NASA JSC Mission Design

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Flight Mechanics and Trajectory Design Branch
Aeroscience and Flight Mechanics Division
Engineering Directorate
NASA / Johnson Space Center

Outline

- JSC / EG5 Capabilities
- Software Tools – Copernicus
  - Video
  - Overview
  - Mission Examples – General
- Lunar and Cislunar Mission Examples
  - Constellation
  - MARE
  - EM-1
  - EM-2
  - Other –Station keeping Moon, NRO, Project M

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JSC Flight Mechanics and Trajectory Design Branch (EG5)

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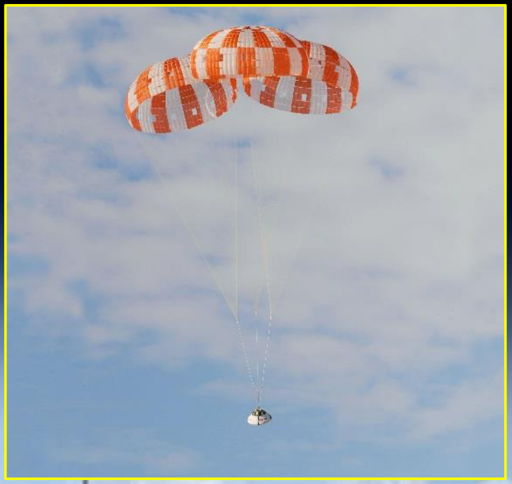
Charter



The Flight Mechanics and Trajectory Design Branch (EG5) is responsible for the design and evaluation of reference trajectories and flight vehicle performance capabilities for all missions assigned to JSC

Flight Mechanics and Trajectory Design Roles

Program/Project Directives
- *Destinations; Missions*
- *Requirements; Resources*

Vehicle Designs and Performance Capabilities

Subsystem and Technology Impacts

Mission Analyses

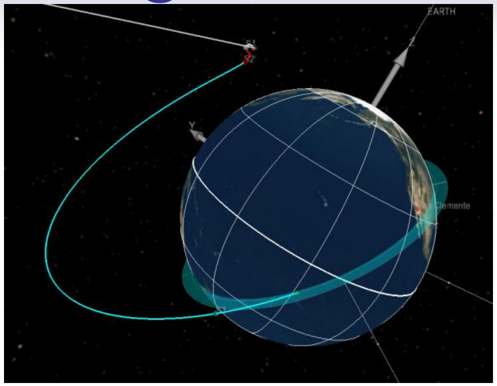
Systems Design(s)

Structures
Propulsion
Thermal PS
Aero
Power
Avionics
Software

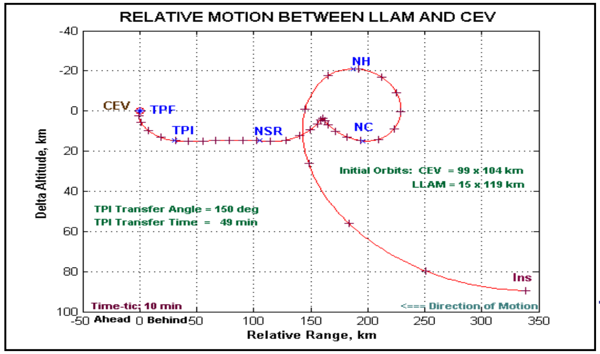
Examples from Flight Mechanics

GN&C Design
Flight Environments
Technology Needs
Flight Testing Design and Evaluation

Flight Mechanics and Trajectory Design Roles

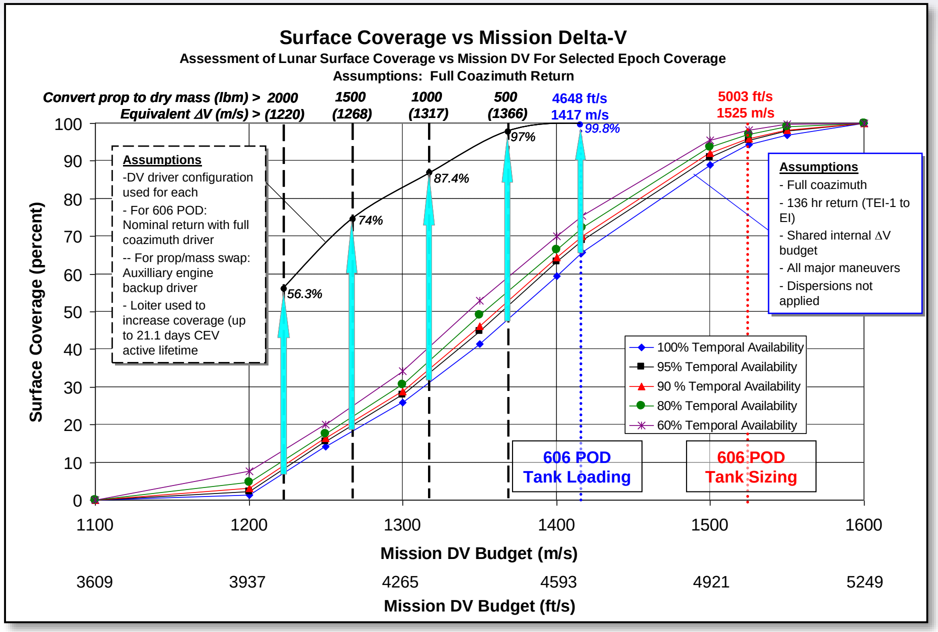


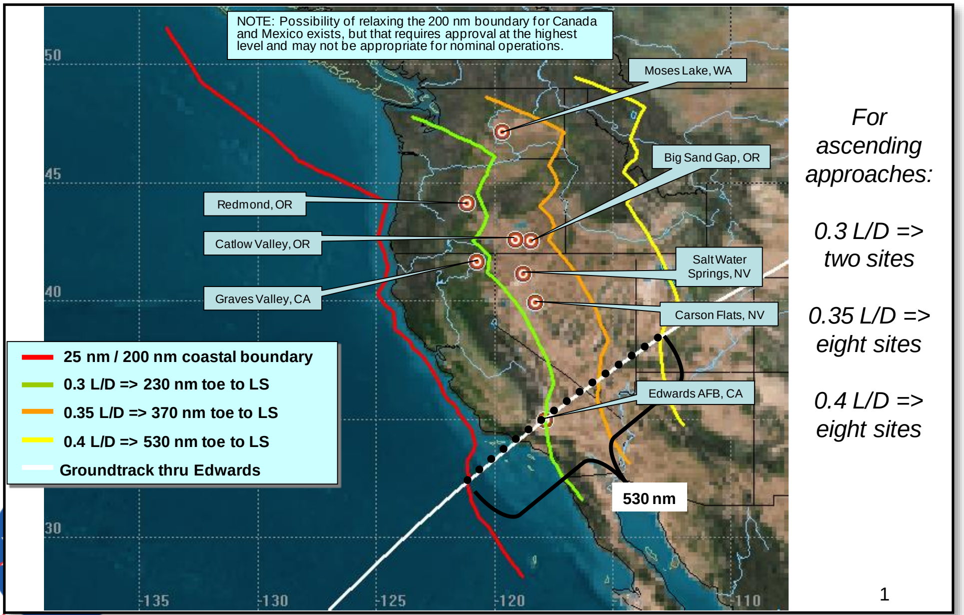
- Design/development of mission design and associated trajectories for all flight phases of a space mission, including:
  - Ascent/Orbit/Rendezvous/Interplanetary/Entry/ Aerocapture/Terminal Descent
  - Integrated Design Reference Missions
  - Conceptual Flight Profiles
  - Flight Performance Envelopes and Corridors
  - Windows – Launch; De-orbit (including Phasing); Trans-lunar and Trans-Mars Injections
  - Vehicle Capability Evaluations and Requirements
  - Preliminary GN&C Algorithms and Architectures
  - Parachute/Parafoil System Design and Performance
  - Entry Demise and Debris Predictions
  - Optimal Performance Analysis
  - Loads and Dynamics Design for Human Rating
  - Trajectory/Vehicle /Flight Mechanics Visualization
- Software tool development



Flight Mechanics and Trajectory Design Roles

Vehicle Capability Evaluations and Requirements



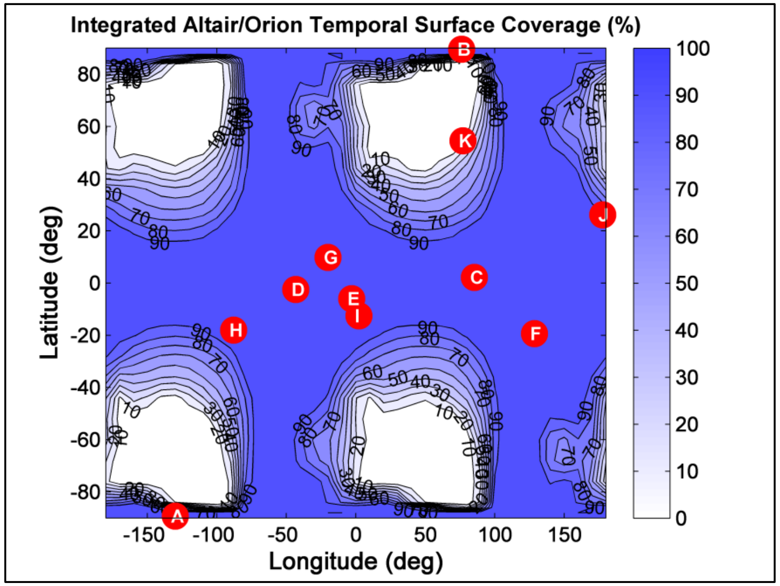


For ascending approaches:

0.3 L/D => two sites

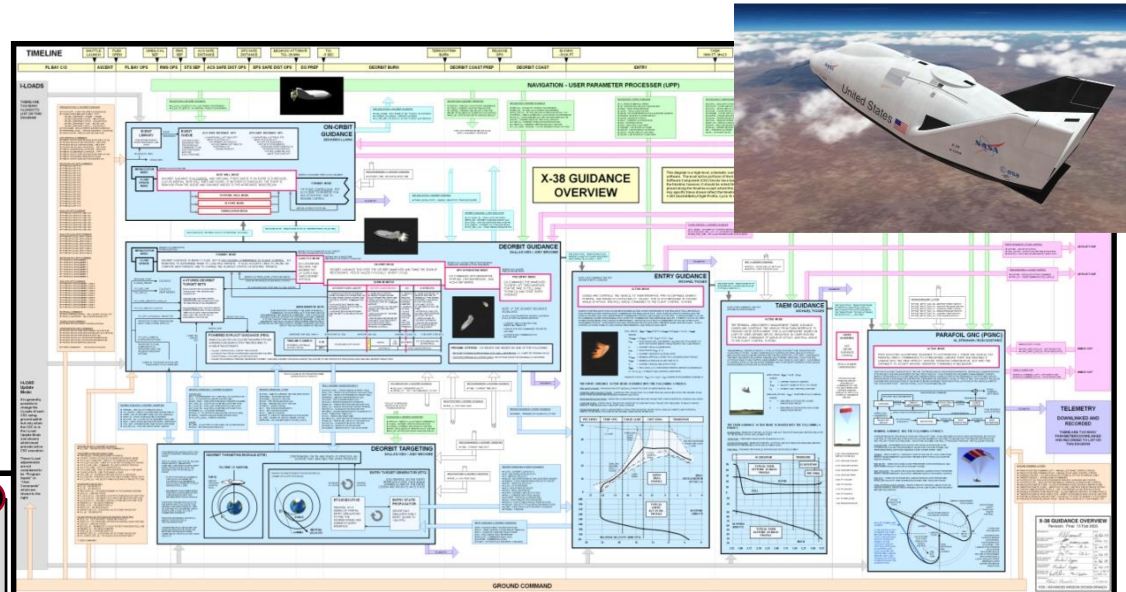
0.35 L/D => eight sites

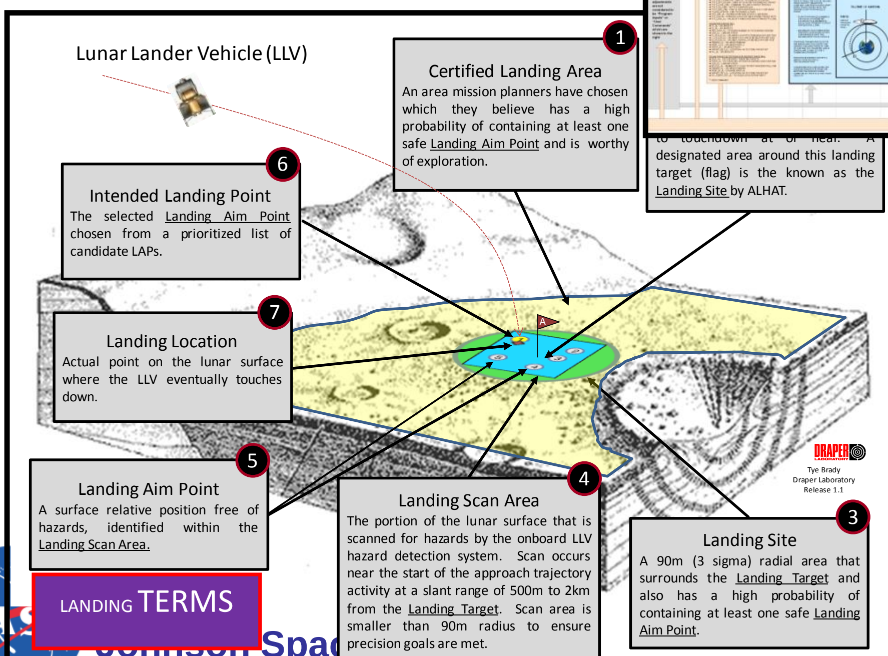
0.4 L/D => eight sites

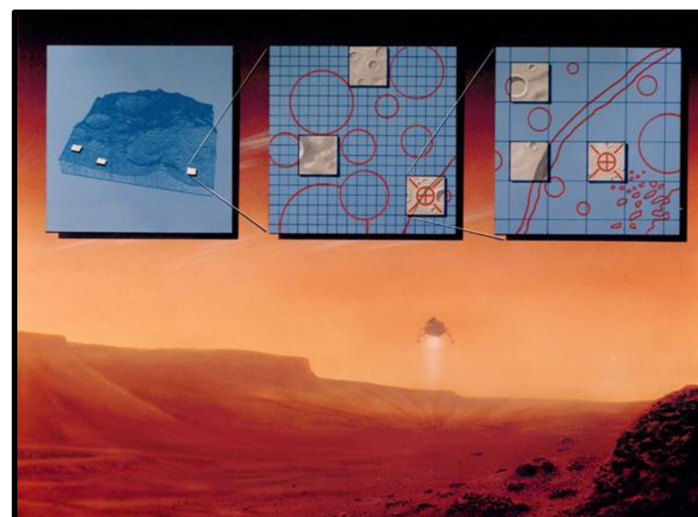


Flight Mechanics and Trajectory Design Roles

Preliminary GN&C Architectures & Algorithms



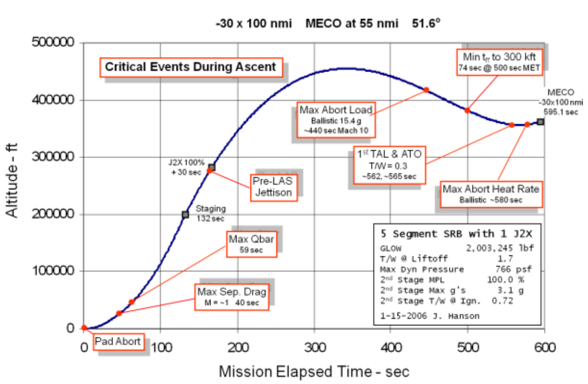


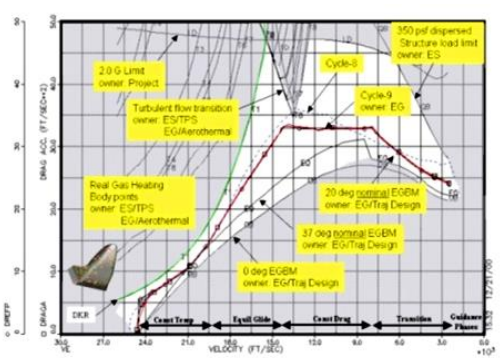


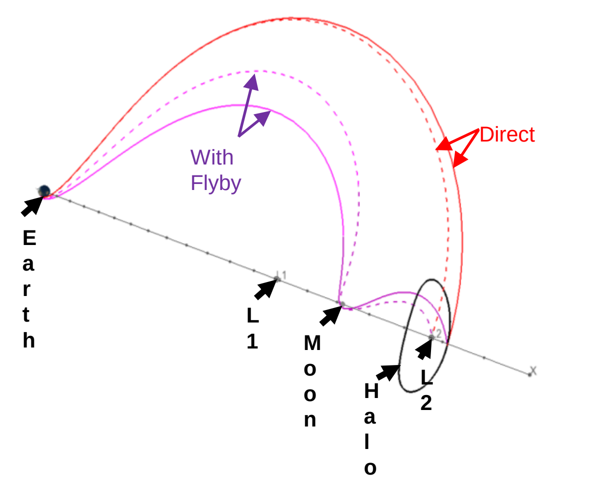
Core Strengths

- Collaborative systems engineering approach to mission, trajectory, and vehicle designs
- Optimal trajectory designs for atmospheric and exo-atmospheric flight
- Terminal descent systems design and dynamics
- Guidance algorithm development
- Corridors formulation based on multiple systems constraints
- Monte Carlo evaluation of guided trajectories

Orbital Mechanics
Flight Mechanics
Dynamics
Optimization
Flight Testing
Systems Engineering







Analysis Tools

- **Ascent/Entry/Aerocapture/ Powered Descent**
  - SORT & POST
    - 3 DOF - 6 DOF
    - Monte Carlo
    - Optimization w/ GN&C
  - Antares
    - 6 DOF w/ GN&C
    - Monte Carlo
    - Ares/Orion
    - Multi-body
  - FAST
    - 3 - 6 DOF w/ GN&C
    - Monte Carlo
    - Capable of modeling different vehicles
    - Multi-body
- **Orbital**
  - Flight Analysis System (FAS)
    - 3 DOF
    - Launch targeting, rendezvous design, orbital maneuvering
  - STK and LandOpp
    - Trajectory graphics
    - Landing opportunities analyses
- **Interplanetary**
  - Copernicus
    - 3 DOF
    - Optimization to any destination
    - Low thrust/High thrust
    - Multi-body
    - Patched conic to Fully integrated
  - Mission Assessment Post-Processor (MAPP)
    - Trajectory design scanning and mission planner
- **Entry Debris**
  - Simulation for Prediction of Entry Article Demise (SPEAD)
    - 6 DOF
    - Combined heating, structural break-up, and trajectory
    - Predicts break-up sequence and pieces survival
- **Terminal Descent**
  - Decelerator Systems Simulation (DSS)
    - 6 DOF – 18 DOF
    - Chute system design, dynamics, and performance
  - Parafoil Dynamics Simulation (PDS)
    - 8 DOF parafoil simulation
    - Parafoil design, dynamics, and performance
    - GN&C design

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Copernicus

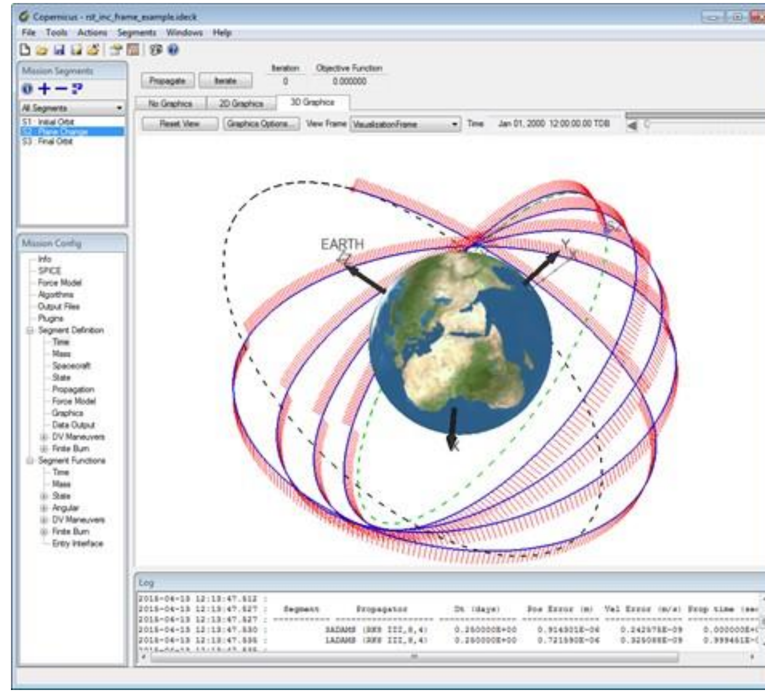
Video

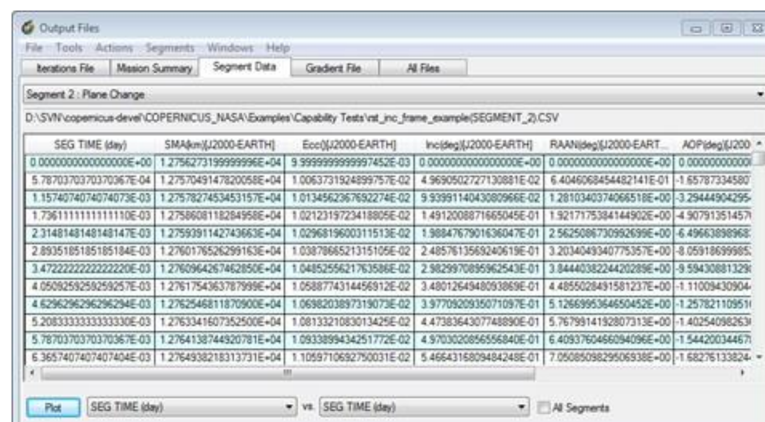
What is Copernicus?

A generalized spacecraft trajectory design and optimization application

An integrated Graphical User Interface (GUI)

Real-time 3D interactive visualization

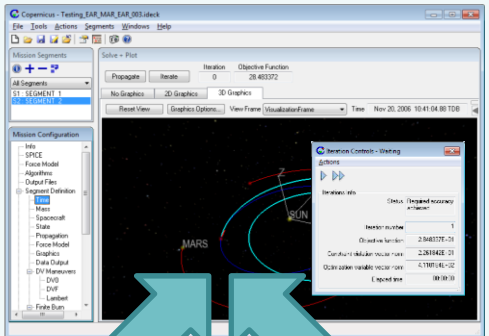




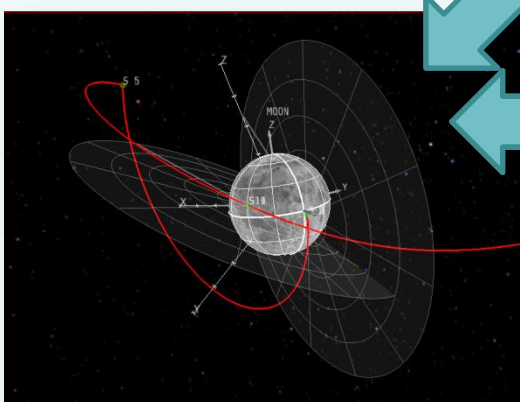
Copernicus Architecture

Copernicus marries a powerful computation engine with a friendly GUI and an interactive OpenGL graphics visualization capability.

