Orion Launch Abort System Nominal Jettison Performance on Exploration Flight Test – 1

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Orion Multi-Purpose Crew Vehicle (MPCV)

Orion Multi-Purpose Crew Vehicle will serve as the next generation exploration vehicle
-Capable of transporting astronauts on a variety of expeditions beyond low Earth orbit

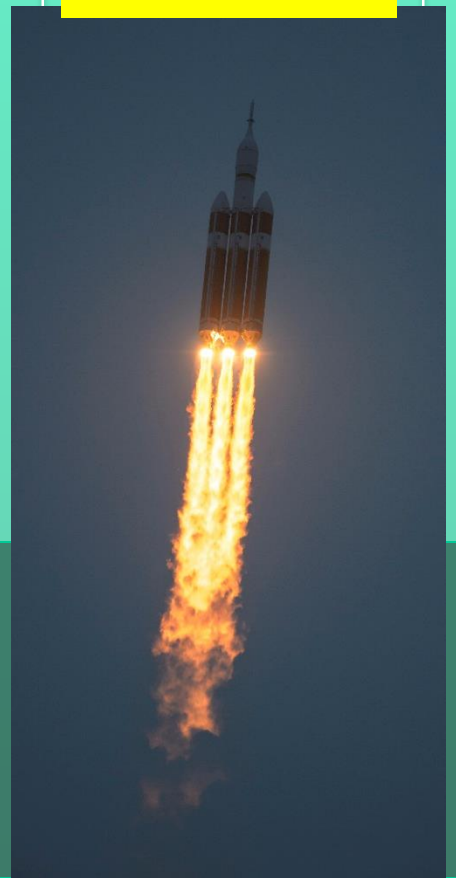
Orion Spacecraft
- Crew Module is larger than Apollo
    -16.5 ft diameter at the heat shield
-Can support crew members for short or long-duration spaceflight missions
    -Crew up to 4
    -Deep space missions of up to six months

Timeline
- Program started in 2005
- Contract awarded to Lockheed-Martin in 2006
- Abort system flight test May 2010 (Pad Abort – 1)
- Exploration Flight Test-1 successfully conducted December 2014
- Spacecraft orbit and re-entry test launched on Delta-VI Heavy from Space Launch Complex 37 at Cape Canaveral Air Force Station

