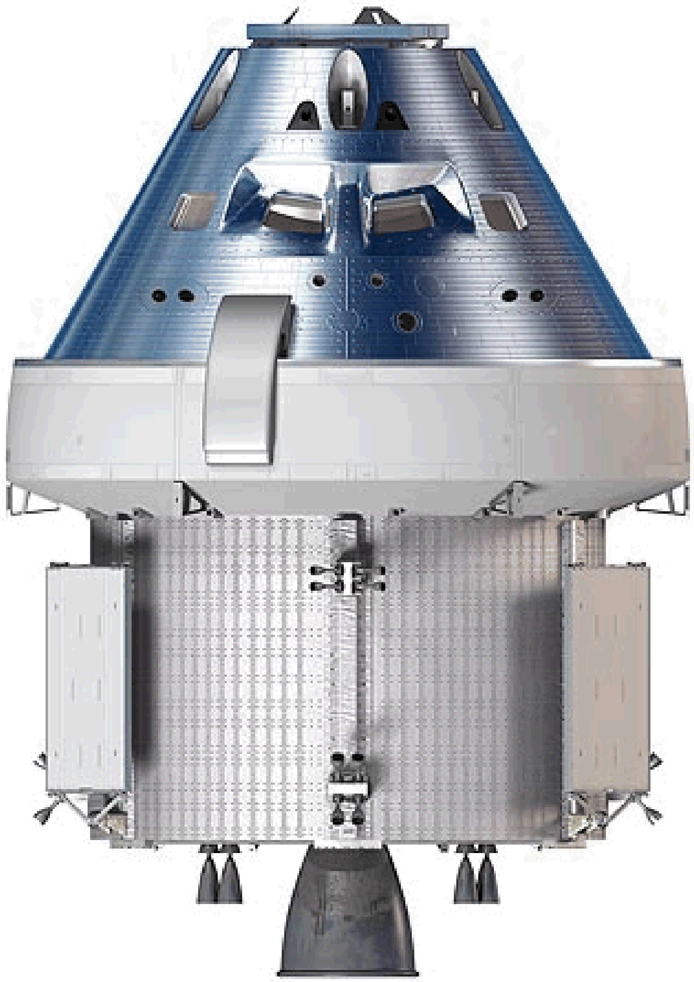

Mass Simulator of Orion

2018 SAWE Fall Regional Conference and Planning Meeting

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NASA Langley Research Center

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OUTLINE

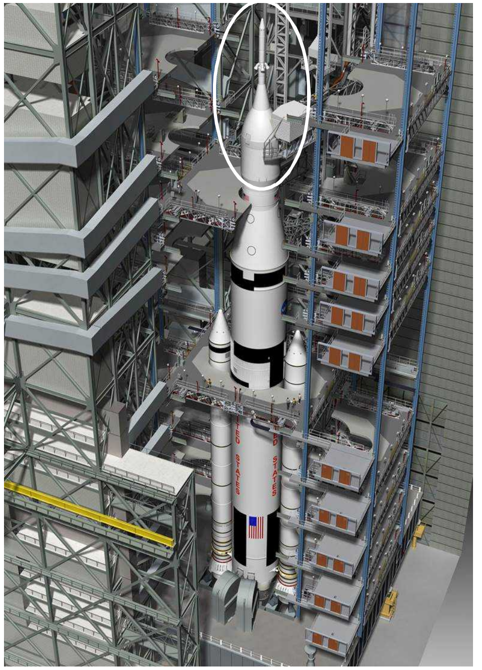
- Mass Simulator Purpose and Background
- MSO Mass and Material Properties
- Finite Element Model Summary
- Modal Analysis
- Mass/CG and Modal Testing Configurations
- Summary

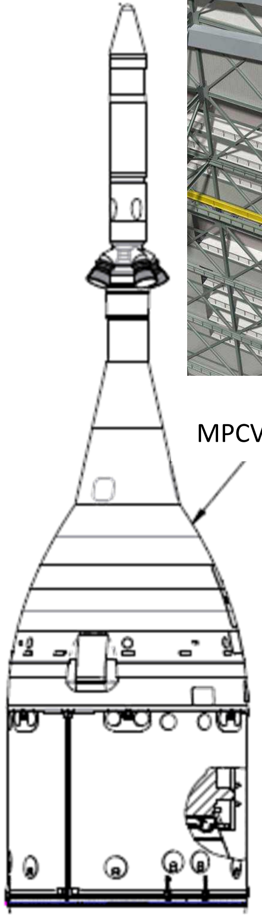
ORION SIMULATOR FOR INTEGRATED MODAL TEST

- Risk that Orion arrives later than Space Launch System (SLS). MSO mitigates this risk by using a mass simulator for SLS' tests. An Orion simulator for the Integrated Modal Test (IMT) and Umbilical Release and Retraction Tests (URRT) mitigates schedule risk by significant timeframe.

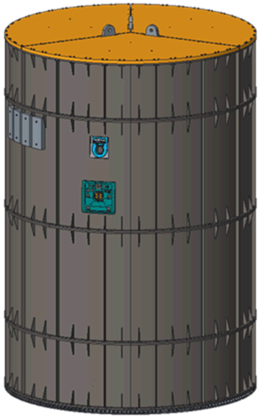
- A clean sheet alternate being pursued
  - Analysis shows matching modal characteristics unnecessary; rigid simulator is acceptable wrt existing SLS accelerometer locations and shaker placement/size

- Key Simulator Requirements: Representative mass, CG, rigid modal characteristics, high fidelity interface at MSA
  - Pre-test analyses show that MSO vertical CG could be up to 40" low without affecting IMT





MPCV Full Stack



Rigid Mass Simulator
(not to scale)

MSO MASS PROPERTIES REQUIREMENTS

National Aeronautics and Space Administration

MSO.F.003

MSO baseline mass shall be within Orion EM-1 predicted mass, +/- 1000 lbm with optional additional ballasting to EM-1 mass + 4,000 lbs, +/- 1000 lbm.

Rationale: MSO could be used to replicate EM-1 mass or EM-2 wet mass (4,000 lbs > than EM-1 mass).

1000 lbm mass error based on expected instrumentation (load cell, dynamometer) error band.

