Jet Propulsion Laboratory
California Institute of Technology

Impacting Earth: Testing and Analysis for Mars 2020 and Future Missions

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Jet Propulsion Laboratory,
California Institute of Technology

International Planetary Probe Workshop 13
July 12th – 17th 2016

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Overview

Potential MSR Campaign

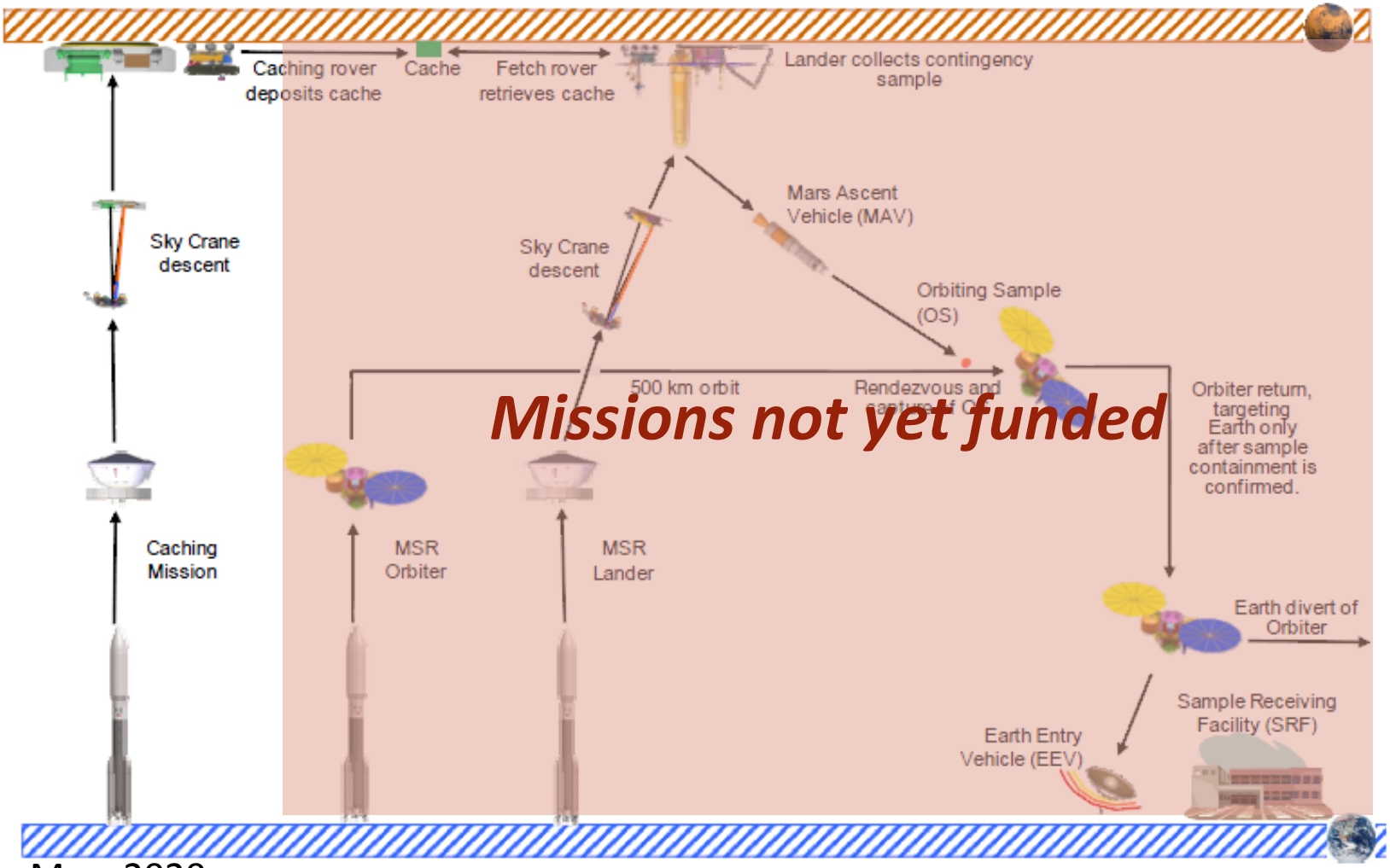
Mars Advanced Development Team Overview

Impact Tower
Impact Tower Concept
Impact Tower Analysis
Impact Test Planning (Phase A - D)
Penetrometer Design and Instrumentation
Impact Analysis

OS Hardware Design
Current OS Design Concept ‘OS-3D’
OS Analysis

Conclusion

Potential Mars Sample Return (MSR) Campaign



Mars 2020

How do we ensure the success of Post-M2020 missions without funded projects?

Mars Advanced Design Team

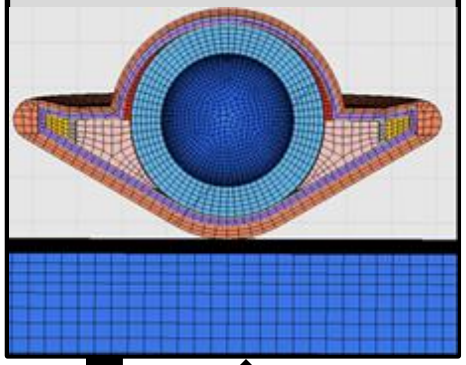
ADT: Define + Verify Requirements

ADT advocates on behalf of and is the pathfinder team for the post M2020 missions

Finite Element Modeling

What environment would the M2020 tubes be exposed to on Earth landing?

How does landing environment change as EEV and OS designs change?



Impact Testing

What are soil properties should be assumed in the Finite Element Model?

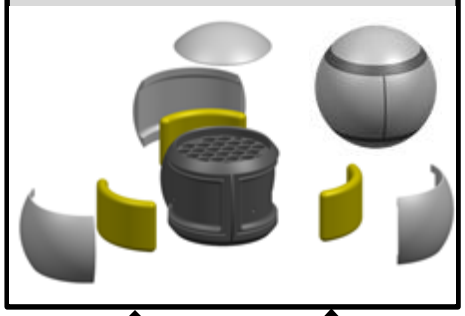
Are the finite element model predictions correct?

Does the developed hardware function as expected?

Hardware Development

Are the interfaces on the M2020 tubes adequate?

Can adequate OS hardware be designed to be compatible with M2020 tubes and the impact environment?



