

Ascent Abort 2 (AA-2) Integrated Flight Test Vehicle: How Mass Properties are Used to Manage Flight Test Objectives for the SAWE Hampton Roads Regional Conference on November 29, 2018

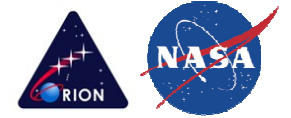
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Engineering and Integration Team (SEIT) Deputy Lead
Engineering Directorate (ED) Systems Engineering &
Engineering Methods Branch (SEEMB)
NASA Langley Research Center (LaRC)



Agenda



- NASA Vision and Missions



- Space Launch System (SLS) and Orion Overview

- Orion Ascent Abort 2 Flight Test Overview



- Mass Properties to Manage AA-2 Flight Test Objectives

- Go forward Plans



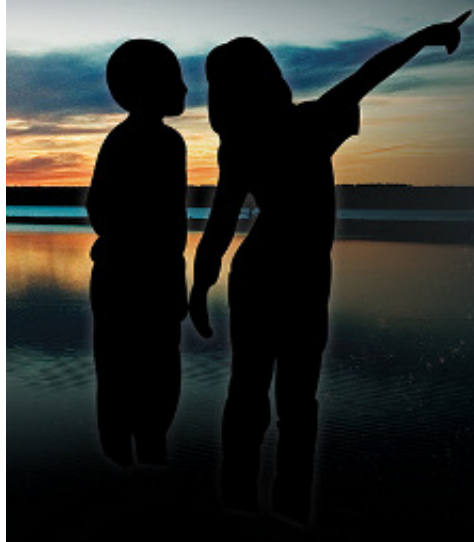
National Aeronautics and Space Administration

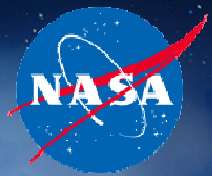


REACH
—NEW—
HEIGHTS

BENEFIT
—ALL—
HUMANKIND

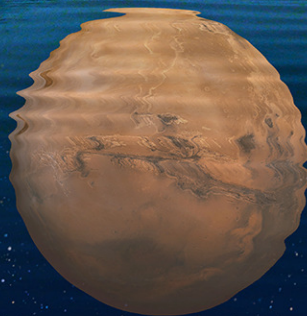
REVEAL
—THE—
UNKNOWN





EXPLORE MOON_{to}MARS

MOON LIGHTS THE WAY



A close-up, low-angle shot of an astronaut in a white space suit floating in space. The astronaut's helmet is prominent, reflecting the interior of the suit and the Earth. The background shows the deep blue of Earth's atmosphere and the dark, textured surface of the planet. A solar panel structure is visible in the upper right corner.

EXPLORE HUMANS *in* SPACE

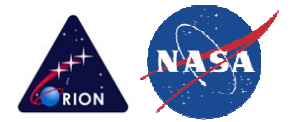
Leading Discovery, Improving Life on Earth



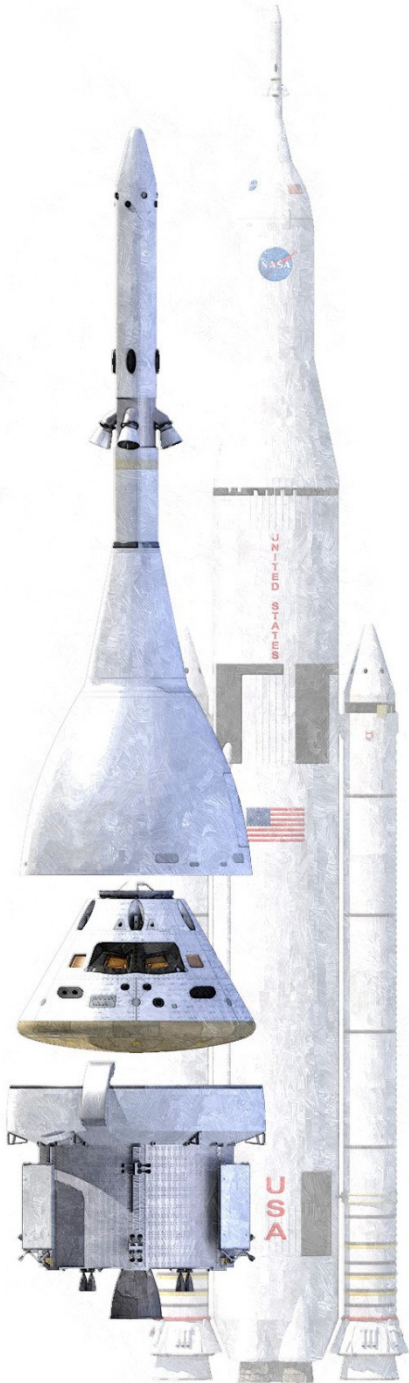
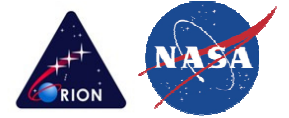
EXPLORESPACE TECH

TECHNOLOGY DRIVES EXPLORATION

Space Launch System (SLS)

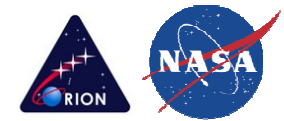


Orion on SLS

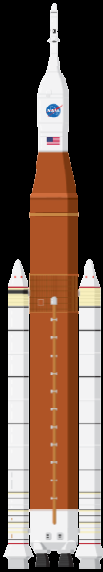
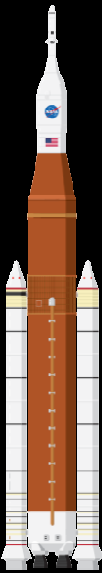


NASA's Orion spacecraft is built to take humans farther than they've ever gone before. Orion will serve as the exploration vehicle that will carry the crew to space, provide emergency abort capability, sustain the crew during the space travel, and provide safe re-entry from deep space return velocities.