Verification Method: Test

MSO.F.004

MSO X-Axis Center of Gravity meet EM-1 X-Axis CG target with a tolerance of +42.85 in./-4.15 in .

Rationale: ATA Report No. 67243, "Final Report for Evaluation of MPCV Mass Simulator for SLS IMT Test" concluded that currently designated non-MPCV sensor locations and all shaker locations for the Integrated Modal Test are acceptable if the MPCV were replaced with a rigid mass simulator. The evaluation also shows X-Axis CG locations ranging from 193 inches to 240 inches above the MPCV to MSA interface are acceptable. This allows the MSO to have a X-axis CG tolerance of **+42.85 in./-4.15 in** from EM-1 Target CG.

Verification Method: Analysis; Test

Parent Requirement: Final Report for Evaluation of MPCV Mass Simulator for SLS IMT Test, ATA Project No. 67243 Prepared for NESC

MSO MASS PROPERTIES REQUIREMENTS (CONT)

MSO.F.005

MSO Y-Axis Center of Gravity shall EM-1 Y-axis CG target with a tolerance of +/- 2.58 in.

Rationale: MPCV 70026 provides a table of limits for the Orion Center of Mass. ATA Report No. 67243 did not vary the position of the Y-axis Center of Mass, so the position and tolerance is defined in MPCV 70026.

Verification Method: Analysis; Test

Parent Requirement: Final Report for Evaluation of MPCV Mass Simulator for SLS IMT Test, ATA Project No. 67243 Prepared for NESC

MSO.F.006

MSO Z-Axis Center of Gravity meet EM-1 Z-axis CG target with a tolerance of +/- 2.37 in.

Rationale: MPCV 70026 provides a table of limits for the Orion Center of Mass. ATA Report No. 67243 did not vary the position of the Z-axis Center of Mass, so the position and tolerance is defined in MPCV 70026.

Verification Method: Analysis; Test

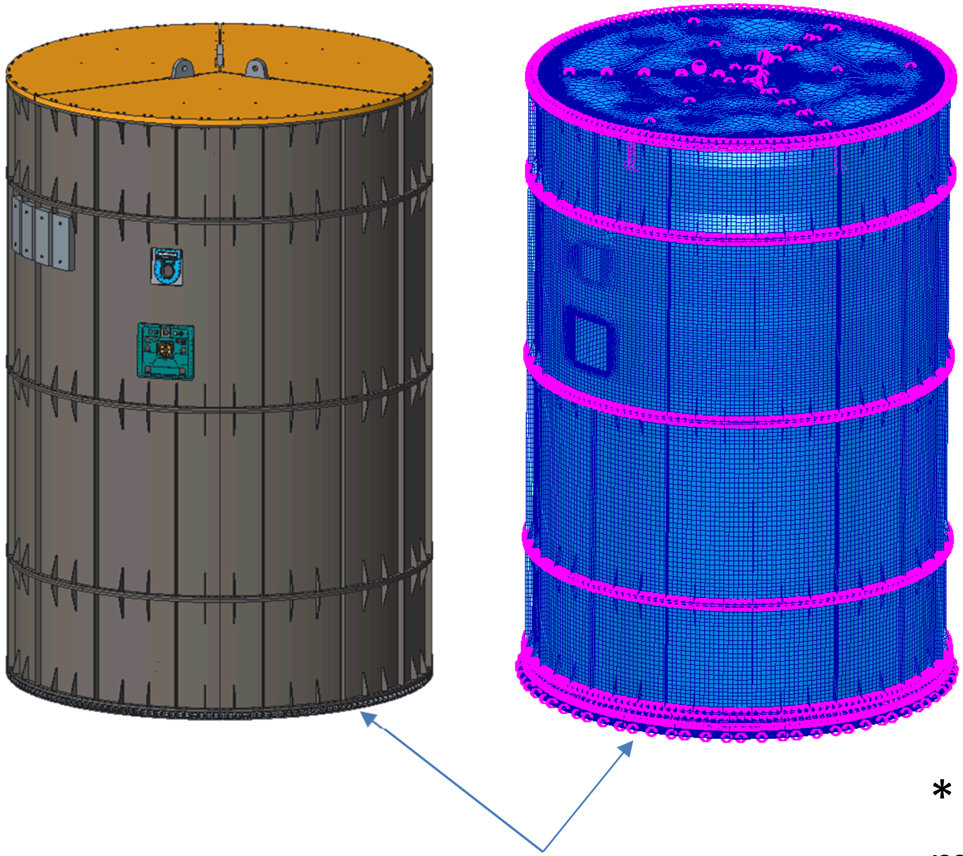
Parent Requirement: MPCV 70026 Rev G: MPCV Program To-SLS Program IRD

MSO MASS PROPERTIES AND MATERIALS

National Aeronautics and Space Administration

- FEM model generate from latest CAD step files
- Standard FEM checkouts completed