Model Validation

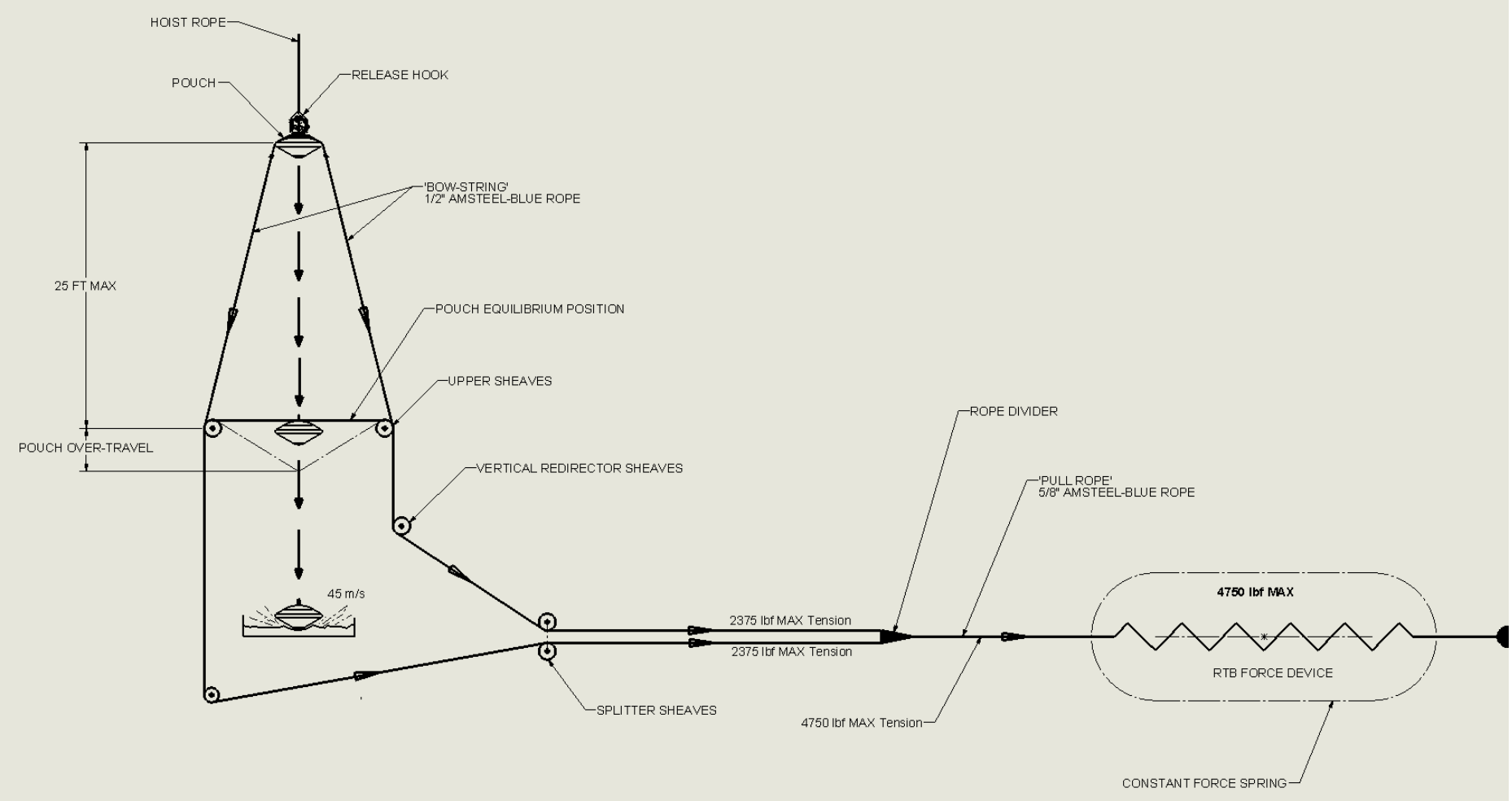
Hardware Verification

Hardware Requirements

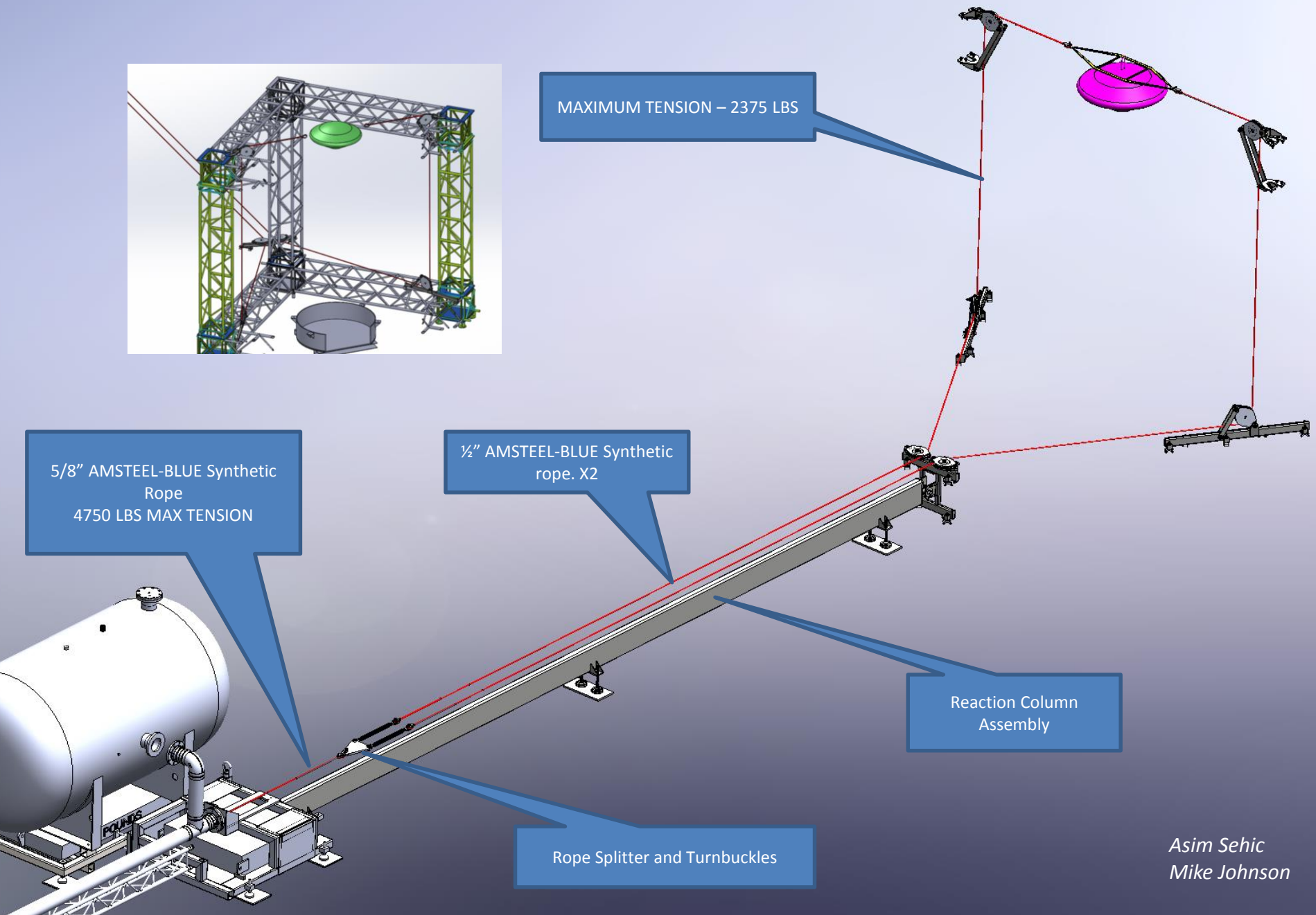
Test Stand, ADT, and M2020

- Notional MSR EEV impacts UTTR playa (shown below)
- Deformation of playa decelerates EEV at roughly 1,300 g
  - Response of playa to EEV impact would impart loads to M2020 tubes
  - JPL must characterize playa response to make “correct” requirements
- Impact test stand provides playa characterization capability
- Anticipated EEV impacts velocity range: 30 – 50 m/sec
- Anticipated EEV mass range: 40 kg – 130 kg