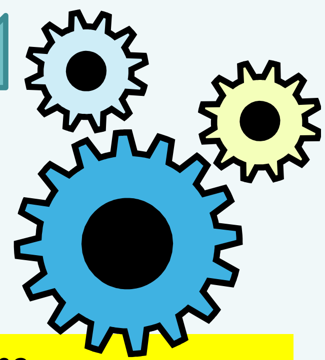
Main Program



GUI
User Inputs
Mission Design
Design Modifications
Numerical Feedback



Visualization
Aid in Problem Set-Up
Trajectory Solution Feedback
“Real” Trajectory Insights



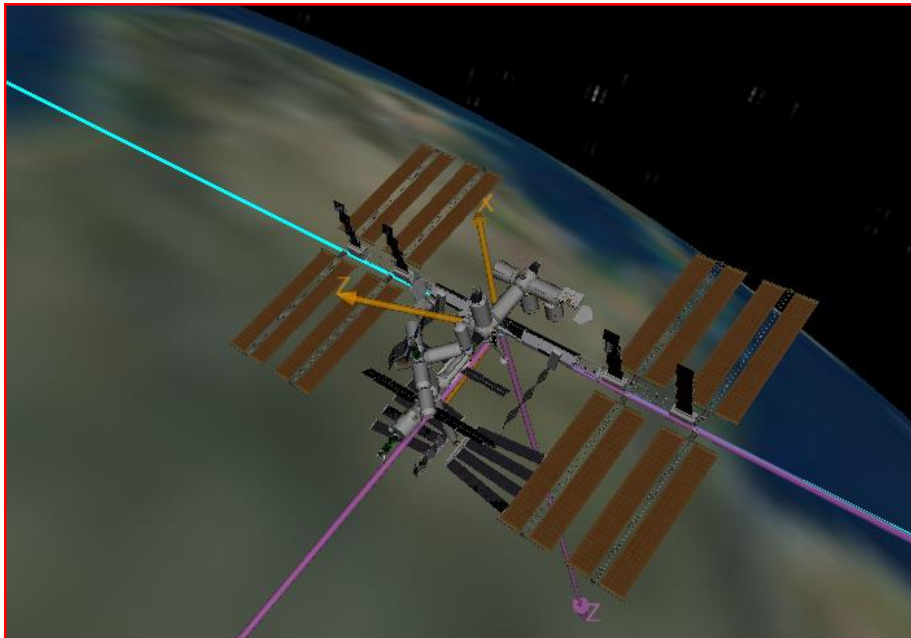
Engine
Trajectory Segments
Optimization
Integration
Control Algorithms
Engine Models

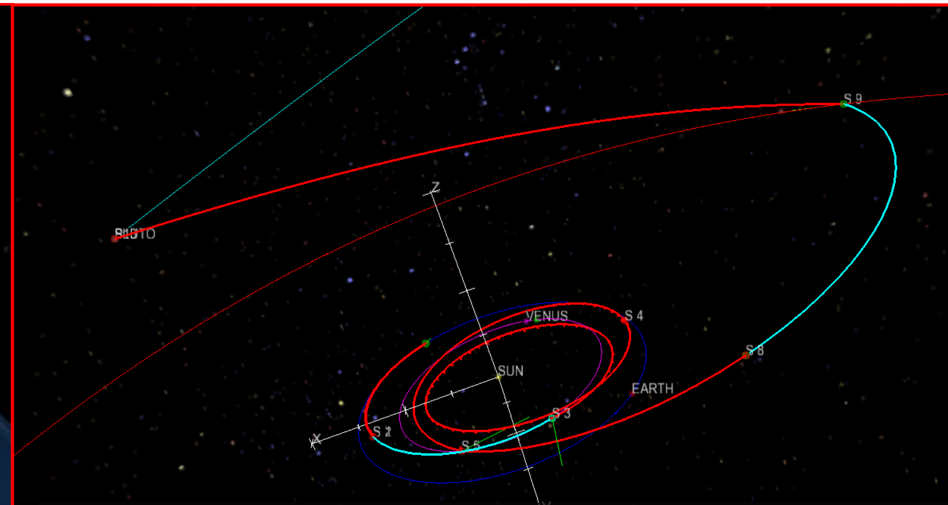
Copernicus Libraries

Toolkit Library
Celestial Mechanics Routines
SPICE Interface
Math Utilities
Coordinate Transformations
Binary File I/O
Gravity Models

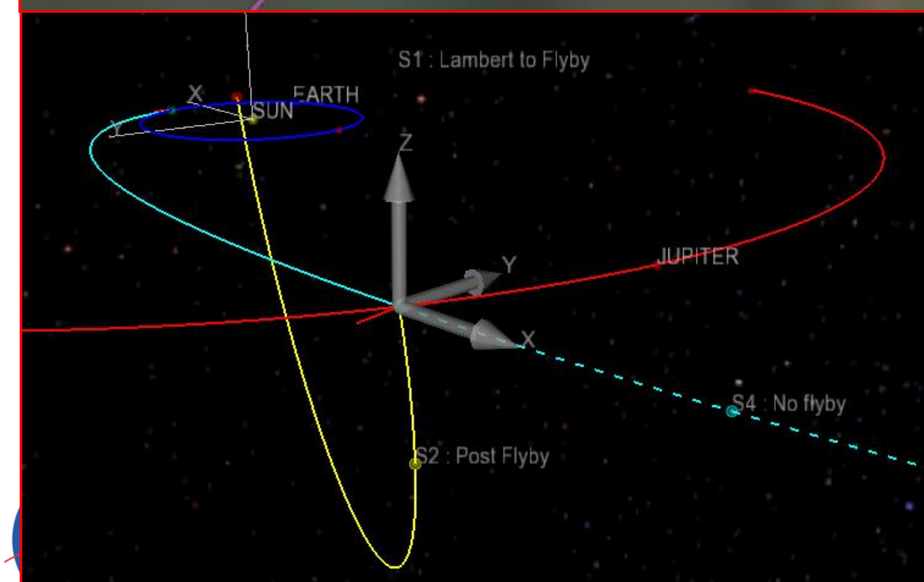
Batch Library
Distributed Processing
Automated Copernicus Runs
Production Data Output

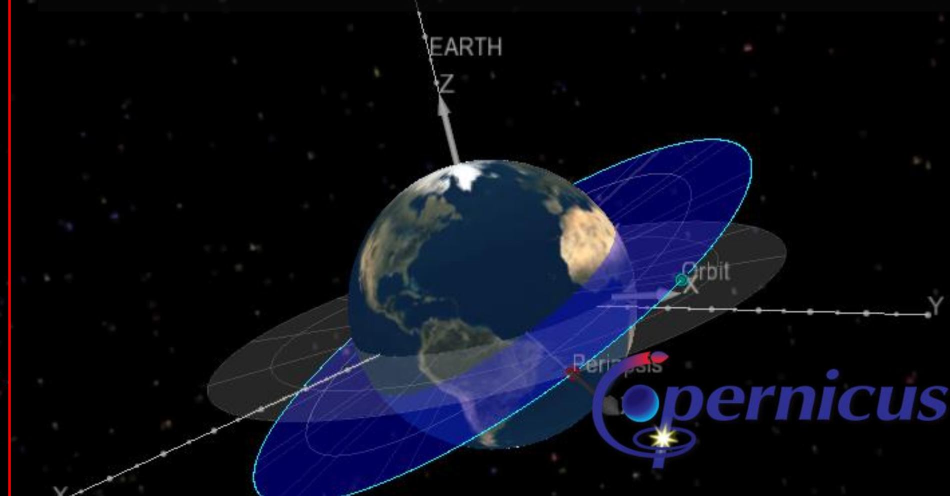
Copernicus: Interactive 3D Graphics



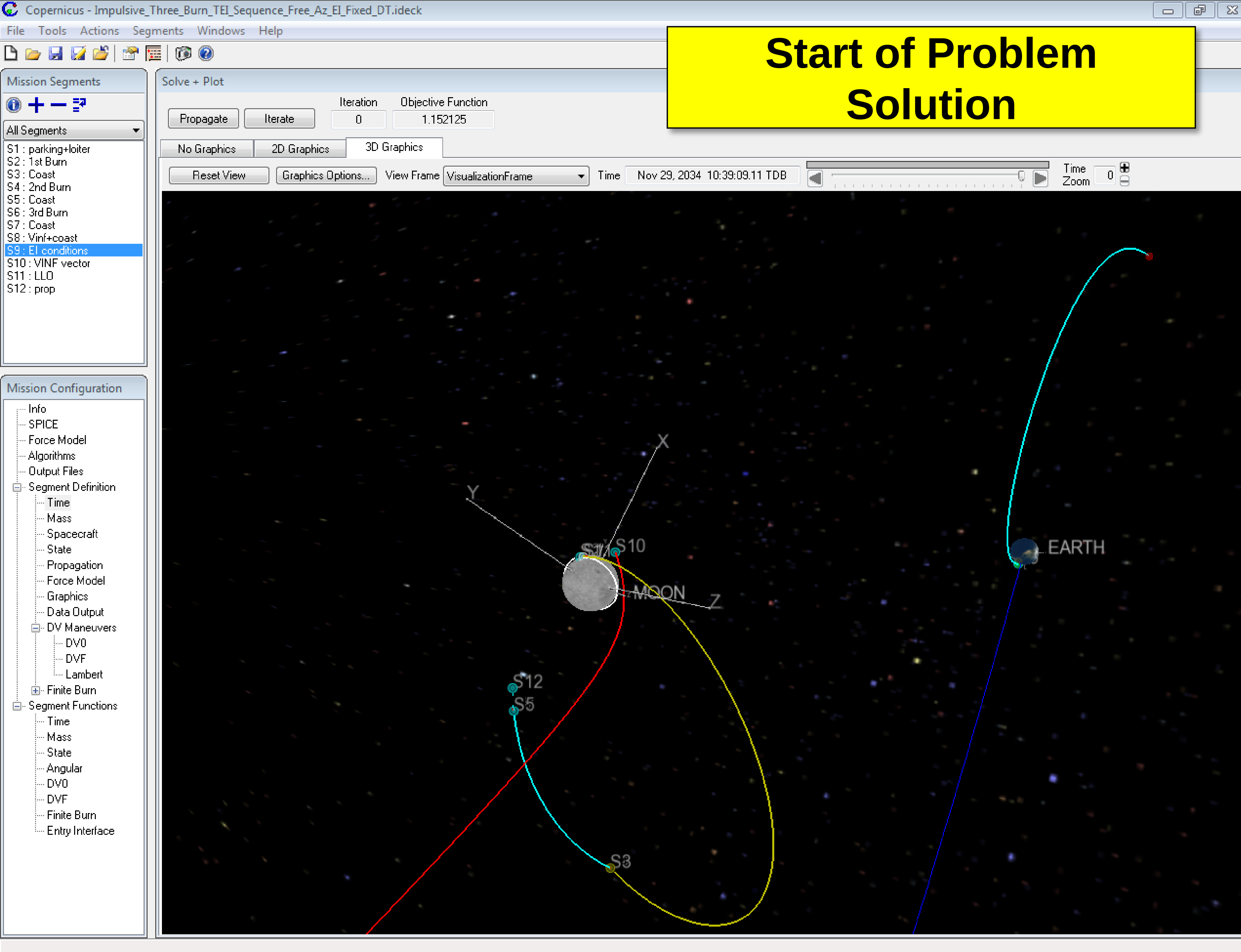


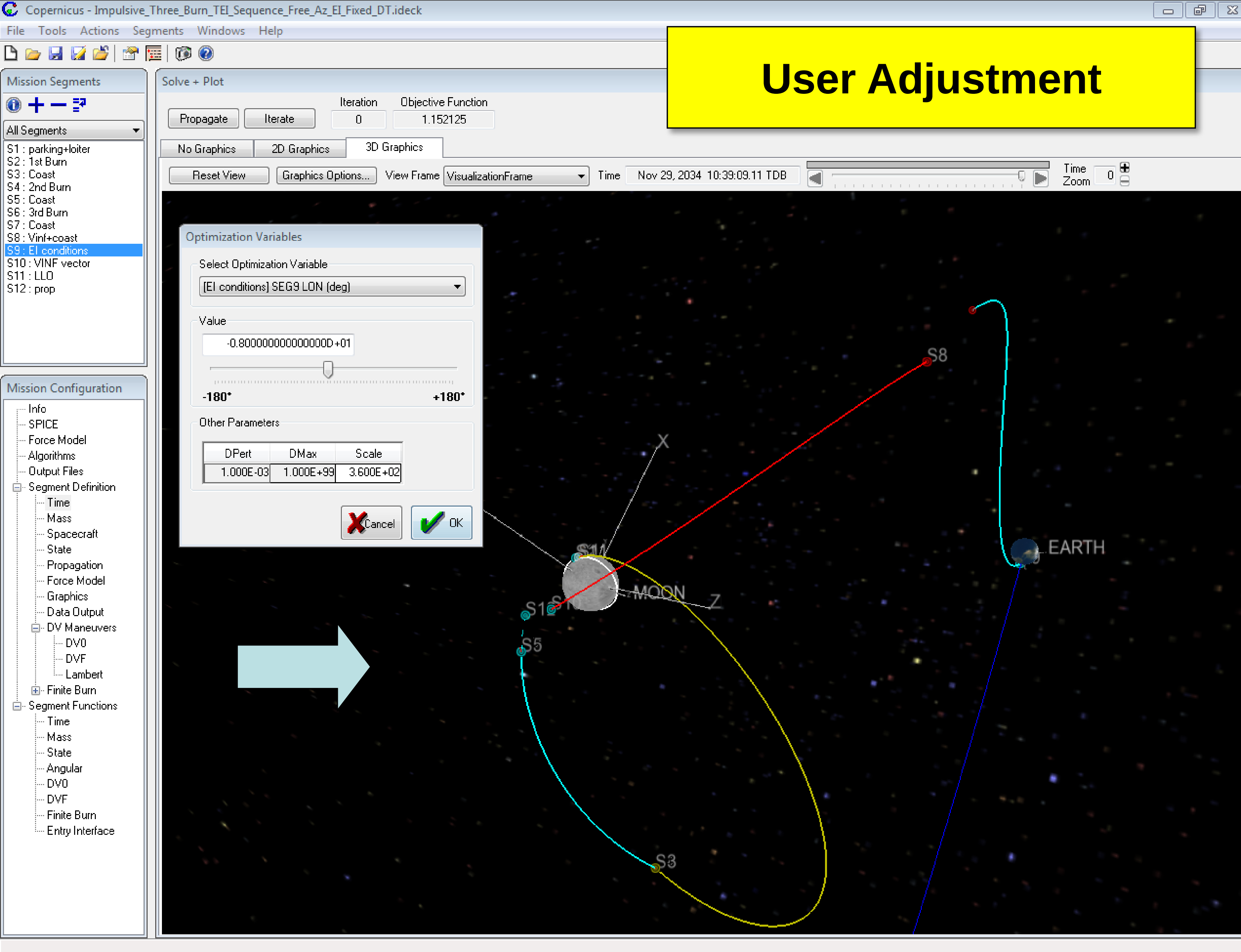
High resolution 3D graphics provide continuous feedback when using Copernicus to solve an optimization problem.



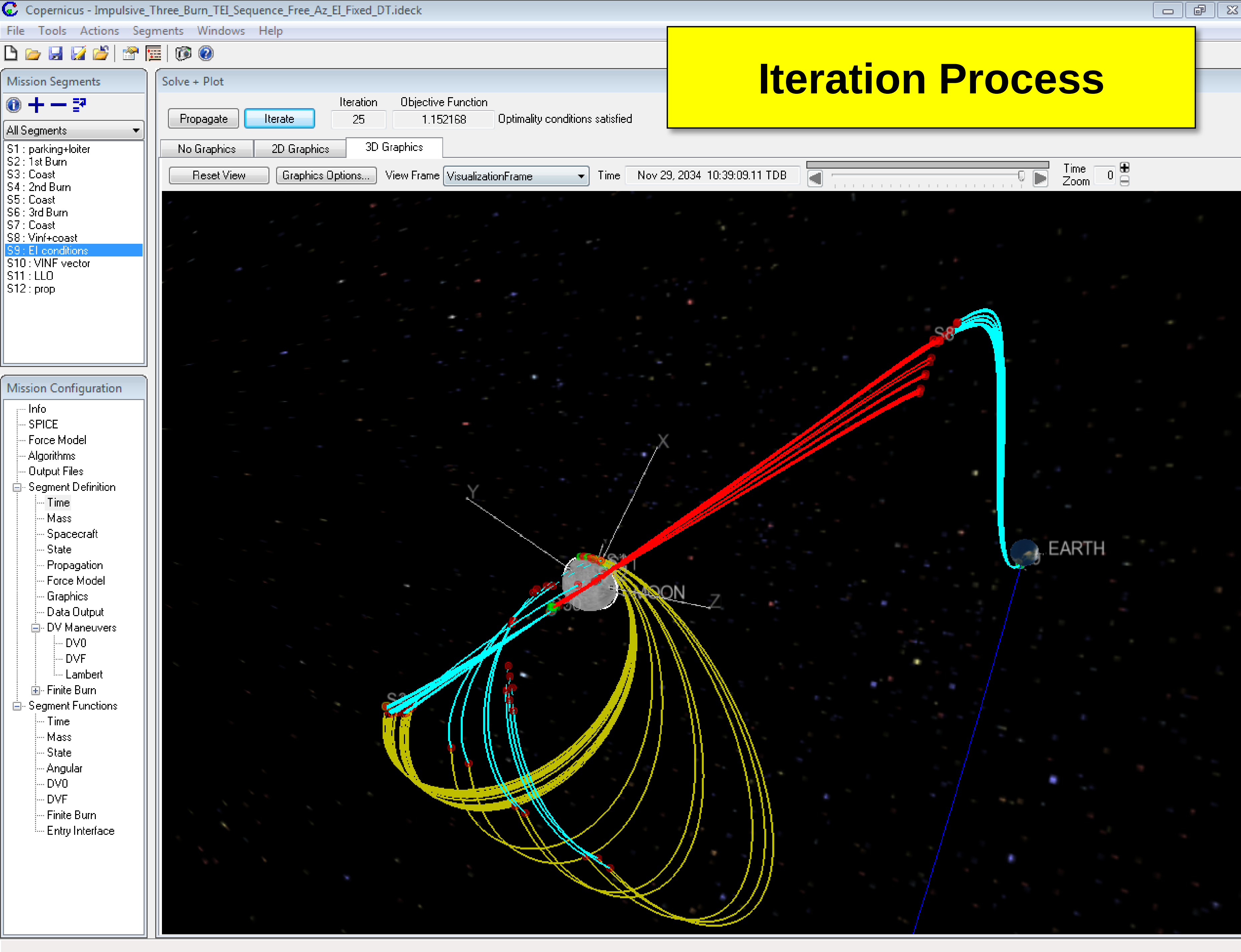


Start of Problem Solution

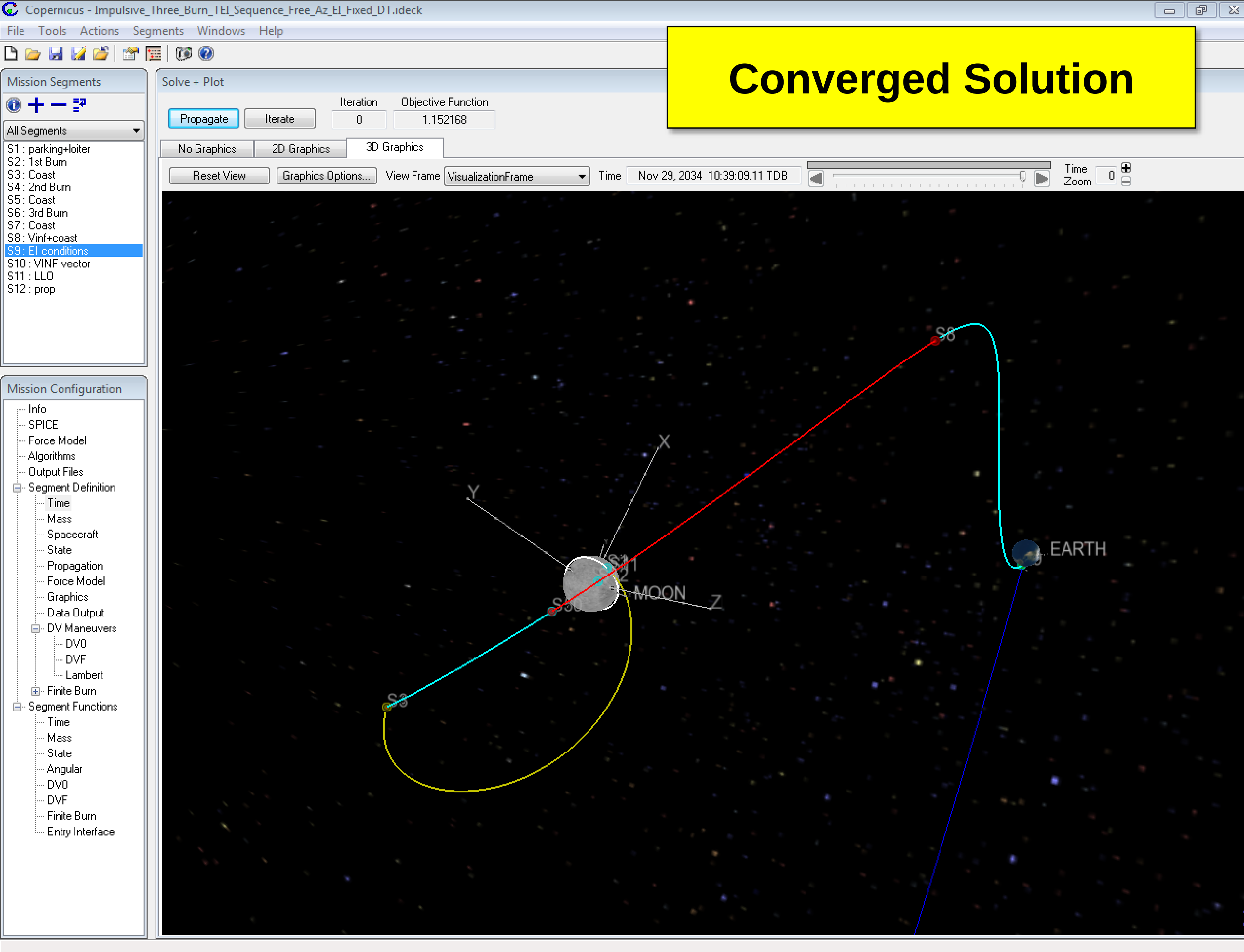



User Adjustment
Copernicus - Impulsive_Three_Burn_TEI_Sequence_Free_Az_EI_Fixed_DT.ideck
File Tools Actions Segments Windows Help
Mission Segments
All Segments
S1 : parking+loiter
S2 : 1st Burn
S3 : Coast
S4 : 2nd Burn
S5 : Coast
S6 : 3rd Burn
S7 : Coast
S8 : Vinf+coast
S9 : EI conditions
S10 : VINF vector
S11 : LLO
S12 : prop
Mission Configuration
Info
SPICE
Force Model
Algorithms
Output Files
Segment Definition
Time
Mass
Spacecraft
State
Propagation
Force Model
Graphics
Data Output
DV Maneuvers
DV0
DVF
Lambert
Finite Burn
Segment Functions
Time
Mass
State
Angular
DV0
DVF
Finite Burn
Entry Interface
Solve + Plot
Propagate
Iterate
Iteration 0
Objective Function 1.152125
No Graphics
2D Graphics
3D Graphics
Reset View
Graphics Options...
View Frame VisualizationFrame
Time Nov 29, 2034 10:39:09.11 TDB
Time Zoom 0
Optimization Variables
Select Optimization Variable
[EI conditions] SEG9 LON (deg)
Value
-0.8000000000000000D+01
-180°
+180°
Other Parameters
DPert 1.000E-03
DMax 1.000E+99
Scale 3.600E+02
Cancel
OK
S8
X
Z
MOON
EARTH
S1
S5
S3

Iteration Process



Converged Solution



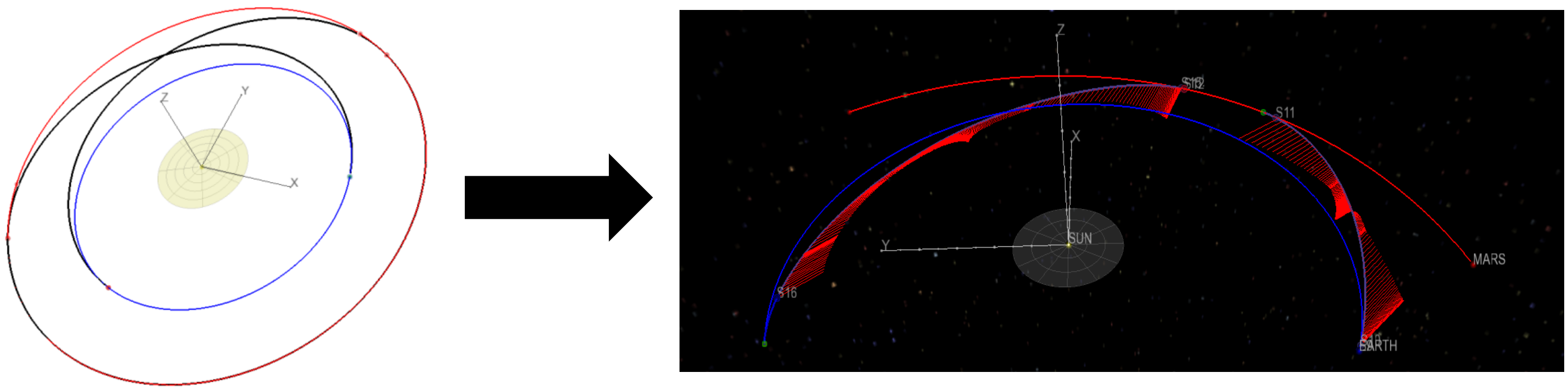
Trajectory Design Features

Copernicus provides enough design features to allow the user to create a myriad of trajectories of varying level of complexity.

- Mission Segments
- Integrators/Propagators
- Optimal Control Theory
- Parameter Optimization
- Numerical Differentiation
- Ephemerides
- Reference Frames
- Finite Burn Engine Models
- Finite Burn Maneuver Models
- Impulsive Maneuvers
- Lambert Targeting
- State Parameterizations
- Maneuver Parameterizations
- Gravity Assists
- Halo Orbits
- Gravity Models
- Visualization
- Text Output
- Batch Capabilities

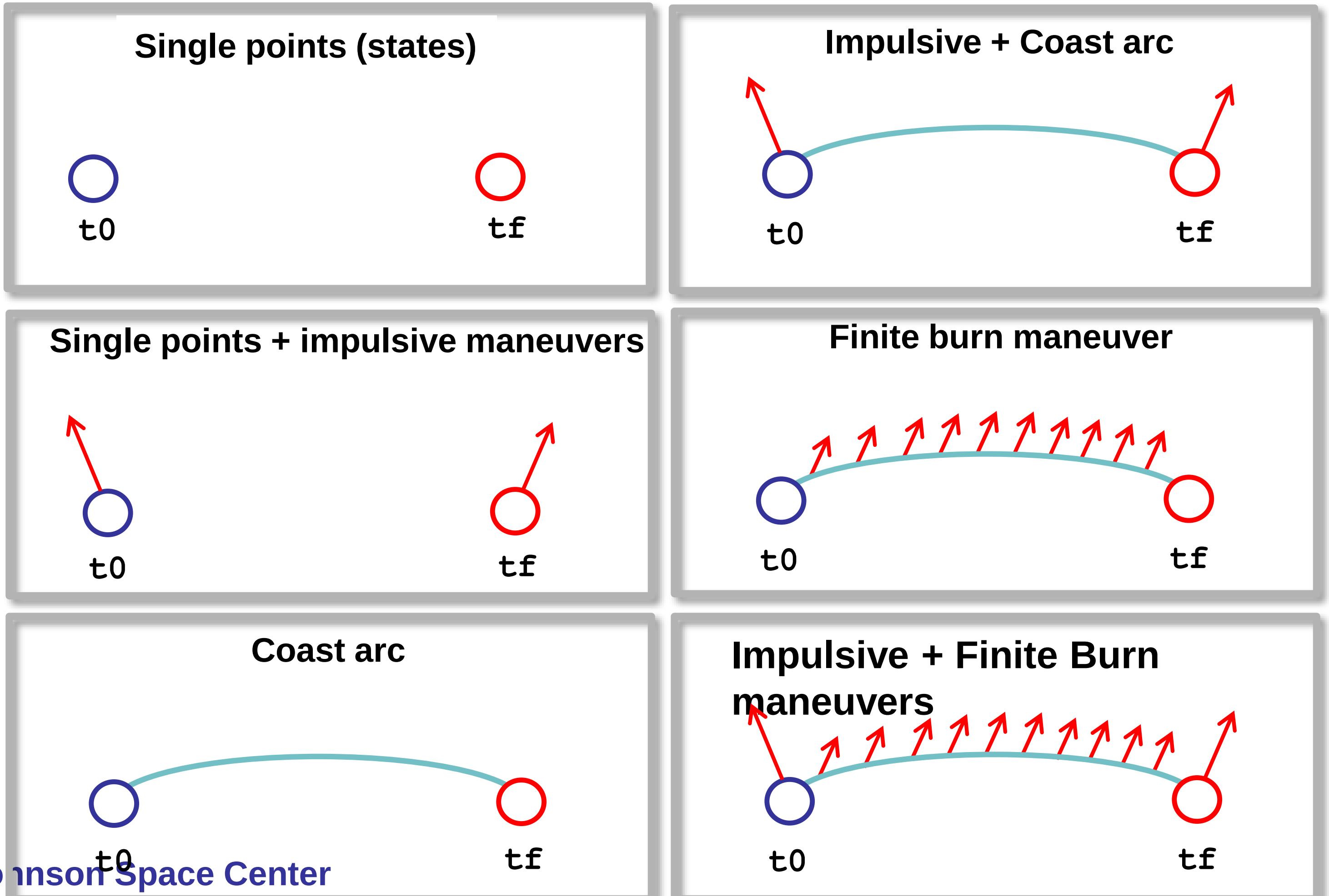
Levels of Fidelity

- Low fidelity → High fidelity [within the same tool]
  - Scans/trade studies → Detailed mission design
  - Impulsive Δv → Optimized finite burn maneuvers
  - Circular planet orbits → Real ephemeris (SPICE)
  - Evolutionary (DE) → Gradient-based (SNOPT,…)
  - Patched conic model → High fidelity force model

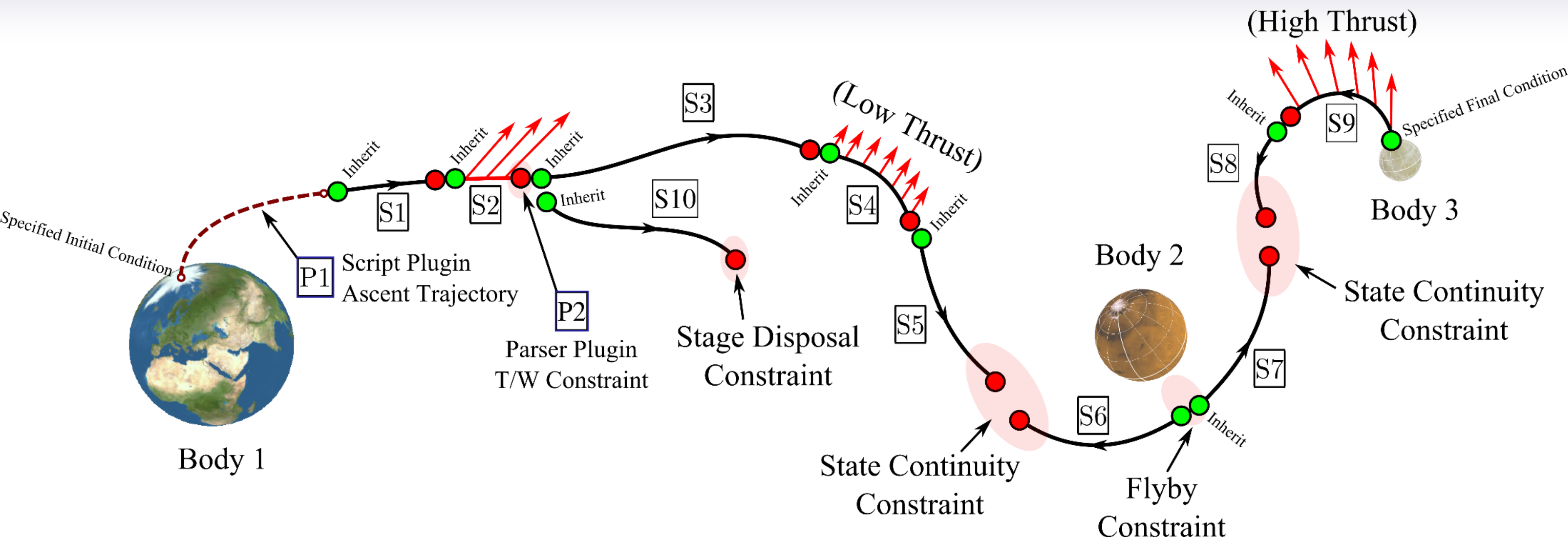


Copernicus Building Blocks: Segments

Many, many classes of problems can be modeled with the segment concept. There are many ways to solve the same problem.