CAD DESIGN **FE MODEL**



Interfaces to SLS/MSA

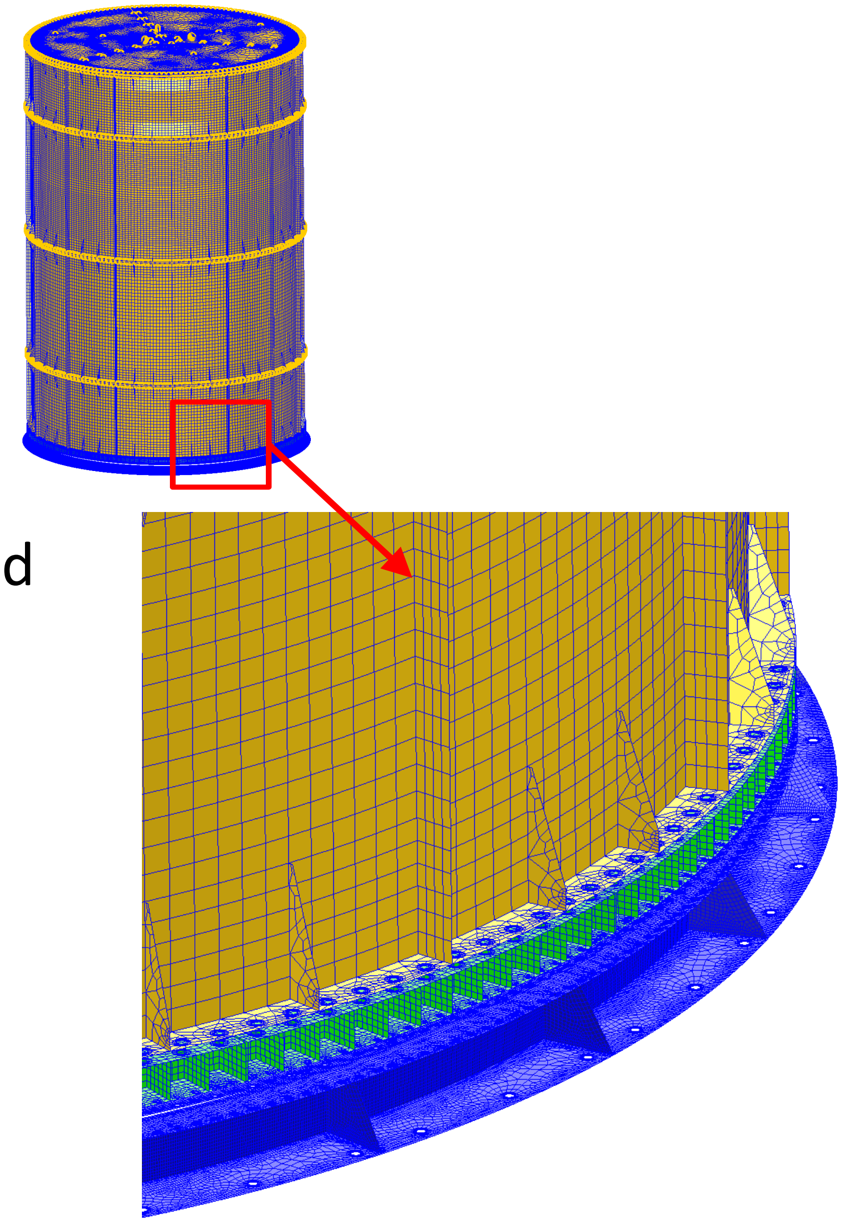
MATERIAL		
PROPERTY	ALUMINUM 7075-T7651	STEEL A572 GRADE 50
APPLIED COMPONENTS	MSO/MSA INTERFACE RING	BARRELS & LIFTING STRUCTURE

CONFIGURATIONS			
Quantity		DESIGN	FE MODEL
CENTER OF GRAVITY	X	226.56 in	227.0 in
	Y	1.93 in	2.35 in
	Z	-1.17 in	-1.11 in

* Total weights between CAD and FEM models are less than 1%. CAD model includes fastener weights, FEM does not.

MSO FINITE ELEMENT MODEL SUMMARY (2)

- Barrel wall, gussets, and vertical stringer thickness: **0.5** in.
- Horizontal flange thickness: **1.25** in.
- FEM assembled as though all welded structure are full penetration welds
  - Weld assessments recover section cut forces
  - Hand calcs are used to assess stress at welds

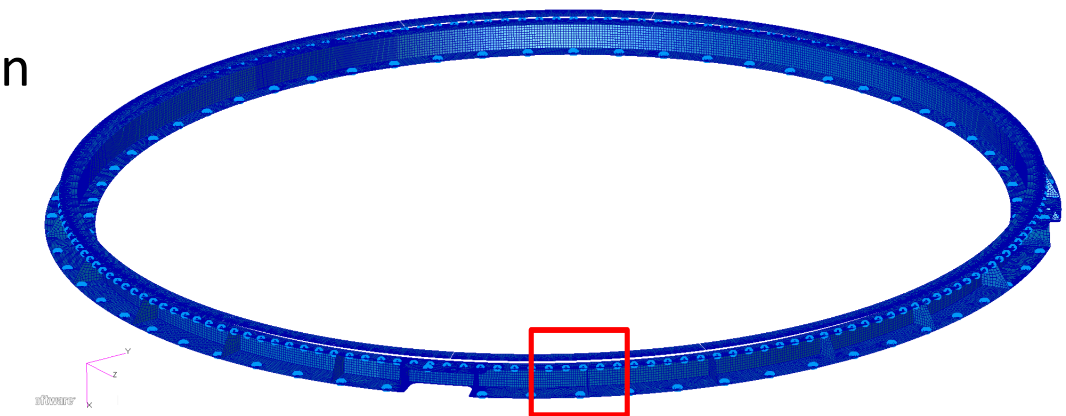


MSO TEST STAND FEM

National Aeronautics and Space Administration

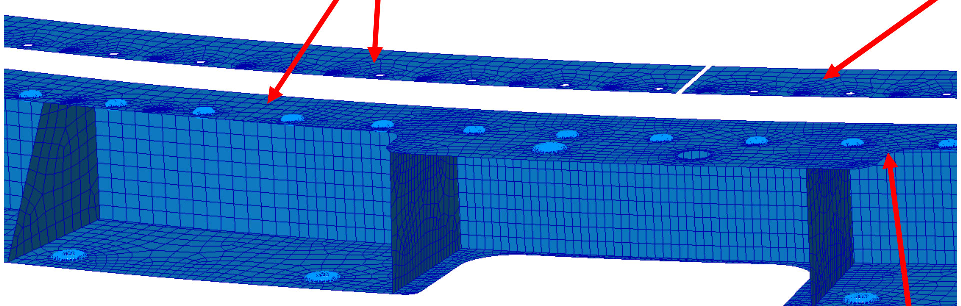
- A572 Grade 50 and Mic-6 Aluminum

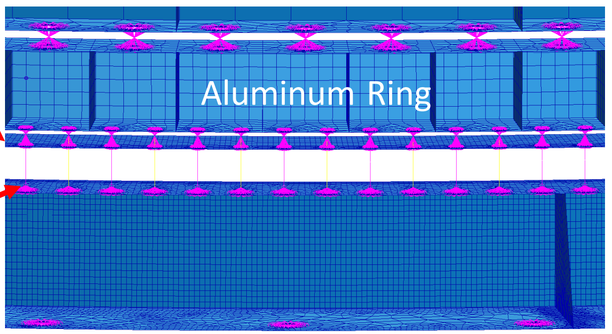
  Material Thickness:
  - Gussets and web: 0.75 in
  - Mass/CG Lift Gussets: 1.0 in
  - Base plate: 2.0 in
  - Mic-6 plate 1.0 in
  - Upper ring plate: 3.0 in