Impact Test Stand Theory



Schematic of Rope and Sheave Layout

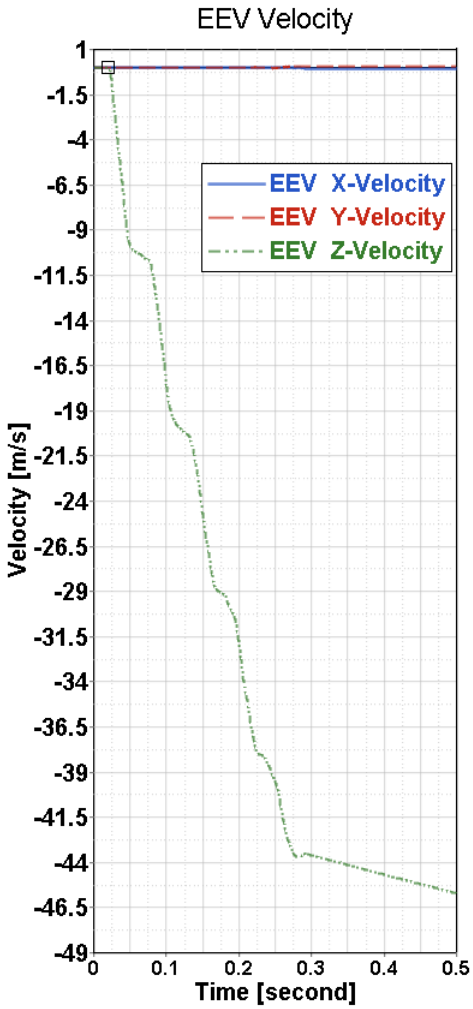


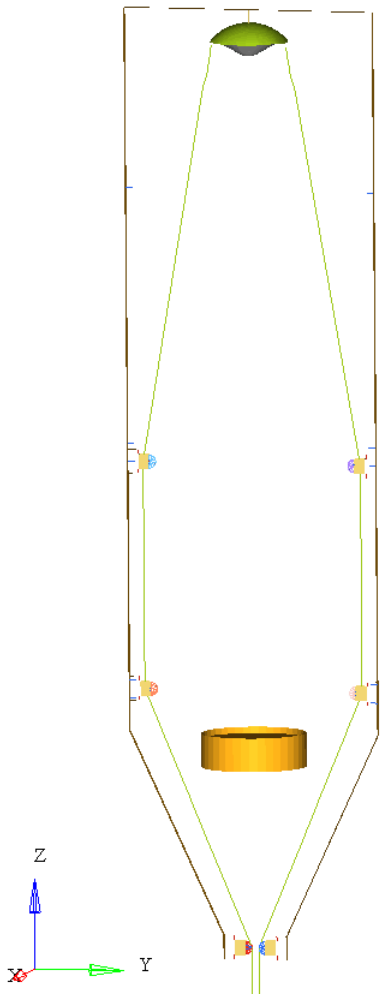
Asim Sehic
Mike Johnson

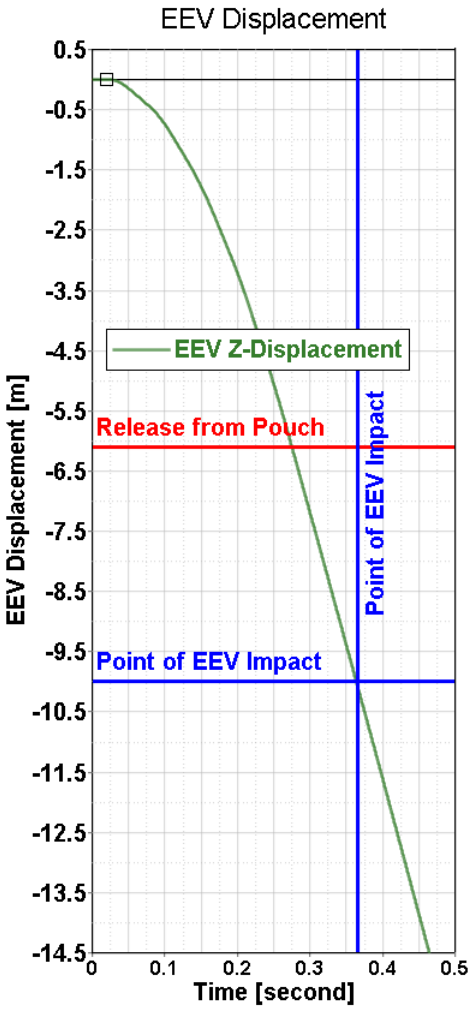
Completed ADT Impact Tower

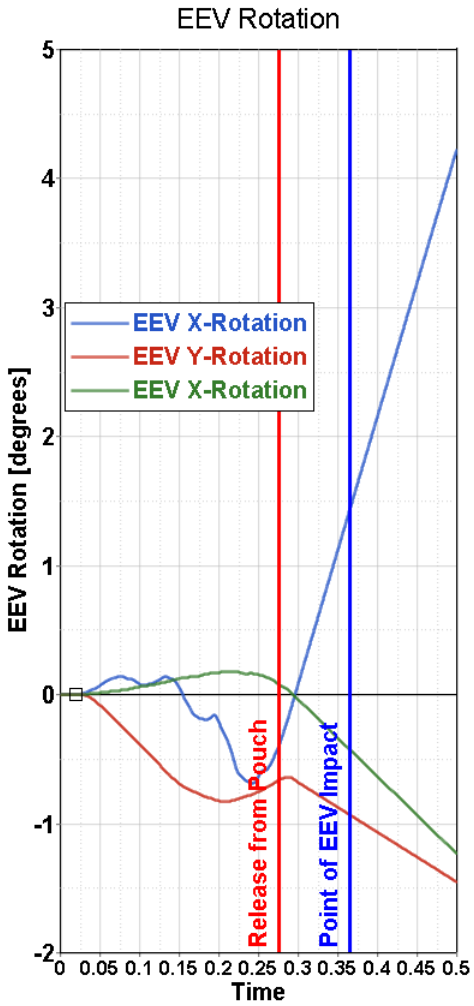
Sling Shot Feasibility Study

(use slide show for animation)









Penetrometer was accelerated to 46 m/s + in analysis and up to 67 m/s in test.

Tower Test Plan Overview

Phase A: Soil Characterization – *Finished May 2015 – 14 Impact Tests*

A learning and confidence building process for test and analysis

Phase B: Interface Loads Characterization – *July - Dec 2016*

Know the real loads at the OS interface

Phase C: OS Design and Tube Loads Verification *– Jan – May 2017*

Verify OS design and satisfy M2020 test requirements at the heart of the vehicle

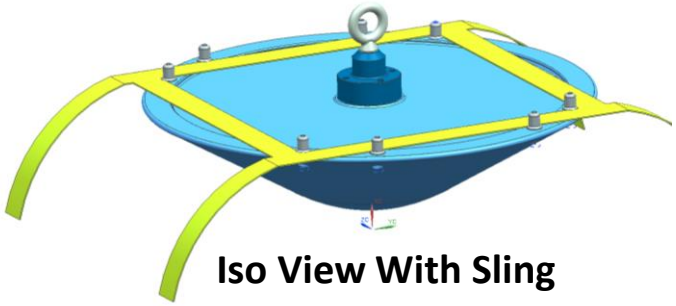
Phase D: EEV Hardware/Robust Container Validation – *June – Sept 2017*

Show that an EEV can satisfy Planetary Protection Requirements and survive the 'off nominal'

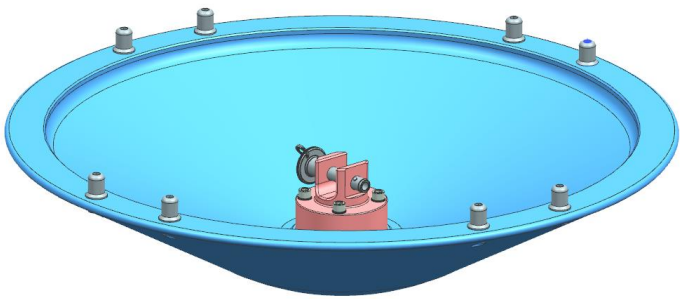
Phase A Penetrometers

60° Sphere Cone Penetrometers

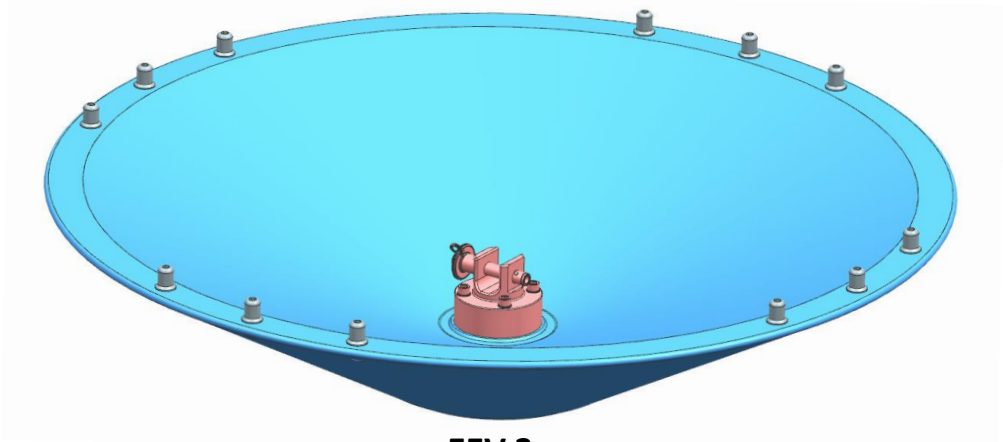
	EEV 1	EEV 2	EEV 3
Nose Radius	300 mm	300 mm	300 mm
Max Diameter	740 mm	740 mm	1080 mm
Height	189 mm	189 mm	276 mm
Mass	**40 kg**	**90 kg**	**140 kg**