Building Blocks: Segments + Plugins



- Multiple spacecraft and propulsion systems
- Segment to segment information inheritan
- Plugins allow user-defined capabilities.
- Optimization variables and constraints.
- Forward and backward propagation.

The simple segment construction method can be used to create anything from a simple trajectory to an extremely complex set of interdependent trajectories .

Copernicus User Base

ARC GSFC JSC
JPL, KSC,
LaRC MSFC

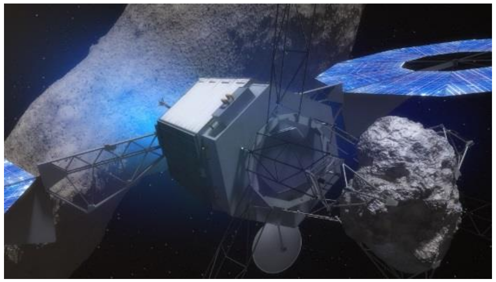
JSC	LARC
GRC	KSC
MSFC	GSFC
ARC	JPL
APL	DARPA
USNRL	AFRL
Numerous Contractors (Lockheed, Boeing, SpaceX, Orbital, Ad Astra, …)	

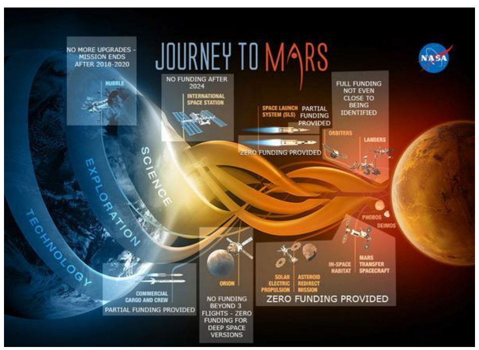
Copernicus is released through *JSC Tech Transfer* under a government use license. 199 licenses issued to 155 individual recipients

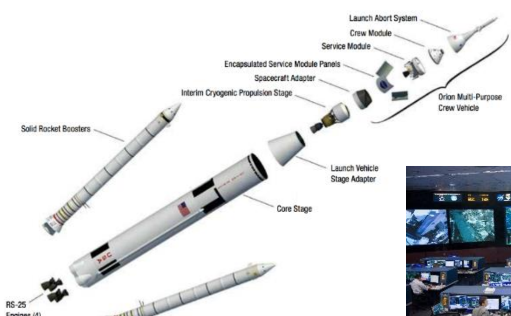
Complete user list (all previous versions) includes ~250 people.

Some Key Uses For Copernicus at JSC

The extensibility of Copernicus covers multiple robotic and human mission applications. Here's an example of some of the activities at JSC that use Copernicus.

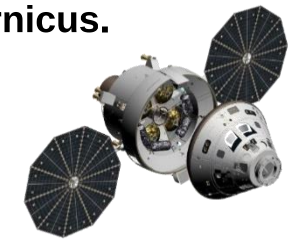






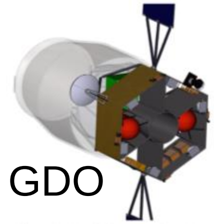
- ARRM/ ARCM
- Orion EM1/EM2
- Autonomous On-Orbit Mission Planning
- Orion Displays
- Future Capabilities / Proving Ground / ISECG
- Ground Support for Flight Operations
- SLS
- Evolvable Mars Campaign

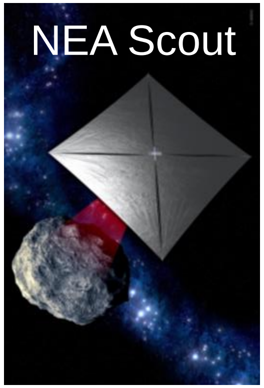
Copernicus

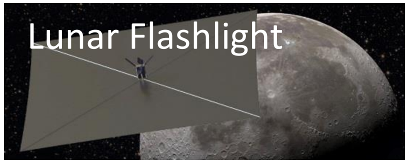


Copernicus Usage Across NASA

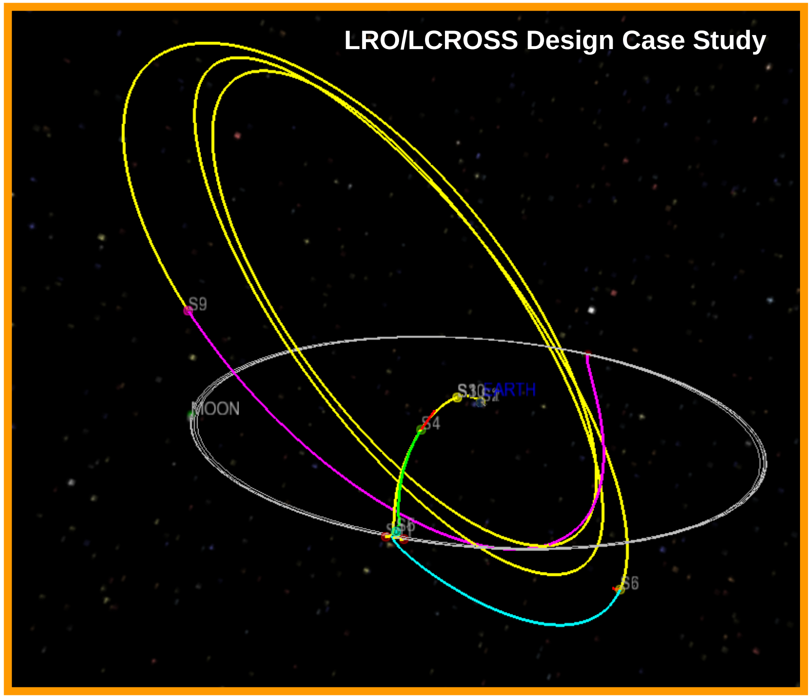
Orion/MPCV/EM1 & EM2/SLS [JSC]
ARM (Asteroid Redirect Mission) [JSC, LaRC, JPL]
Lunar Crater Observation and Sensing Satellite (LCROSS) [ARC]
Commercial Orbital Transportation Services (COTS)
ISS Terrestrial Return Vehicle (TRV) [IM/JSC]
Moon Age and Regolith Explorer (MARE) [JSC, SwRI]
Europa Impactor Studies
High Altitude Venus Operational Concept (HAVOC)
Venus Atmosphere and Surface Explorer (VASE)
Mars Atmosphere and Volatile Evolution (MAVEN) [GSFC, CU/LASP]
Nuclear Cryogenic Propulsion Stage
Interstellar (heliopause) Probe [JPL]
Geospace Dynamics Observatory (GDO) [MSFC]
Fission Fragment Rocket Engine (FFRE) [MSFC]
Large Ultraviolet/Optical/Infrared (LUVOIR) Surveyor [GSFC]
iSat [MSFC]
Near Earth Asteroid Scout (NEA Scout) [MSFC, JPL]
Lunar Flashlight [JPL]

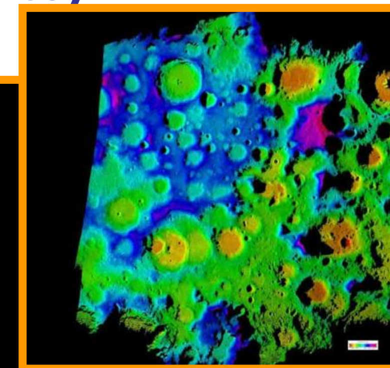


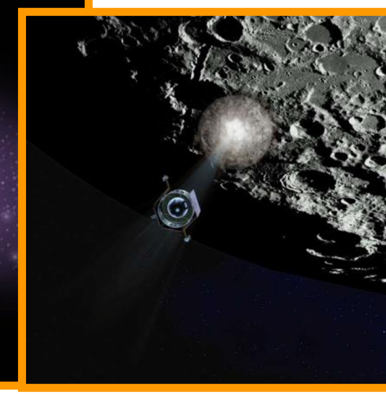




Design and Operational Example
LCROSS Mission
(Lunar Crater Observation and Sensing Satellite)

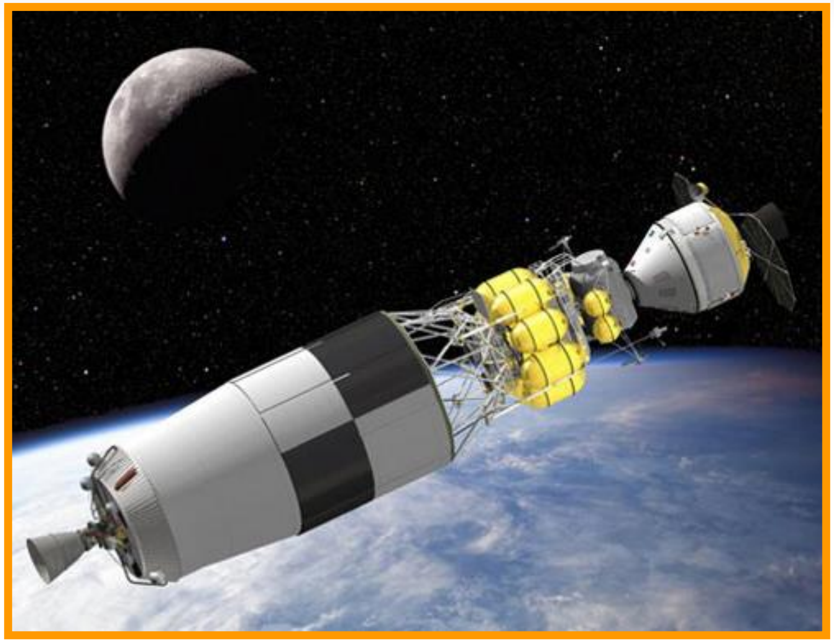


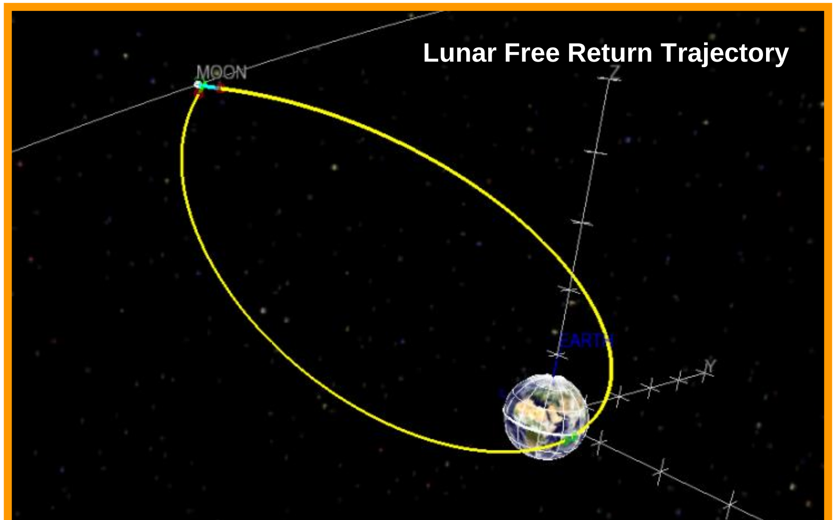




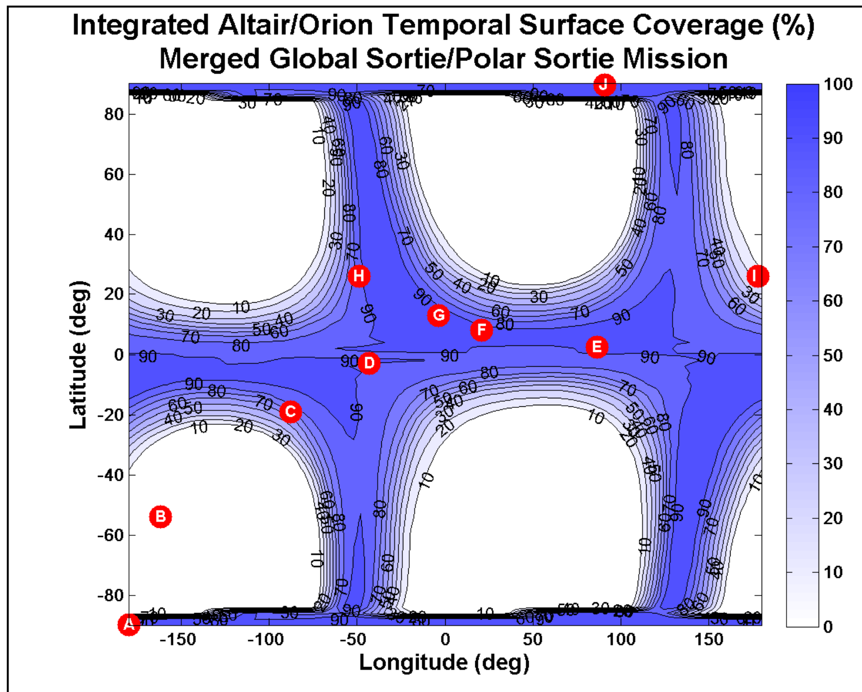
- Copernicus was used to construct hundreds of optimal Earth-Lunar flyby-to-Lunar impact trajectories including the separation phase from the original LRO trajectory which was bound for Lunar orbit.
- Also used post-launch to examine under/over burns en route.

Constellation Program

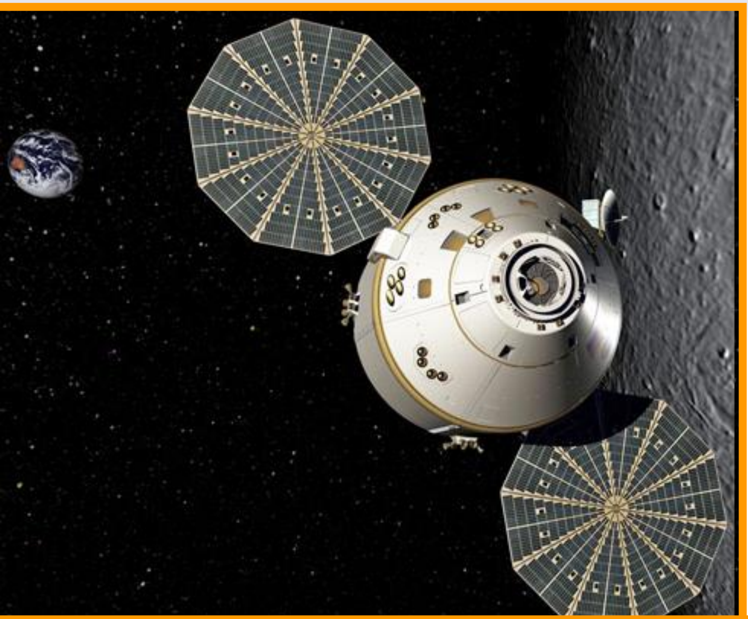




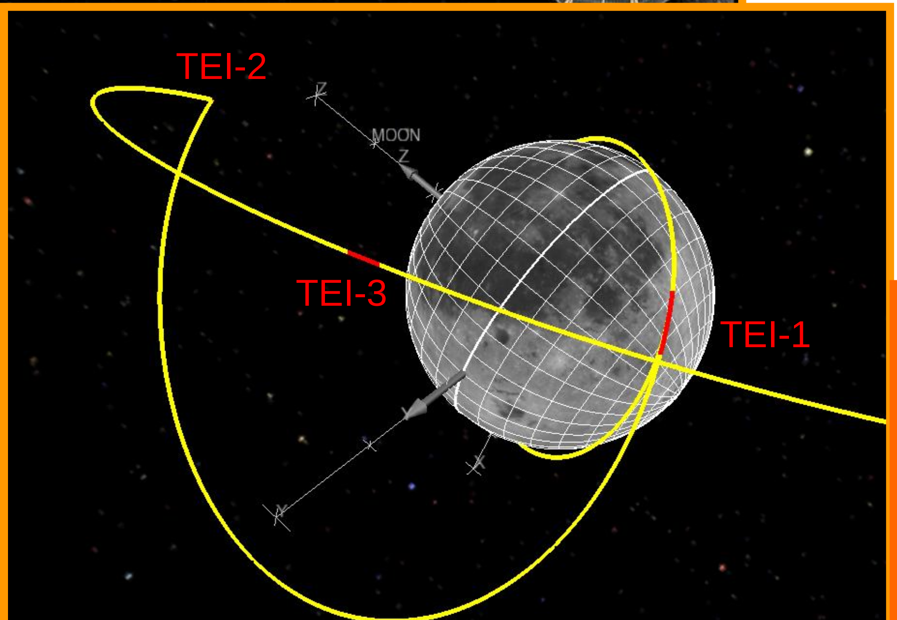
- Architecture evaluation
- Trade studies (TLI, LOI, TEI)
- Lunar Capability Concept Review (LCCR)
- Copernicus changed the way we look at mission design



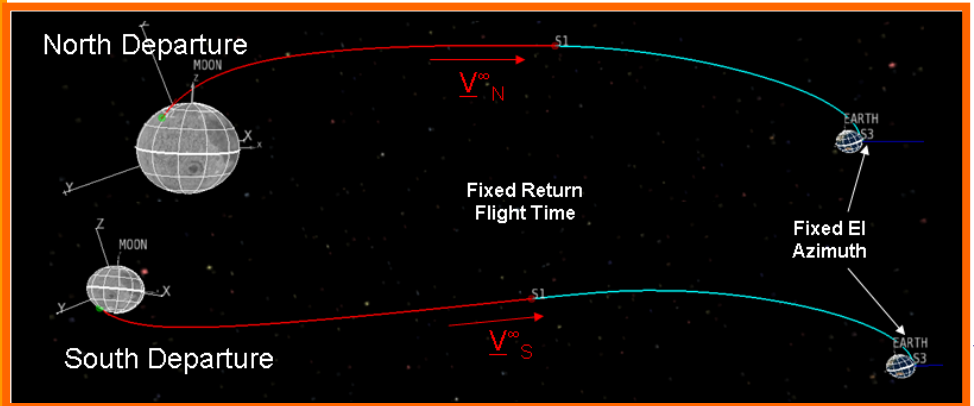
Orion Project (Lunar Missions)



- Copernicus used extensively for Orion vehicle design and performance
- Databases developed to characterize Orion lunar missions over the entire planned operational lifetime.
- Millions of optimized trajectories using Copernicus on a computing cluster.
- Ground support