Glued contact for modal analyses

Mic-6 Plate



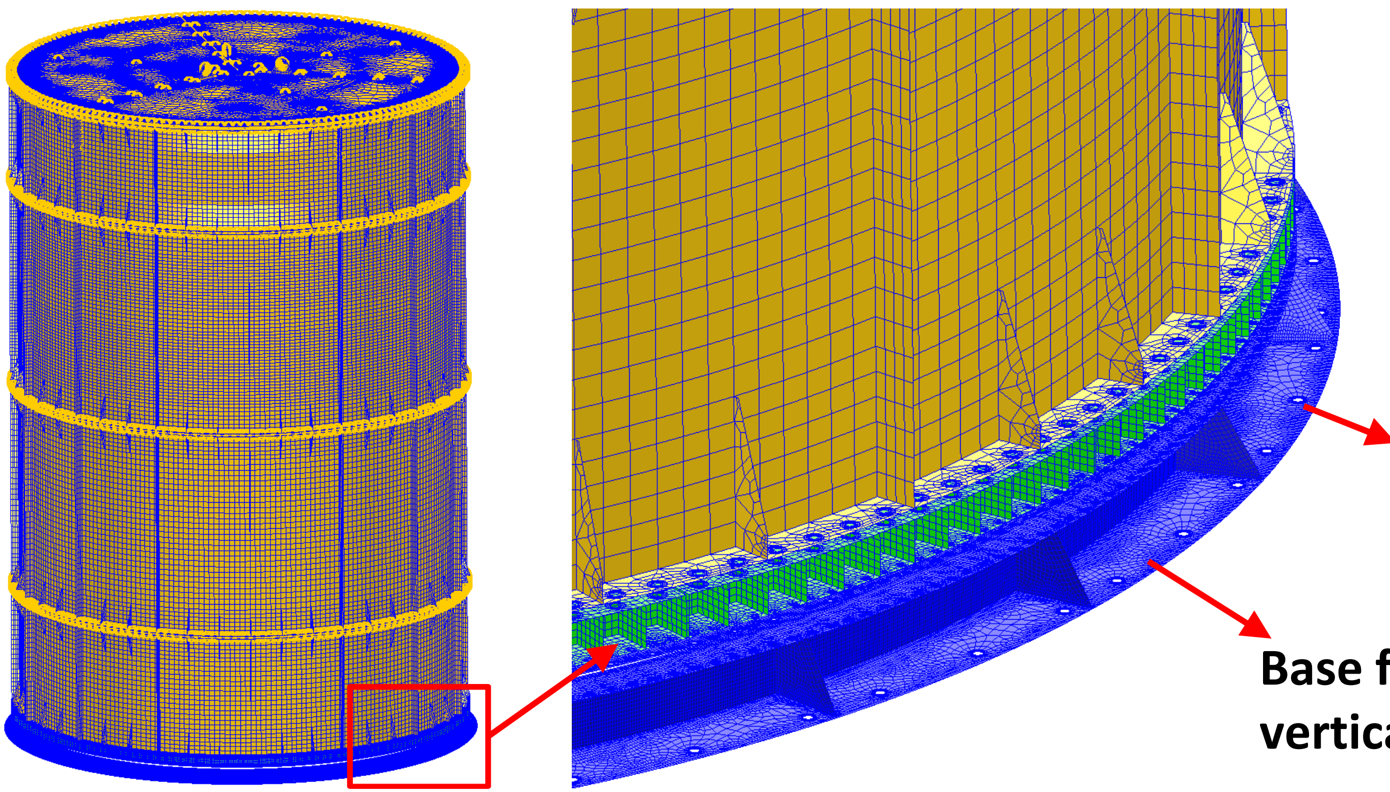


Upper ring plate

MPC connections for stress analysis

MODAL ANALYSIS – MSO WITH TEST STAND

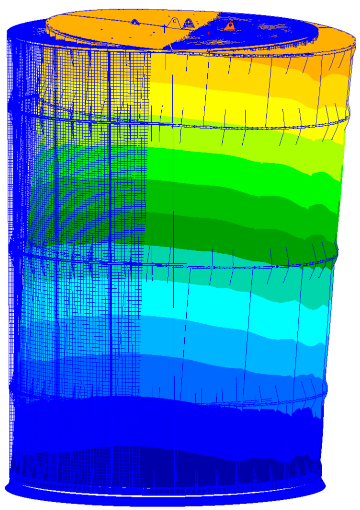
- Normal modes analyses using SOL103 in MSC NASTRAN
- Free boundary conditions for model checks
- Fixed test stand bolt hole grids in lateral dof’s
- Fixed all base flange grids in vertical dof



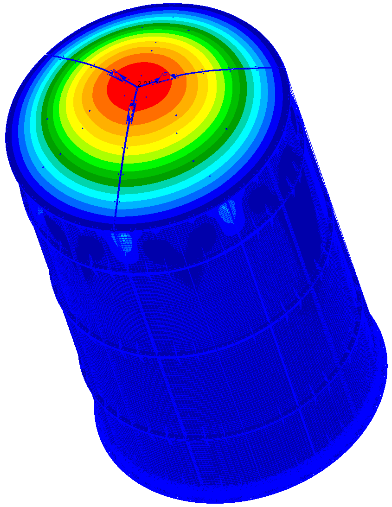
MSO WITH TEST STAND MODAL RESULTS

National Aeronautics and Space Administration

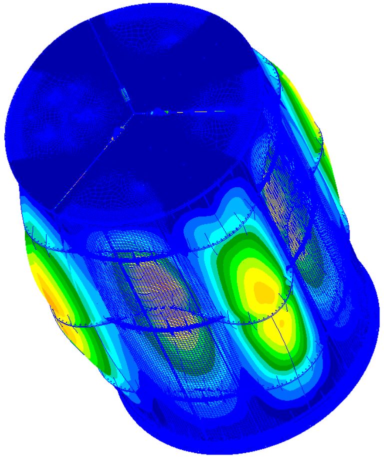
Meets frequency/stiffness requirements for >18 Hz