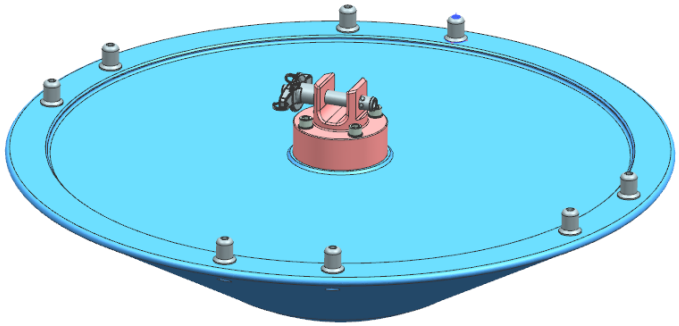
Iso View With Sling



EEV 1



EEV 3



EEV 2

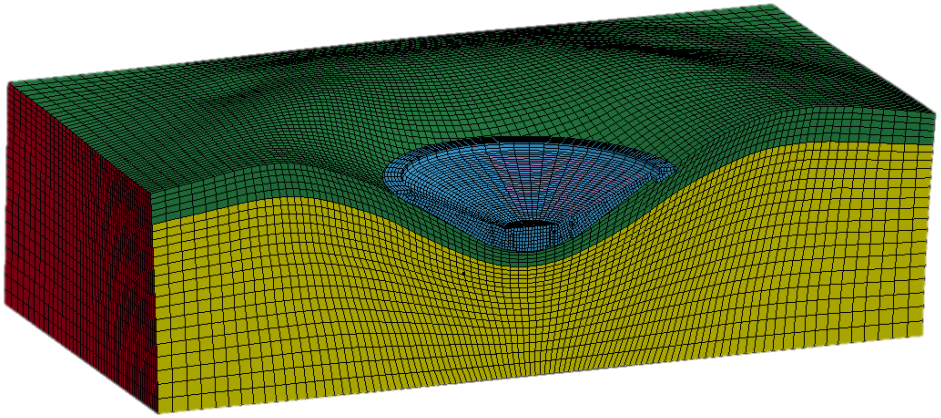
Self Contained Shock Recorder: DTS, Model: TSR 3DXP
Internal Accelerometer: Piezo-Electric Triaxial
Sample Rate: 75 kHz
G Limit: 6000 g
Shock Trigger: 90 g

Impact Testing and Analysis

All 14 penetrometer impact tests were modeled in LS-DYNA

Surface and sub-surface soil properties were modeled separately

A broad range of soil and penetrometer impact conditions were evaluated



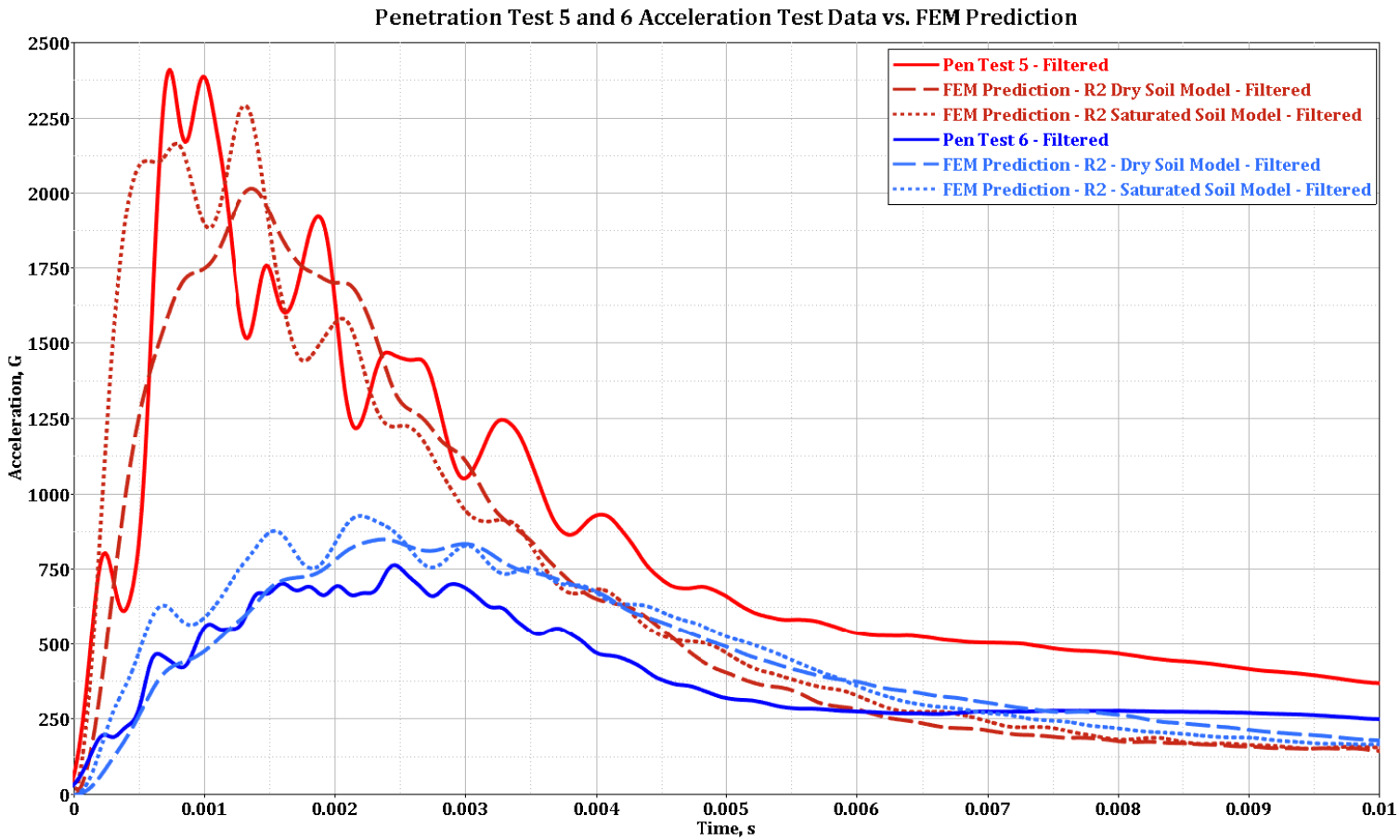
Soil Characterization

14 sphere-cone penetrometer impact tests have been completed

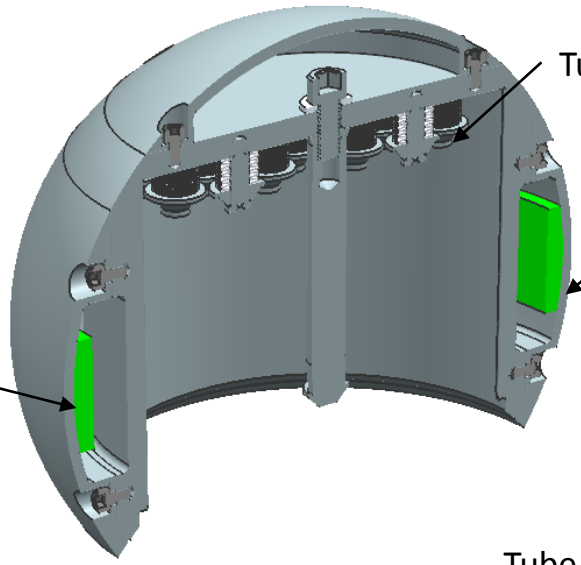
Current impact models + soil models predict peak accelerations from test to ±15%