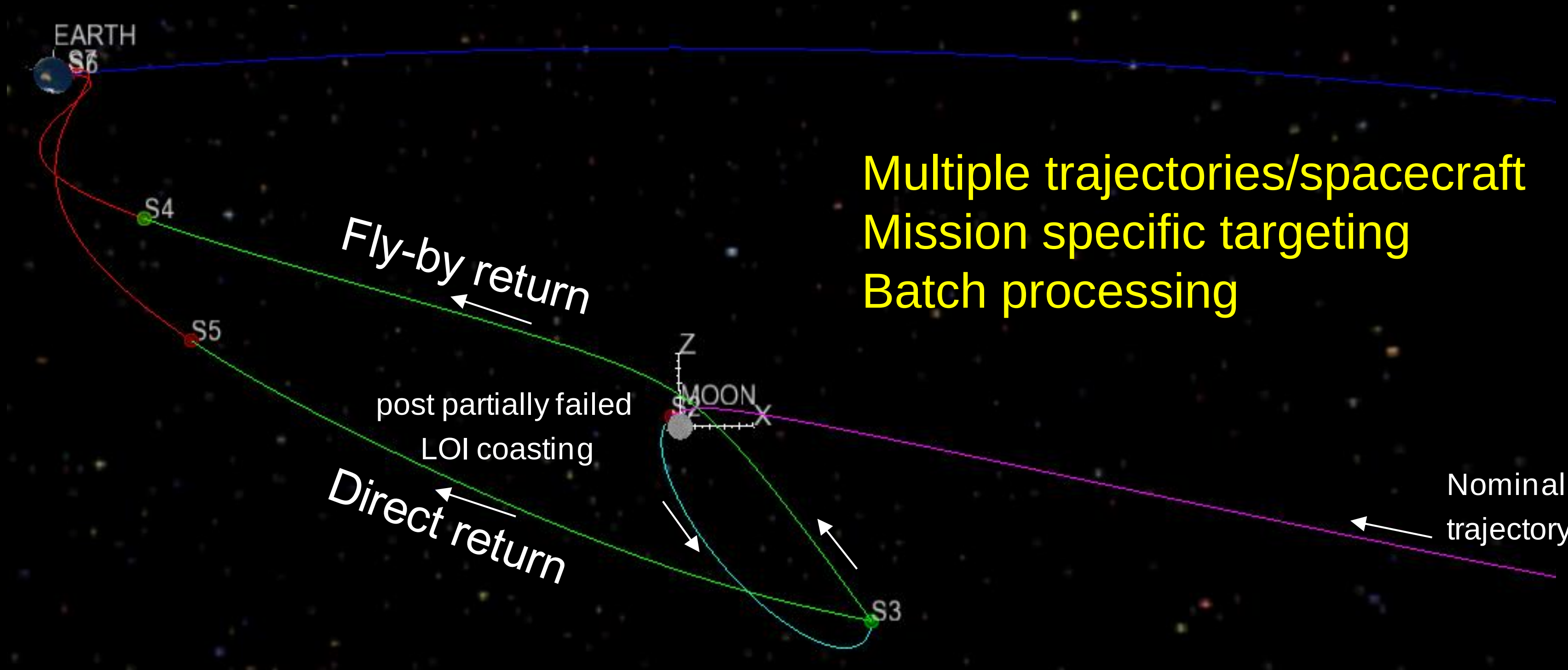


Three-Burn Trans-Earth Injection Maneuver Sequence

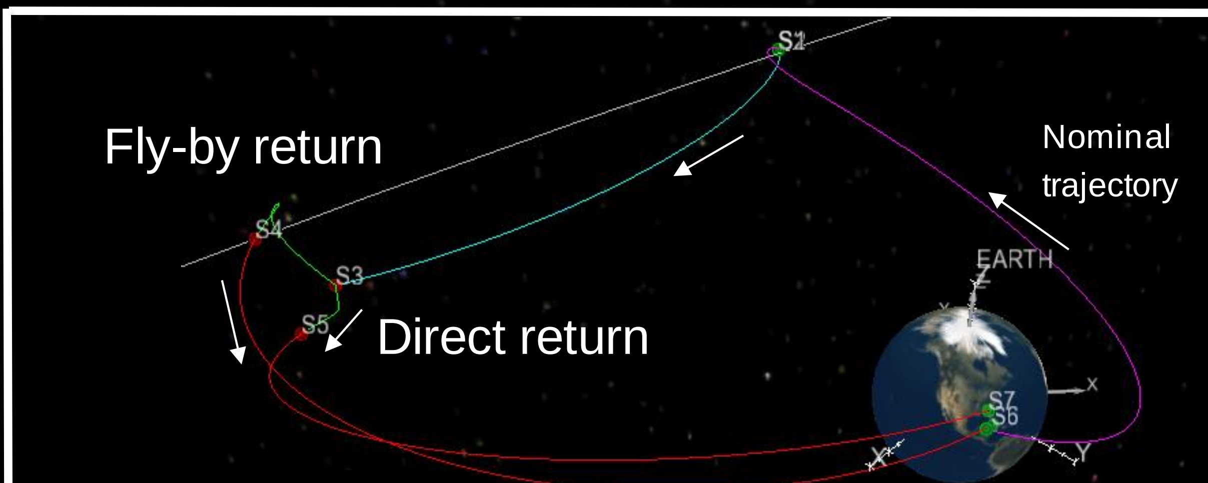


Abort Analysis

Multiple trajectories/spacecraft
Mission specific targeting
Batch processing

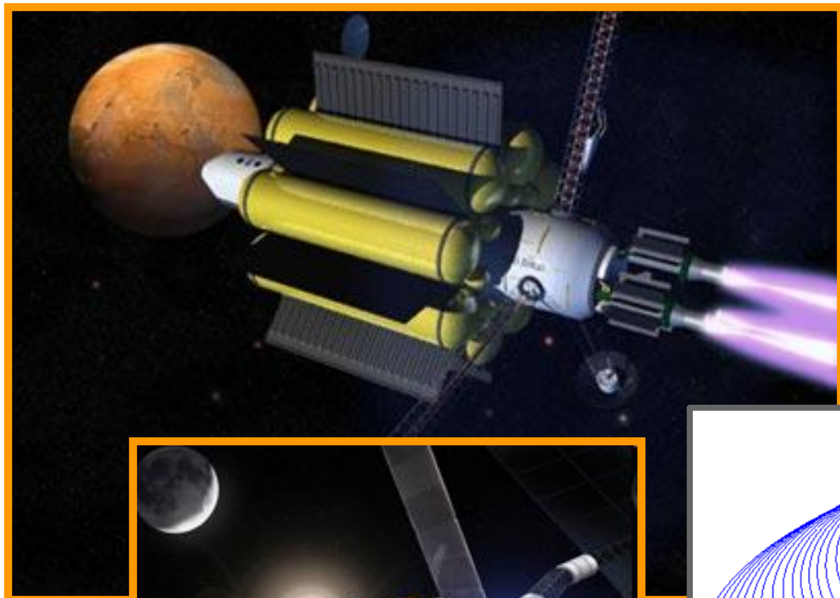


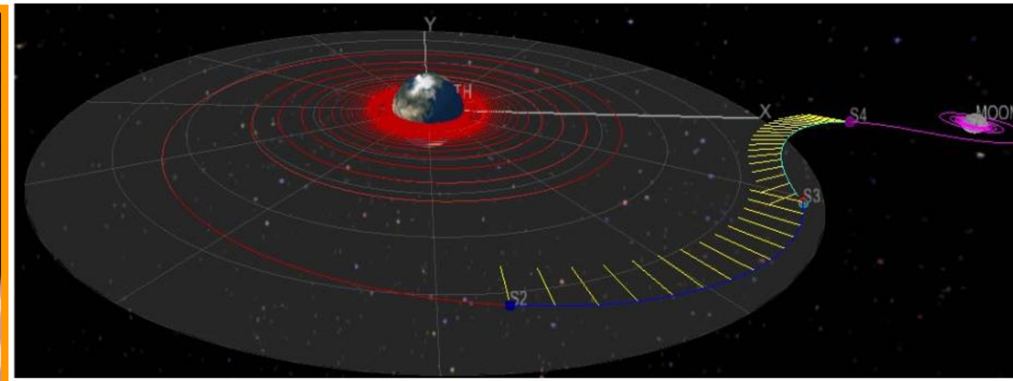
Moon-centered view

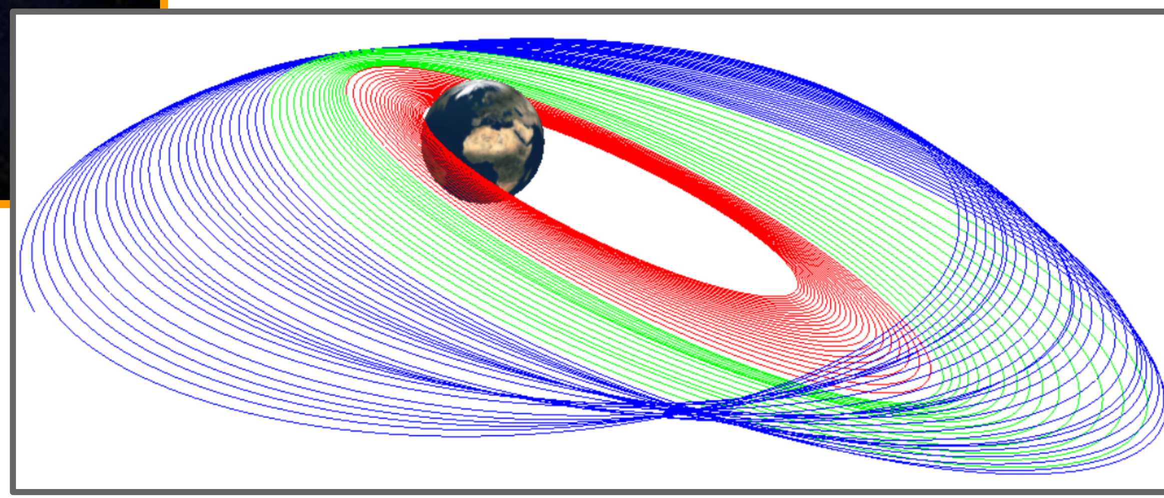


Earth-centered view

VASIMR / Low Thrust



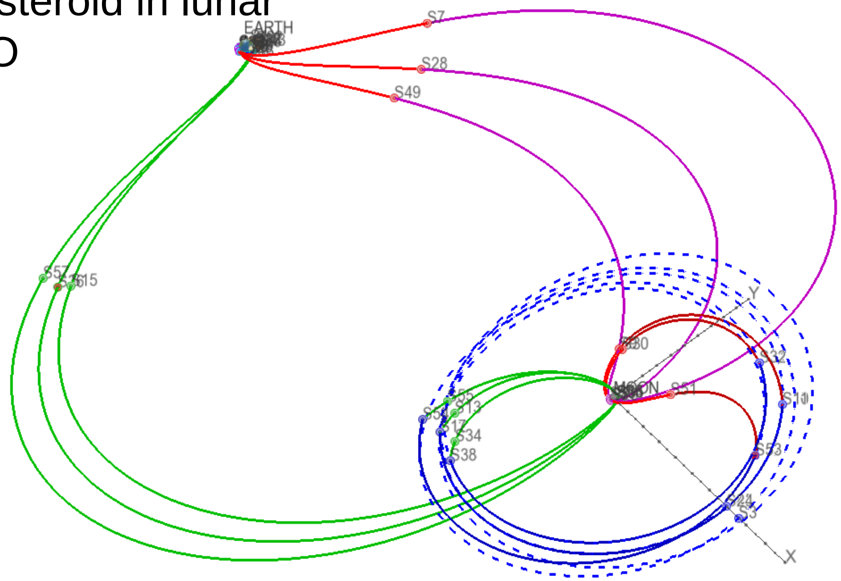


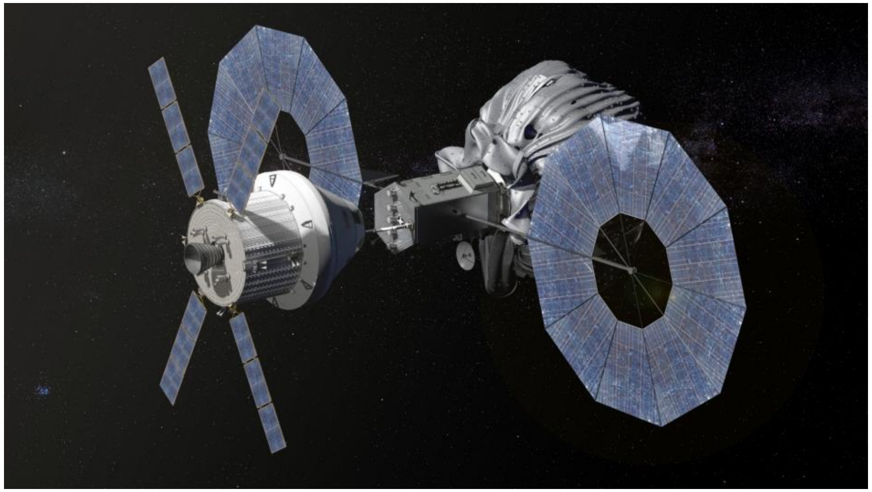


- Variable specific impulsive engine
- Earth orbit transfer, Earth to Moon, Earth to Mars.

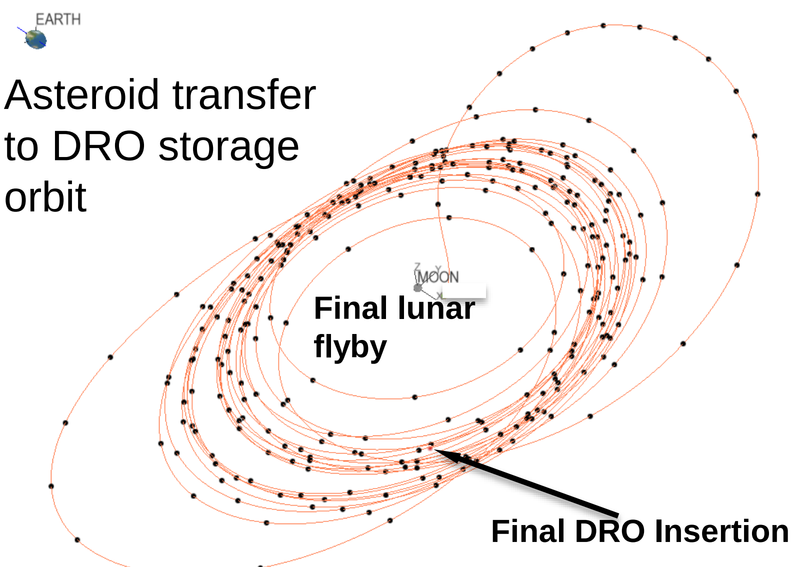
Asteroid Redirect Mission

Crewed missions to asteroid in lunar DRO

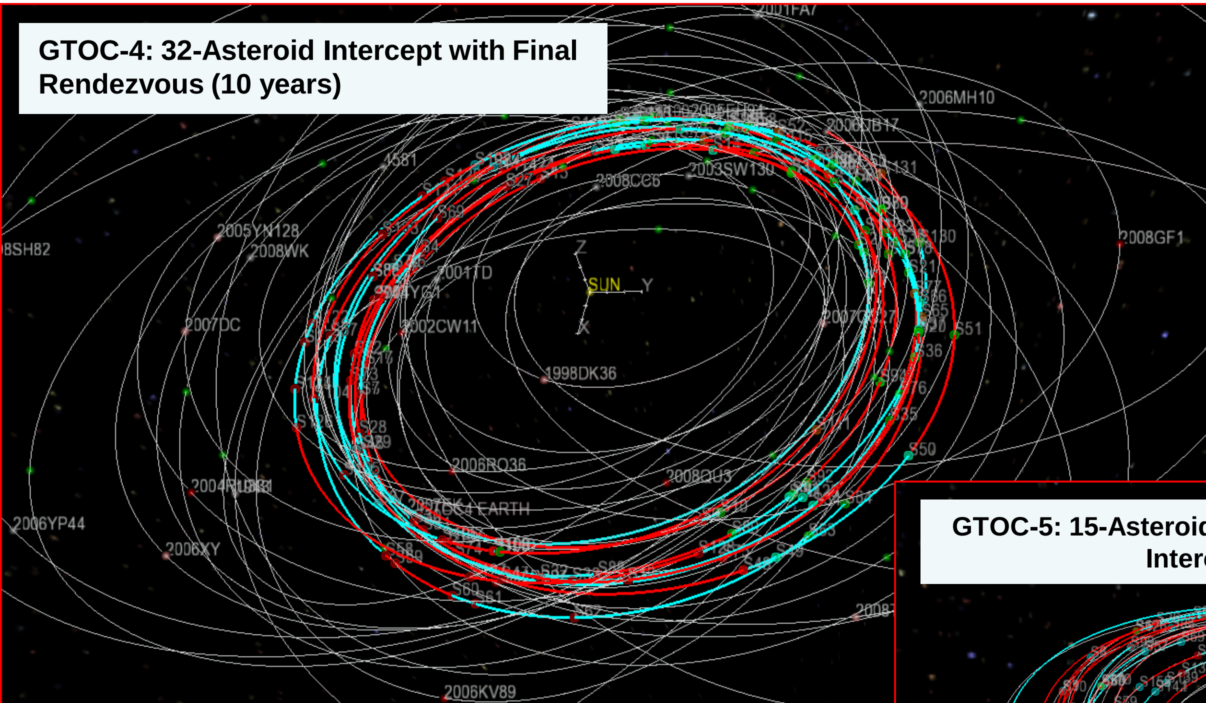




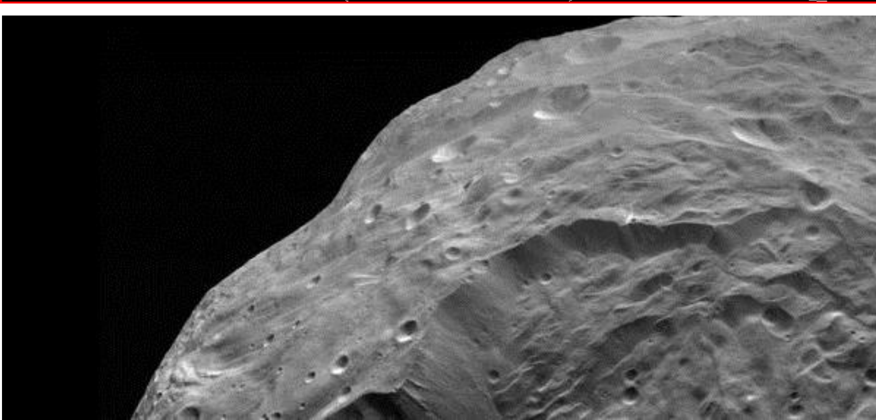
Asteroid transfer to DRO storage orbit

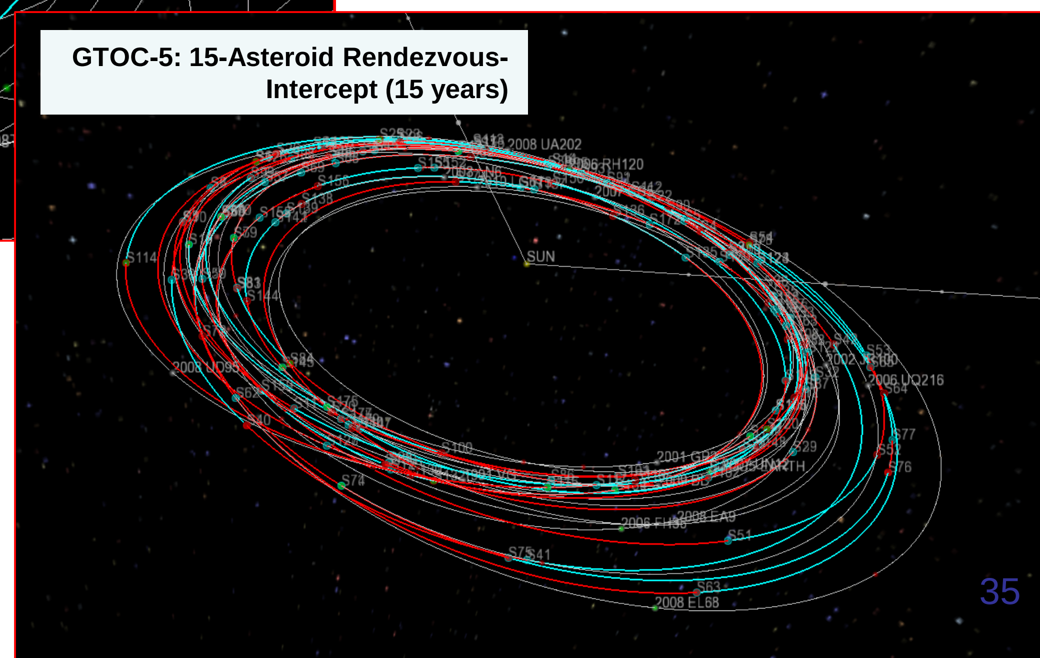


Asteroid Tour Mission Design



GTOC-4: 32-Asteroid Intercept with Final Rendezvous (10 years)

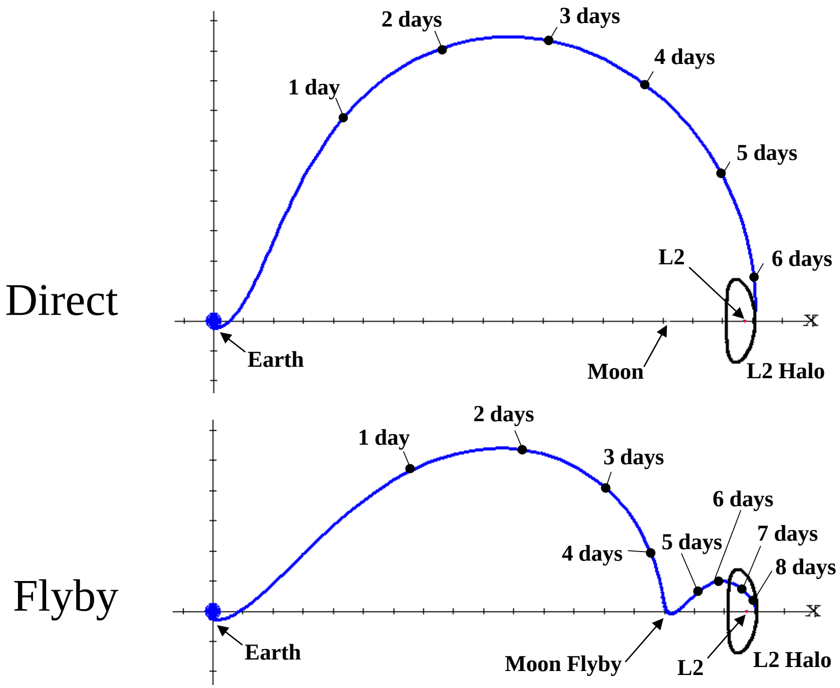


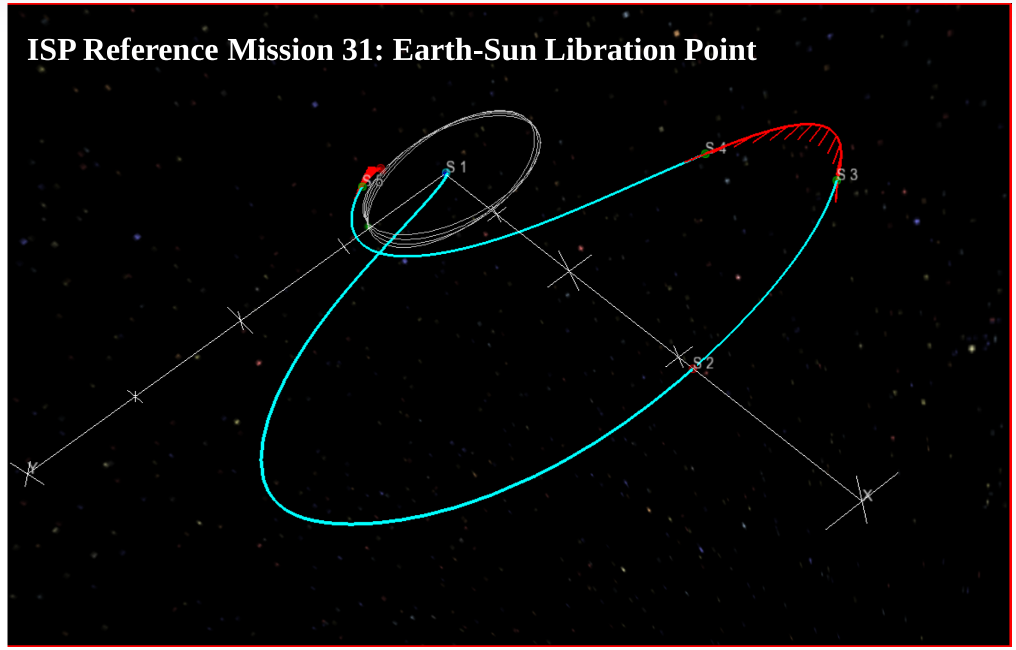


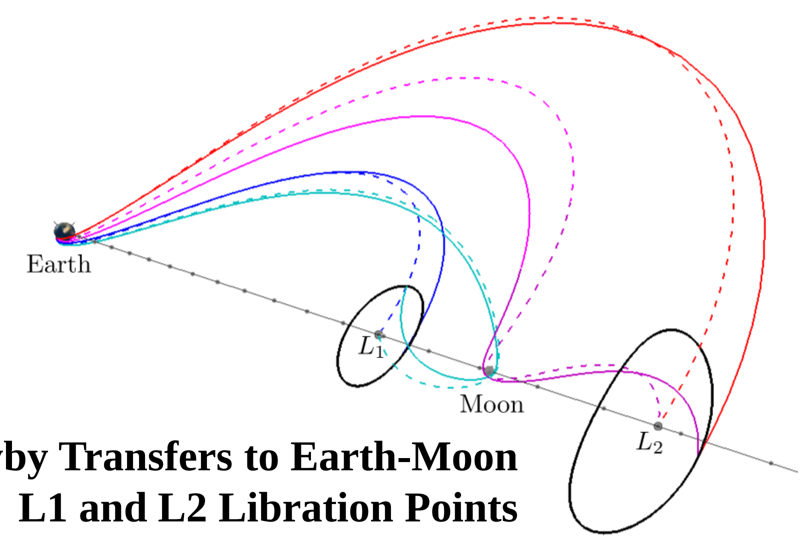
GTOC-5: 15-Asteroid Rendezvous-Intercept (15 years)

Halo Orbit & Transfers

**Transfer Options to
Earth-Moon L2 Halo Orbit**

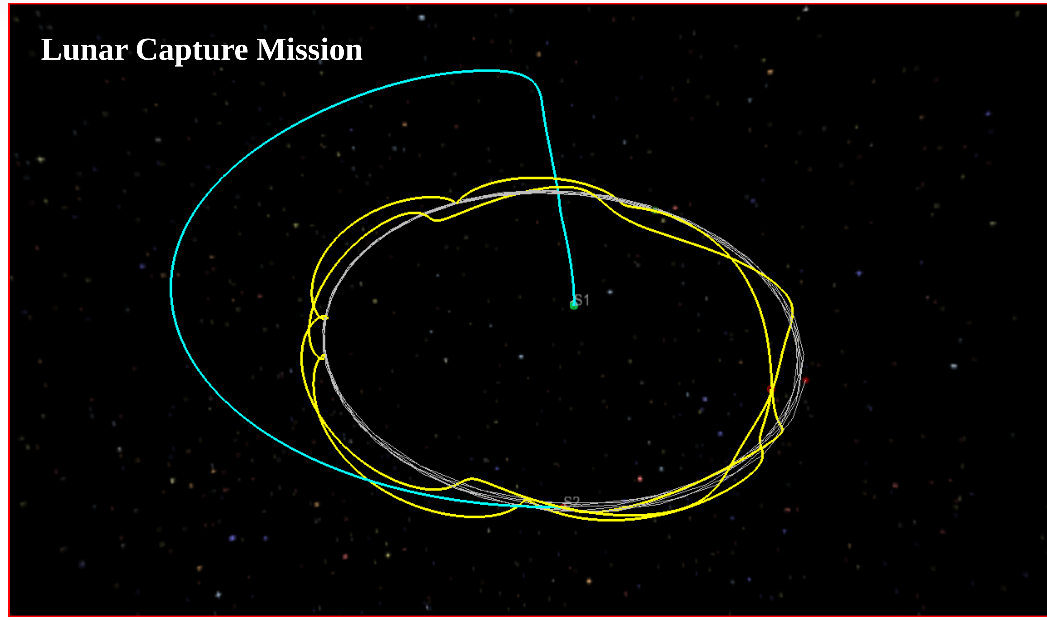






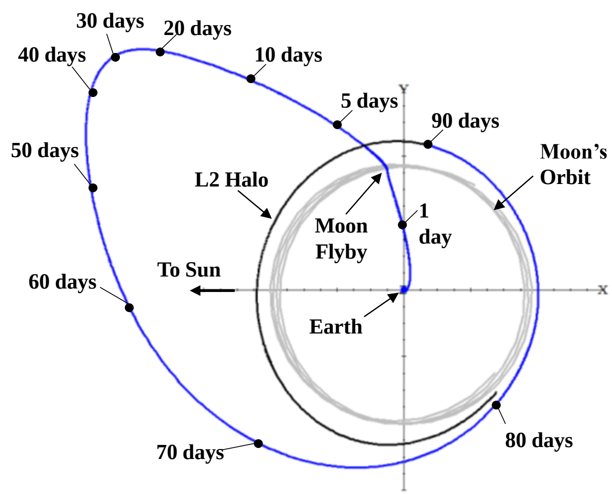
**Direct and Flyby Transfers to Earth-Moon
L1 and L2 Libration Points**

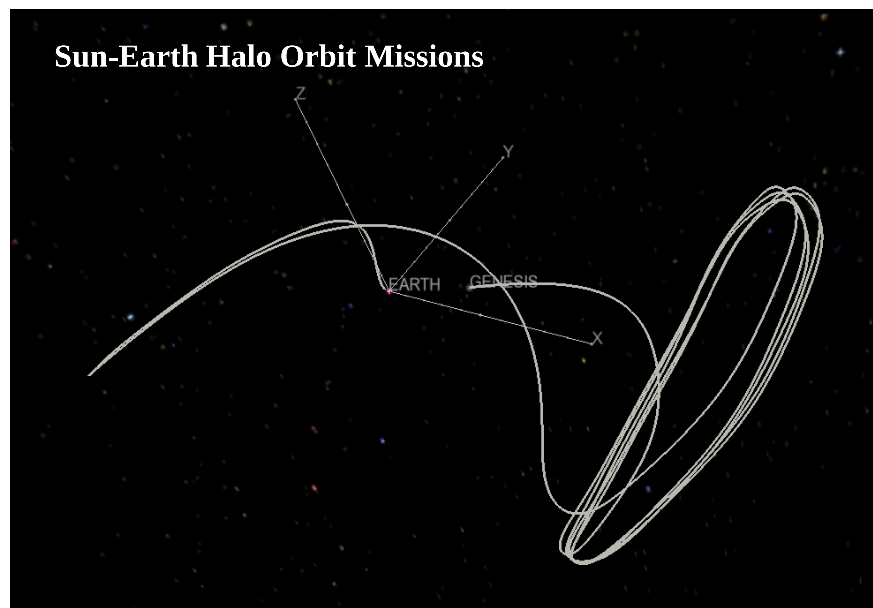
Weak Stability Boundary/Ballistic Capture



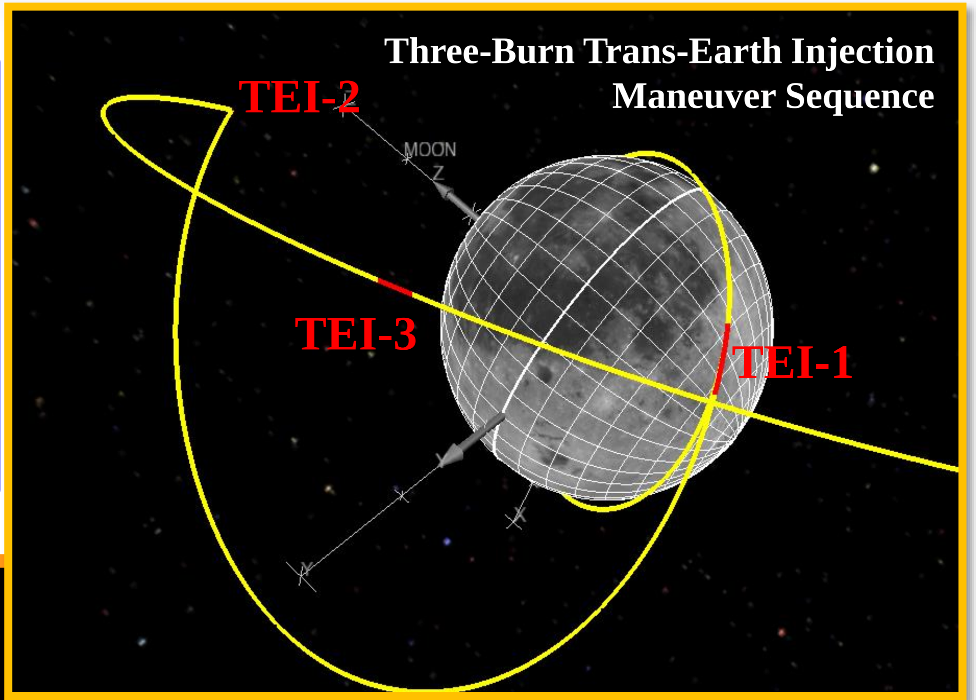
Lunar Halo – Cargo Mission

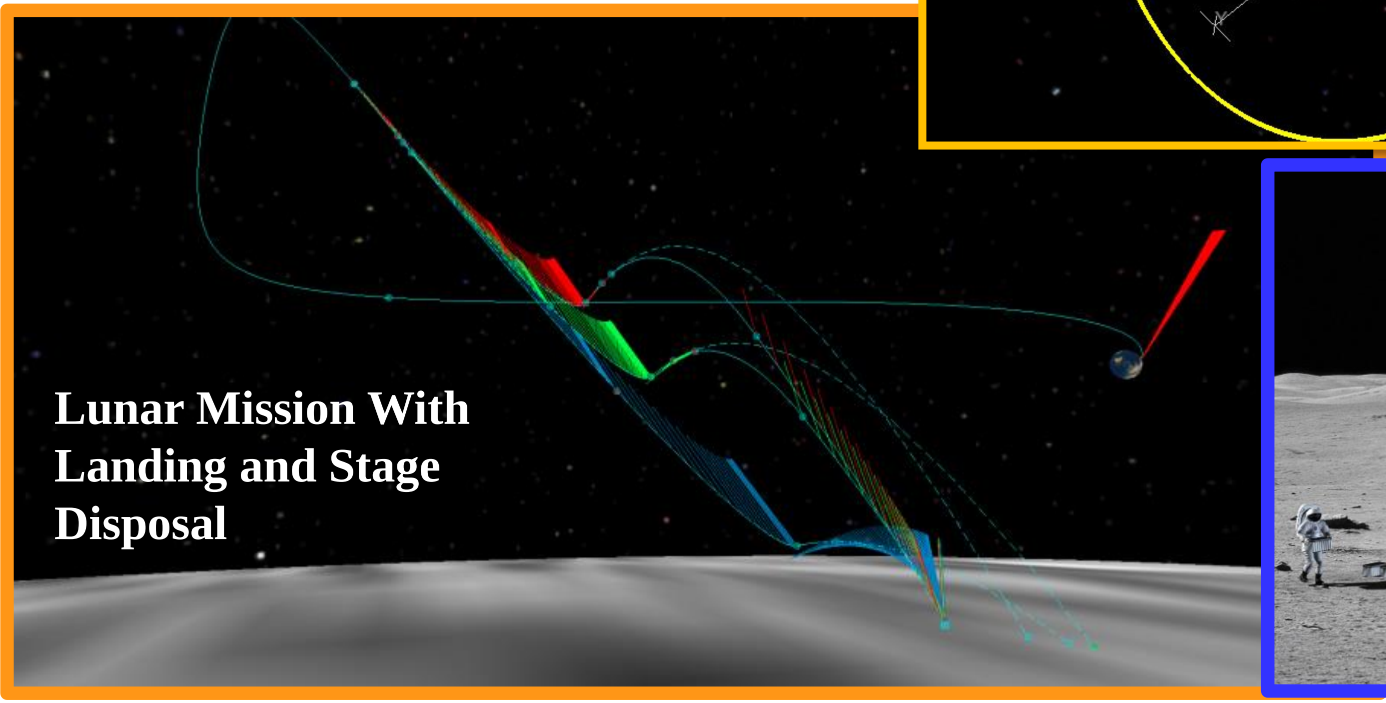
Low Energy
(Manifold)