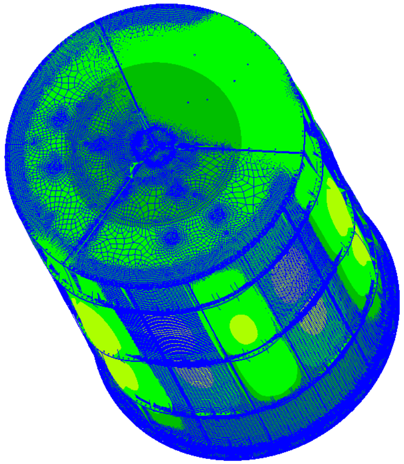
1st and 2nd Bending Mode 23.0 Hz



3rd Mode: 28.4 Hz



Breathing Modes ~36 Hz – 60+Hz (<1% mass frac)

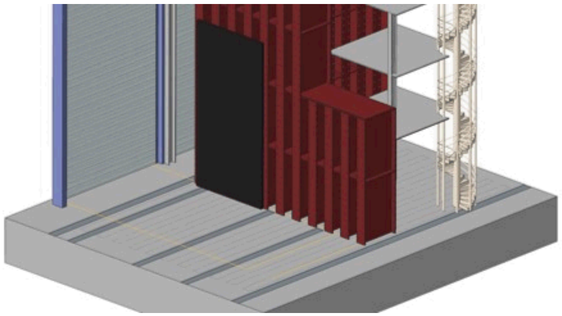


1st Torsion Mode 55.3 Hz

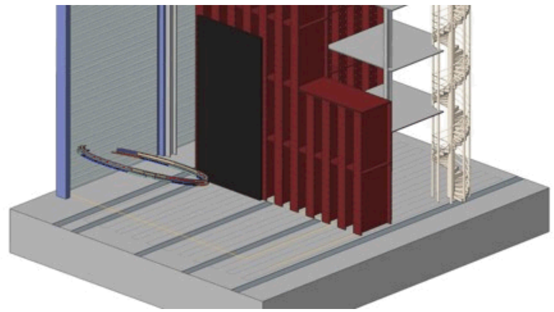
MSO ASSEMBLY FOR MASS/CG AND MODAL TESTING

National Aeronautics and Space Administration

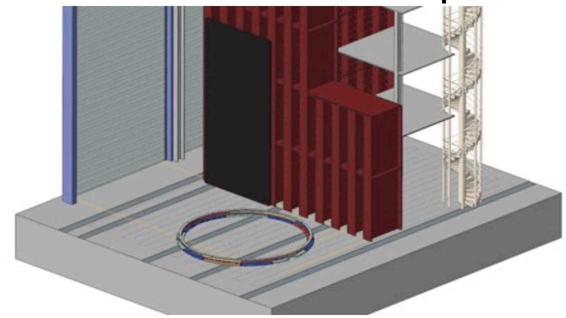
1: Prepare Test Area



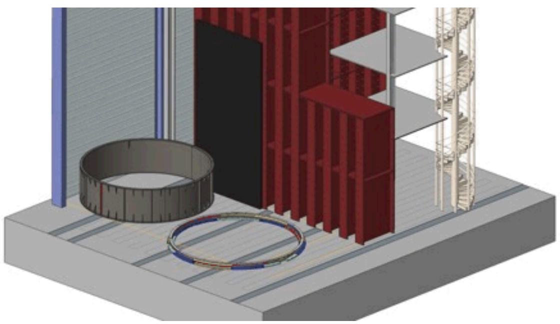
2: Lift Test Stand (7100 lb)



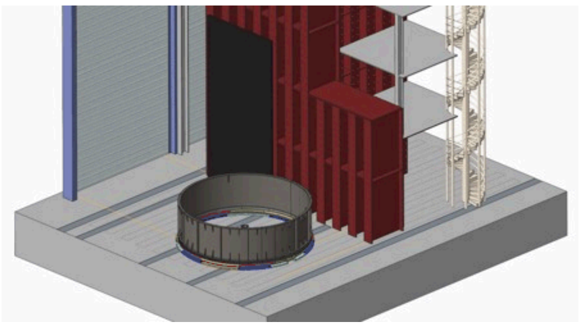
3: Weld Test Stand to I-Beams, Perform Fixture Evaluation Tap Tests