Orion Flights

FY 13	FY 14	FY 15	FY 16	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22

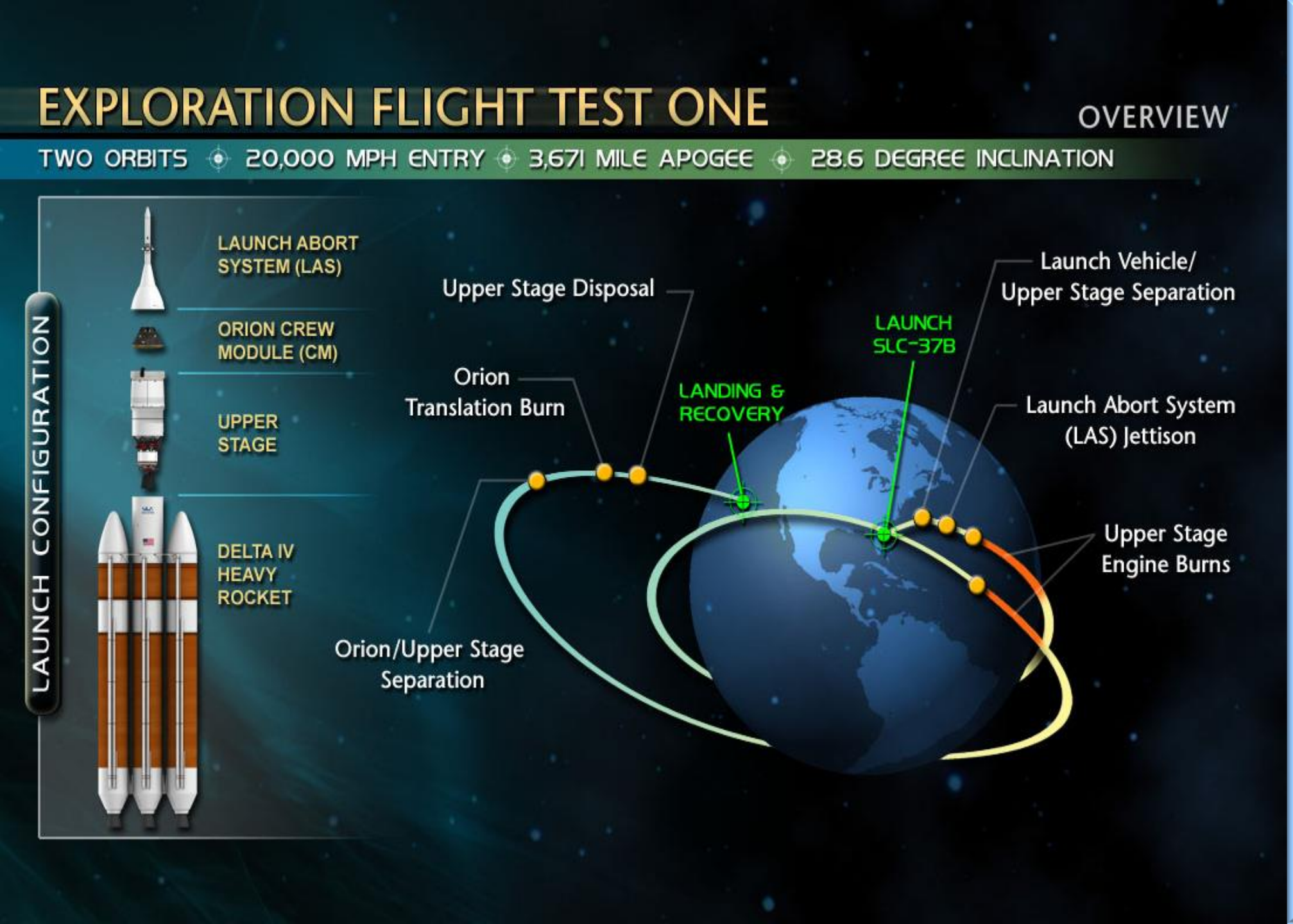
Exploration Flight Test-1 Uncrewed



Exploration Mission-1 Uncrewed

Ascent Abort-2 Test Uncrewed

Exploration Mission-2 Crewed



EFT-1 mission used to validate and test systems critical to crew safety

- Demonstrate nominal LAS jettison during ascent
- Demonstrate high speed entry, including Thermal Protection System, entry guidance and control, and landing recovery system

Orion Spacecraft Overview

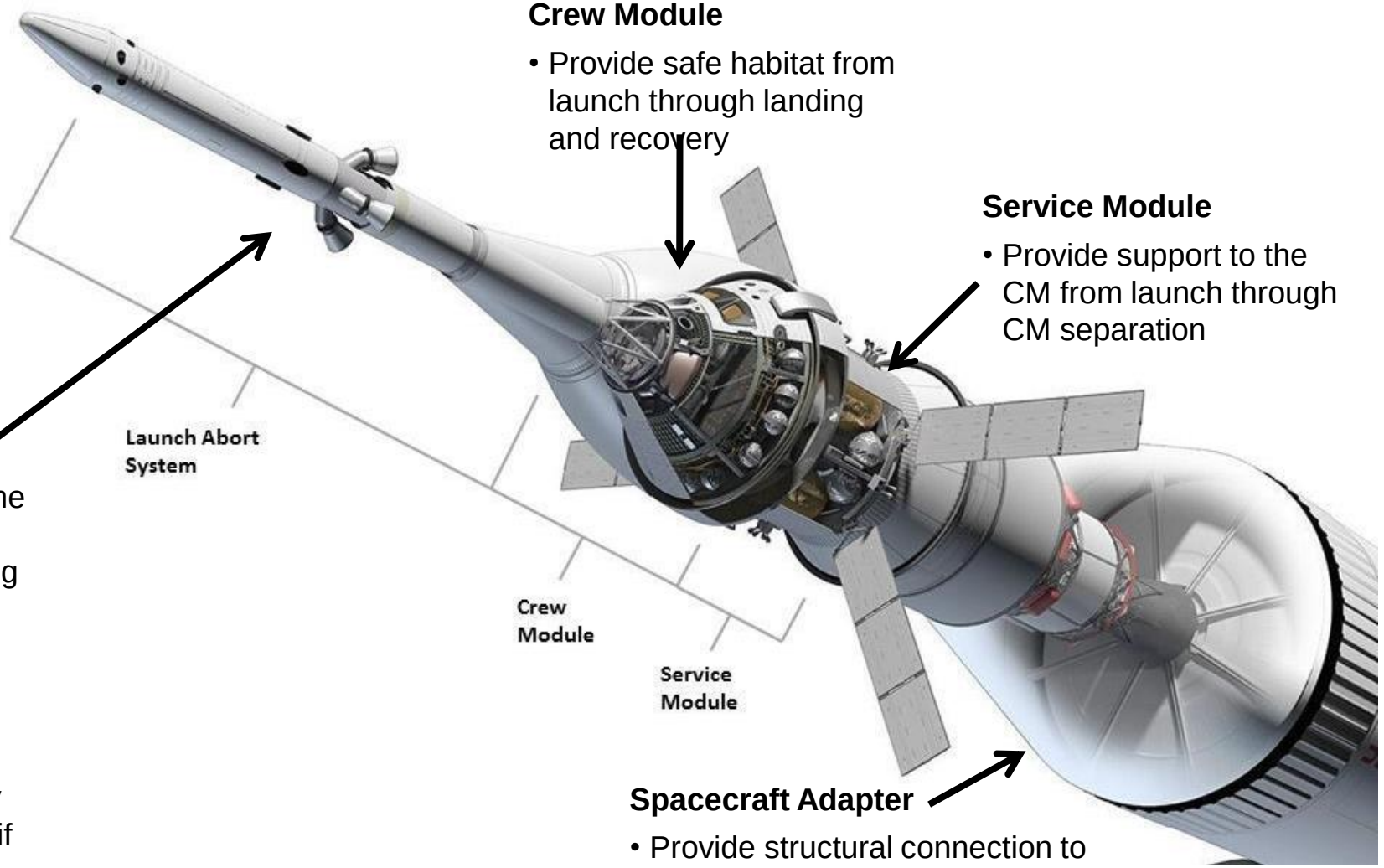
Orion consists of four modules:
-Spacecraft Adapter
-Service Module
-Crew Module
-Launch Abort System