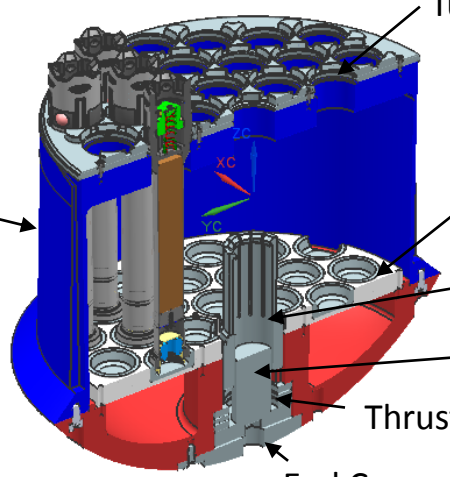
Future improvements to soil modeling is underway

Test data will soon be implemented into the NASA Langley M-SAPE tool



Current OS Design (1 of 2)



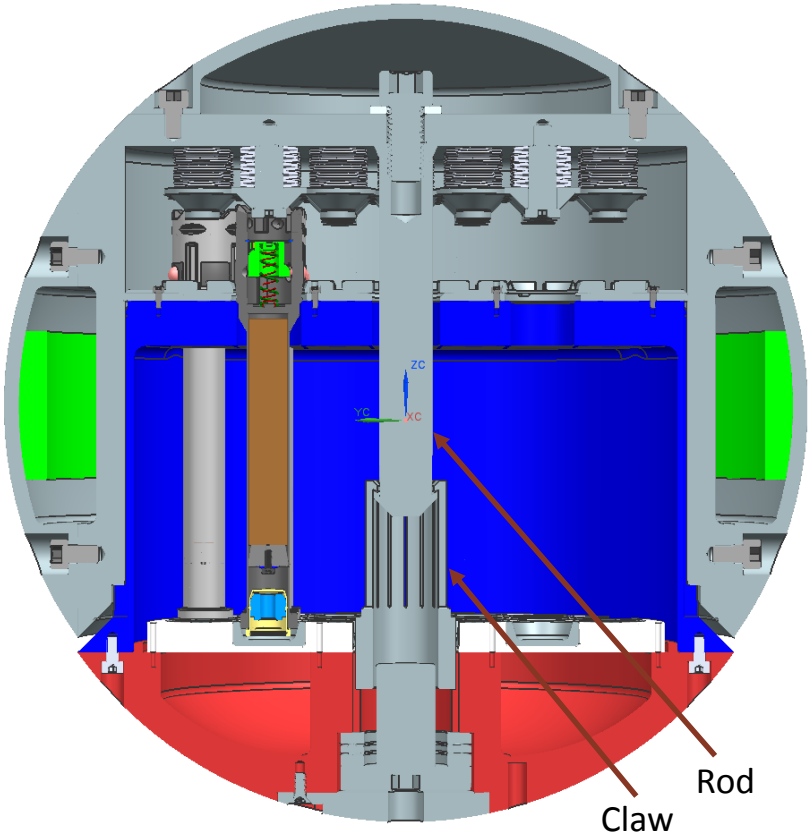


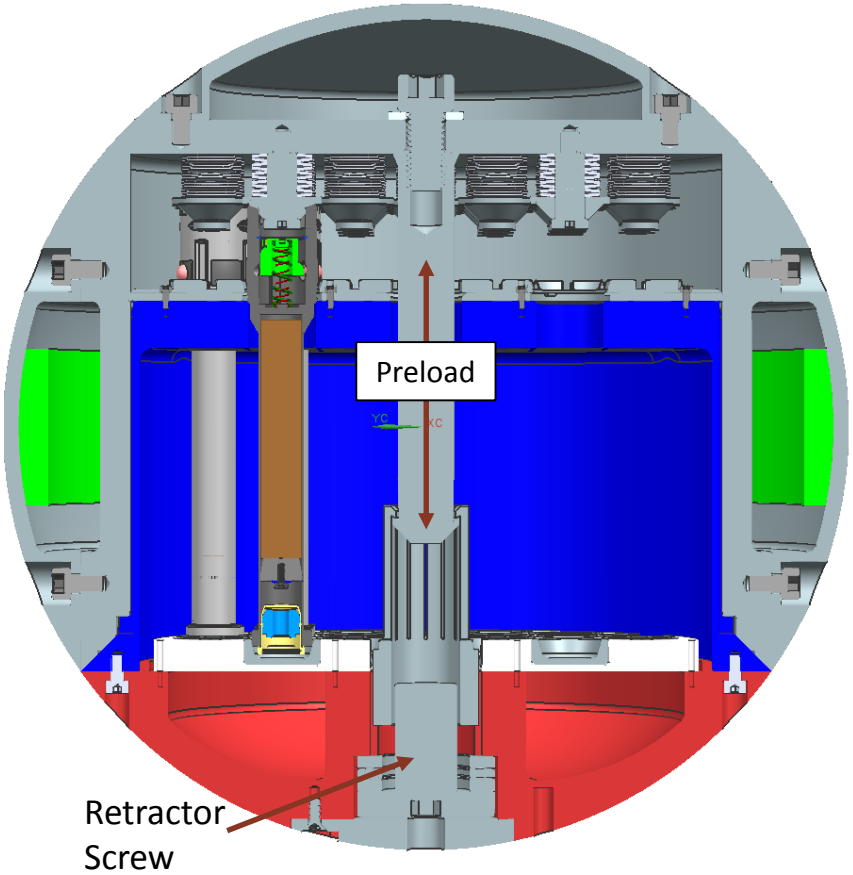
OS Mark III:

- 27 cm OD Sphere
- Less than 12 kg
- Accommodates 31 sample tubes
- Capable of accommodating:
  - Air Samples
  - Tracking Beacon

Current OS Design (2 of 2)