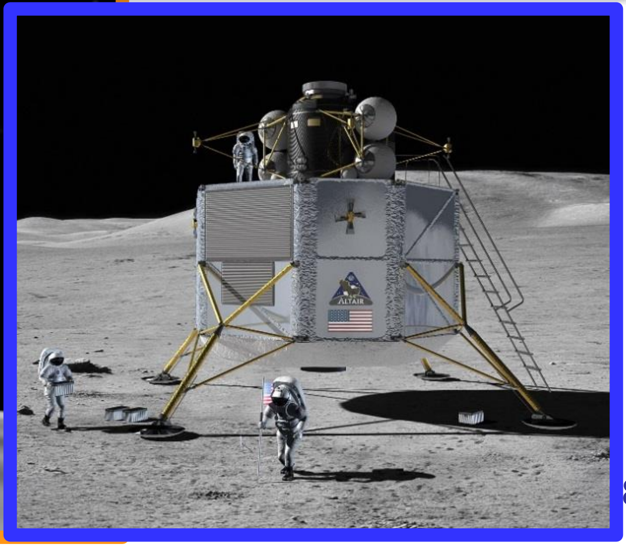




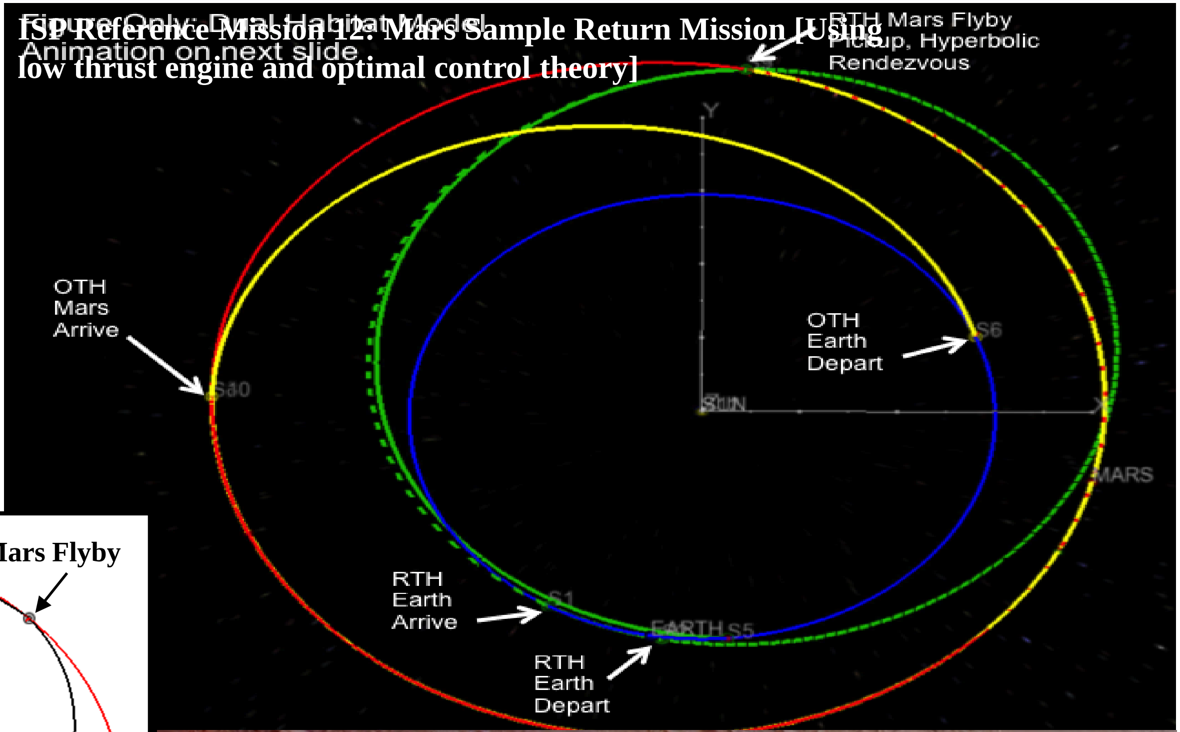
Lunar Missions

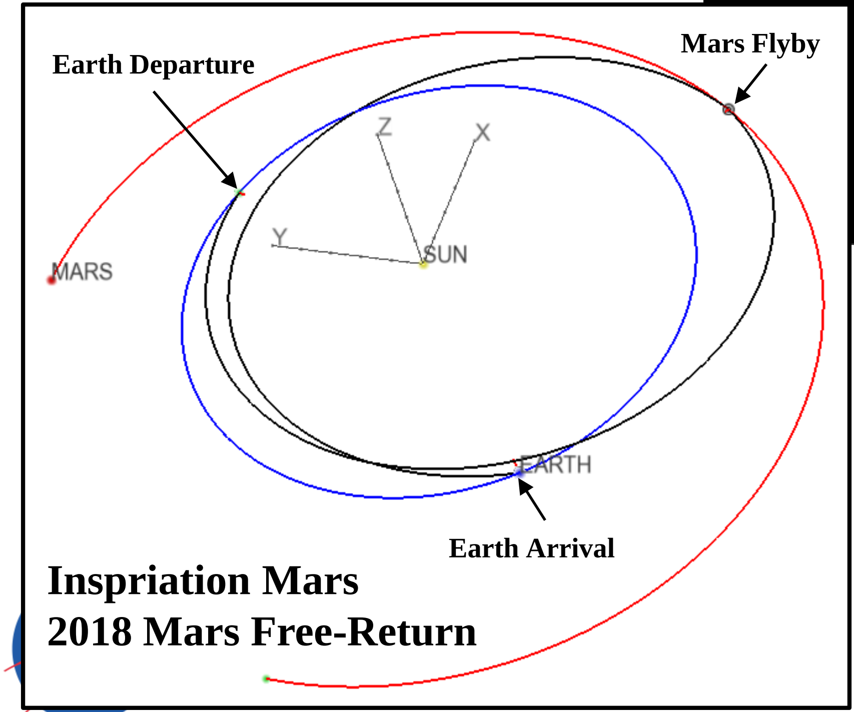




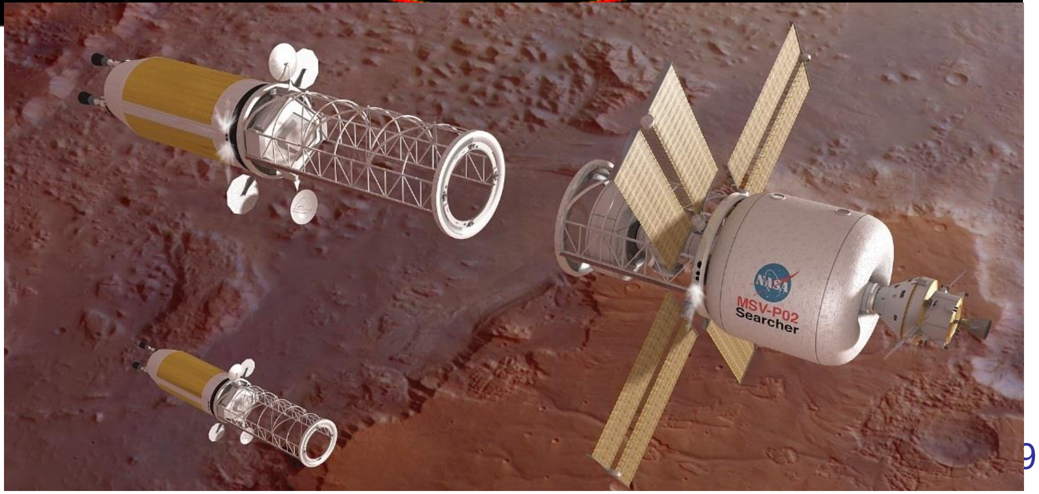


Mars Mission Studies

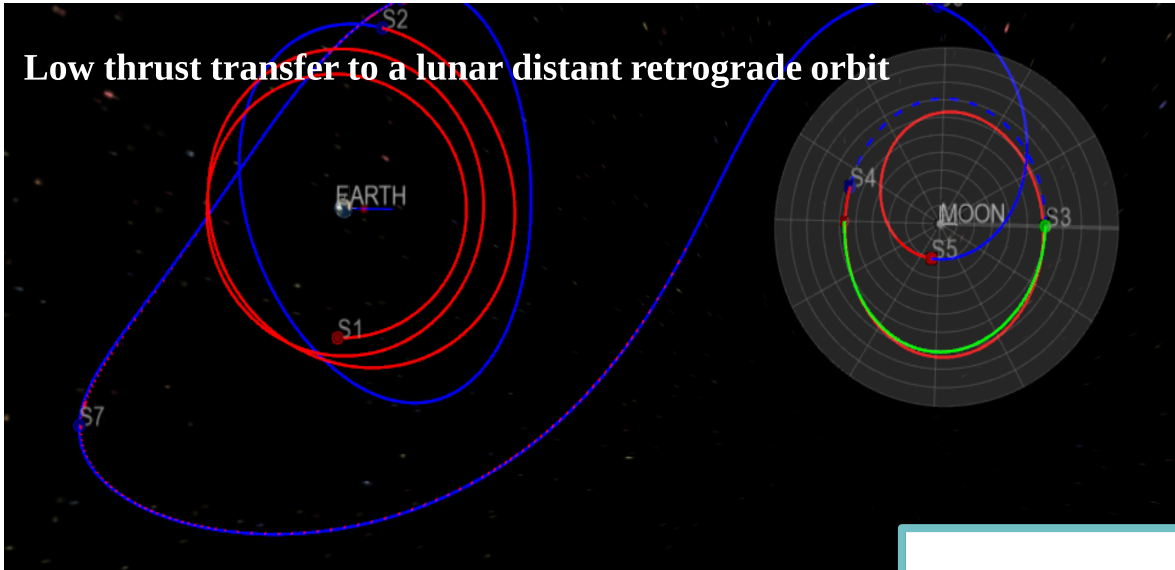




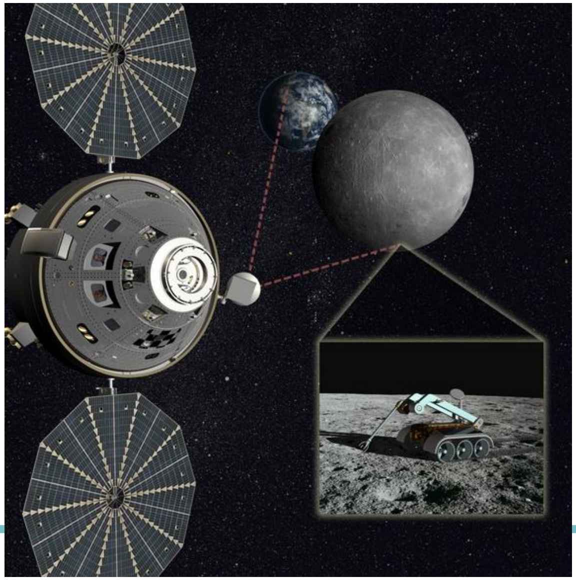
Inspriation Mars
2018 Mars Free-Return

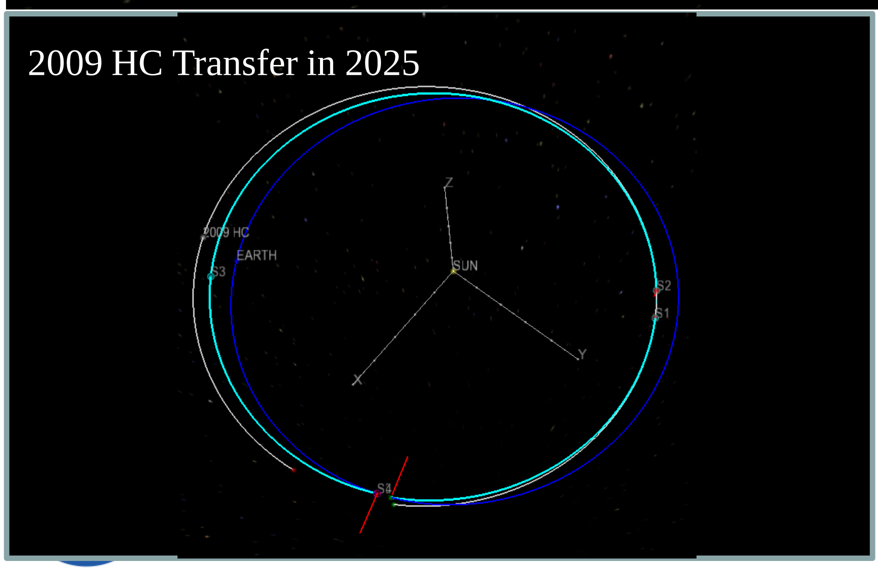


Ongoing Explorations Studies

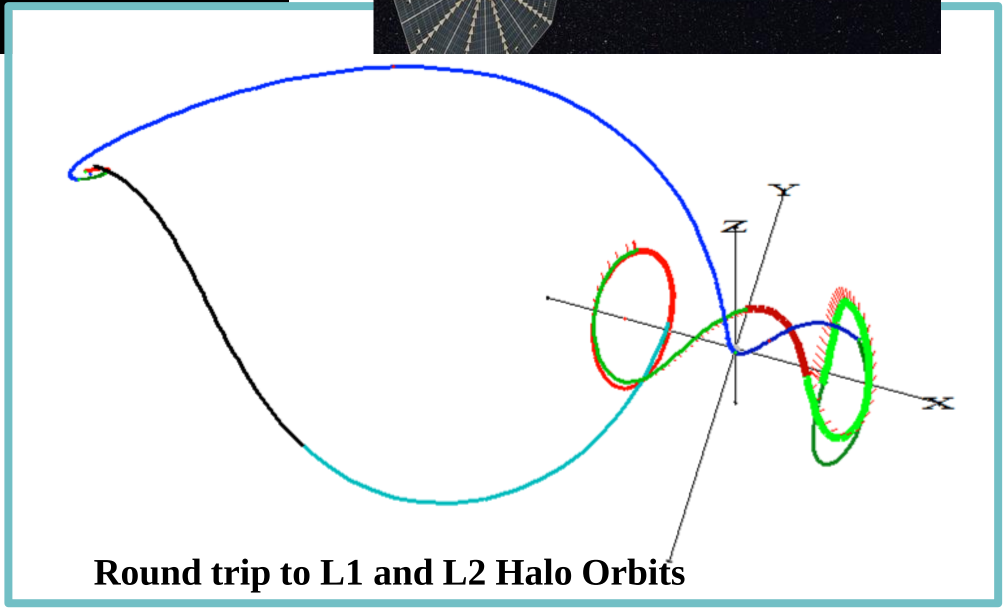


Low thrust transfer to a lunar distant retrograde orbit



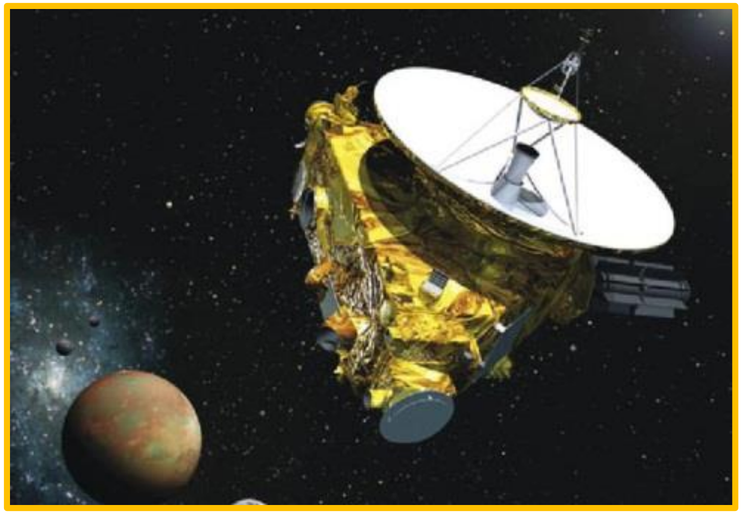


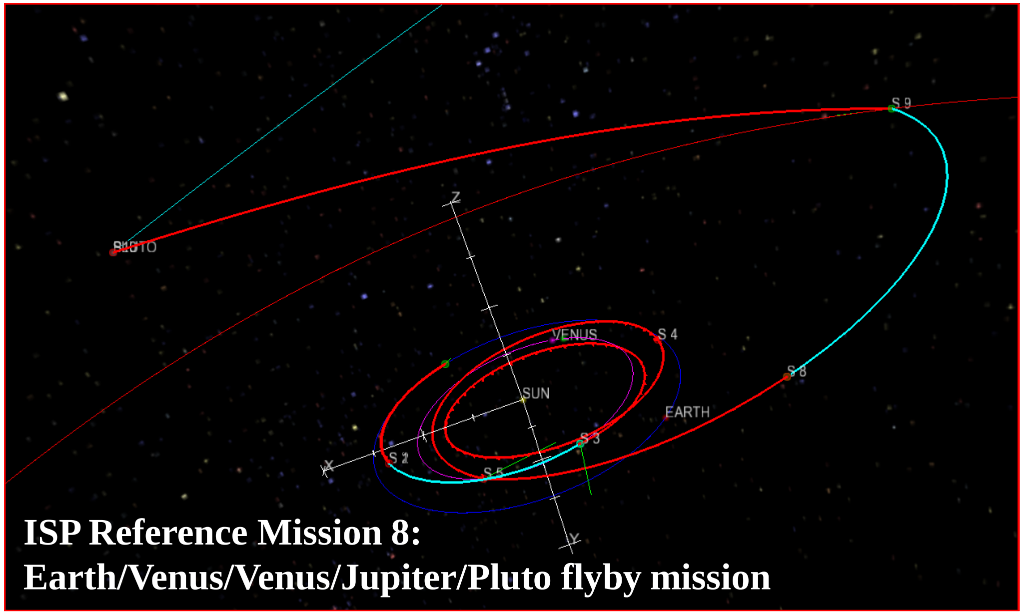
2009 HC Transfer in 2025



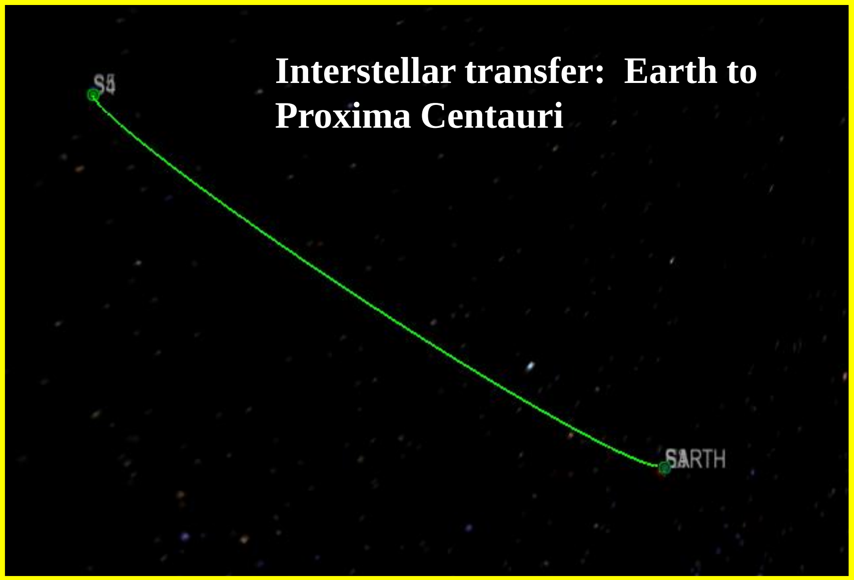
Round trip to L1 and L2 Halo Orbits

Outer Planet/Interstellar Trajectory Design

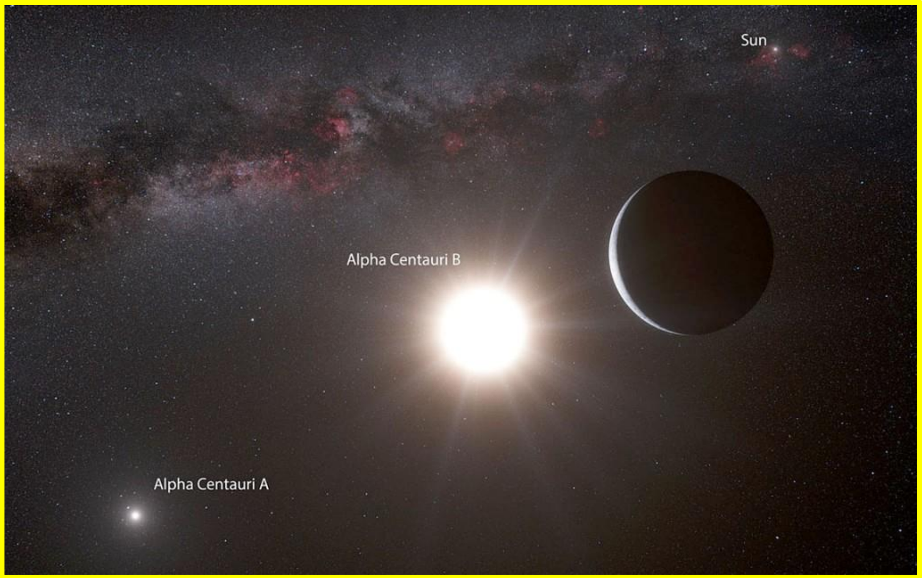




ISP Reference Mission 8:
Earth/Venus/Venus/Jupiter/Pluto flyby mission

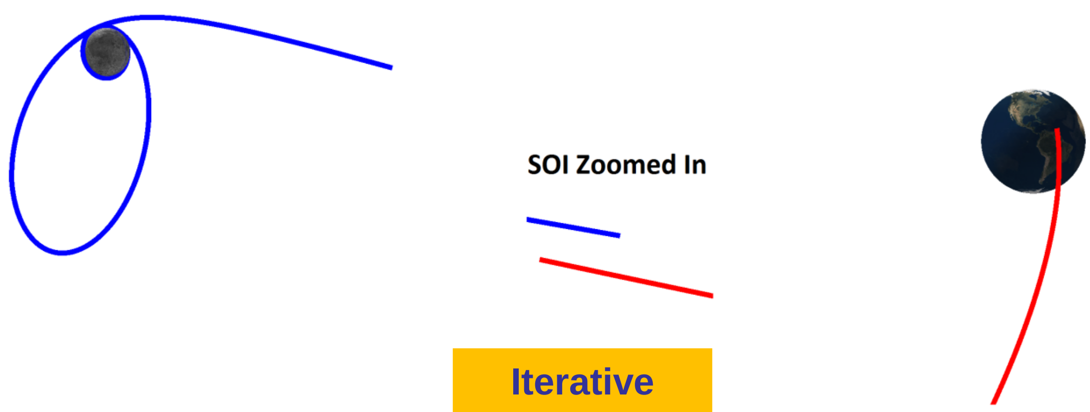


Interstellar transfer: Earth to Proxima Centauri

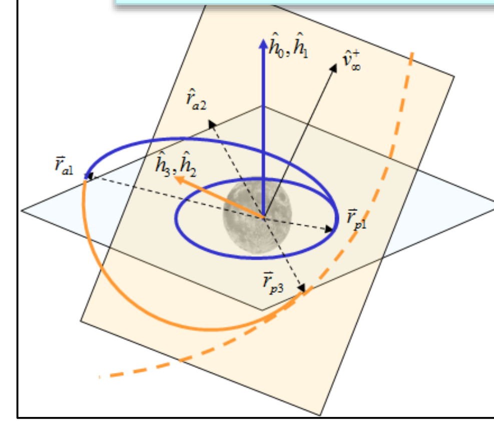


TEI Autonomous Targeting

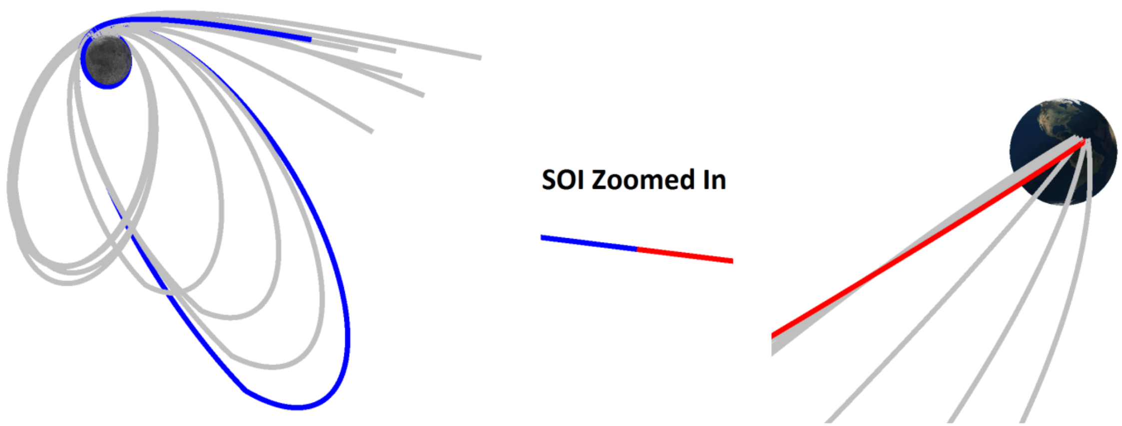
Initial Guess Generation



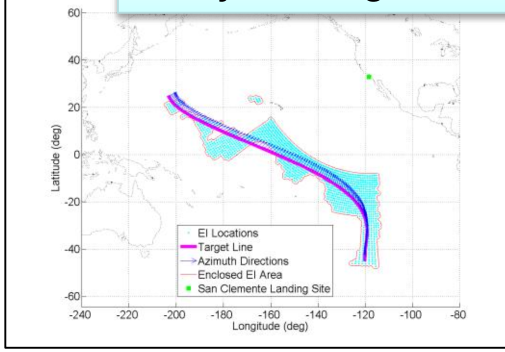
Fully Analytic



Iterative Algorithm

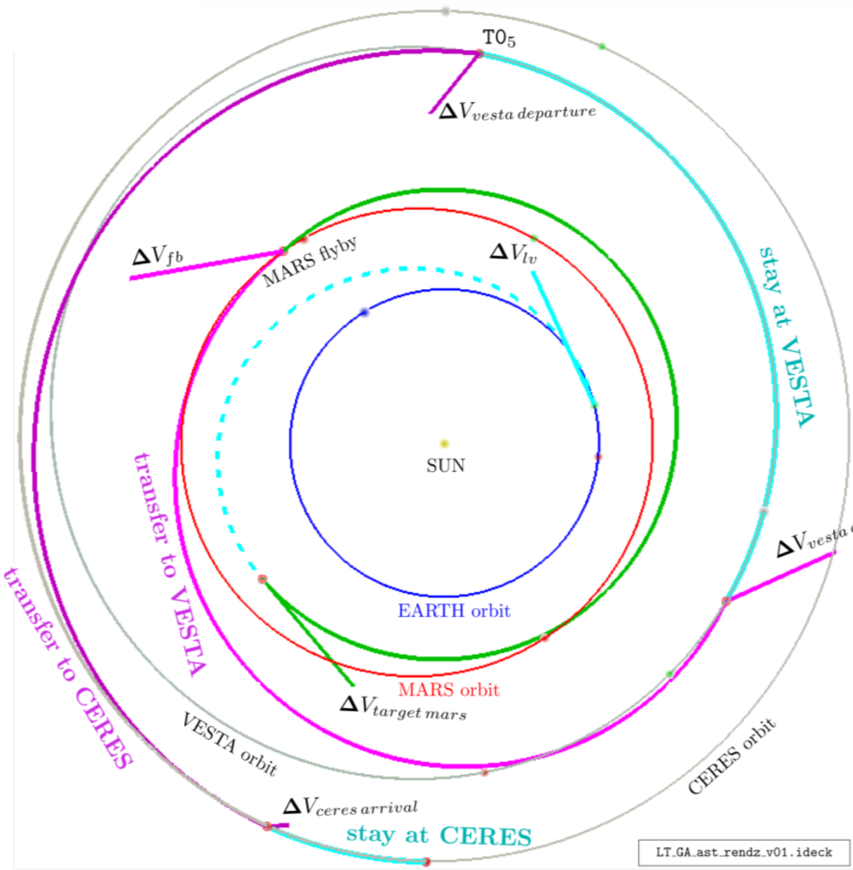


Entry EI Target Line

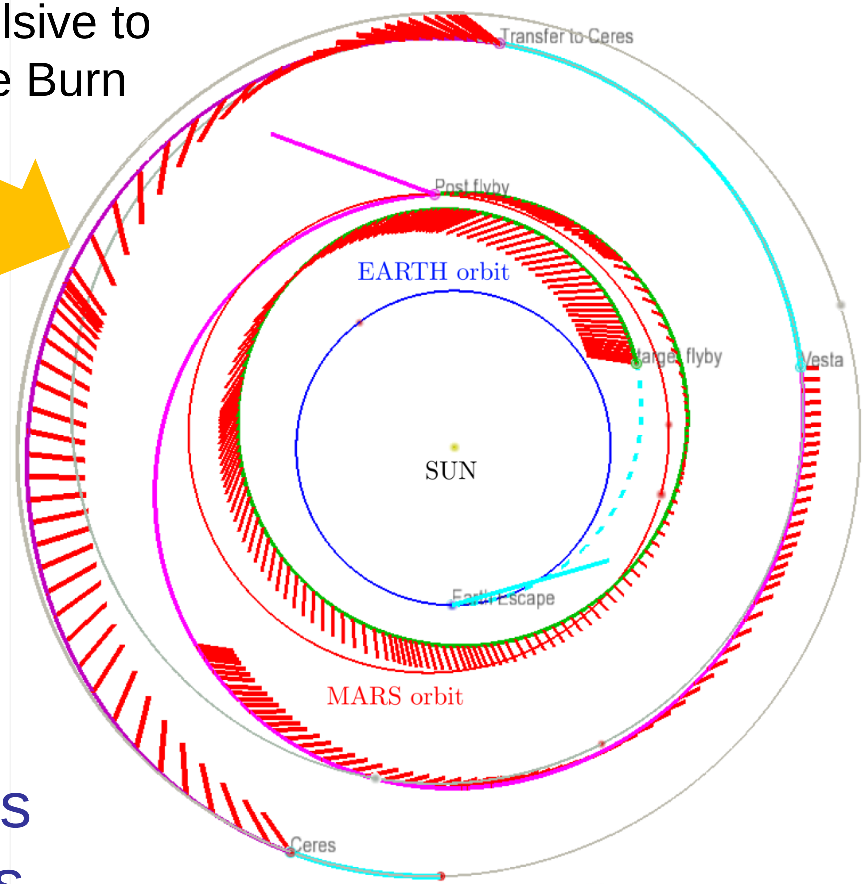


Impulsive Solution

Advanced Mission Design: Asteroid Missions