Exploration Systems Development Flight Manifest



AA-2 is the next flight test in the Exploration Systems Development Program

2010		2014	2015	2016	2017	2018	2019	2020	2021	2022
										
PA-1		EFT-1					AA-2	EM-1		EM-2

PA-1 Pad Abort 1

EFT-1 Exploration Flight Test 1

AA-2 *Ascent Abort 2*

EM-1 Exploration Mission 1

EM-2 Exploration Mission 2

Abort from Launch Pad

Un-crewed high speed entry flight

Un-crewed Ascent Abort

Un-crewed circumlunar flight

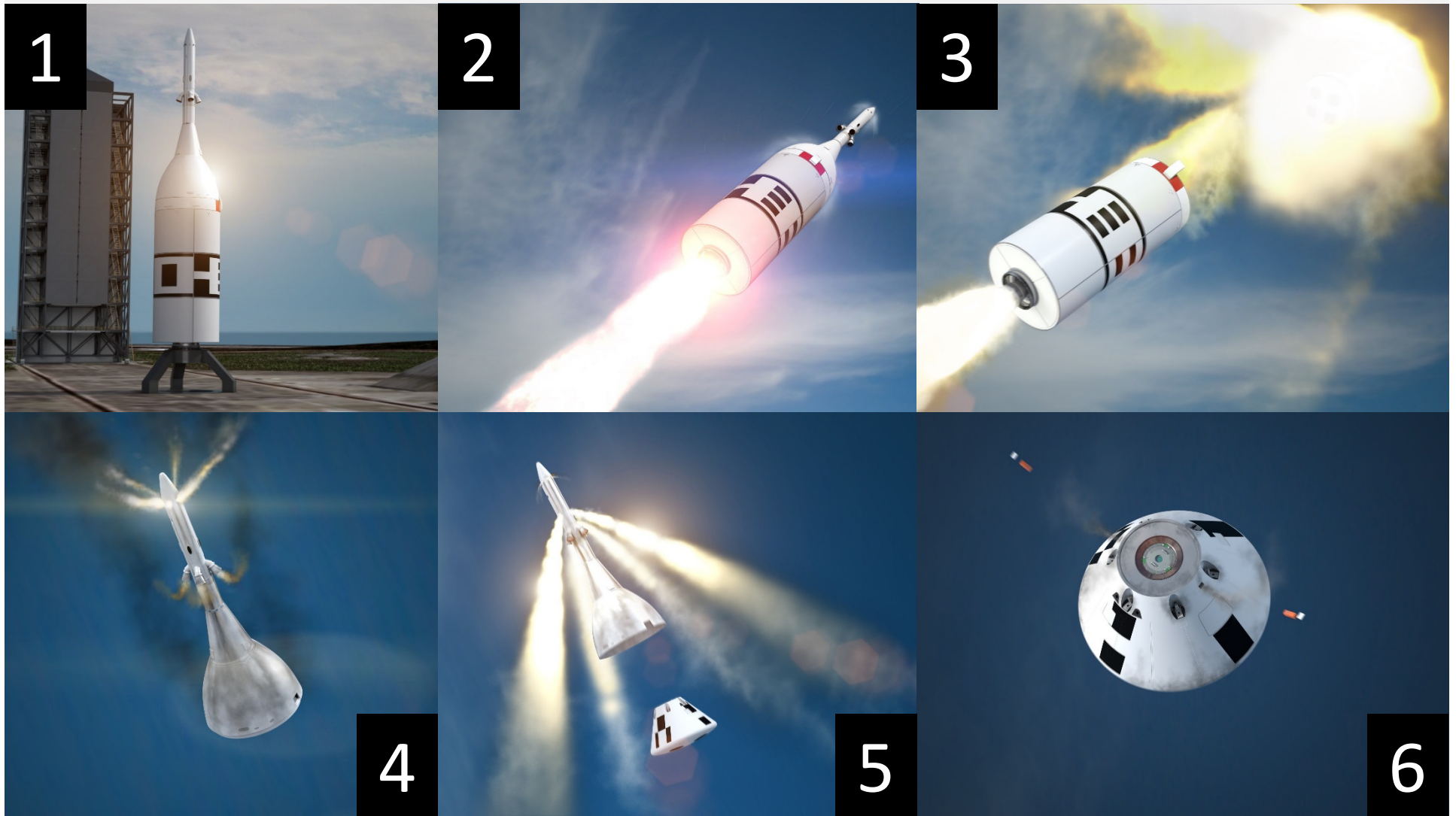
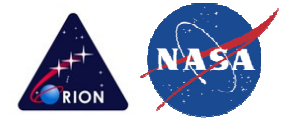
Crewed high lunar orbit flight

Occurred May 6, 2010

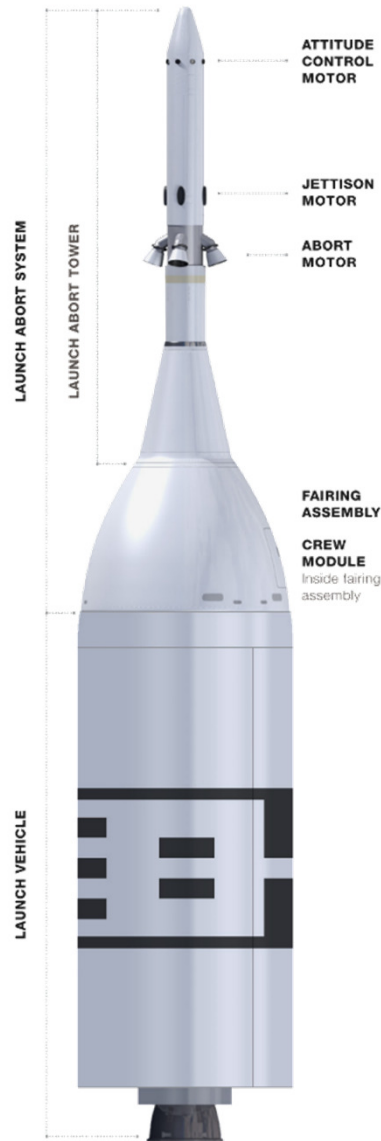
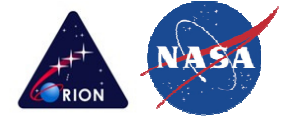
Occurred December 5, 2014

Spring 2019

Orion Ascent Abort 2 (AA-2) Flight Test

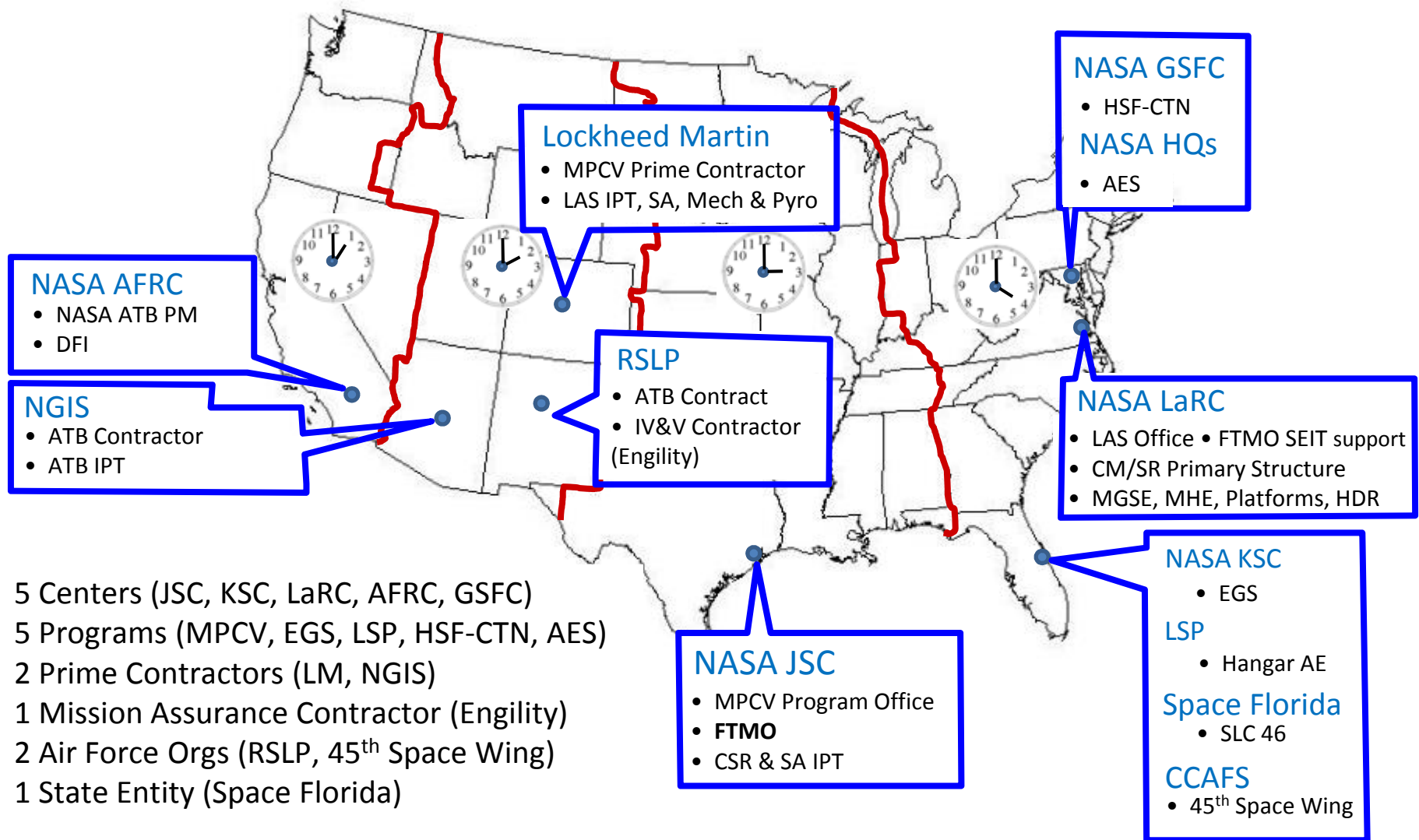
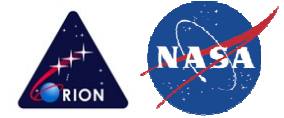