1. Canister is inserted into shell and claw engages with rod → 2. Retractor screw retracts claw and applies preload





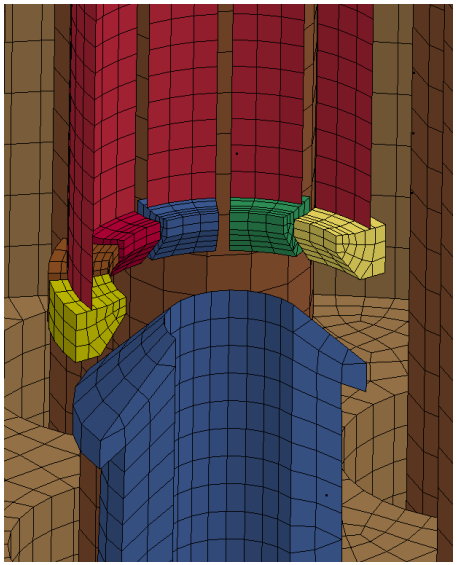
OS Dynamic Modeling

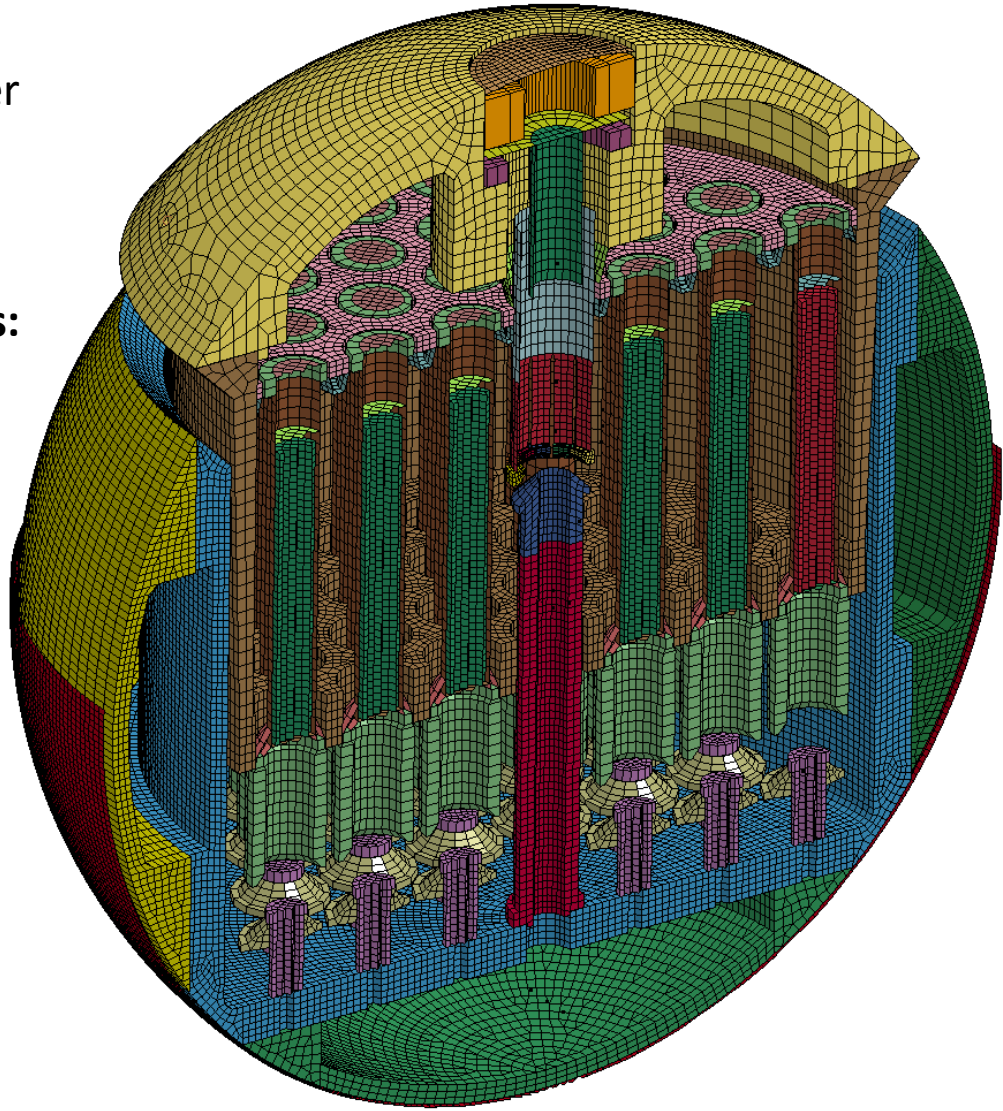
The current OS dynamic model is shown.

The two sides of the OS are inserted together and then preload is applied to the tubes and seals via an axial latch bolt system.

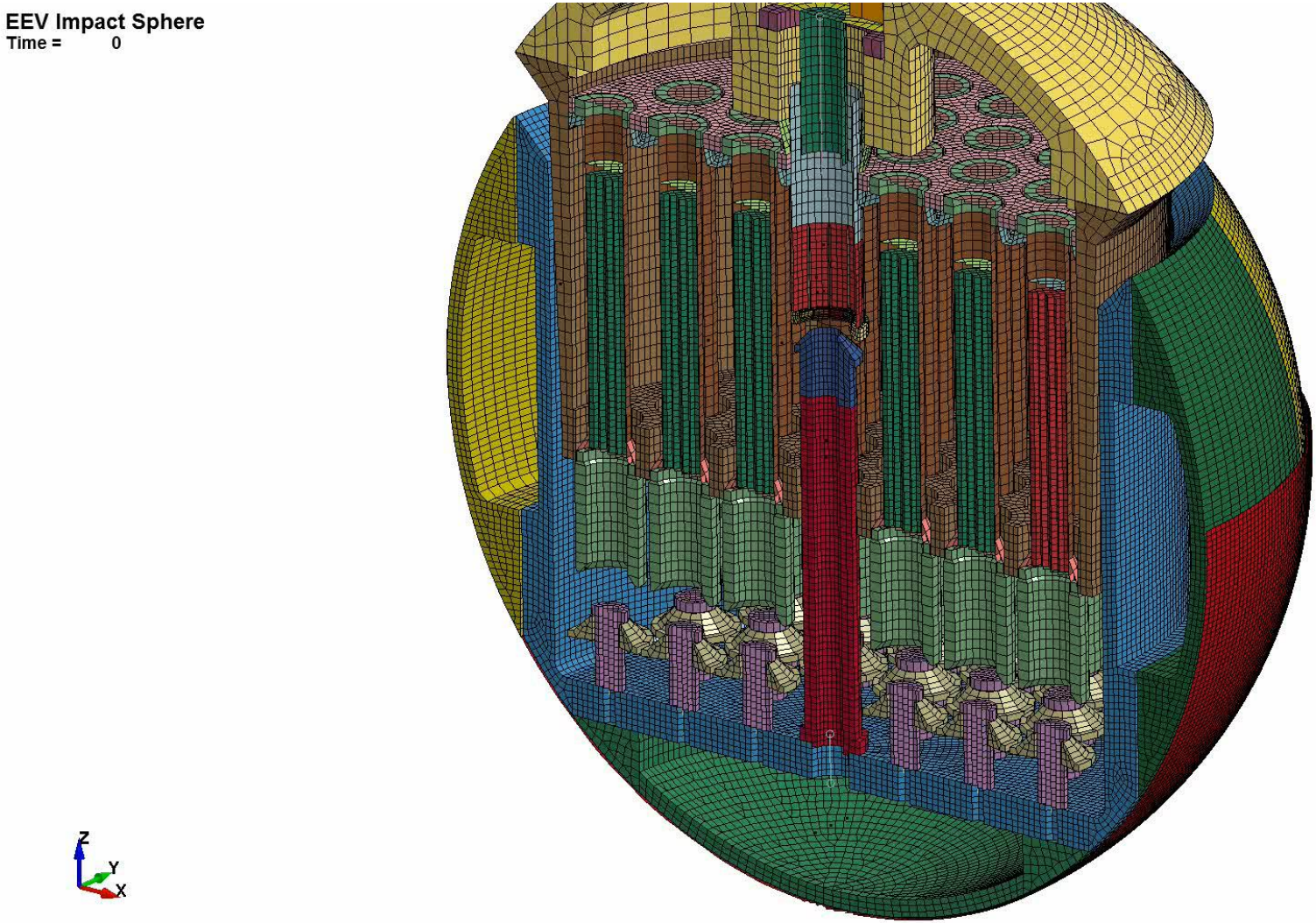
Three phases dynamically modeled in series:

1. Canister insertion and bolt engagement
2. Tube and OS seal preload
3. Earth impact loading





OS Analysis Video



Conclusion

The ADT team is acting as a proxy for the as of yet unfunded potential MSR – SRO and SLR

ADT's primary goal is the generation of requirements on the present Mars 2020 to ensure the success of follow-on missions and a potential MSR campaign as a whole

To fulfill this goal ADT has a comprehensive impact test campaign, preliminary hardware development, and analysis.

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Thank you.