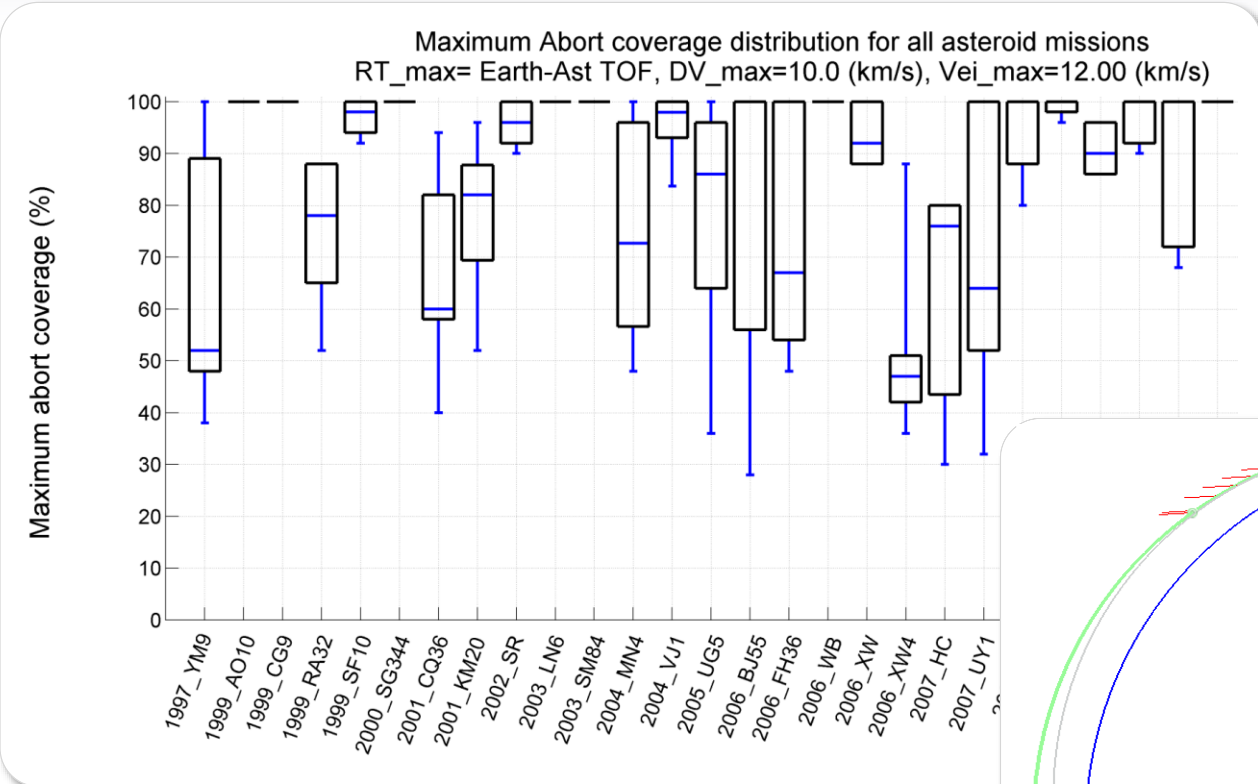


Impulsive to Finite Burn



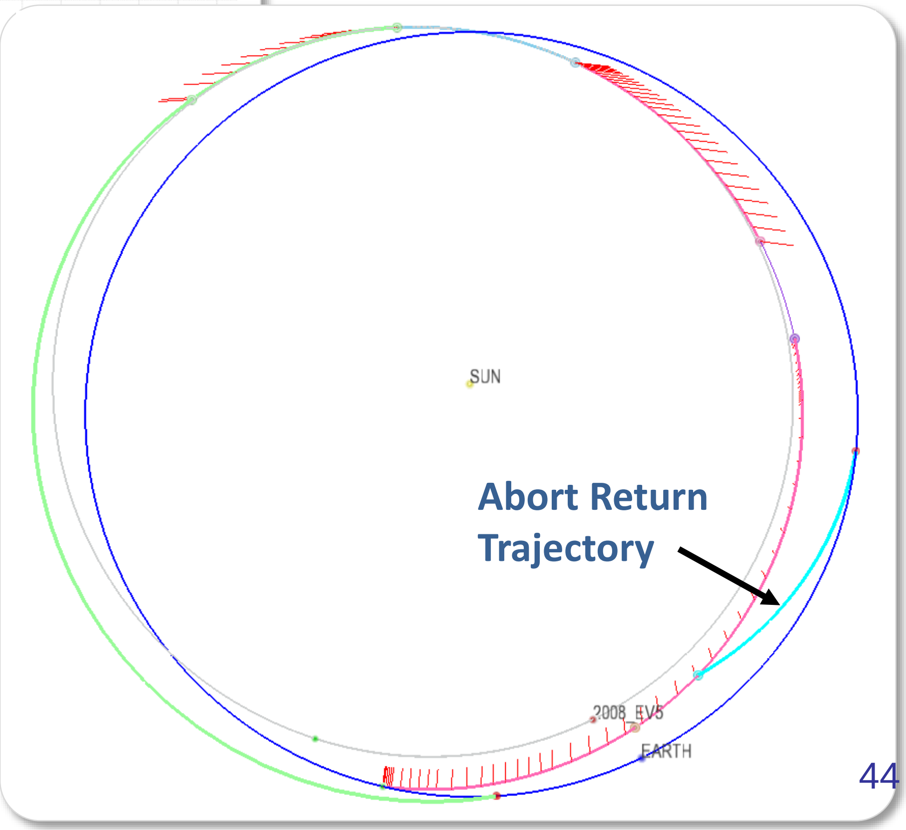
- Earth-Mars gravity assist flybys with Vesta & Ceres encounters

NEO Abort Studies

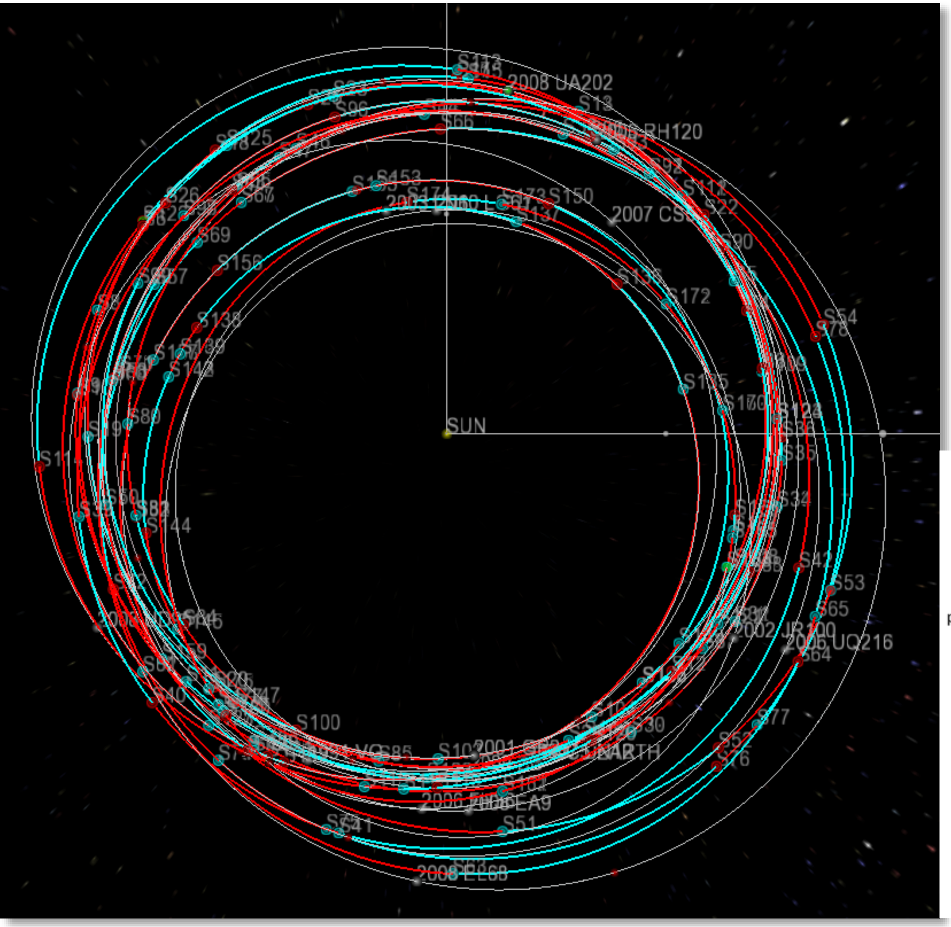


Temporal abort coverage for human missions to NEOs

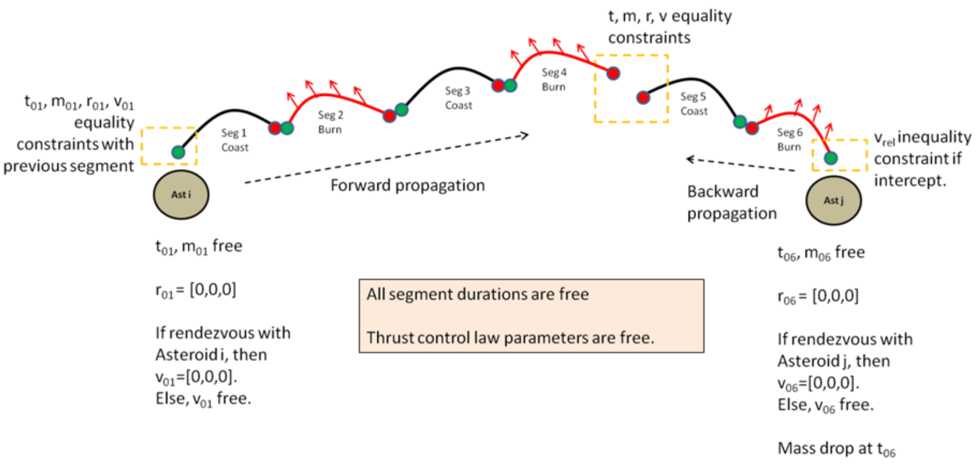
Low-thrust mission to asteroid with possible abort trajectory



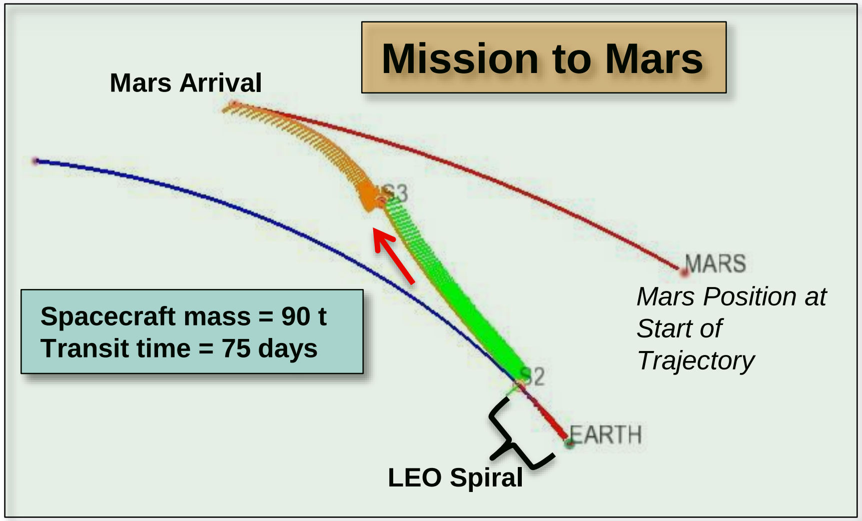
Advanced Mission Design: Asteroid Tours

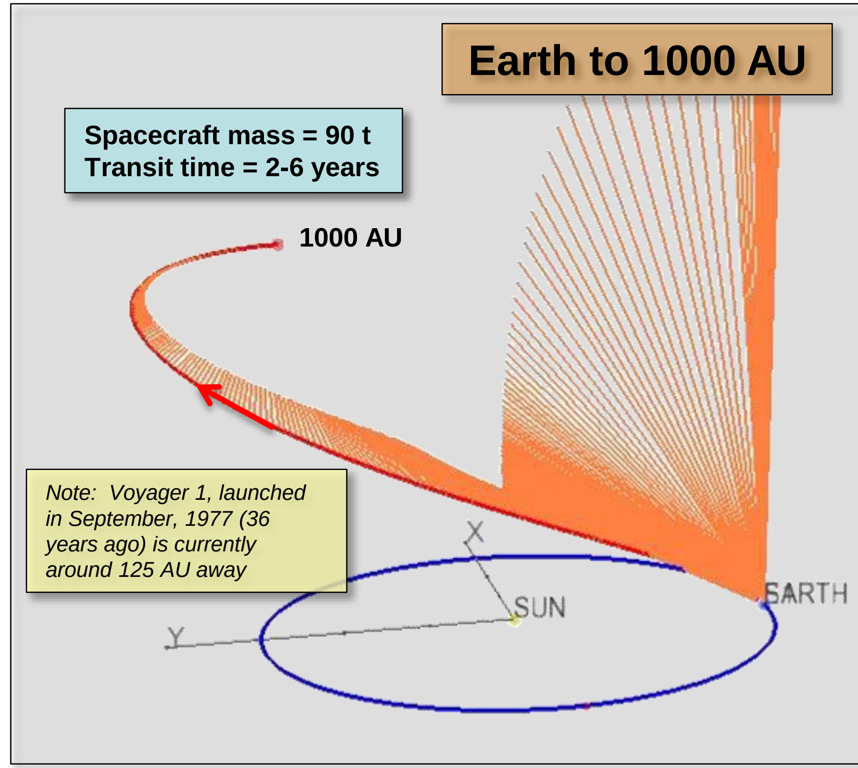


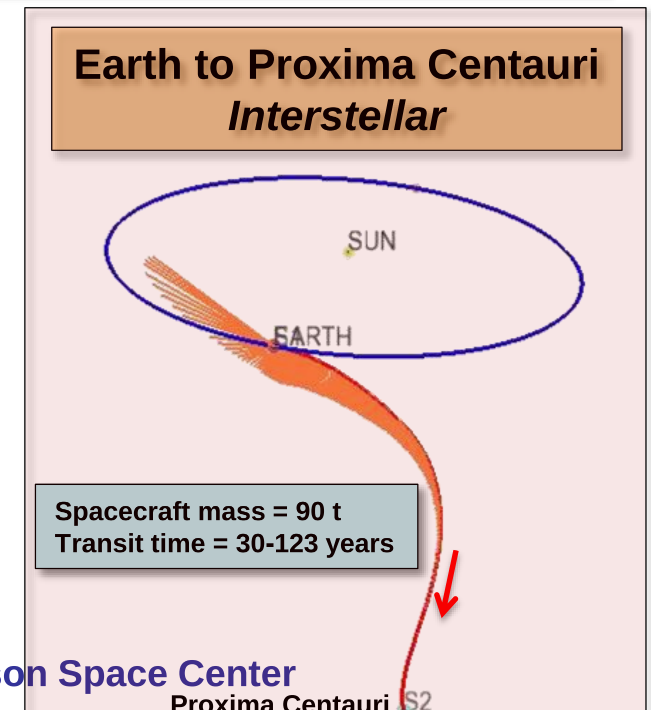
- Global Trajectory Optimization Competition
- Rendezvous and intercept the maximum number of asteroids in 15 years.



Quantum Vacuum Thruster







Copernicus in Academia

- University technical instruction and research
- Makes spacecraft trajectory design accessible to a much wider audience
- Inspires the interest and creativity of the next generation of engineers and scientists

Outline

- JSC / EG5 Capabilities
- Software Tools – Copernicus
  - Video
  - Overview
  - Mission Examples – General
- Lunar and Cislunar Mission Examples
  - Constellation
  - MARE
  - EM-1
  - EM-2
  - Other

Outline

- JSC / EG5 Capabilities
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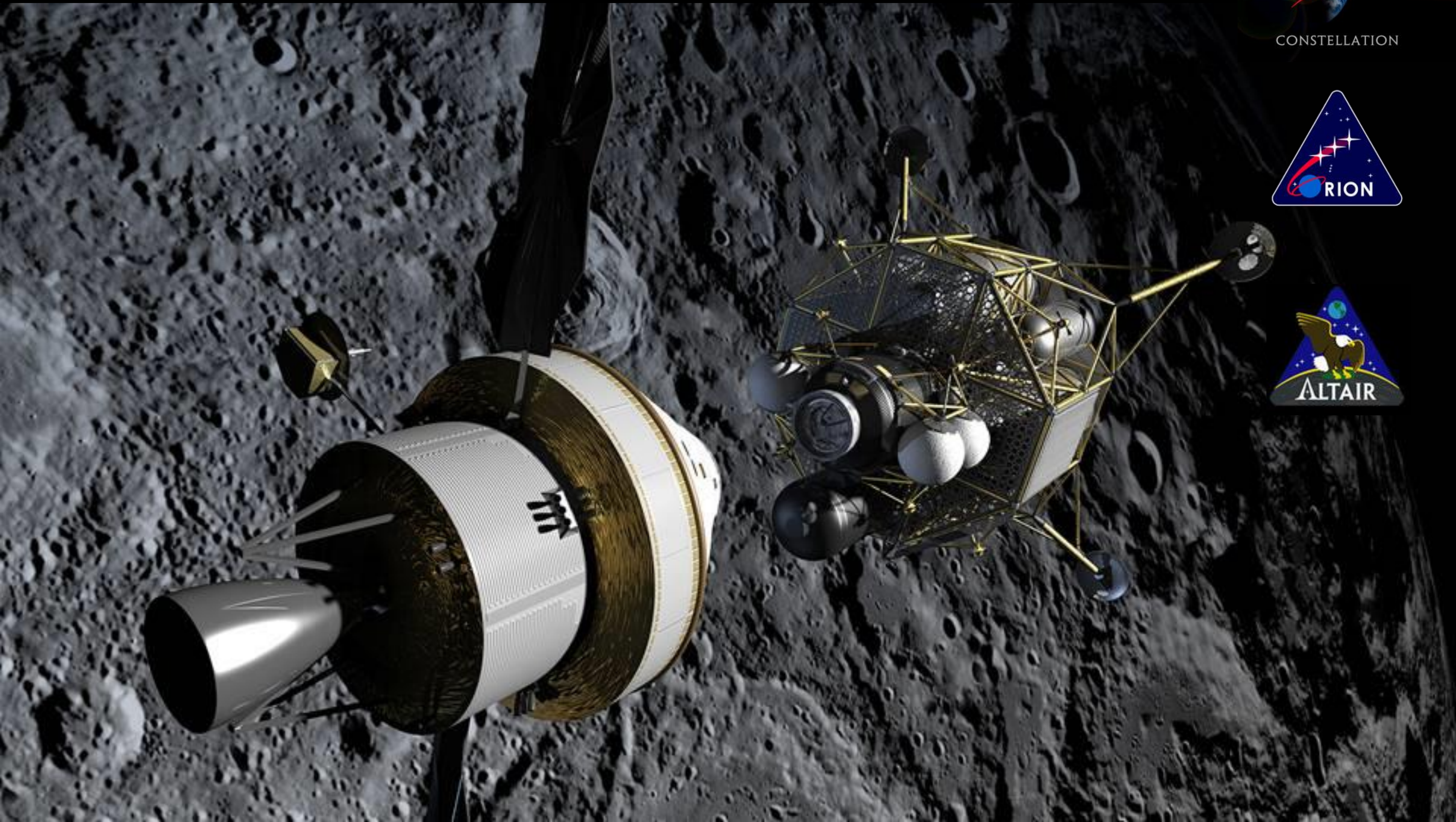
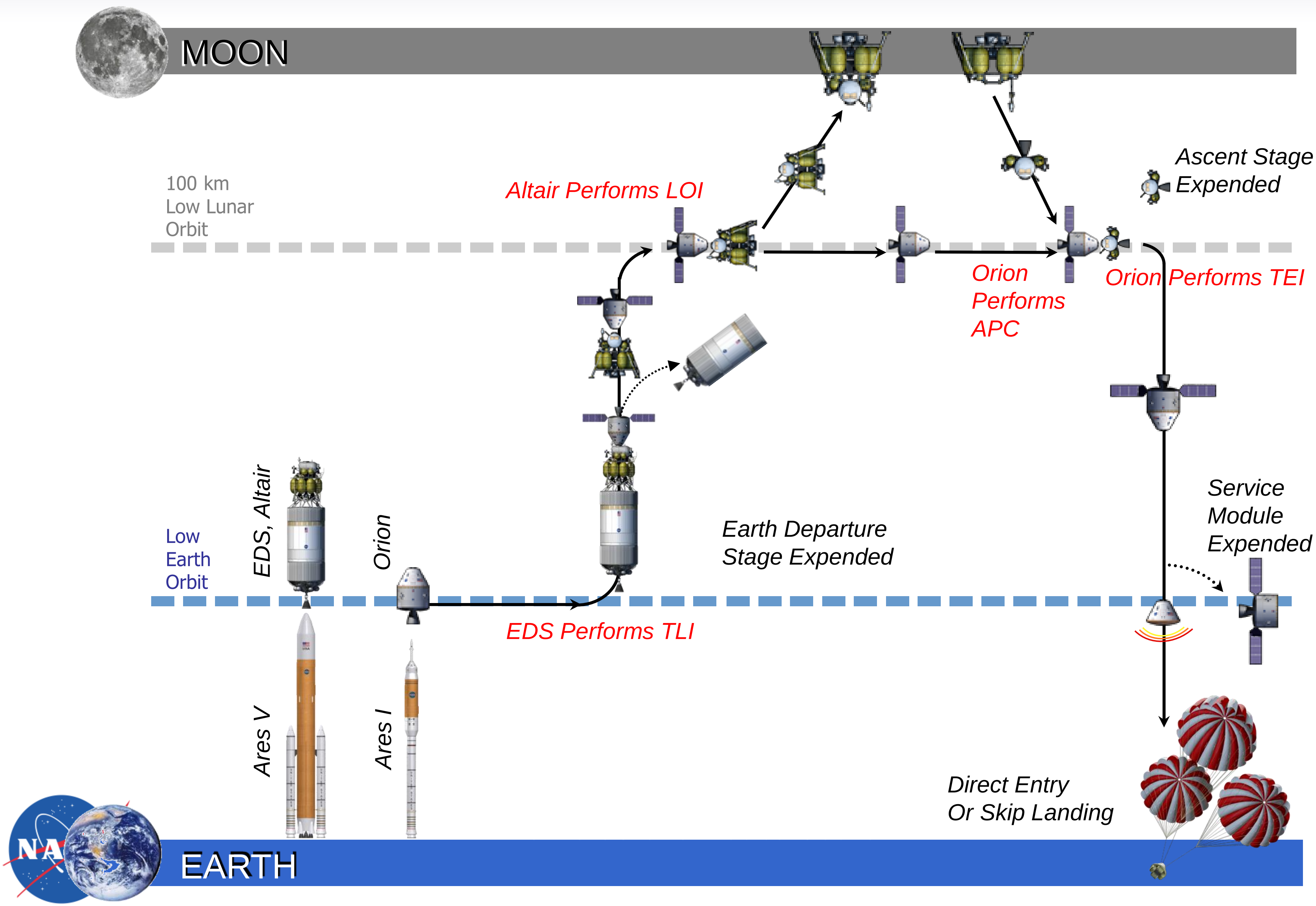
  - Constellation
  - MARE
  - EM-1
  - EM-2
  - Other