Crew Module

- Provide safe habitat from launch through landing and recovery

Service Module

- Provide support to the CM from launch through CM separation



Launch Abort System

- Provide protection for the CM from atmospheric loads and heating during first stage flight
- Safely jettison after successful pad operations and first stage flight
- Provide abort capability from the pad to 300k ft if problem during ascent

Spacecraft Adapter

- Provide structural connection to the launch vehicle from ground operations through CM Separation

Orion Launch Abort System (LAS)

LAS Dimensions (approx)

- 45 ft tall
- 3 ft diameter at the Tower
- 16 ft diameter at the Base

♦ **Attitude Control Motor (Inert on EFT-1)**

- Enables active flight control for steering and stable nose-forward flight during abort
- Controls re-orientation to heat shield forward to enable LAS jettison and chute deployment

♦ **Jettison Motor**

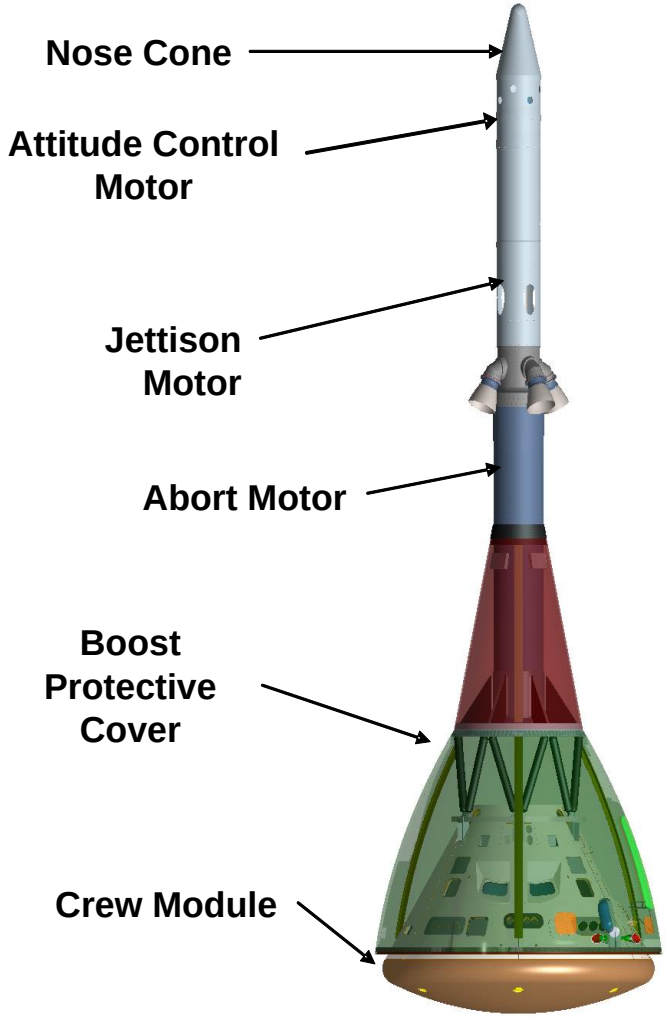
♦ Thrust for LAS jettison during nominal launch and abort

♦ **Abort Motor (Inert on EFT-1)**

♦ Thrust to quickly pull the Crew Module away if problems develop during the launch