AA-2 Flight Test Vehicle



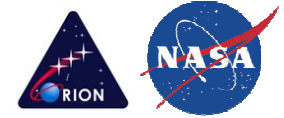
- The AA-2 Flight Test Vehicle (FTV) is composed of four modules
 - Abort Test Booster (ATB)
 - Lifts Flight Test Article (FTA) to desired test condition
 - Separation Ring (SepRing)
 - Attached to ATB
 - Simulates top of Orion Service Module (SM)
 - (Boilerplate) Crew Module (CM)
 - Mass properties & outer mold line (OML) simulation of an actual Orion Crew Module
 - Launch Abort System (LAS)
 - Production article
- The LAS and the CM together are referred to as the Launch Abort Vehicle (LAV)
- The LAV and the SepRing together are referred to as the Flight Test Article (FTA)
- The ATB and the SepRing together are referred to as the Launch Vehicle (LV)

AA-2 Mission Team: Locations



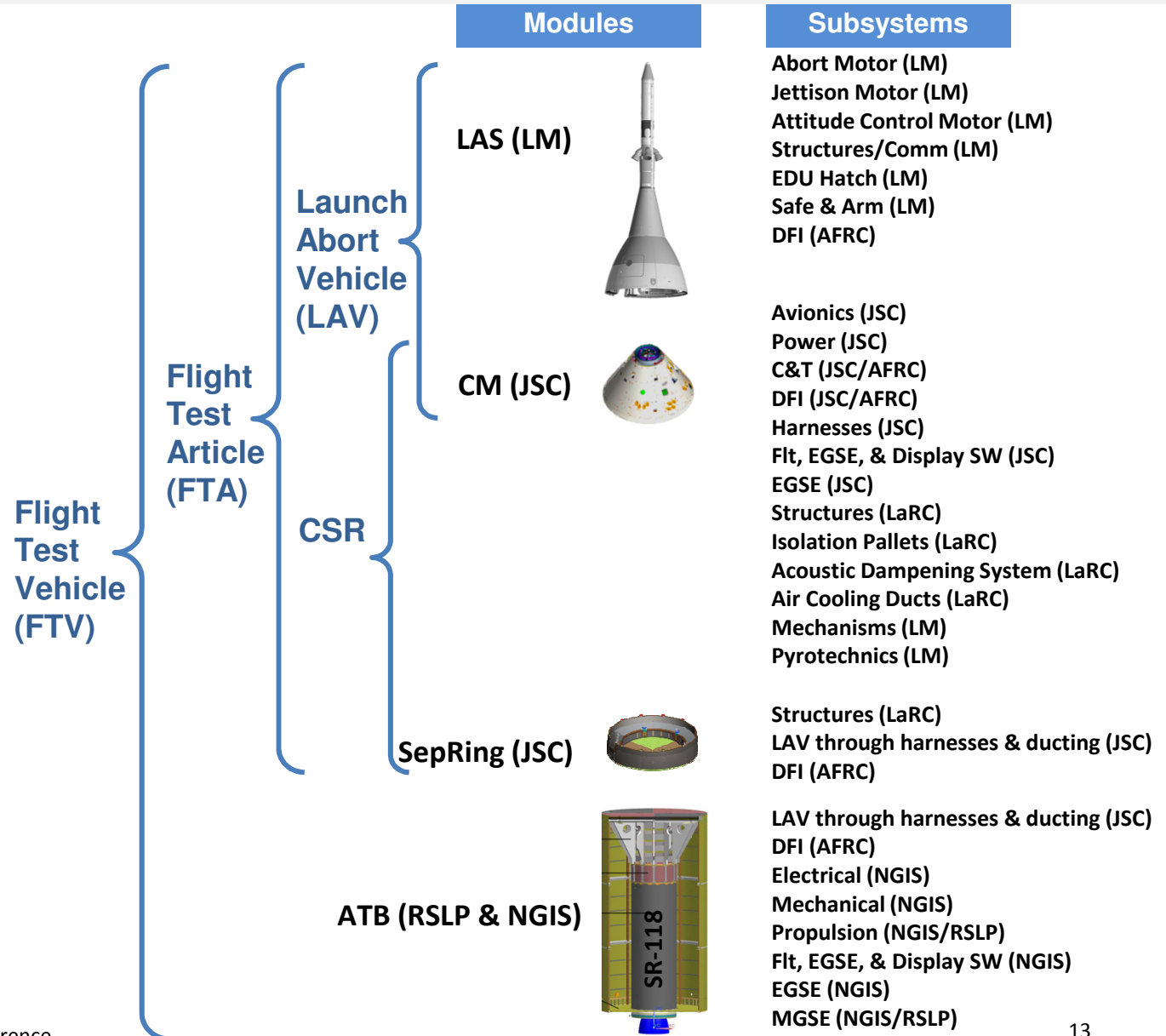
5 Centers (JSC, KSC, LaRC, AFRC, GSFC)
 5 Programs (MPCV, EGS, LSP, HSF-CTN, AES)
 2 Prime Contractors (LM, NGIS)
 1 Mission Assurance Contractor (Engility)
 2 Air Force Orgs (RSLP, 45th Space Wing)
 1 State Entity (Space Florida)

AA-2 Roles & Responsibilities

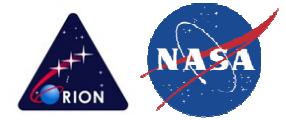


NASA FTMO is the overall Vehicle Integration, Launch, and Test Authority

- Systems Analysis:
 - NASA/LM co-led
 - Integrated LM/NASA/ NGIS analysis team
- Operations:
 - NASA led
 - Support from all team organizations

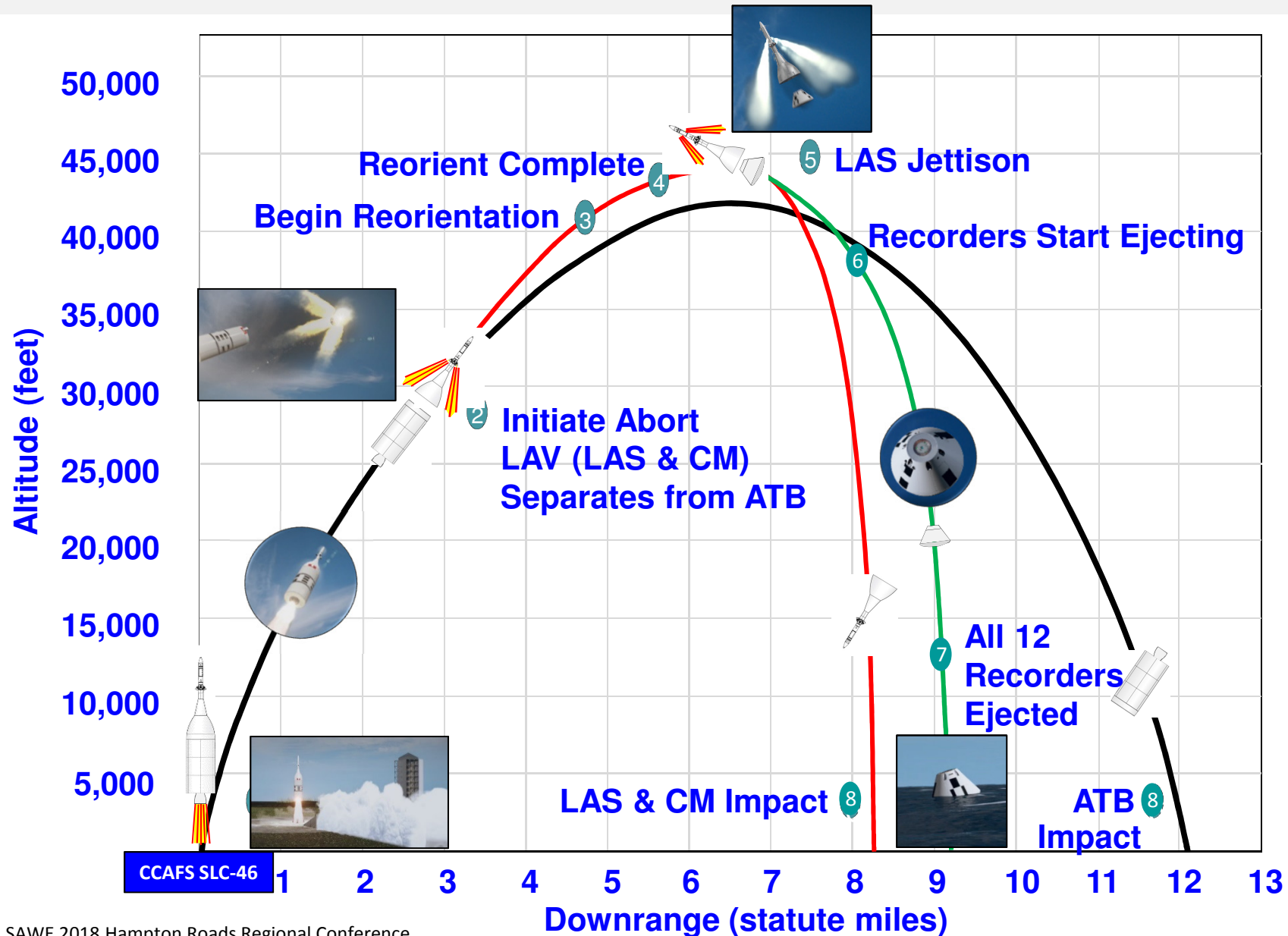
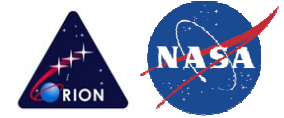