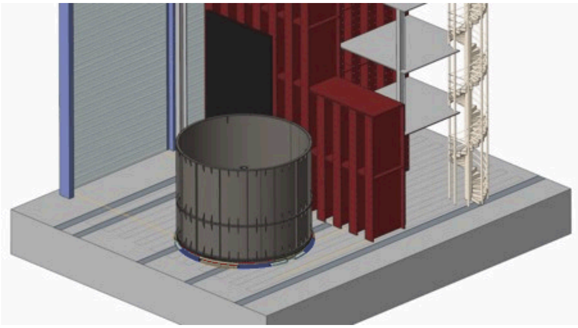
4: Lift Barrel 1



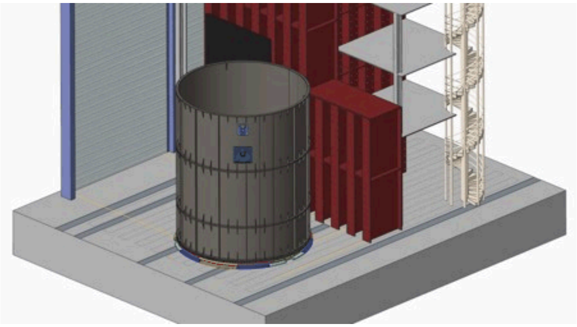
5: Install Barrel 1



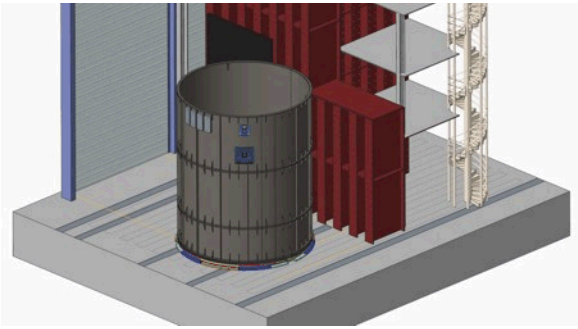
6: Lift & Install Barrel 2



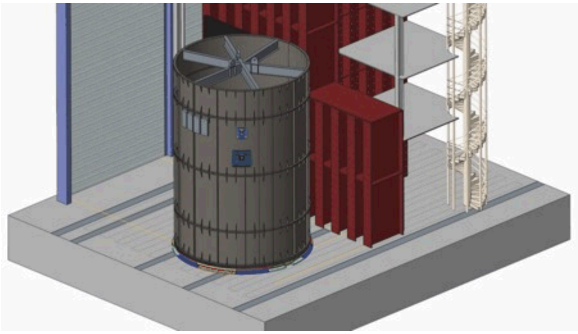
7: Lift & Install Barrel 3



8: Install Ballast Mass



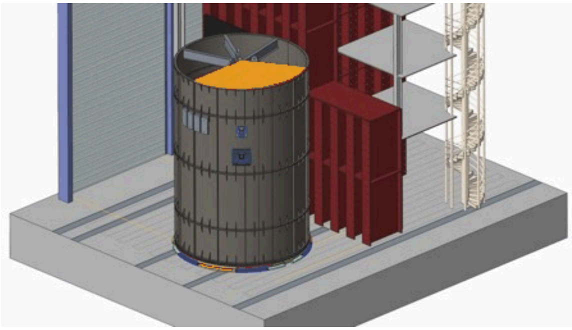
9: Lift & Install Barrel 4



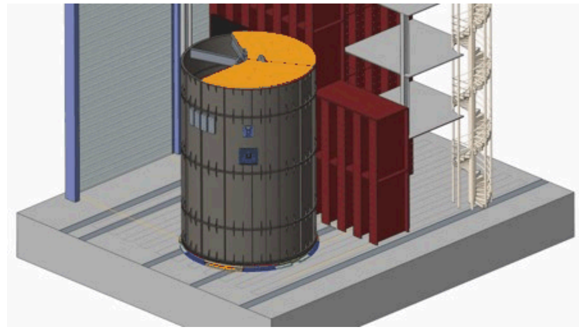
MSO ASSEMBLY FOR MASS/CG AND MODAL TESTING

National Aeronautics and Space Administration

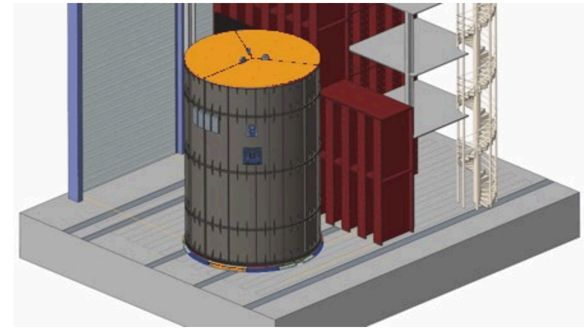
10: Install Top Cover Piece 1 (10,000 lb)



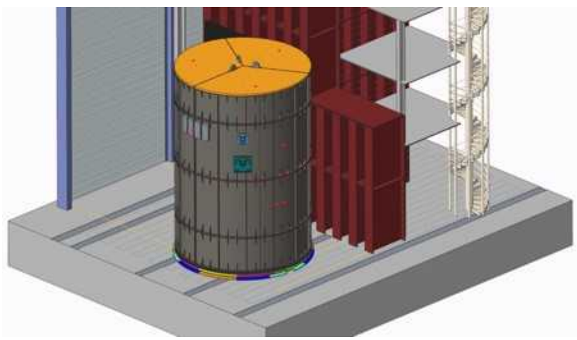
11: Install Top Cover Piece 2 (10,000 lb)



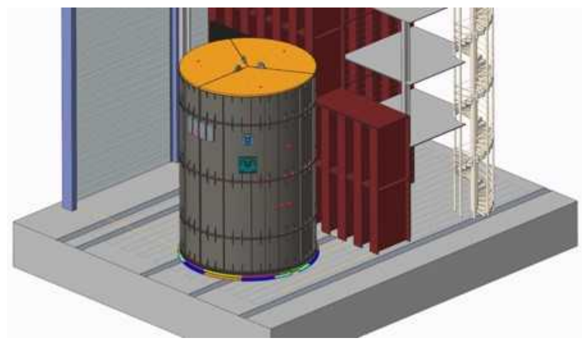
12: Install Top Cover Piece 3 (10,000 lb)