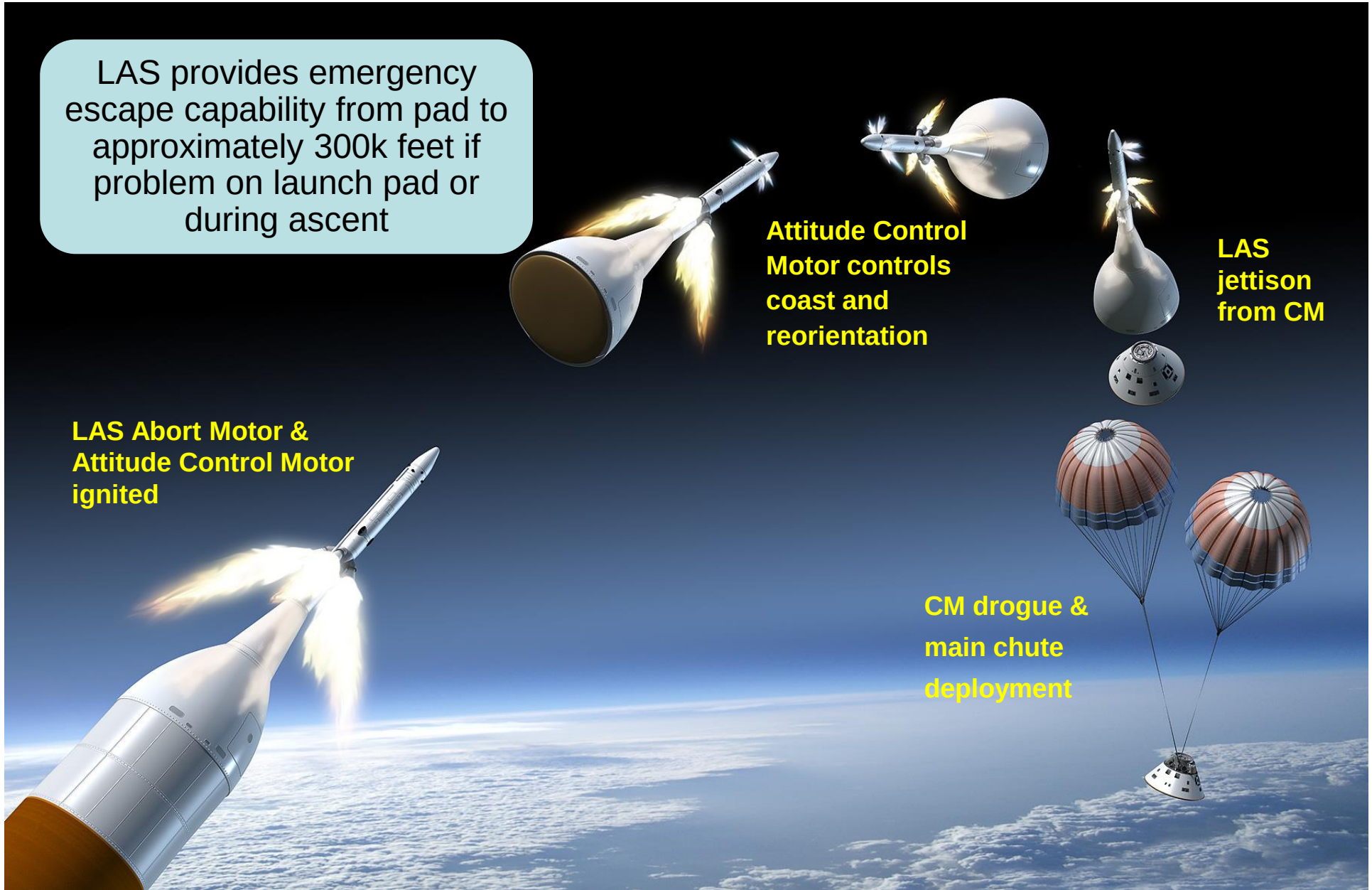
♦ **Boost Protective Cover (Fairing)**

♦ Protection against aero-acoustic loading, heating, and Abort Motor plume impingement



Launch Abort Vehicle: Crew Module + LAS

Orion Launch Abort System Abort Sequence



EFT-1 and LAS Nominal Jettison

For a nominal ascent, LAS provides protection for the CM from atmospheric loads and heating during first stage flight

- Nominal Jettison occurs every launch after successful first stage flight

♦ **EFT-1 mission used to validate and test systems critical to crew safety**

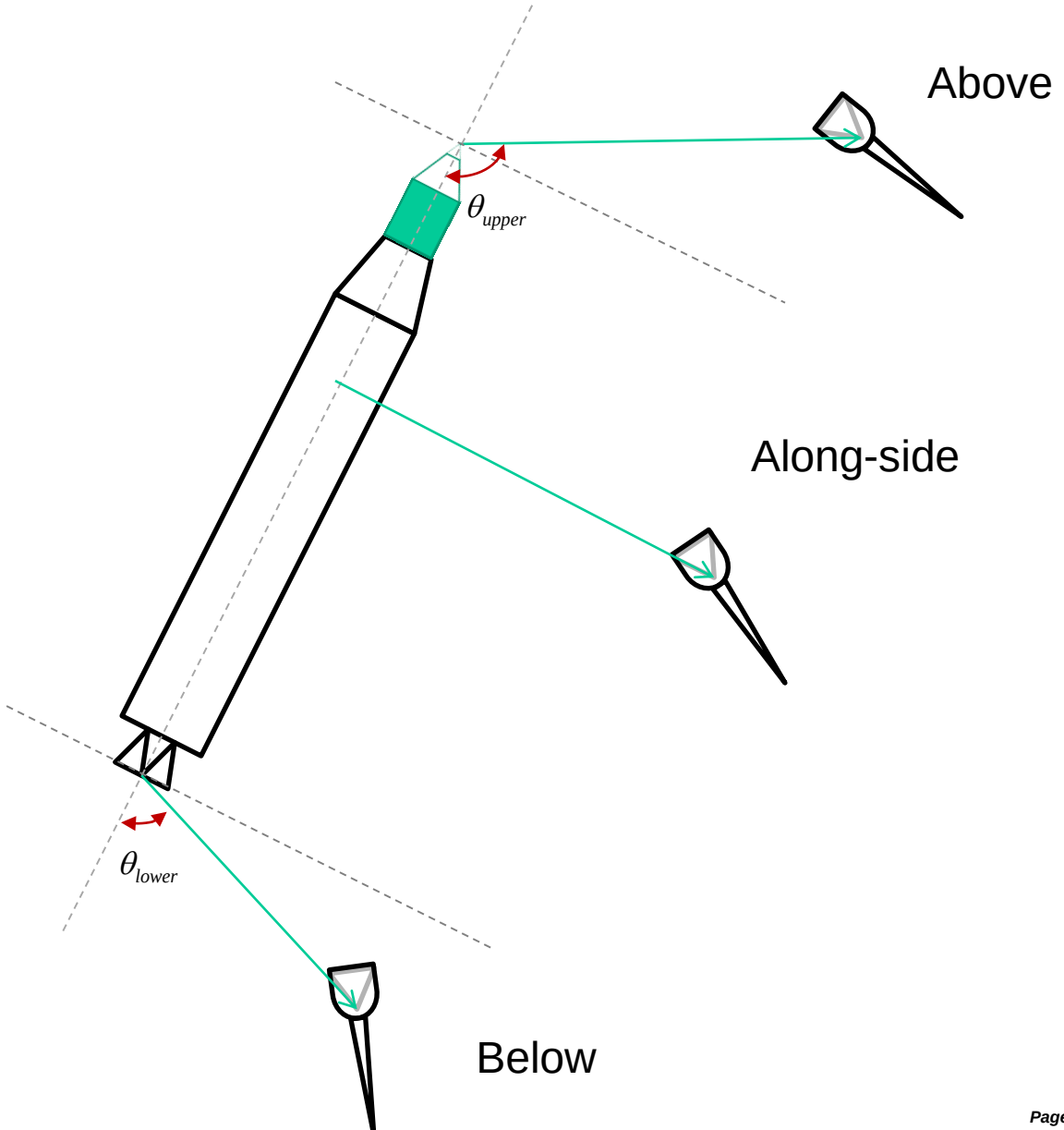
- One of the key separation events tested during EFT-1 was the nominal jettison of the LAS
- LAS nominal jettison event on EFT-1 occurred at approx. six minutes and twenty seconds after liftoff