AA-2 Purpose: Flight Test Objectives (FTOs)

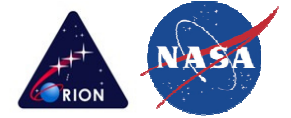


- To demonstrate the Orion Launch Abort System (LAS) can safely separate and maneuver the Crew Module (CM) away from a launch vehicle during an abort in near-transonic conditions:
 - Dynamic Pressure & Mach Number
 - Total Angle of Attack
 - Body Lateral Rate
 - Axial Acceleration
 - Flight Path Elevation
- **Flight Test Objectives Summary**
 - ✓ Demonstrate abort capability at defined conditions
 - ✓ Determine the stability characteristics and reorientation dynamics of the Launch Abort Vehicle (LAV) while under active control of the Attitude Control Motor (ACM)
 - ✓ Obtain LAS structural loads data, assure LAS structural integrity, and obtain LAS/CM interface data
 - ✓ Determine performance of the Abort Motor and ACM
 - ✓ Demonstrate and gather data from the CM/SM separation mechanism and umbilical
 - ✓ Demonstrate and gather data from the CM/LAS separation mechanism
 - ✓ Gather information on the LAV external environment – acoustic, aerodynamic, thermal, acceleration...

AA-2 Flight Test Profile



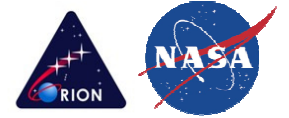
AA-2 Mission Objectives



- There are a total of 38 Mission Objectives in 6 Categories
 - Abort Capability (2)
 - Demonstrate ability of LAS to propel the Launch Abort Vehicle (LAV) safely away from the Launch Vehicle
 - Determine critical performance parameters for the LAV at the test conditions
 - Dynamic Stability (5)
 - Determine stability & control characteristics of the LAV
 - Demonstrate heat-shield-forward flight stability
 - Determine CM dynamic response to LAS jettison
 - Determine the stability characteristics of the CM following LAS jettison
 - Demonstrate stability and control characteristics of the LAV due to the LAS
 - Structural Integrity (6)
 - Demonstrate the structural integrity of the LAS and all critical interfaces to the CM
 - Demonstrate LAS Faring Assembly structural integrity before reorientation
 - Obtain LAS structural loads data
 - Obtain LAS/CM interface structural loads data
 - Obtain CM primary structure loads data for all phases of the test
 - Obtain LAV/SR interface structural loads data

Mass properties are input variables for almost all flight test objectives

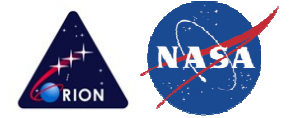
AA-2 Mission Objectives



- There are a total of 38 Mission Objectives in 6 Categories
 - Environment (13)
 - Obtain data to anchor predictions of LAS/CM and LAS/SR interface vibrations from liftoff through LAS separation
 - Obtain data to anchor predictions of CM internal acoustic environment during abort phase of flight
 - Obtain external acoustic data on the LAS after liftoff and prior to LAS jettison
 - Obtain cavity acoustic data for the LAS Fairing Assembly / external CM cavity after liftoff and prior to LAS jettison
 - Obtain venting data during ascent
 - Determine thermal environments through LAS jettison
 - Determine low and high frequency acceleration environments after liftoff up to LAS jettison
 - Determine aerodynamic environments during all phases of launch and ascent, including LAV separation
 - Determine the aerodynamic environment of the CM post LAS jettison
 - Obtain subsonic dynamic aerodynamic data for the CM
 - Determine ascent aerothermodynamic environment during nominal and abort segments of flight
 - Determine aerodynamic and aerothermodynamic environments on the CM due to jettison motor plume impingement during LAS jettison
 - Determine critical environment and functionality data for the LAS hatch and associated mechanisms during an abort

Mass properties are input variables for almost all flight test objectives

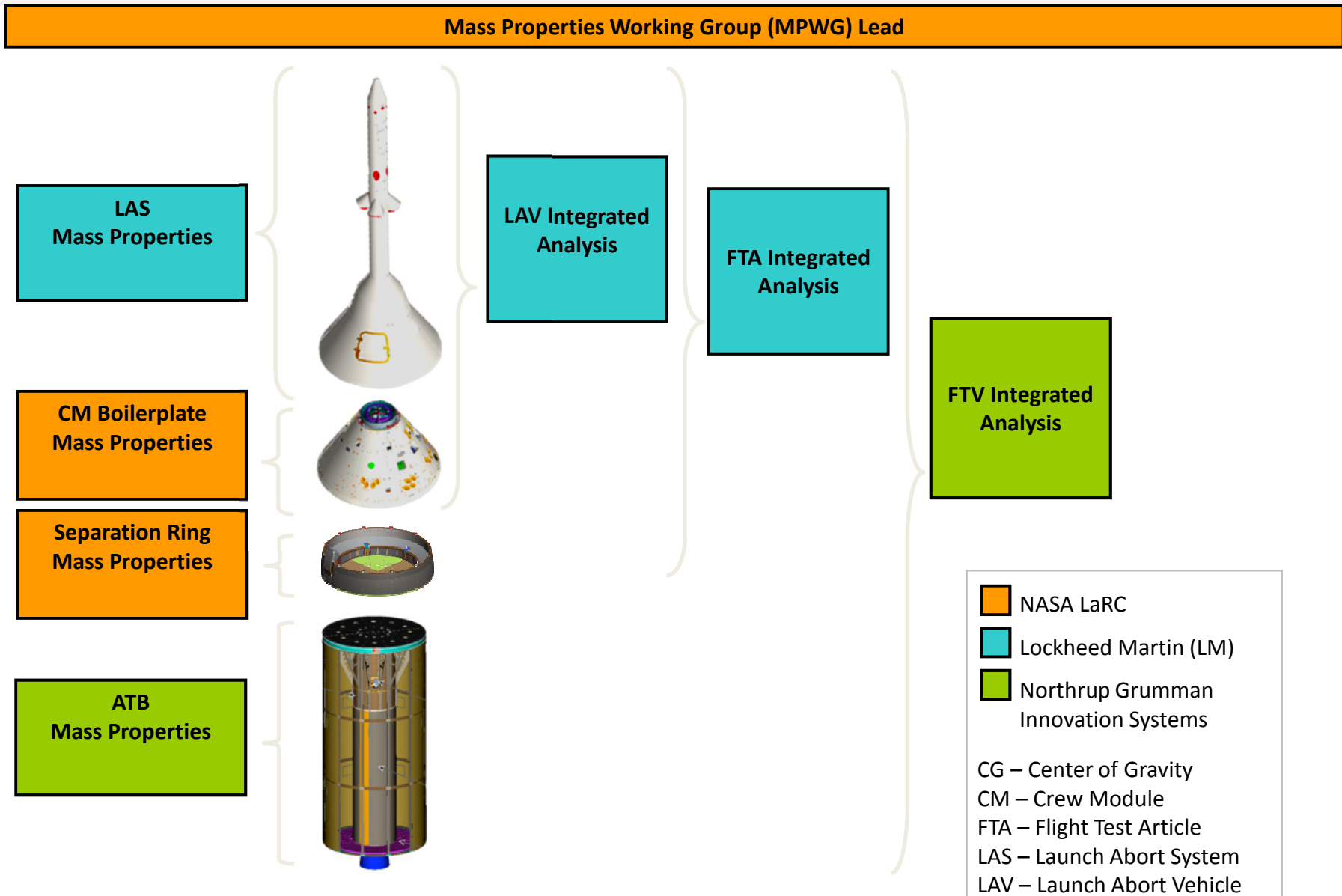
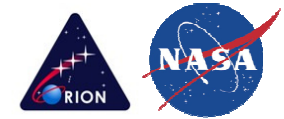
AA-2 Mission Objectives