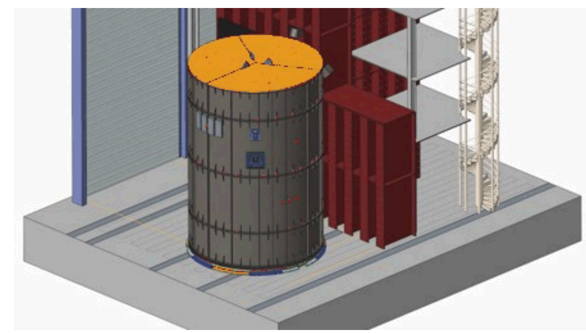
13: Install Accelerometers



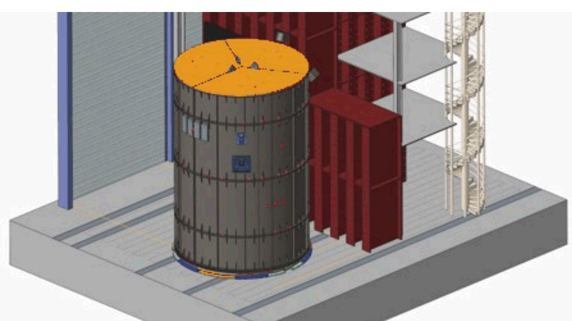
14: Perform Modal Tap Tests



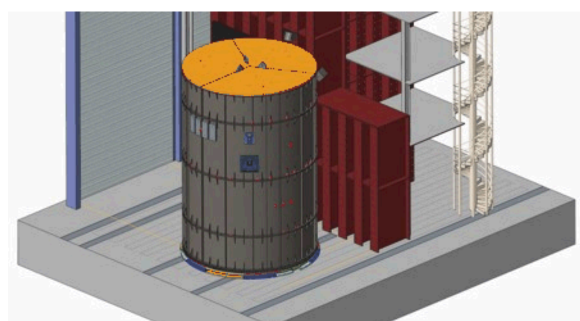
15: Install Shakers



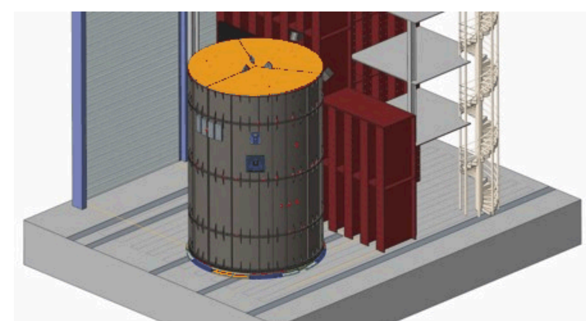
16: Perform Modal Shaker Tests



17: Install Ground-Side Umbilical Plates



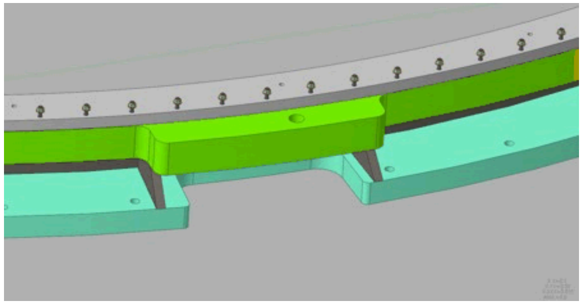
18: Perform Modal Shaker Tests



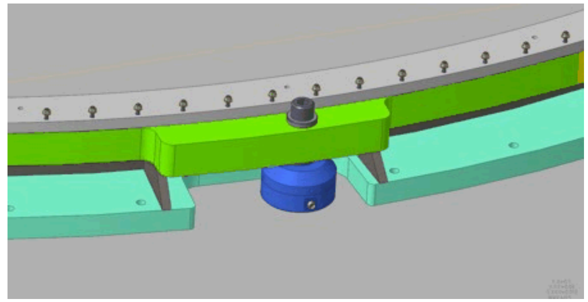
MASS & CG TEST, LIFTING PROCESS

National Aeronautics and Space Administration

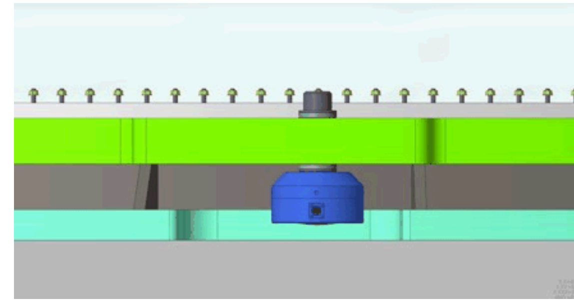
1: Stand Ready for Tare Measurement



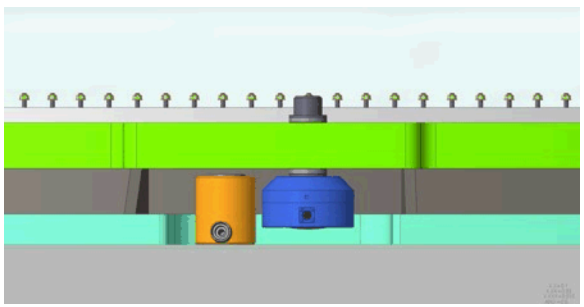
2: Install Load Cell with Cap Screw and Spherical Washers, Torque



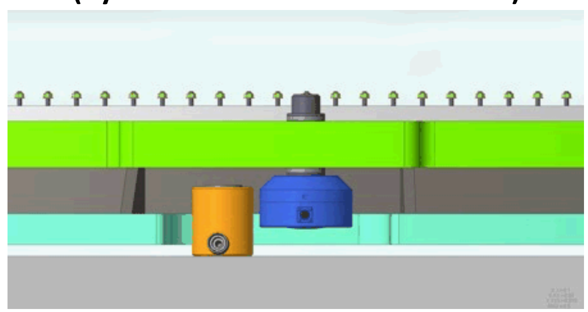
3: Verify Load Cell is Level, Adjust as Necessary



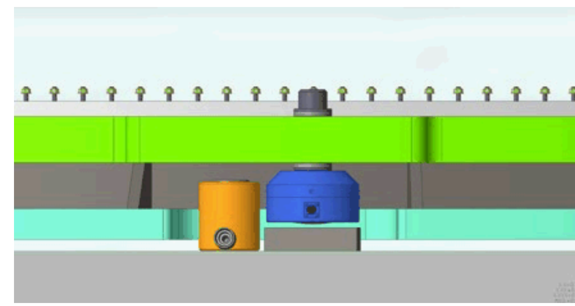
4: Insert Hydraulic Cylinder



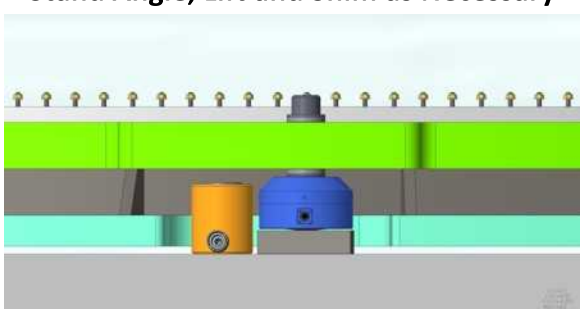
5: Lift Stand ~0.75”
(Cylinder at 1.12” of 2.44” Stroke)