A suite of developmental flight instrumentation (DFI) was included on the flight test to provide data on spacecraft subsystems and separation events

- Data used to verify function of the jettison motor to separate the Launch Abort System from the crew module

EFT-1 LAS Nominal Jettison Flight Test Objectives

- **Demonstrate LAS separation during nominal ascent**
  - *No CM/LAS recontact detectable by onboard data or post-flight inspection of the CM.*
  - *Visual observation of LAS jettison to include onboard observation assets to observe initial release and separation dynamics, LAS fly-away trajectory, and second approach and clearance of the Orion spacecraft and launch vehicle.*
  - *No LAS contact with launch vehicle after separation detectable by onboard observation assets.*



EFT-1 LAS Nominal Jettison Trajectory Reconstruction

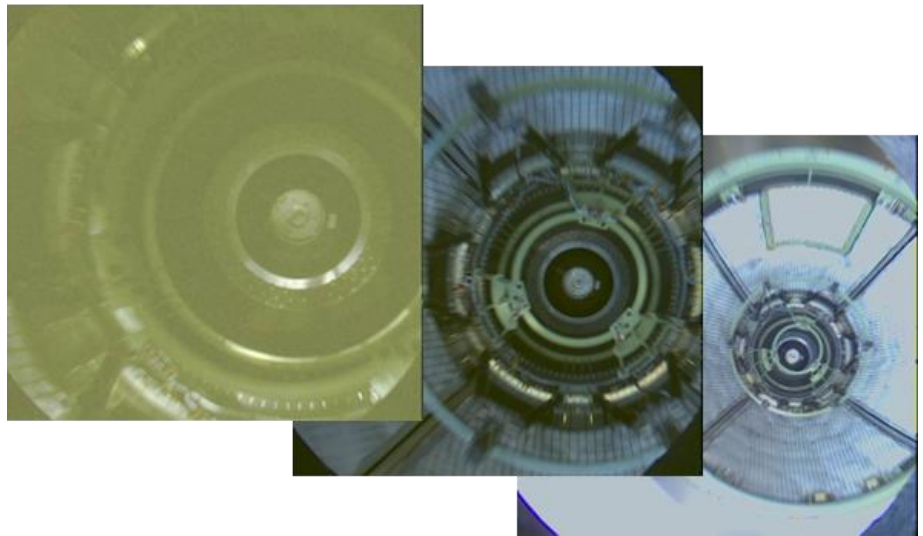
EFT-1 LAS nominal jettison flight trajectory reconstruction being used for

- Assessment of performance vs flight test objectives
- JM thrust profile assessment and LAS water impact analysis

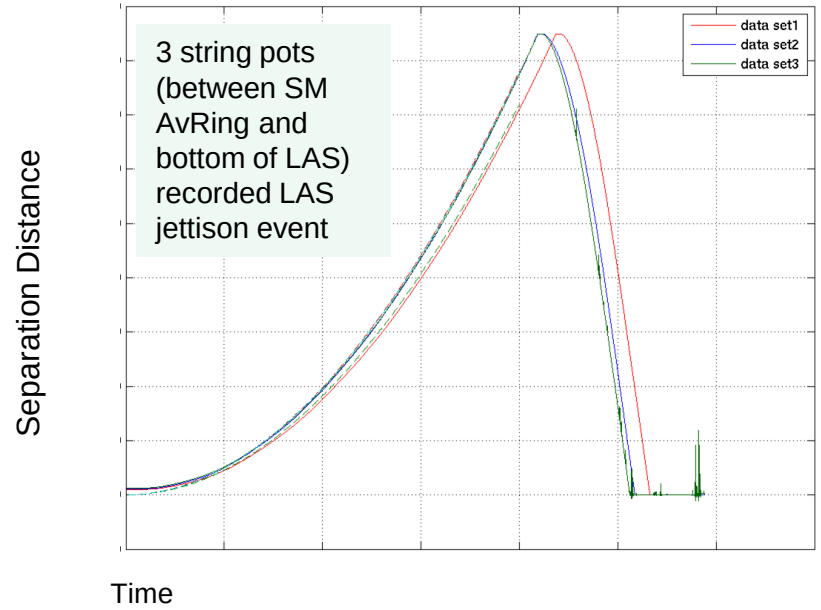
Two measurements being used to analyze the near/mid-field LAS-to-CM relative motion