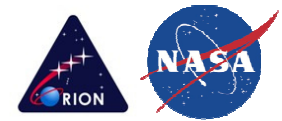
- There are a total of 38 Mission Objectives in 6 Categories
 - Performance (4)
 - Determine the performance of the abort motor
 - Demonstrate the ability of the LAS to jettison from the CM
 - Determine separation trajectory of the LAS relative to the CM
 - Determine the performance of the Attitude Control Motor (ACM)
 - Separation (8)
 - Demonstrate SR/LAV separation at the selected angle of attack
 - Demonstrate the umbilical separation between CM and SM
 - Determine the CM and SR umbilical separation characteristics
 - Demonstrate CM/LAS separation
 - Obtain data of the separation of the LAS from the CM
 - Obtain data on water impact location of the LAS
 - Obtain data of the separation of the LAV from the SM
 - Demonstrate abort event sequencing from abort initiation through LAS jettison

Mass properties are input variables for almost all flight test objectives

AA-2 MPWG Roles and Responsibilities



AA-2 Geometry & Mass Properties Reqs. Document (G&MPRD) Structure Similar to PA-1 Flight Test



- Purpose: Provides a single source of reference data and requirements for the flight test vehicle (FTV) that will be used to support AA-2 for geometry and mass properties
 - Drawings are used to define geometry, Outer Mold Line (OML), and reference configurations for modules: FTV, FTA, LAV, CM, LAS, and SepRing
 - Design tolerances are identified as requirements
 - Approved and accepted coordinate frames are identified
 - Mass properties targets and ranges are defined as requirements for some configurations (CM, LAV, SepRing, & FTA) and references for others (LAS)
- Key Notes:
 - PA-1 and AA-1 used as a guideline and lessons learned were incorporated
 - CM mass properties requirements include unique adjustable ballast capability

Geometry & Mass Properties Requirements Document (G&MPRD): Overview

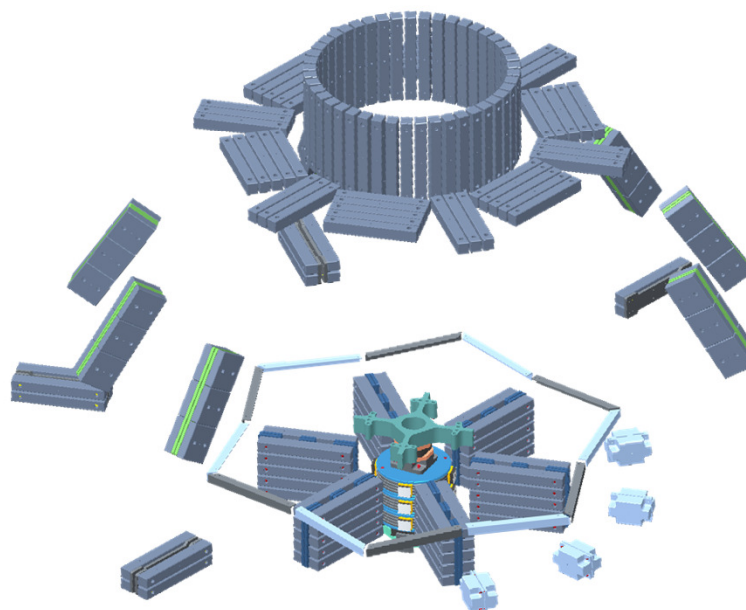
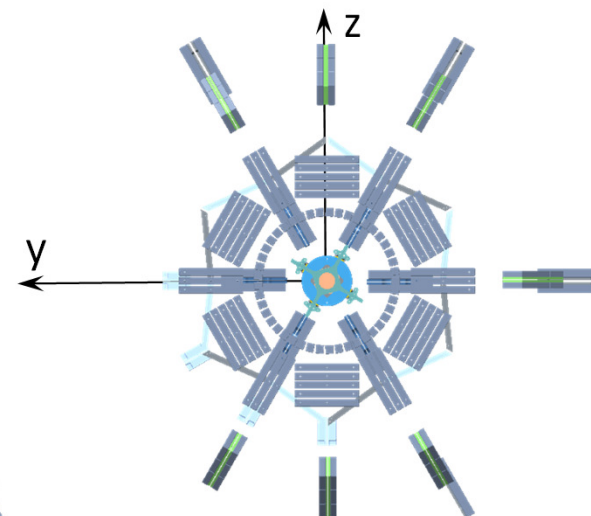


- Driving Requirements
 - Mass Properties mass and Center of Gravity (CG) target values
 - LAV targeting EM-2 values and AA-2 performance
 - CM boilerplate currently targeting EM-2 configuration
 - Also includes unique adjustability requirements in order to remain flexible in the possible event the target evolves over the lifecycle of the project
 - Separation Ring mass and CG
 - FTA mass and CG envelope box as combination of LAV and SepRing modules
 - FTV does not have an explicit mass properties requirement, instead the mass properties will be reported in integrated reports as a function of considering design of ATB, including necessary ballast, to meet flight test objectives based on performance requirements and the FTA mass properties
 - Inertias are listed for reference and are not requirements

Geometry & Mass Properties Requirements Document (G&MPRD): Overview – Mass Properties Control

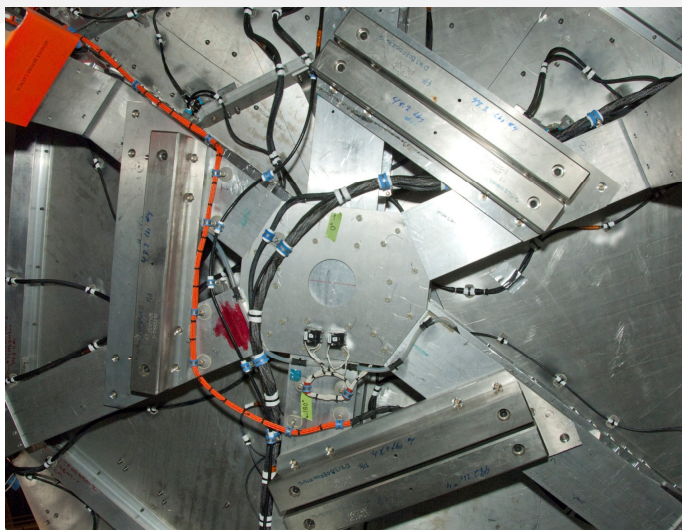


- Mass properties requirements CM, LAV, SepRing, and FTA
- Ballast adjustability
- Only some subsystems have mass allocations
- Mass Growth Allowance (MGA)
- Uncertainties assessments, which will include:
 - Actuals measured and tested
 - Modeled Components
 - Monte Carlo evaluations of MP databases