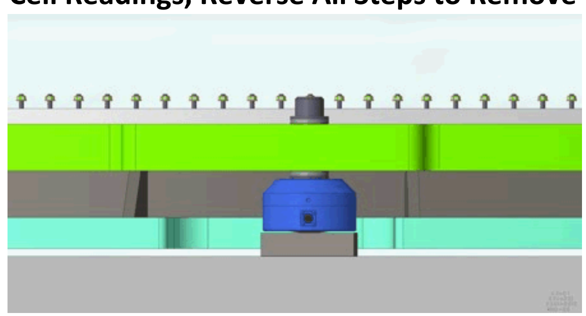
6: Insert 1.50” Steel Plate



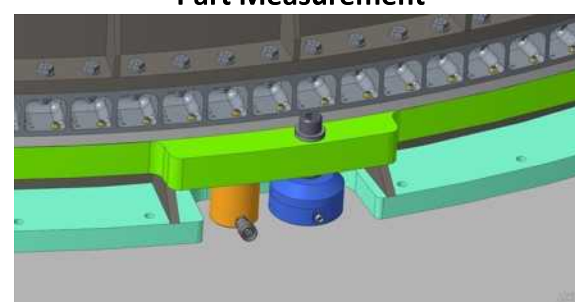
7: Lower Load Cell onto Plate, Measure Stand Angle, Lift and Shim as Necessary



8: Remove Hydraulic Cylinder, Record Load Cell Readings, Reverse All Steps to Remove



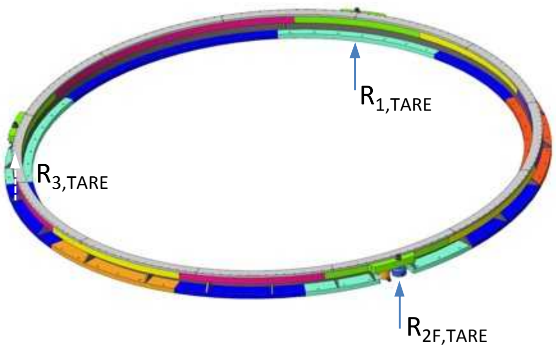
9: Install MSO, Repeat Steps 4 through 8 for Part Measurement



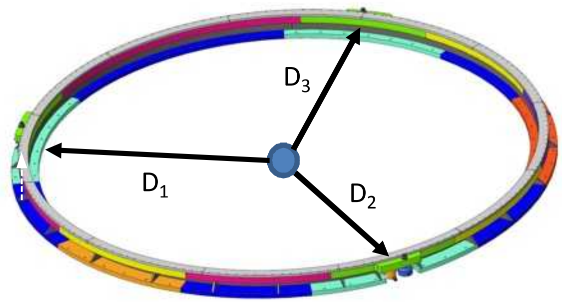
MASS & CG TESTING

National Aeronautics and Space Administration

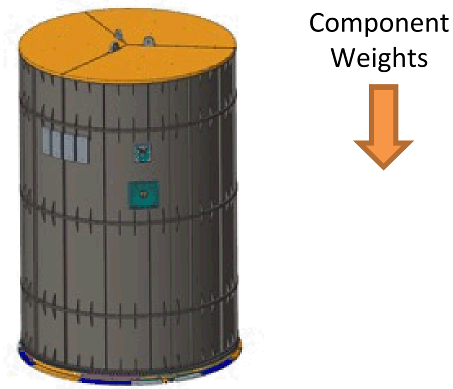
1: Rest Test Stand on Concrete (Test Fixture Tare)



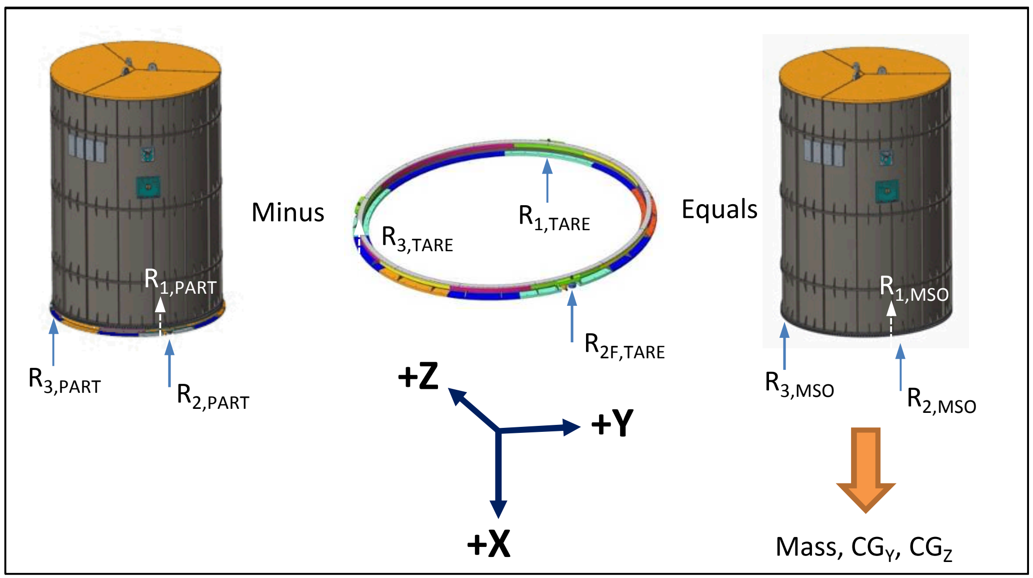
2: Measure Distances to Reference



3: Install MSO on Test Stand, Component Weights During Assembly



4: Mass & CG Test



- X CG will be obtained via calculation after measuring individual components during assembly
- Obtain Y and Z axis CG from reaction loads (R1, R2, and R3) and distance to center reference

$$CG(y) = \frac{R_1D_1(y) + R_2D_2(y) + R_3D_3(y)}{W_{Total}}$$

$$CG(z) = \frac{R_1D_1(z) + R_2D_2(z) + R_3D_3(z)}{W_{Total}}$$

MSO SUMMARY OF RESULTS

- Final MSO design first modal frequency at 23.2 Hz, requirement at 18 Hz
  - MSO on test stand frequency is 23.0 Hz
  - Meets 18 Hz requirement
- MSO primary and secondary structural designs meet all design load requirements
- MSO Weight and CG will be verified upon completion of the fabrication process (ECD 01/2019)
  - Low risk meeting large X-axis CG tolerance
  - Will ballast as necessary to meet Y and Z CG targets during/after mass and CG test