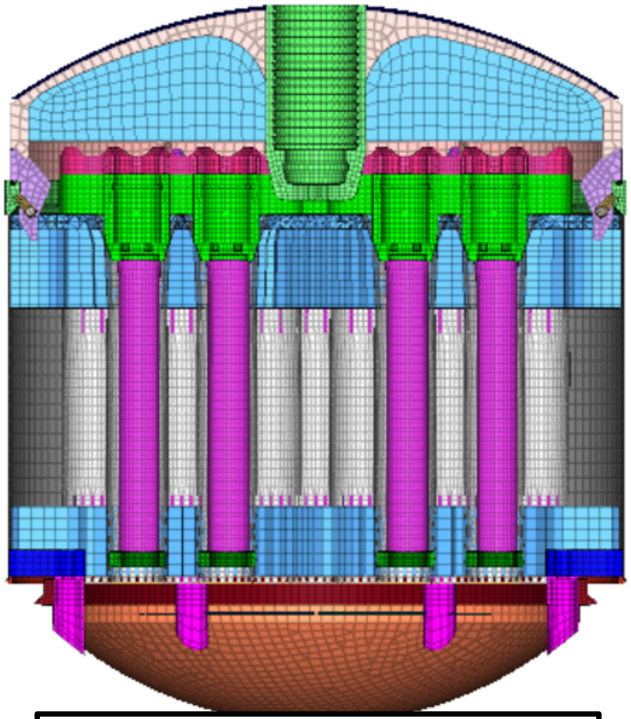




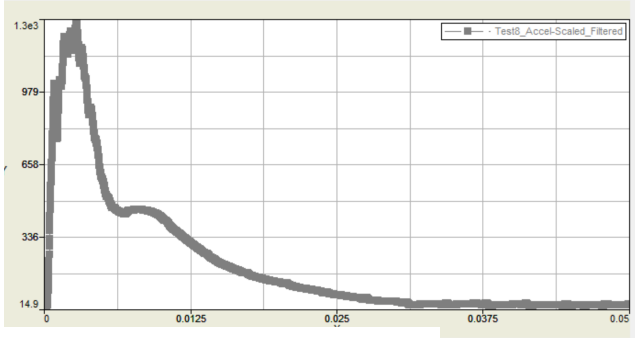


OS Behavior under Impact





Prescribed acceleration applied to rigid shell



Animation of Assembly