- Docking hatch window camera video frame dimensional analysis
- String potentiometer (3x) lanyard spool DFI measurement
  - Lanyard Extension Displacement Transducer (String Pot) uses a lanyard to turn a rotary potentiometer to measure extension of lanyard from lanyard drum

Video Data



EFT-1 String Pot LAS Jettison Data



EFT-1 LAS Nominal Jettison Trajectory Reconstruction from Flight Data

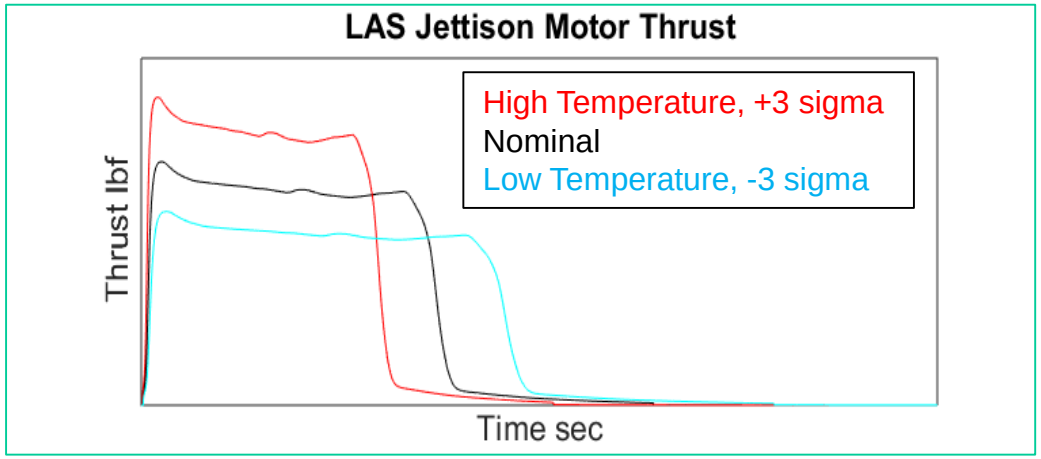
Conducted comparison of EFT-1 LAS jettison separation potentiometer flight data with LAS POST2 Non-Linear 6-Degree-of-Freedom trajectory simulation results

- Simulation model analysis includes
  - EFT-1 Day of Launch Mass Properties
  - EFT-1 Best Estimated Trajectory LAS Jettison initial conditions
  - Jettison Motor thrust model
    - Includes effects due to propellant temperature variations and motor burn rate uncertainty

Analysis results show LAS jettison consistent with pre-flight analysis

- Analysis indicates a strong correlation between LAS separation distance trajectories and JM propellant temperature
  - Daily temperature varied between 60 degF and 78 degF during 2 days before launch
  - Estimated internal LAS temperature at jettison point = 73.7 degF

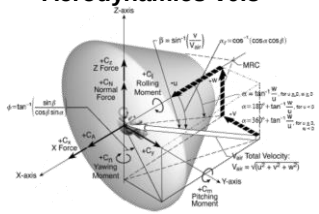
Temperature Data (degF)	Dec 3, 2014	Dec 4, 2014	Dec 5, 2014
Maximum	77	78	77
Average	68.5	69.5	71.5
Minimum	60	61	66

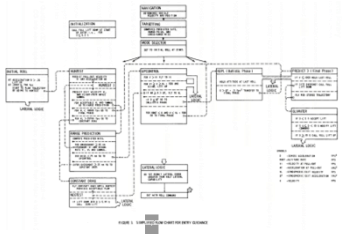


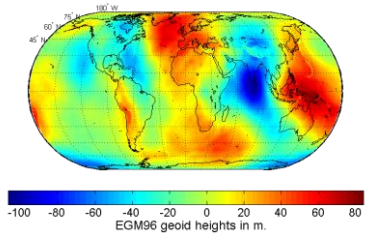
LAS POST2 Simulation Architecture

Guidance, Navigation, and Control Systems

Orion MPCV Aerodynamics v0.8







Interface Routines

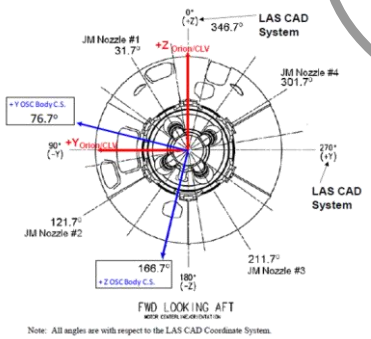
Gravity Model EGM96

POST2

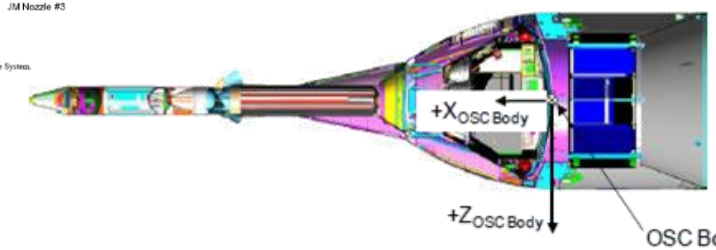
Subsystem models are brought together and integrated into trajectory simulation