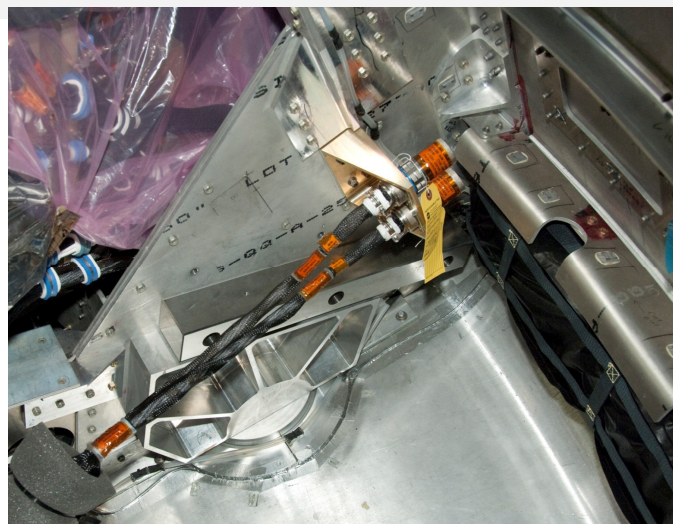


CAD representation
of CM boilerplate
adjustable ballast
blocks with over 200
possible mounting
locations

AA-2 CM will use similar adjustable ballast as PA-1



Bulkhead Ballast



Gusset Ballast



Stiffener Ballast

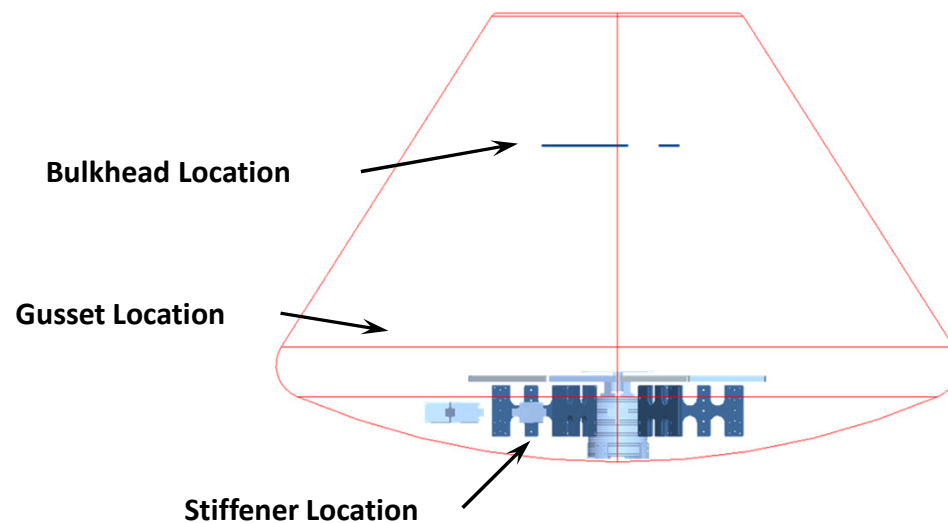
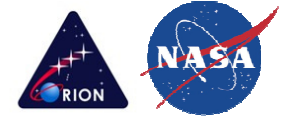
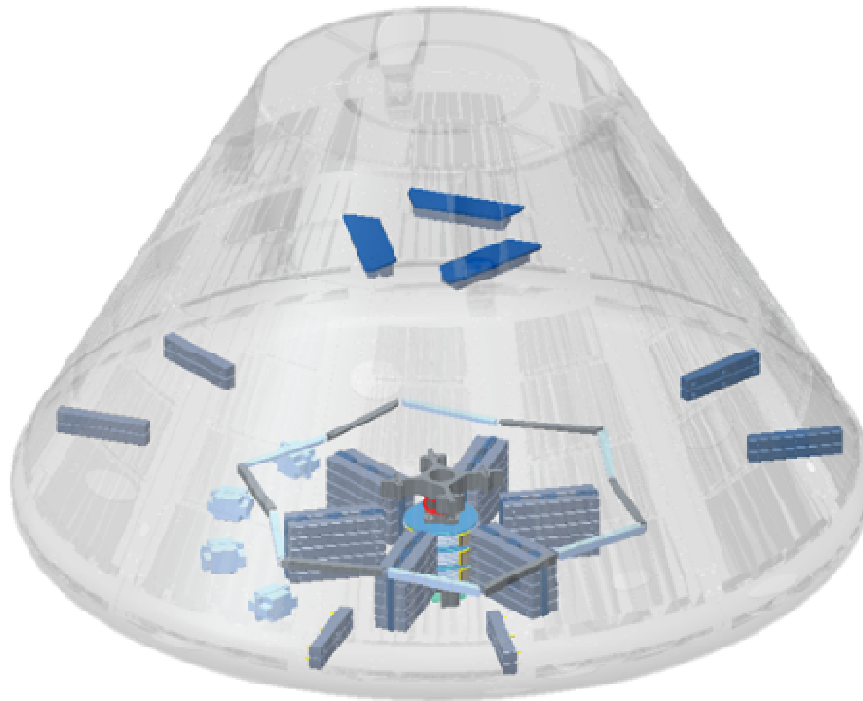


Photo Credit: NASA DFRC

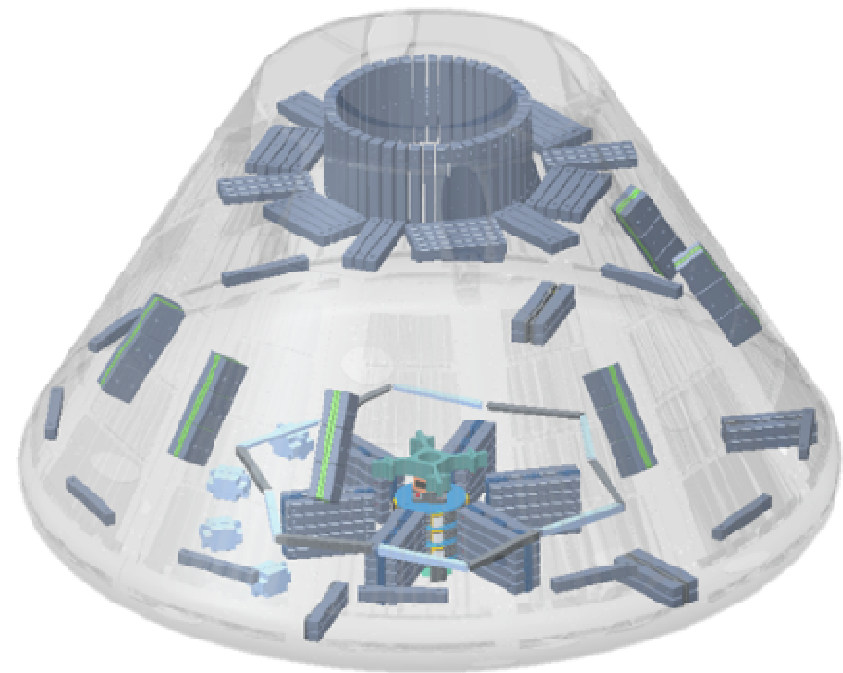
Adjustable ballast comparison from PA-1 to AA-2



PA-1 adjustable ballast blocks
with over 78 possible mounting locations



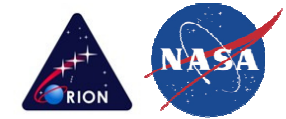
AA-2 adjustable ballast blocks
with over 200 possible mounting locations