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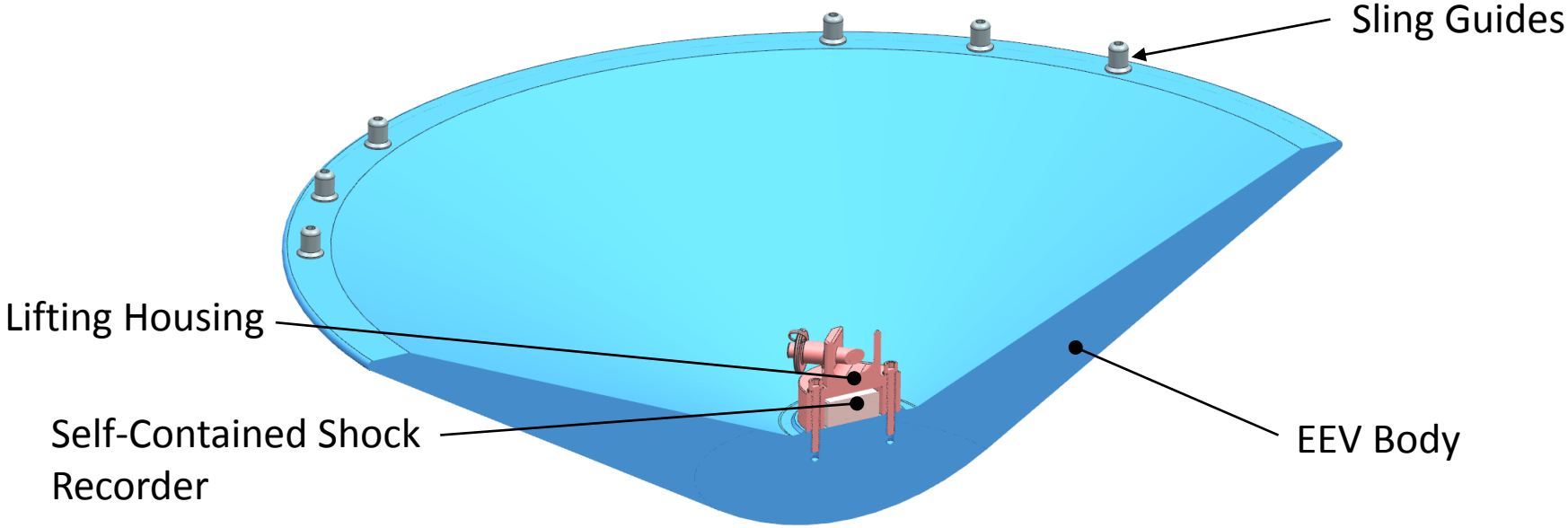
Penetrometer Design and Instrumentation

Penetrometer Material: Aluminum (6061), Monolithic

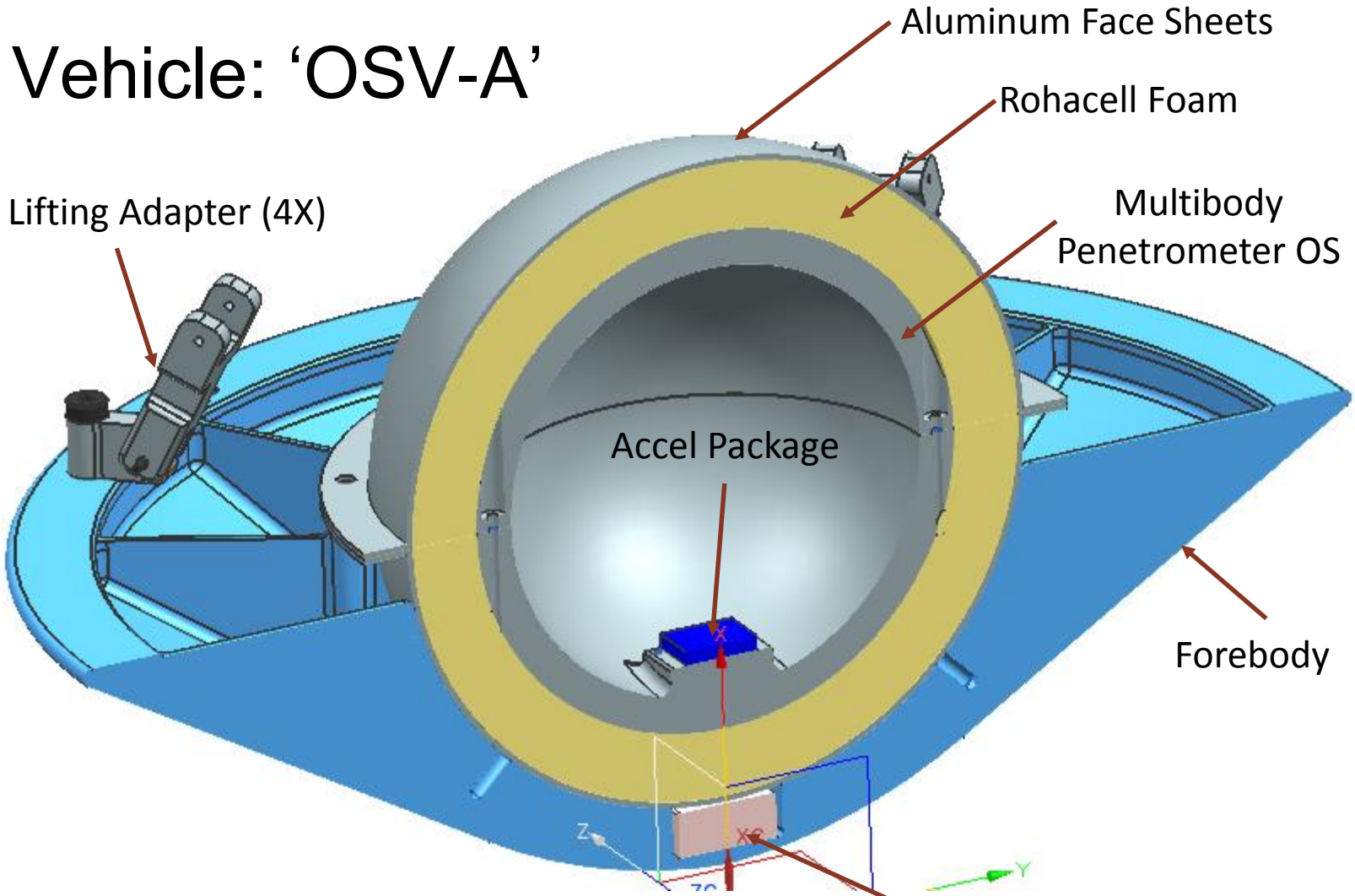
Self Contained Shock Recorder: DTS, Model: TSR 3DXP
Internal Accelerometer: Piezo-Electric Triaxial
Sample Rate: 75 kHz
Shock Trigger: 90 g's



EEV 3 Cross Section

Phase B Penetrometer – PICA

OS Vehicle: 'OSV-A'



Soil Modeling Approach Basics

Errors in previously reported results were discovered that required full analysis reruns.
<u>All data presented today uses the consistent analysis methodology as described below</u>

We have developed a consistent approach for soil model construction, impact FEM model construction, and data extraction

1. Soil Model build using approach developed by Len Schwer with soil collected from the field and tested at the ARA geotechnical lab
2. Impact model constructed with similar boundary conditions as test
3. Deformable impactor with high solid element count should be used.
4. In-situ soil density and water content is different for every test and at every depth.
   - Match FEM surface soil element material density to in-situ tested surface soil density
   - Match FEM sub-surface soil element material density to in-situ density measurement at 8” at-depth measurement
5. Run simulation and recover Z- Direction ‘rigid body approximate’ acceleration from impactor, For simulations with 10°+ degrees of impactor rotation, recover resultant rigid body approximate acceleration from impactor
6. Filter all data with low-pass 1000 Hz using SAE J211 – Backwards-Forwards method with padding

OS Key and Driving Requirements

The Orbiting Sample (OS) Shall:

- Have a spherical outer mold line (OML) with a tolerance of ±1mm; the OS may have negative features penetrating into this OML, however the OS shall not have positive extending beyond this OML.
- Have a mass ≤ 12 kg when fully loaded with samples and ready for launch of the Mars Ascent Vehicle. Note: If 31 tubes with an average mass of 140 grams is assumed, the mass of the OS without the tubes is thus ≤ 7.66 kg.
- Have a diameter ≤ 28 cm.
- Accommodate at least 31 M2020 sample tubes, each with a diameter ≤ 24mm, length ≤ 147mm, mass ≤ 140 grams.
- Acquire and return to Earth with a Martian atmospheric sample at Mars-ambient pressure and temperature with a volume of at least 100 cm^3.
- Secure the sample tubes and atmospheric sample when subjected to the 1300 g Earth impact acceleration pulse.
- Retain the sample tubes prior to securing in any orientation in a 1 g environment.
- Accommodate a beacon electronics module with dimensions of 67mm x 33mm x 20mm.
- Accommodate two beacon batteries, each 51mm long and 15mm diameter.
- Accommodate two beacon antennas, each 50mm x 7mm (minimum thickness) x 175mm (circumferential run length).
- Interface to the Mars Ascent Vehicle per drawing XXXXXX.
- Use optical surface properties to maintain the temperature of the OS between XX C and XX C while in orbit around Mars.
- Use optical surface features to allow for identification the longitudinal axis of the tubes inside the OS.
- Be capable of securing all tubes and readied for launch of the Mars Ascent Vehicle when a spherical particle with a diameter of X mm is present on any location of any interfacing surfaces.

Phase B Penetrometers – Multi-Body

GOAL: *Characterize the OS response that depends on the interfaces within the vehicle*

METHOD: *Accurately match all interfaces between the soil and OS*

1. *Match the energy absorber geometry and material*
2. *Basic BTC hardware*
3. *OML and mass accurate OS simulator – (Internal hardware not matched)*

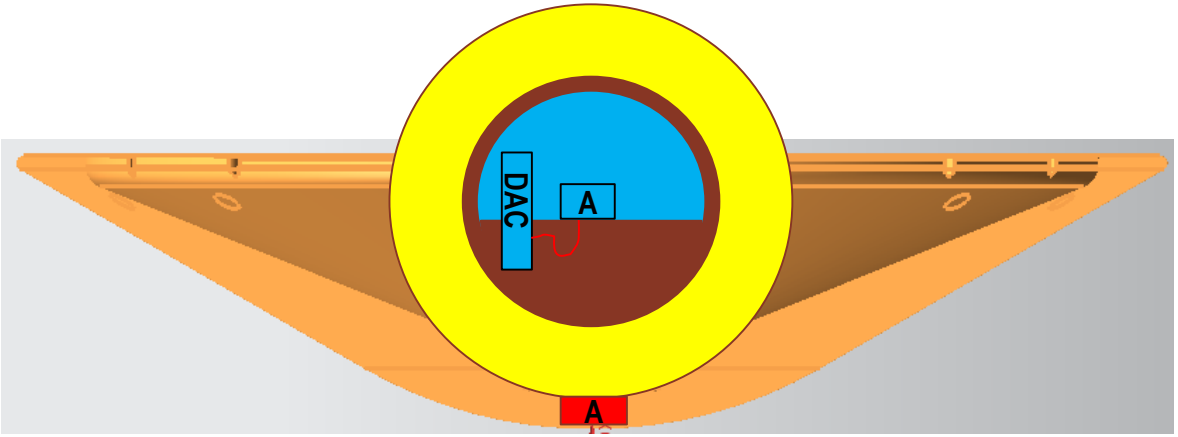
'OS Vehicle' OSV-A w/ OS Simulator

Same total mass as PICA-A EEV

12 kg - 28 cm dia. OS Simulator

2x Accels: OS Sim. + Penetrator Body

Reusable aluminum aero shell body



Preliminary Test Start Date: July '16

Phase C Penetrometers – Multi-Body

Same EEV representative soil contact side OML as Phase A penetrometers

OSV-A w/ OS EM

Same total mass as PICA-A EEV

12 kg - 28 cm *Structurally functional OS Prototype*

Multiple M2020 and ADT Tubes secured inside

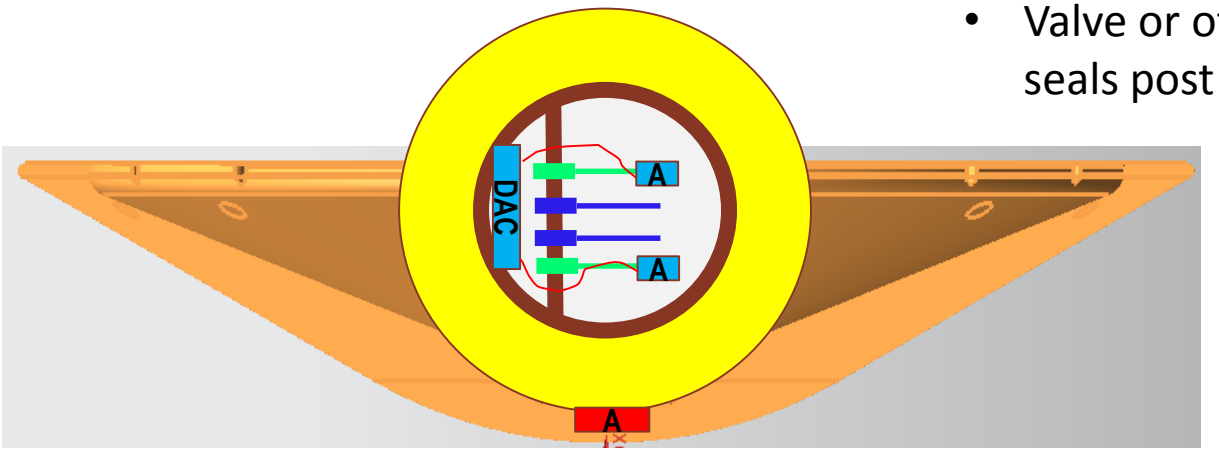
3x+ Accels: On OS, Tubes, & Penetrator Body

'ADT Tube'

- Instrumented with 3 axis shock accel at tip
- Mass similar sample installed
- Structurally analogous Ti tube

'M2020 Tube'

- Provided by M2020
- Flight design tube
- Rock sample,
- Hermetic and Caging plugs
- Valve or other method for checking seals post impact



Preliminary Test Start Date: Jan '17

Soil Model Development

Build numerical soil models from a suite of laboratory tests on the soil

Characterize, verify, and calibrate the soil models with test as necessary

A series of tests are needed to properly define the mechanical behavior of soil during large deformation and impact

Required suite of lab tests:

1. Hydrostatic compression test – up to 50 MPa
2. Uniaxial strain test – up to 50 MPa
3. Confined triaxial compression test – at 10 MPa, 20 MPa, and 40 MPa

Minimum 3x samples sourced from same area for each test.

Three discrete LS-DYNA soil models created

Three test series: Dry, Moist, and Saturated

1. Dry (10% water content) – Below UTTR Plastic Atterberg limit
2. Moist (25% water content)
3. Saturated (45% water content) – Above UTTR plastic limit

Multistep Analysis Approach

Goal

Demonstrate the loading procedure for the three primary phases: Canister Loading, Retain Feature Actuation, and Impact Loading

Process is accelerated for numerical reasons

Preloading and Canister Insertion Phase *- 6 ms*

- 3x Canister bolts are preloaded to 10 kN each
- Canister is inserted into the OS Shell and softly engages the 12 latches

Secure Phase – *3 ms ramped loading + 3 ms settling*

- Axial preload bolt is contracted
- 1 kN of axial preload per tube is induced by the contraction
- OS Shell – Canister Sealing Lip Fully engage and a 30 kN sealing load is applied
- Numerical damping is assigned to remove transient vibration before impact

Impact Phase *- 1 ms Rotation + 3.375 ms acceleration pulse from assigned direction*

- Impact orientation is assigned
- Hemispherical cup 'shoves' the OS from the desired direction

Total simulation time ~ 18 ms