Planet (WGS84) & Atmosphere EarthGRAM 2007

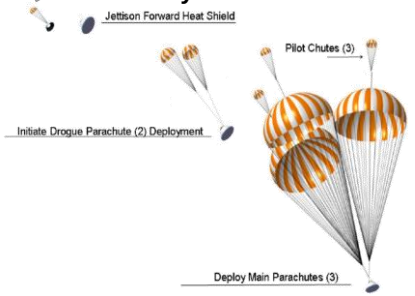
Engine Models



Mass Properties



Multi-body Parachute Model



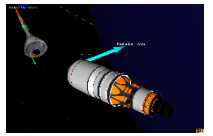
System performance is assessed through augmented cluster computing scripts that enable Monte Carlo and sensitivity analyses

POST Input File

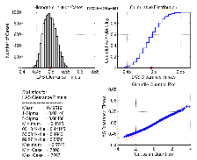
Config Control Input File

Monte Carlo Inputs File

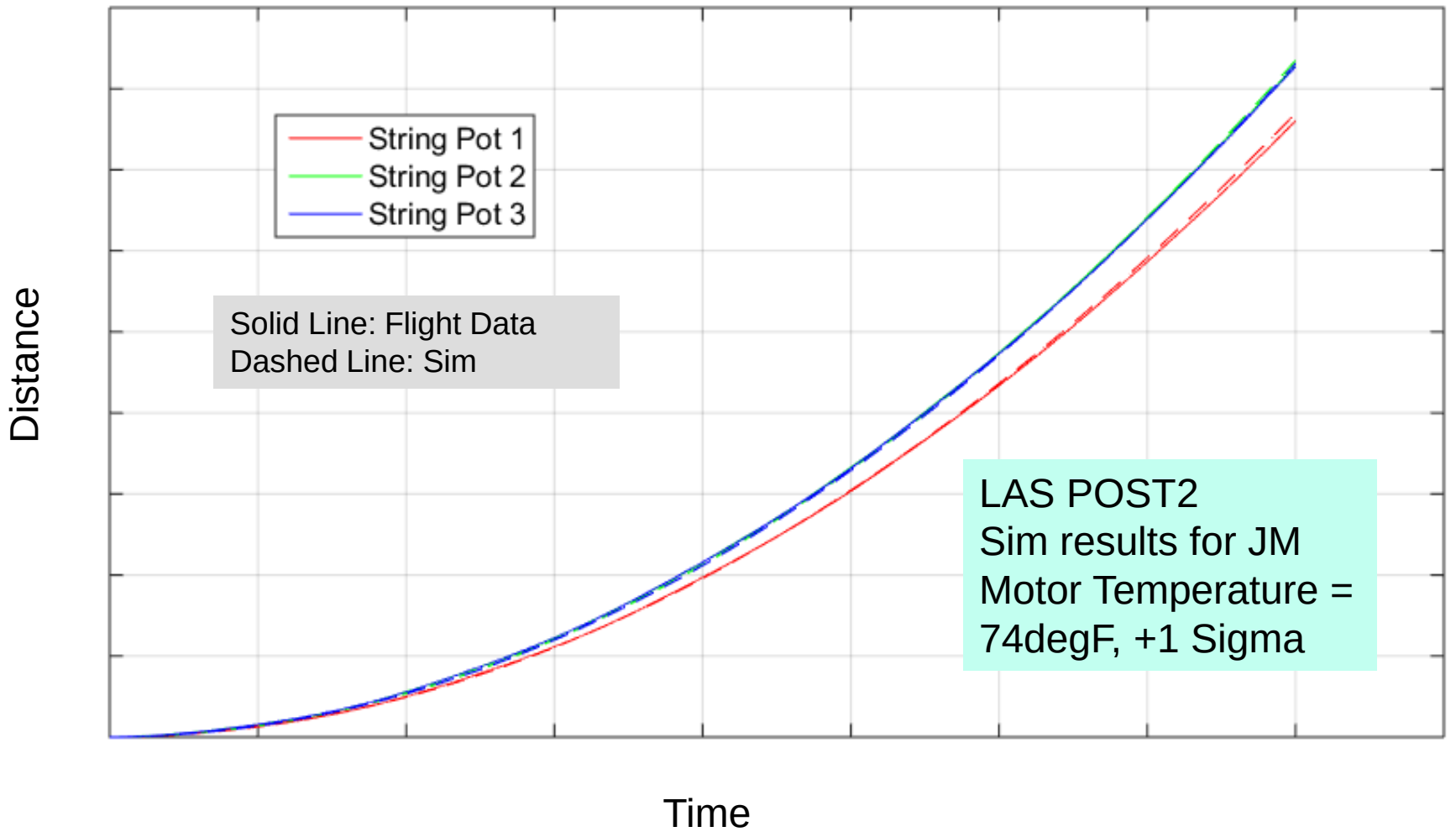
EVE/Google Earth



MATLAB



EFT-1 LAS Jettison Separation Data to LASO POST2 Simulation Comparison

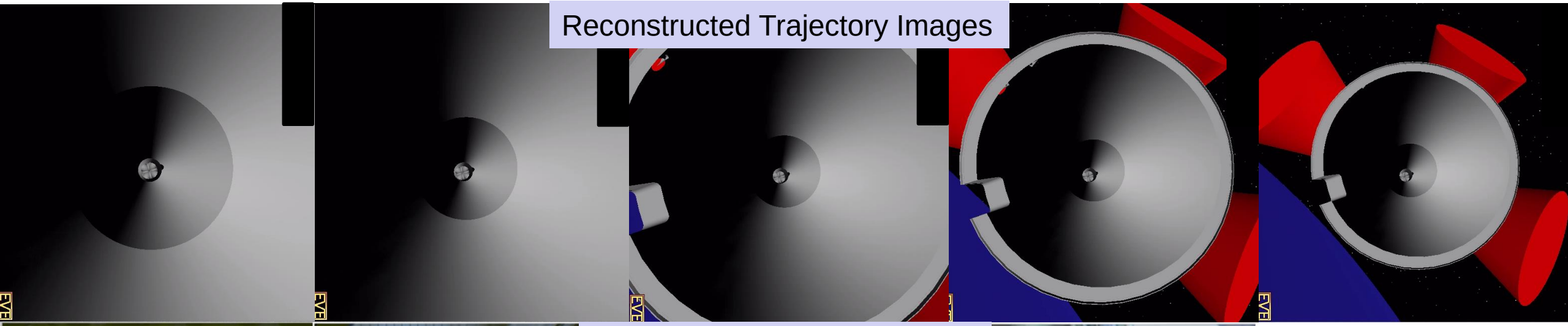


Analysis results show LAS jettison consistent with pre-flight analysis

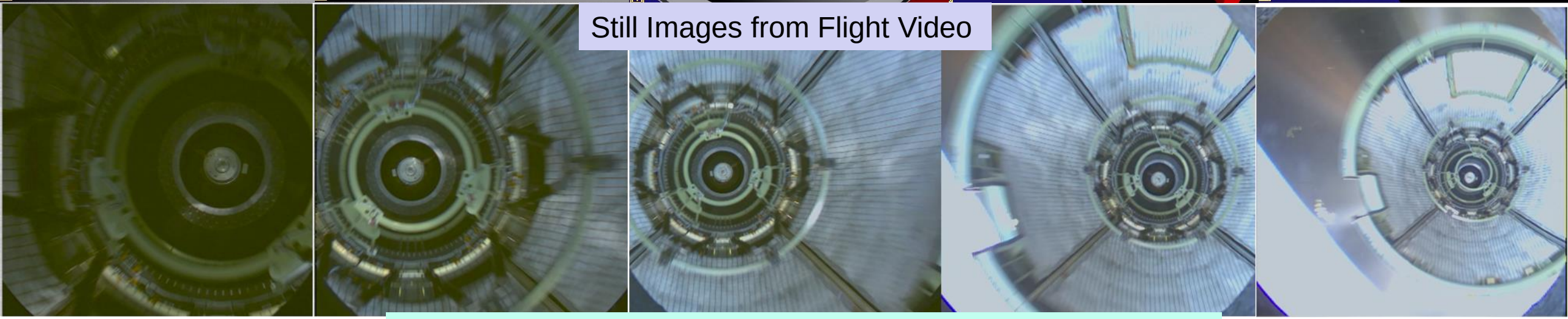
Trajectory Reconstruction vs Flight Imagery

- LASO POST2 jettison trajectories used as input into Engineering Visualization Environment (EVE) to compare reconstructed trajectory to still images from flight video

Reconstructed Trajectory Images



Still Images from Flight Video



LAS jettison trajectory visualization consistent with flight video

Concluding Remarks

- **Orion Multi-Purpose Crew Vehicle will serve as the next generation exploration vehicle**
  - Capable of transporting astronauts on a variety of expeditions beyond low Earth orbit
- **Exploration Flight Test -1 (EFT-1) successfully conducted December 2014**
  - Spacecraft orbit and re-entry test launched on Delta-VI Heavy
  - A suite of developmental flight instrumentation provided data on spacecraft subsystems and separation events
  - Data used to verify the function of the jettison motor to separate the Launch Abort System from the crew module
- **Conducted comparison of EFT-1 LAS jettison separation flight data with POST2 Non-linear 6-Degree-of-Freedom trajectory simulation results**
  - Analysis results show LAS jettison trajectory consistent with pre-flight analysis
    - Performance slightly higher than predicted
  - Met all LAS jettison flight test objectives
- **Next Orion flight test (Exploration Mission-1 (EM-1)) planned for 2018**
  - Launching on Space Launch System (SLS) from KSC