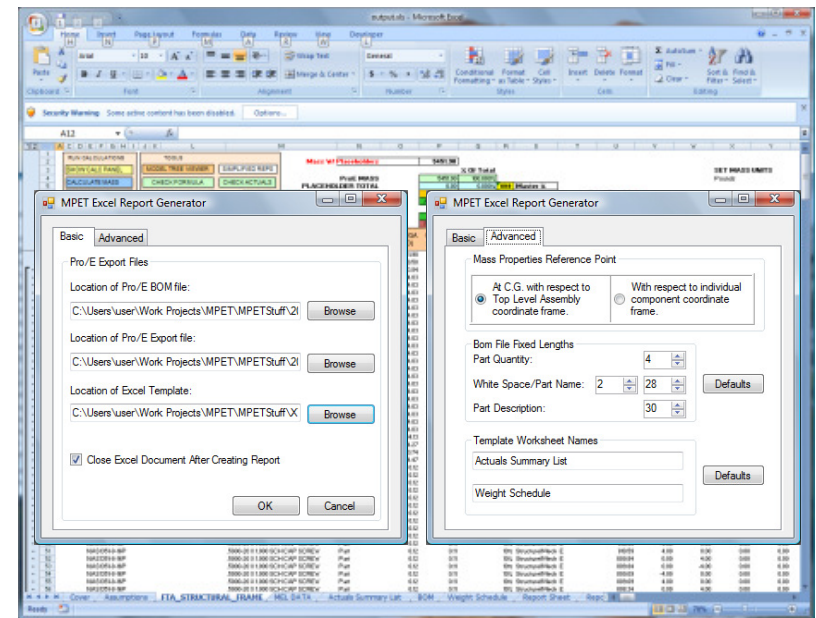
Both flight tests use the same adjustable target requirement envelope philosophy:

- Target requirement value for center of gravity
- Target envelope for adjustability
- Uncertainties envelope

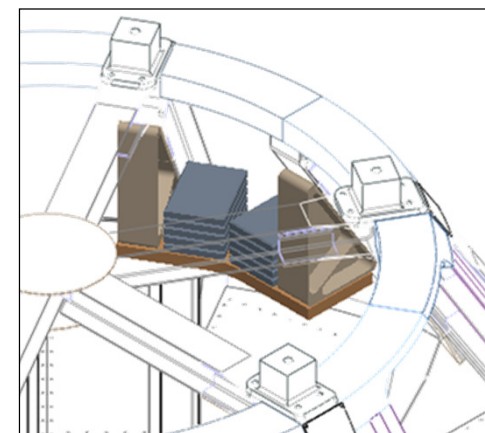
AA-2 CM and SR will utilize same software tools



- Mass Properties Evaluation Tool (MPET)
 - An Excel-based tool for supporting mass properties analysis of large models
 - Benefits of MPET
 - Efficiency
 - Reduction of human error
 - Reproducibility
 - Improved Analysis
 - Reporting
 - Calculations
- Ballast Solver
 - Optimizer for identifying adjustable ballast solution locations
- MPC2
 - Quick mass properties combination tool



MPET Input example



Early Bsolv ballast concept for ballast

PA-1 Weight and CG Measurement

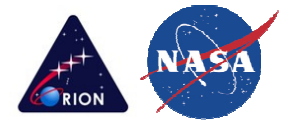
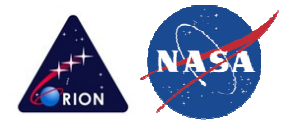
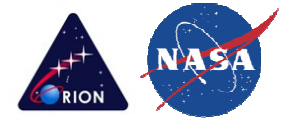


Photo Credit: Amanda Cutright

PA-1 Weight and CG Measurement



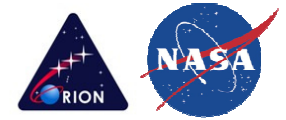
Successful Pad Abort 1 (PA-1) Flight Test!!!!



- May 6, 2010 PA-1 successfully launched at White Sands New Mexico!



Mass Properties Weight & CG Measurement Syst.: X CG Measurement Fixture



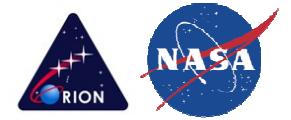
- Completed proof load, using the Heavy Universal Proof Load Assembly (HUPLA), and pathfinder operations for the CM X-CG Measurement Fixture, which was a build-to-print design by Lockheed Martin for mainline Orion based on lessons learned from PA-1 measurements.
- Fixture rotates CM 90 degrees and with a combination of load & location measurements is used to calculate the center of gravity. In this configuration, a mobile crane was successfully used for operations.



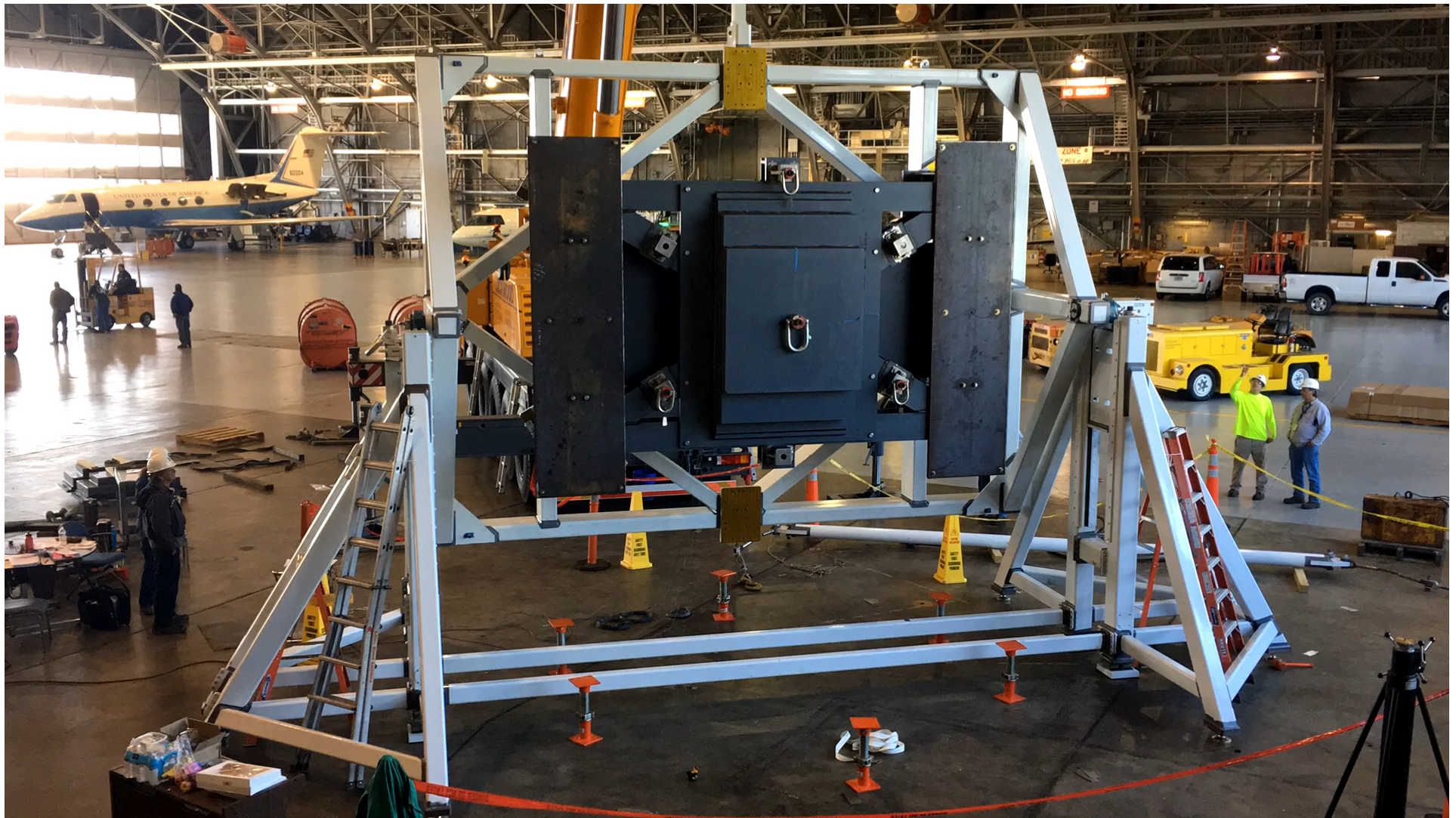
Cradle horizontal at rest
with HUPLA table



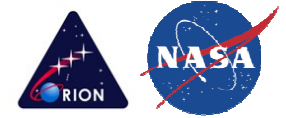
Mass Properties Weight & CG Measurement Syst.: X CG Measurement Fixture



Proof loading X CG fixture with 126% of worst case mass, including full adjustability envelope and CG resulting in worst case moment arm in the 90° configuration



Mass Properties Weight & CG Measurement Syst.: Y and Z CG Measurement

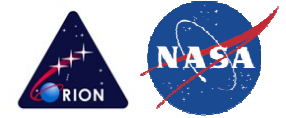


- Used same test set-up tools and ground support equipment as was used for PA-1 to measure



AA-2 CM Boilerplate Y and Z CG measurement at LaRC with structure and ballast installed prior to shipment to JSC. Measurements successfully taken while using mobile crane.

Mass Properties Weight & CG Measurement Syst.: X CG Measurement Fixture

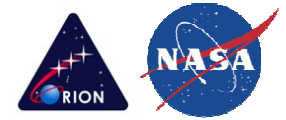


- NASA LaRC built a copy of the X-CG measurement fixture design LM created after PA-1 lessons learned



AA-2 CM Boilerplate X-CG measurement at LaRC with structure and ballast installed.
Measurements successfully taken while using mobile crane.

Conducted Integrated CM Boilerplate Mass Properties Testing at NASA JSC 8/7 - 8/9



Final integrated CM X CG measurement was conducted at JSC.

AA-2 Mass Properties Verification Activities



- FTV mass verification roadmap summary adapted for AA-2 Configuration

- Key:

Test

Analysis

LM Responsibility

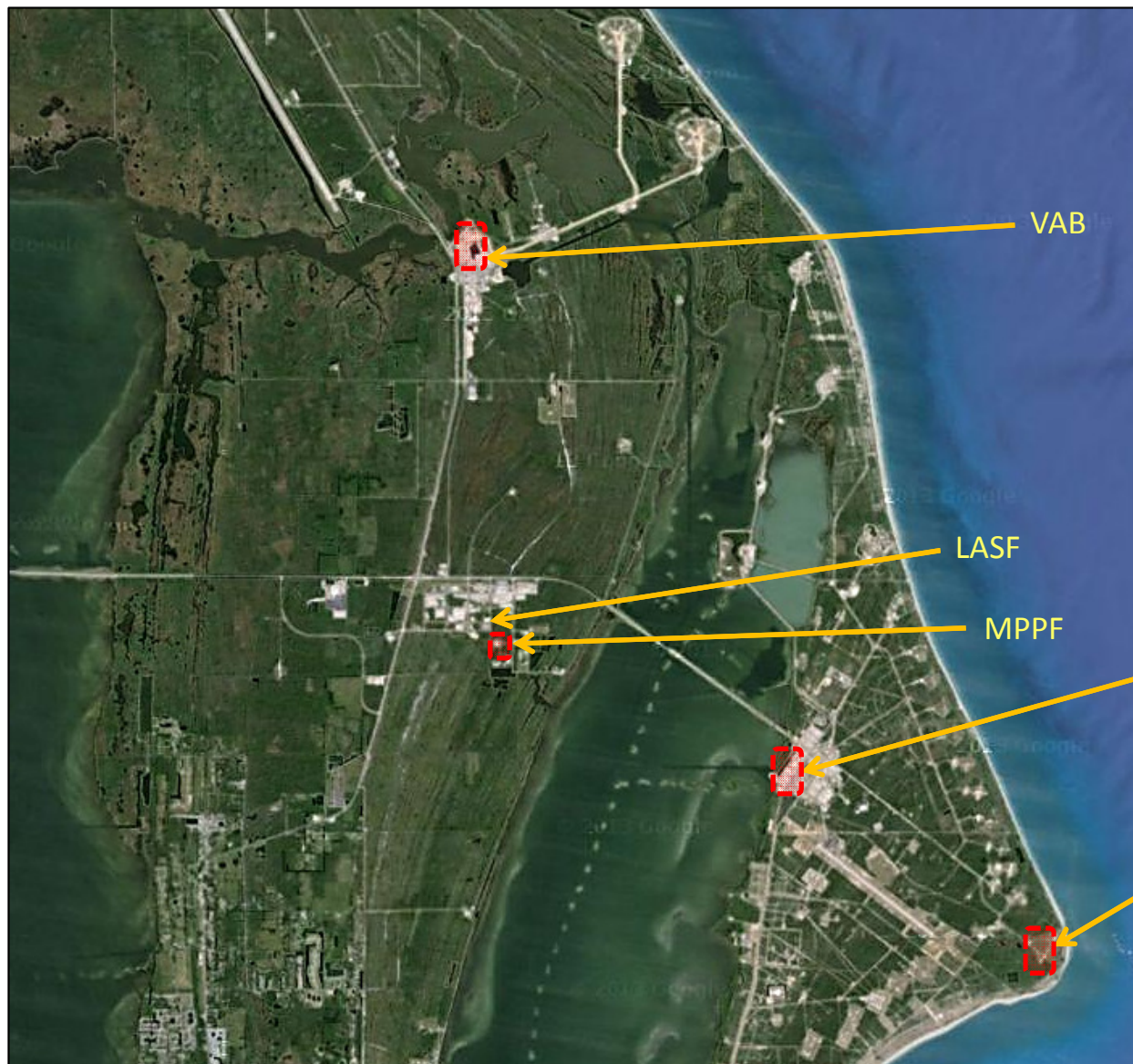
NASA Responsibility

Northrup Grumman Responsibility

AA-2 FTV Geometry and Mass Properties Requirement (G&MP), [LAS Module Requirements](#), ATB Req. Performance Levied

AA-2 LAS	AA-2 CM	AA-2 SR	AA-2 ATB
AA-2 LAS Weight (actuals) (LAS.0031.1) (12/2018)	AA-2 CM Structure Weight & CG and Ballast Adjustability (LaRC) (G&MP 7.4.4) (02/2018)	AA-2 SR Weight (JSC) (G&MP 7.3.1) (NTE ~7K lbm) (08/2018)	All components weighed as part and/or assembly (ex. avionics & ballast)
AA-2 LAS Weight (KSC) (LAS.0031.1) (~17K lbm) Post DD-250 (02/2019)	AA-2 CM Weight & CG (JSC) (08/2018) (G&MP 7.4.1) (~22K lbm) (G&MP 7.4.4)	SR CG (G&MP 7.3.2)	SR118 (Analysis informed by model based on historical data)
AA-2 LAS CG (KSC) (LAS.0062) (02/2019)	CM Mass and CG at Liftoff (G&MP 7.4.4) (L-90 and L-30 days)	SR Mass and CG at Liftoff (L-90 and L-30 days)	ATB Mass and CG at Liftoff (L-90 and L-30 days)
LAS Mass and CG at Liftoff (LAS.0031.1, LAS.0062) (L-90 and L-30 days)			
LAV at Liftoff: Mass (G&MP 7.6.1) (NTE ~40K lbm) and CoM (G&MP 7.6.2) (L-90 days and L-30 days)			
FTA at Liftoff: Mass (G&MP 7.7.1) (NTE ~47K lbm) and CoM (G&MP 7.7.2) (L-90 days (Per ATB Req.) and L-30 days)			
FTV Mass and CG at Liftoff (L-90 days (Per ATB Req.) and L-30 days)			

AA-2 Launch Site Facilities



KSC



KSC VAB:

- ATB Aeroshell Stack & Integration



KSC LASF:

- CM-LAS Tests
- LAS Mate to CM
- Install Ogive Fairing



KSC MPPF:

- CSR Post-Ship Functional
- Interface Fit Check
- SR Developmental Flight Instrumentation (DFI) Checks

CCAFS

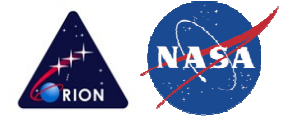
Hangar AE: Launch Operations



SLC-46: Launch Site



AA-2 Mass Properties Go Forward Plans



- Complete final actuals and reports
 - Complete final integration of the FTA at NASA KSC and stack on the ATB
 - Closeout mass properties requirements to provide endorsement for launch
-
- Acknowledgements
 - PA-1 and AA-2 Teams
 - Anjie Emmett, CSR Mass Properties Lead
 - Mass Properties Test Teams
 - Education and Outreach Office at NASA LaRC
 - NASA Communications Team
 - SAWE Community

Thank You!

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29 November 2018