Mission Design and Performance Assessment for the Constellation Lunar Architecture



Mission Overview



Mission Types

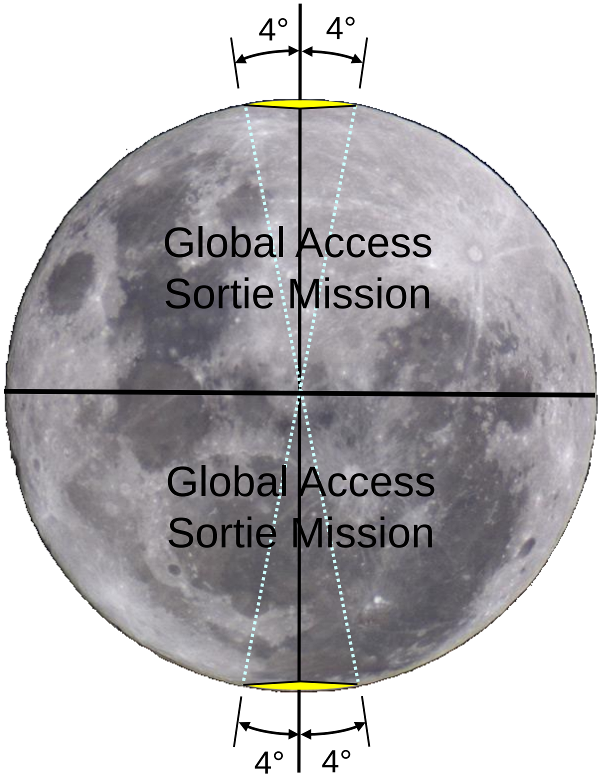
- <u>Polar Sortie</u>
  - Latitude mostly within 4° of either lunar pole
  - Surface stay $\leq$ 7 days
  - Orion low lunar orbit
    - Inclination = 90° ;
    - LAN = free => Minimum LOI ΔV
  - 1-burn LOI

- <u>Global Sortie</u>
  - Landing site (LS) region
    - Latitude = -86° to 86° ; Any longitude
  - Surface stay $\leq$ 7 days

LS latitude, longitude → Low lunar orbit Inclination, LAN

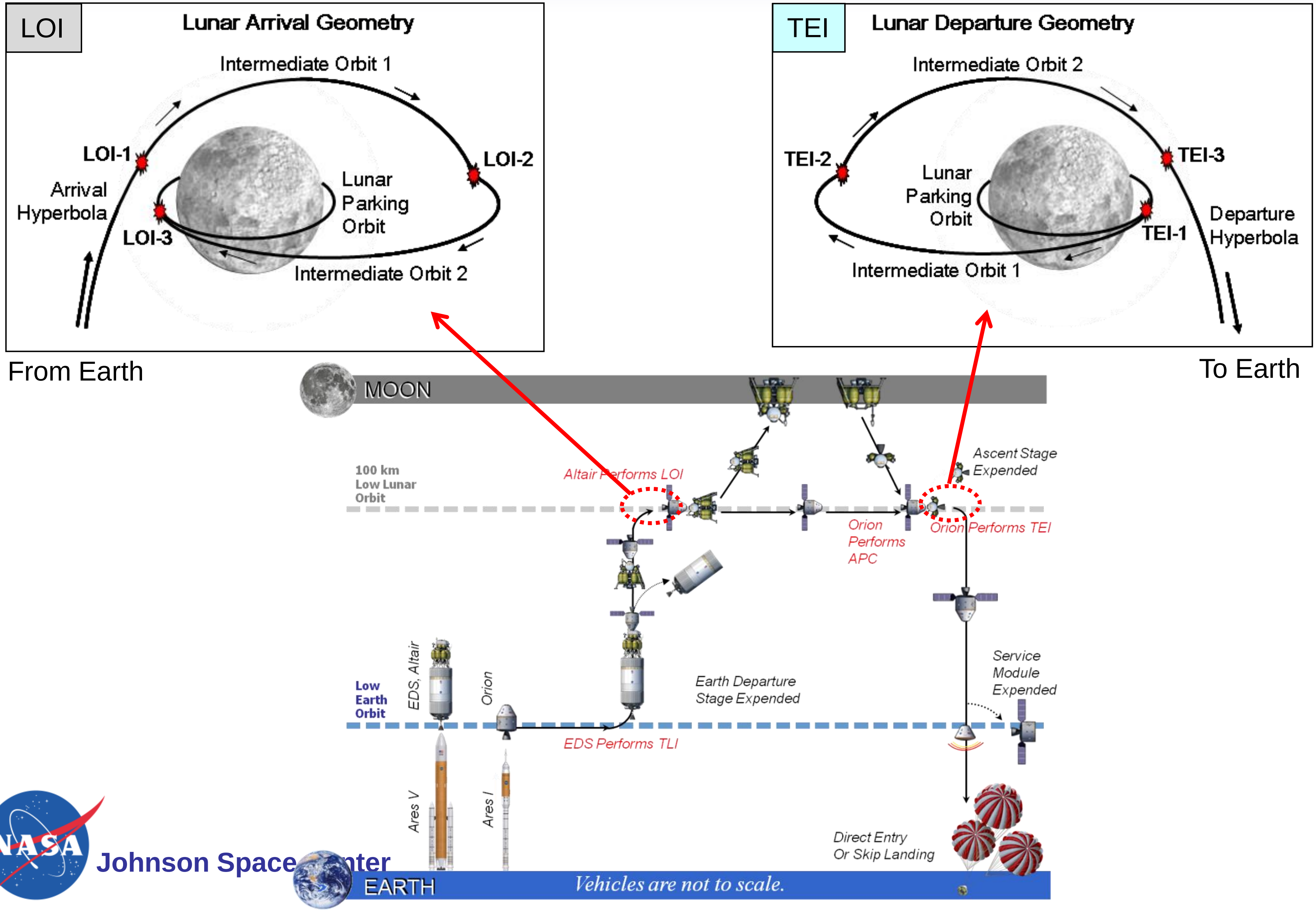
  - 3-burn LOI (in general)

Lunar Sortie/
Outpost Region
+86° to +90° Latitude



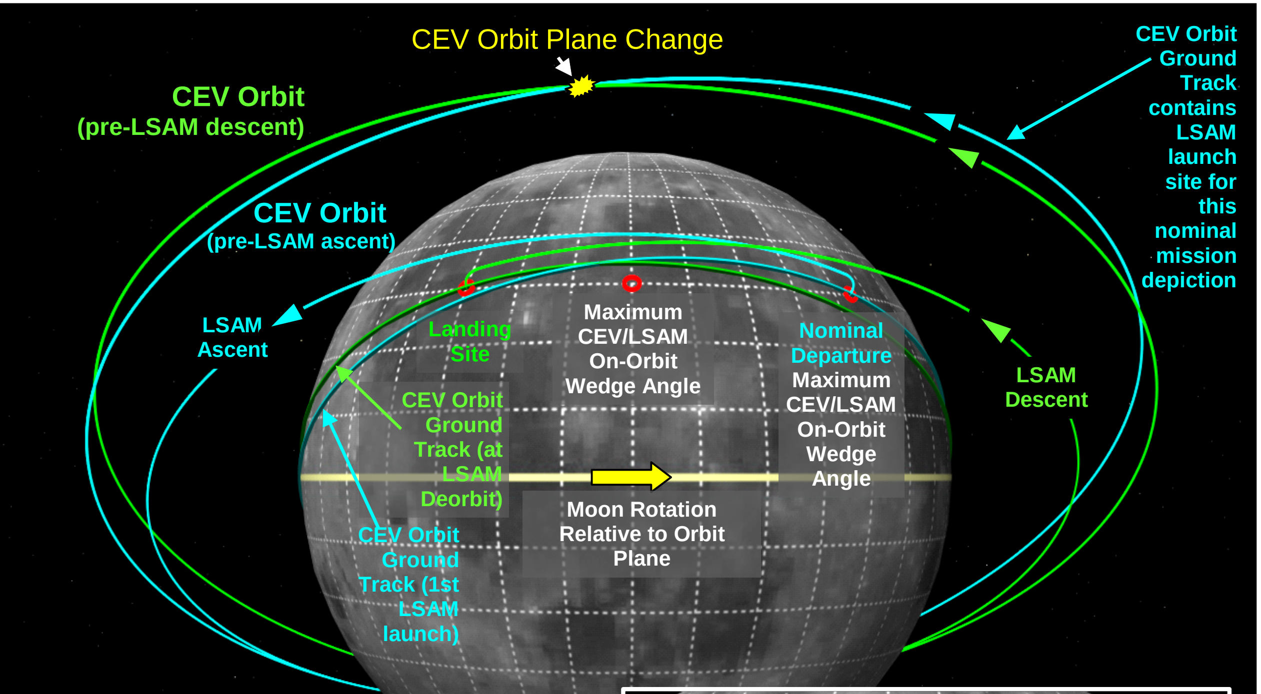
Lunar Sortie/
Outpost Region
-86° to -90° Latitude

Global Sortie Mission Design:
Lunar Orbit Insertion (LOI) and Trans-Earth Injection (TEI)



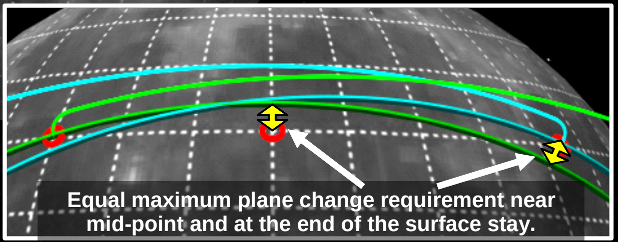
Lunar Mission Design: Abort Considerations

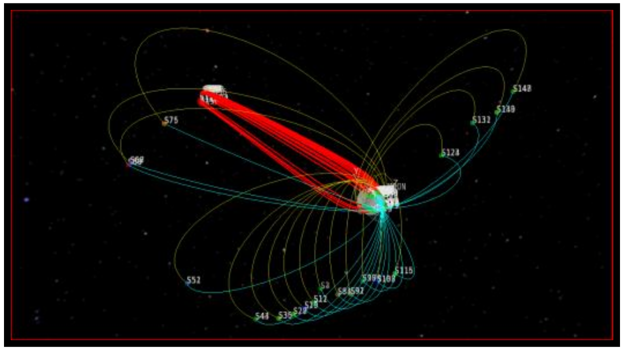
- Anytime departure from the lunar surface
- Anytime return to the Earth using a three-burn TEI sequence.

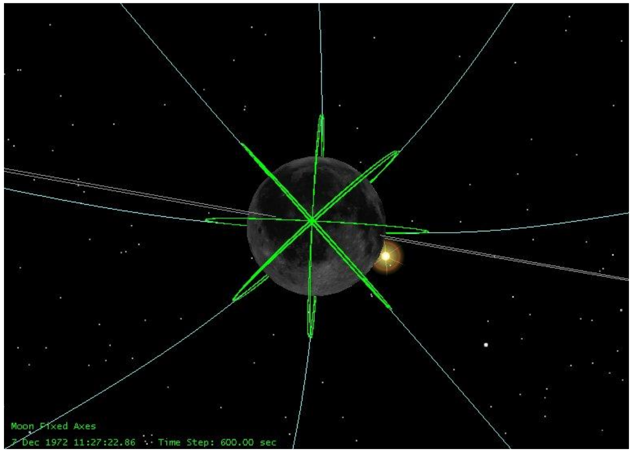


Strategy for Anytime Departure

1. The LOI orbit inclination and longitude of the ascending node are selected so that the plane change required to align the CEV for LSAM ascent/rendezvous never exceeds a specified value, found near the mid-point and the end of the surface stay.
2. Prior to LSAM launch, the post-LOI CEV orbit plane is changed to provide (near) in-plane LSAM ascent.







Temporal Coverage: Blended Polar/Global Sortie Mission Design

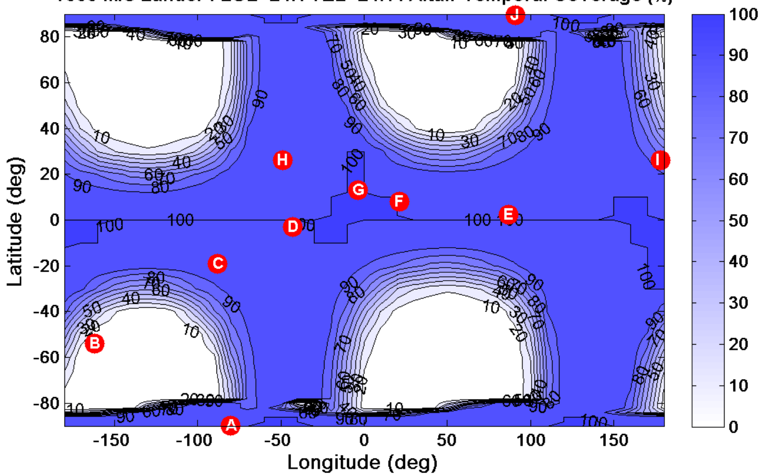
(No Extended TEI Loiter, Altair LOI ΔV = 1000 m/s)

Nominal Mission (no extended Altair loiter)

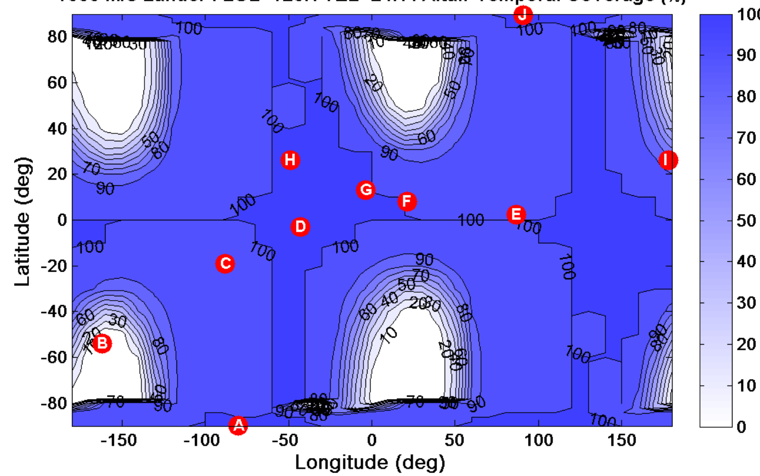
4 Days Altair Post-LOI Extended Loiter

Altair Only

1000 m/s Lander : LOL=24H TEL=24H : Altair Temporal Coverage (%)

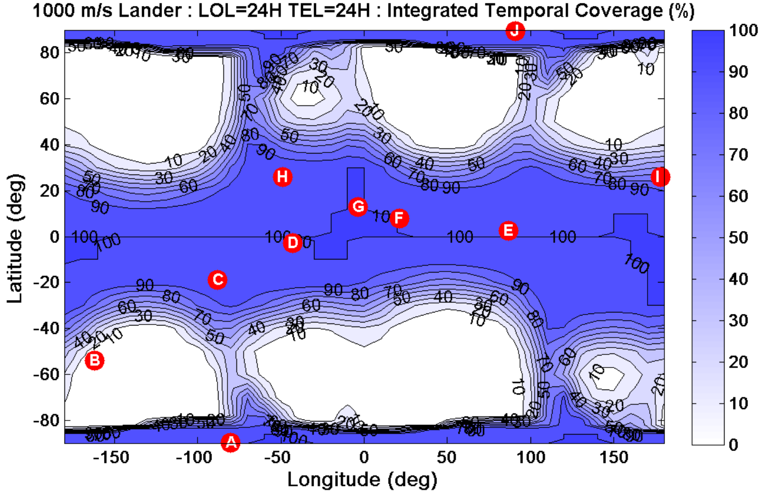


1000 m/s Lander : LOL=120H TEL=24H : Altair Temporal Coverage (%)

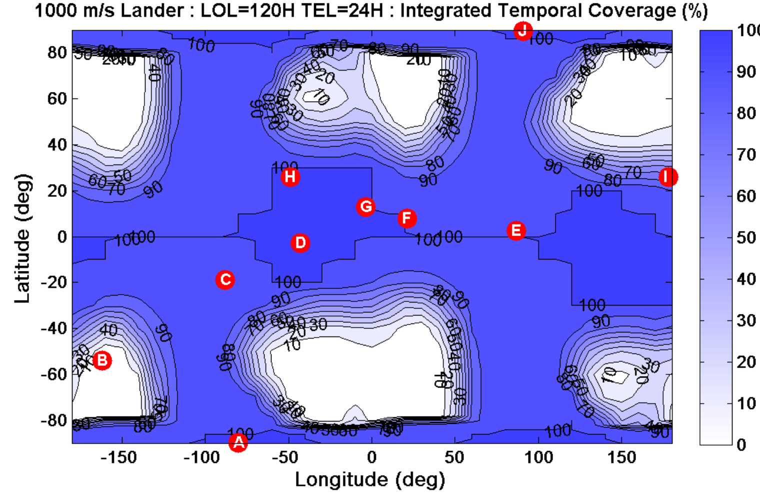


Integrated Altair and Orion

1000 m/s Lander : LOL=24H TEL=24H : Integrated Temporal Coverage (%)



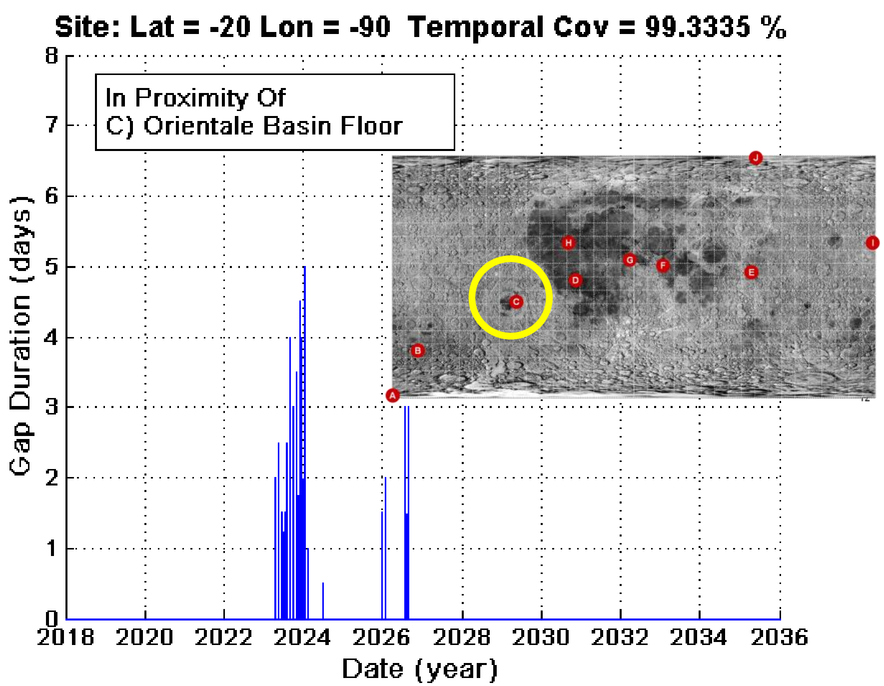
1000 m/s Lander : LOL=120H TEL=24H : Integrated Temporal Coverage (%)



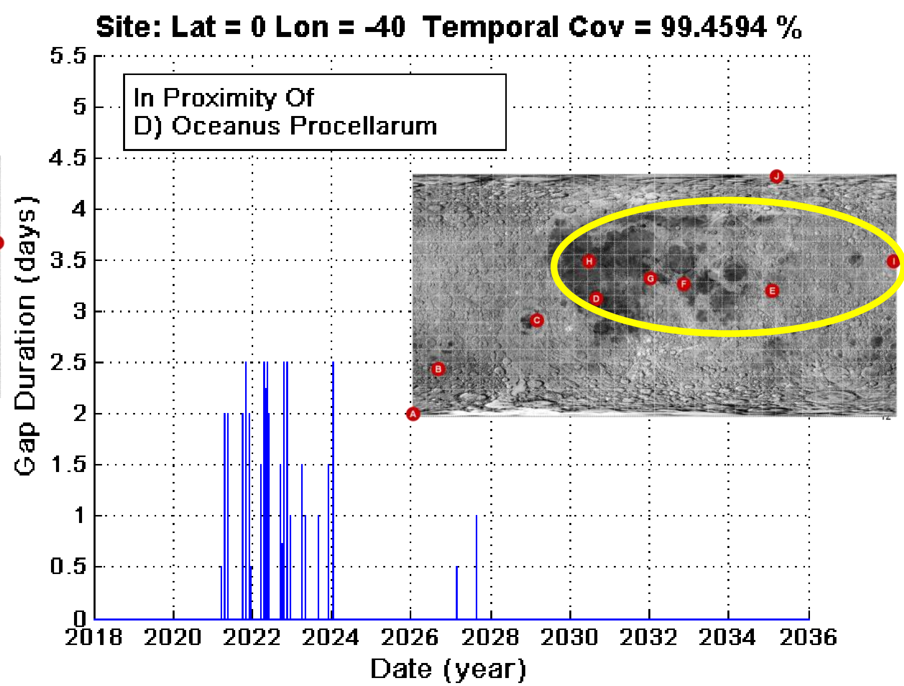
Gap Analysis – ESAS Sites Temporal Coverage

Integrated Altair/Orion gap assessment
4 days of extended LOI loiter and no extended TEI loiter
for landing sites in the proximity of:

C) Orientale Basin Site



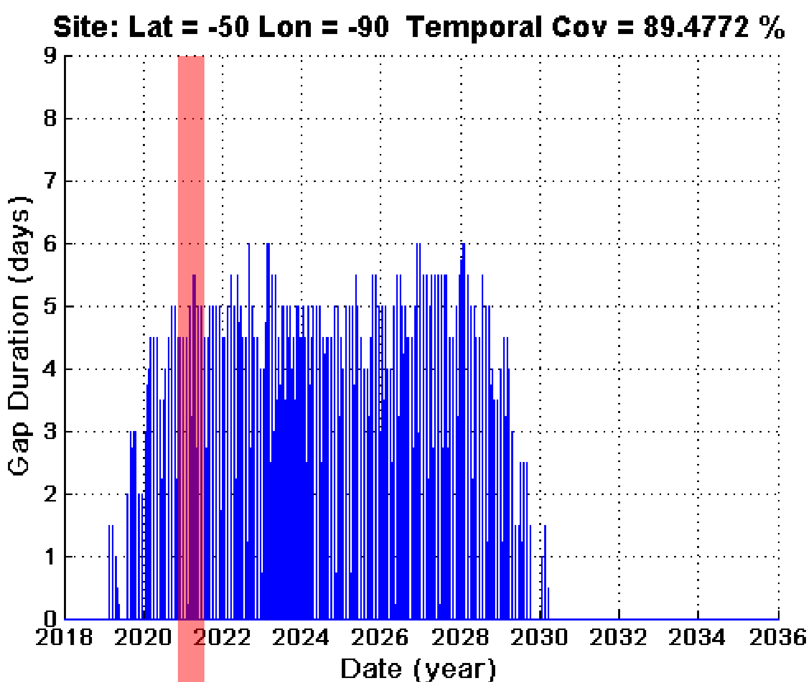
Typical Coverage for Equatorial ESAS Landing Sites (D – H)



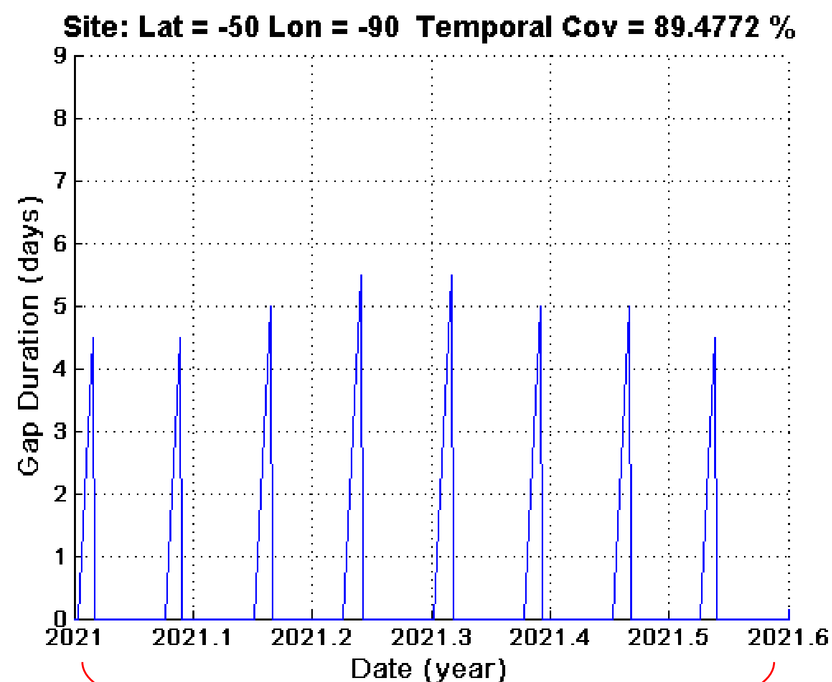
Gap Analysis – 90% Temporal Coverage Example

Integrated Altair/Orion gap assessment
4 days of extended LOI loiter and no extended TEI loiter
for landing sites in the proximity of:

90% Temporal Coverage Site



Zoom-in of Peak Capability Gaps
for the 90% Coverage Case



Lunar Orbit Maintenance - Constellation

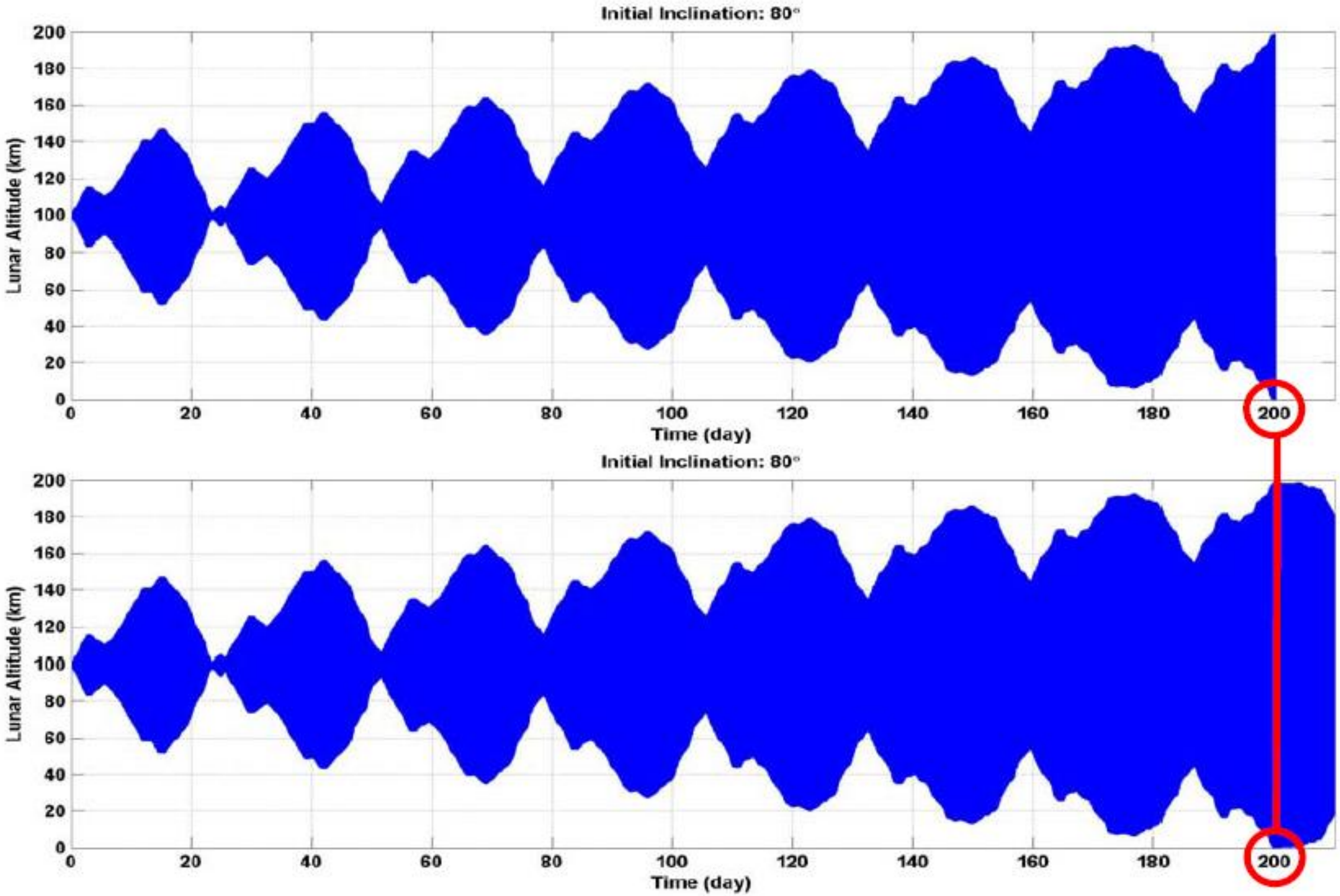
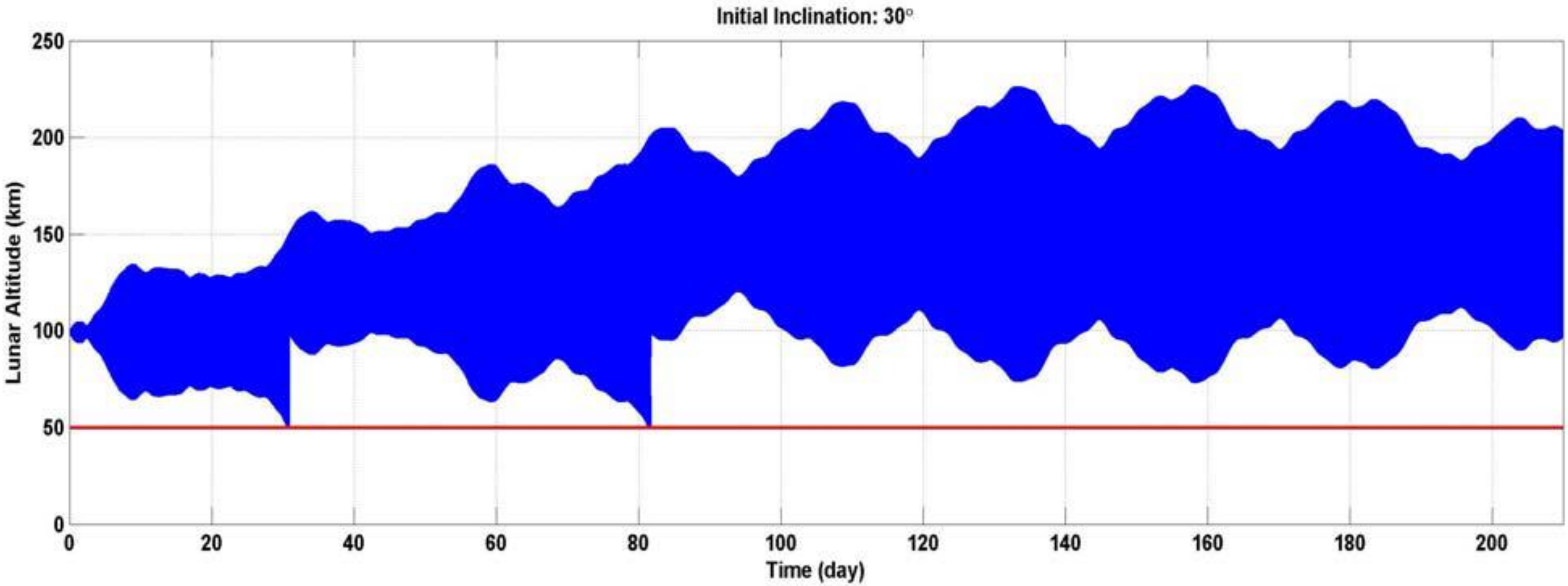


Figure 2-5: Comparison of propagation using the 50 x 50 (top) versus the 150 x 150 (bottom) fields at an 80° inclination.

Lunar Orbit Maintenance - Constellation

- Introduction of lunar orbit maintenance burns
- Deadband – restore periapsis to 100 km; let apoapsis float (until final or pre-departure maneuver)



Lunar Orbit Maintenance - Constellation

- For 100x 100 km lunar orbit, the minimum total DV cost occurs for orbits with inclinations of 85° and 95°

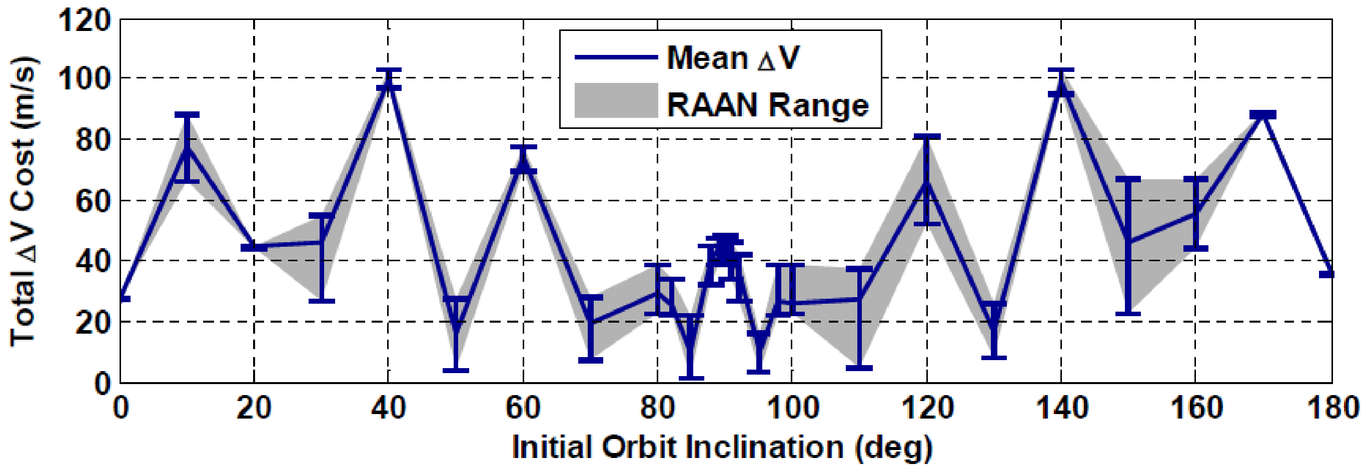
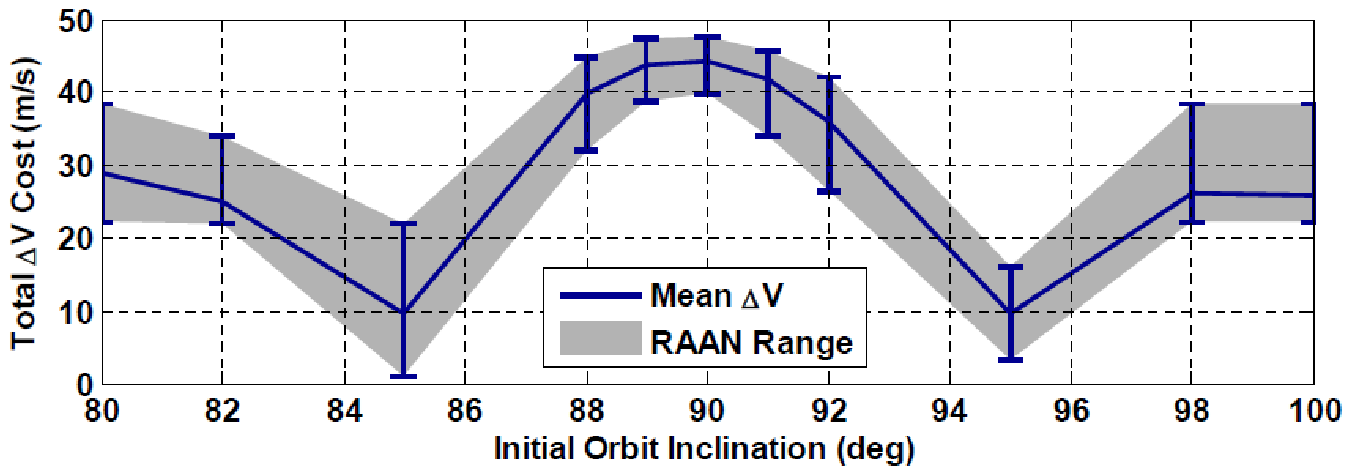


Figure 2-12: RAAN sensitivity across inclination.



Outline

- JSC / EG5 Capabilities
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  - Video
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- Lunar and Cislunar Mission Examples
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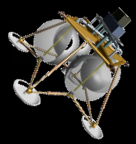
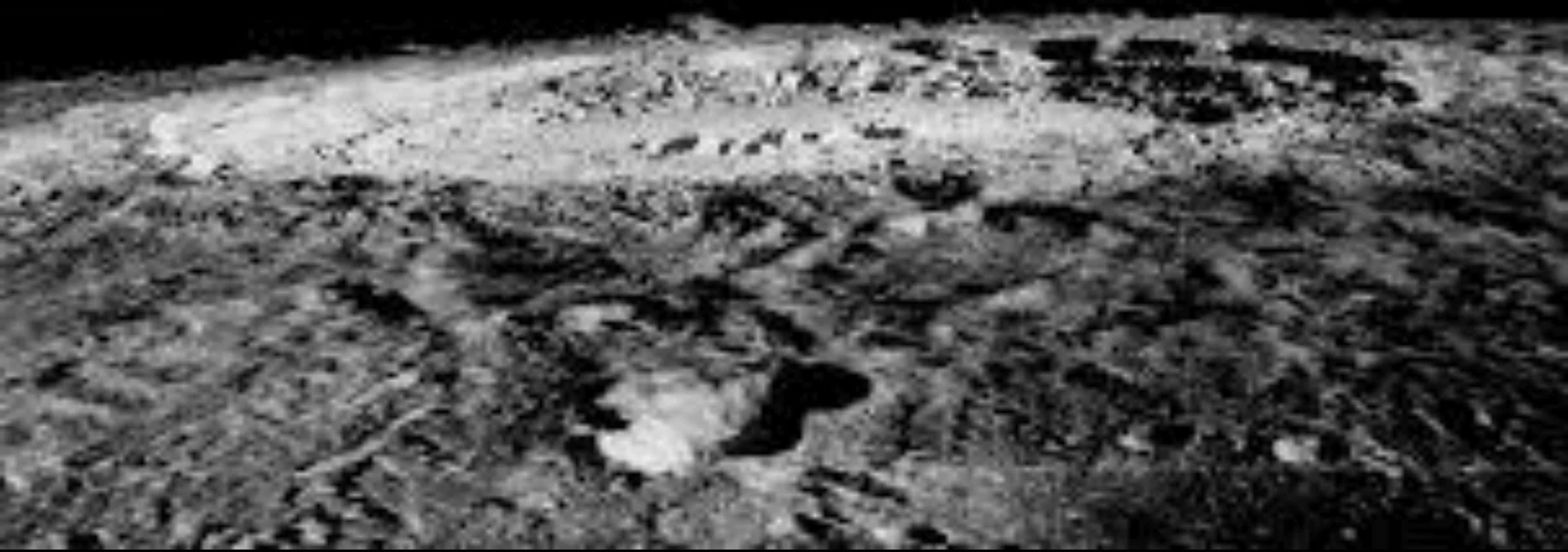
  - MARE
  - EM-1
  - EM-2
  - Other

Moon Age and Regolith Experiment



MARE



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September 4, 2014

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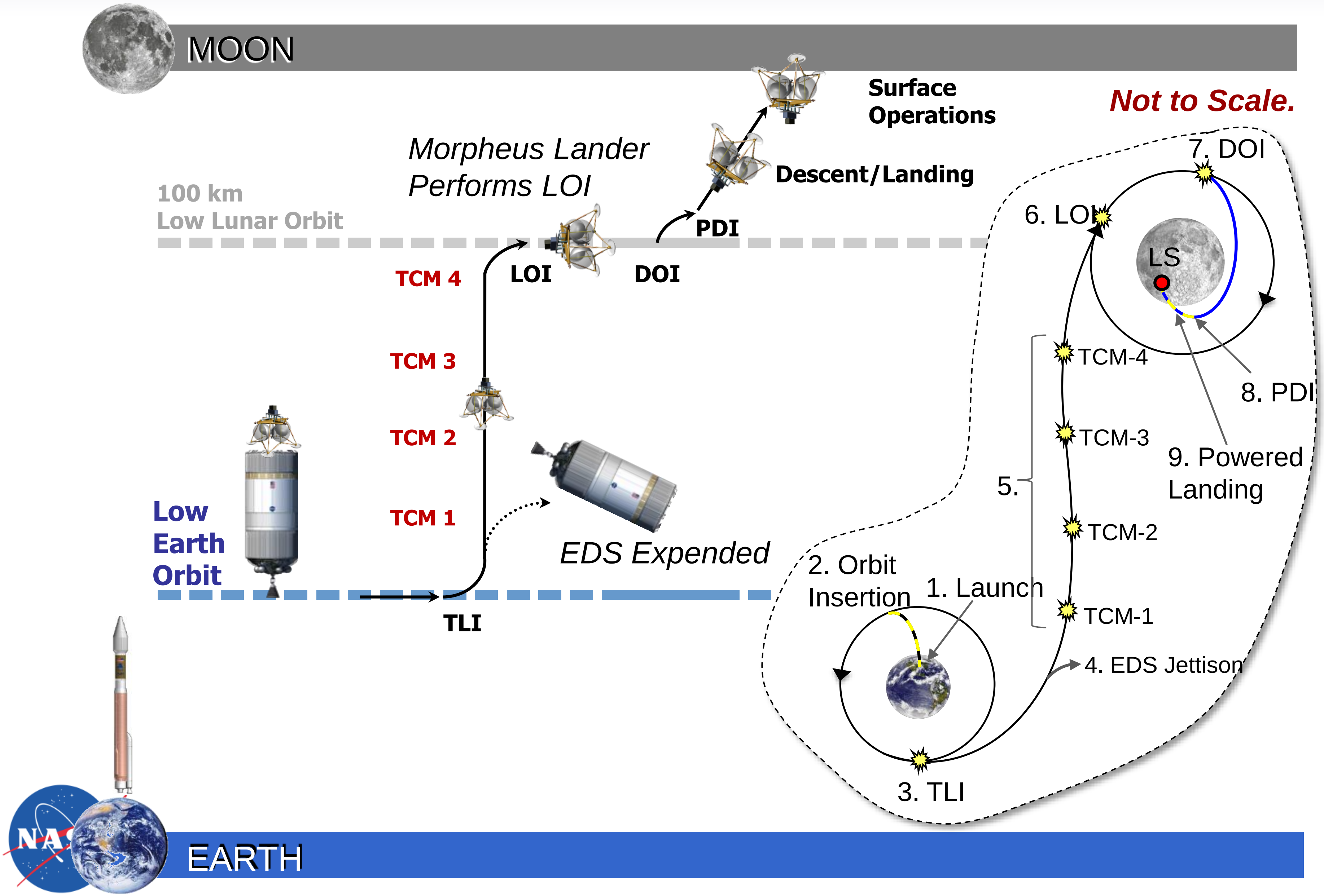
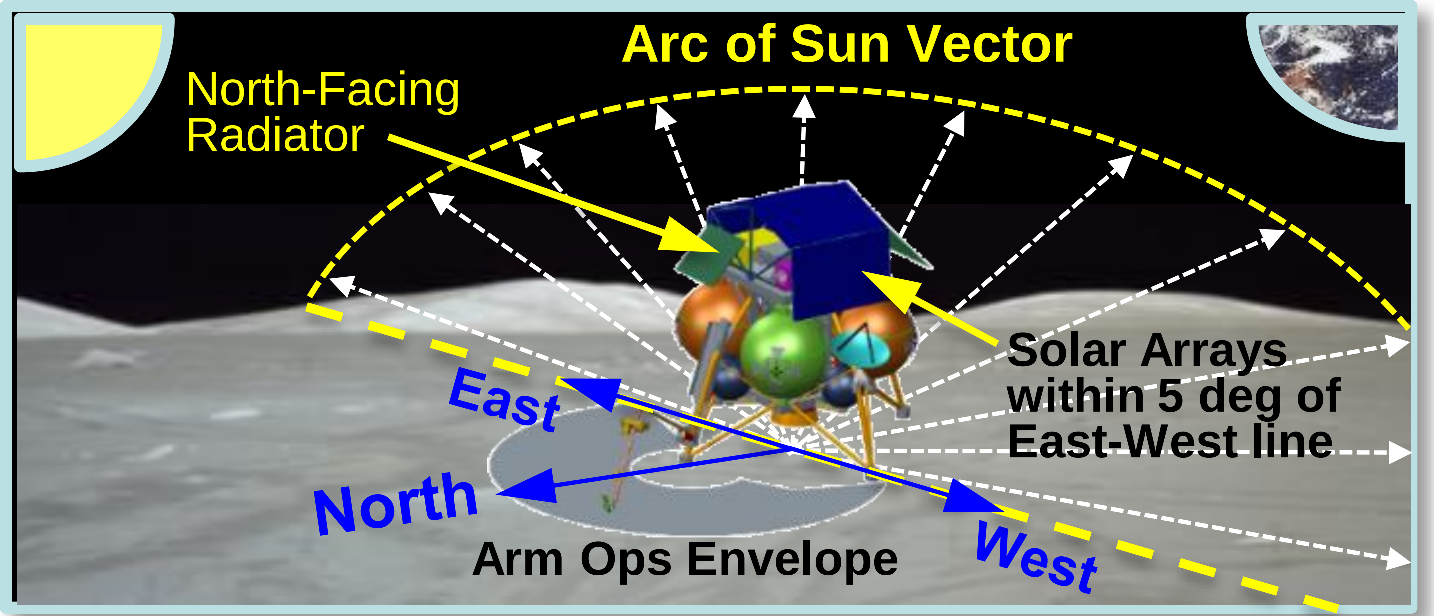
MARE mission overview

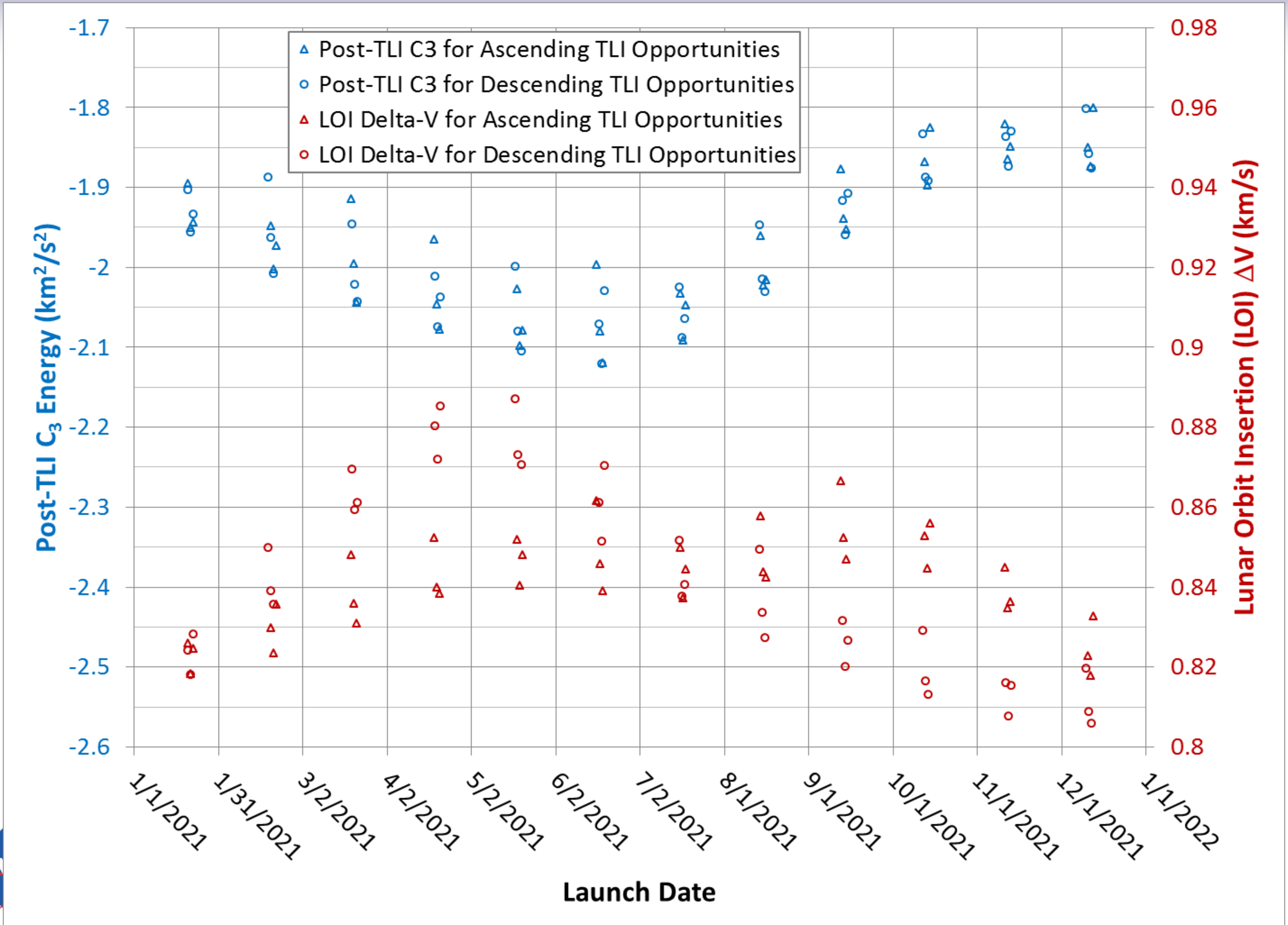


Lunar Day – Solar Arc

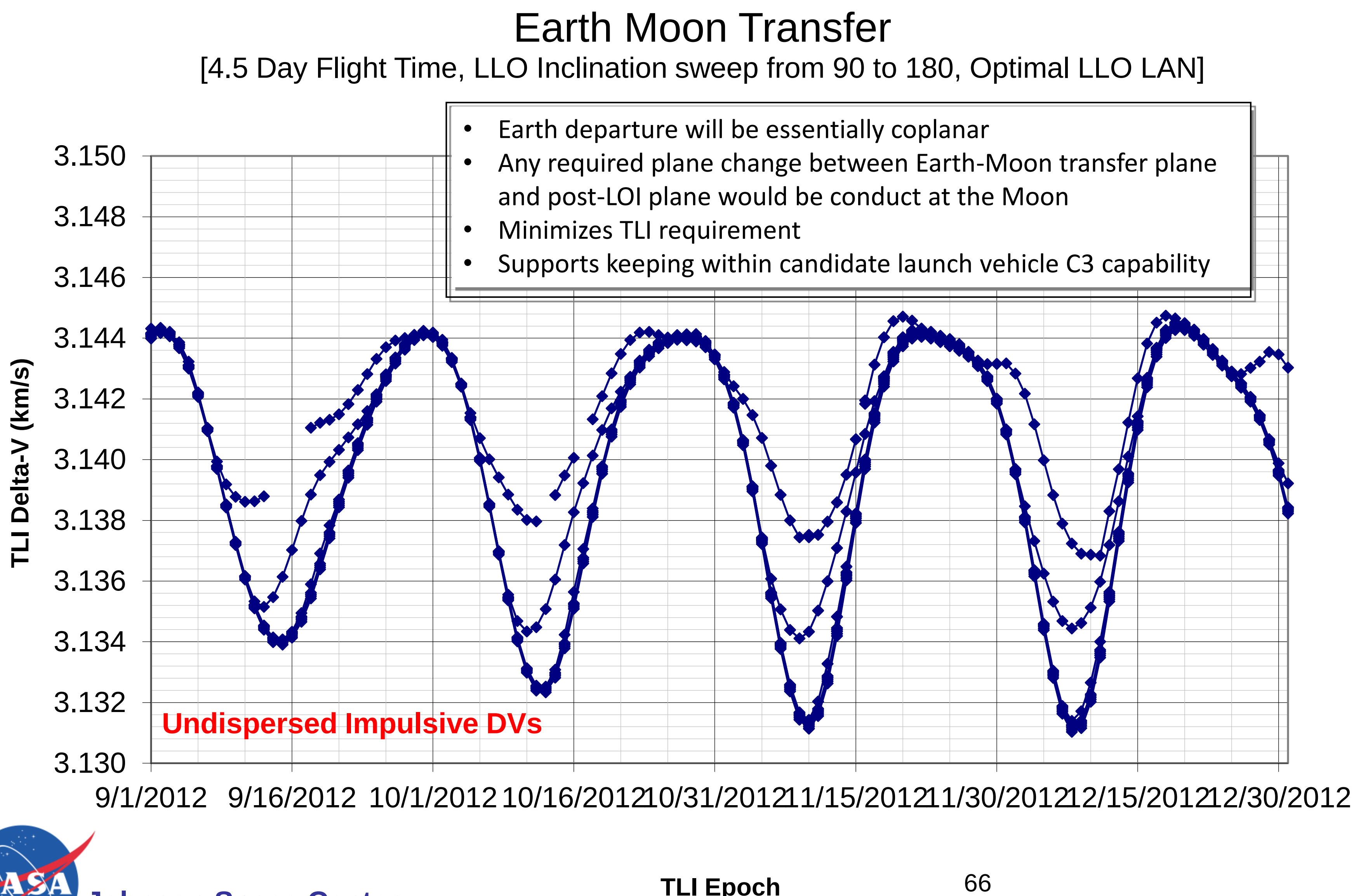
LUNAR SURFACE DAY OPS: ~13.5 DAYS



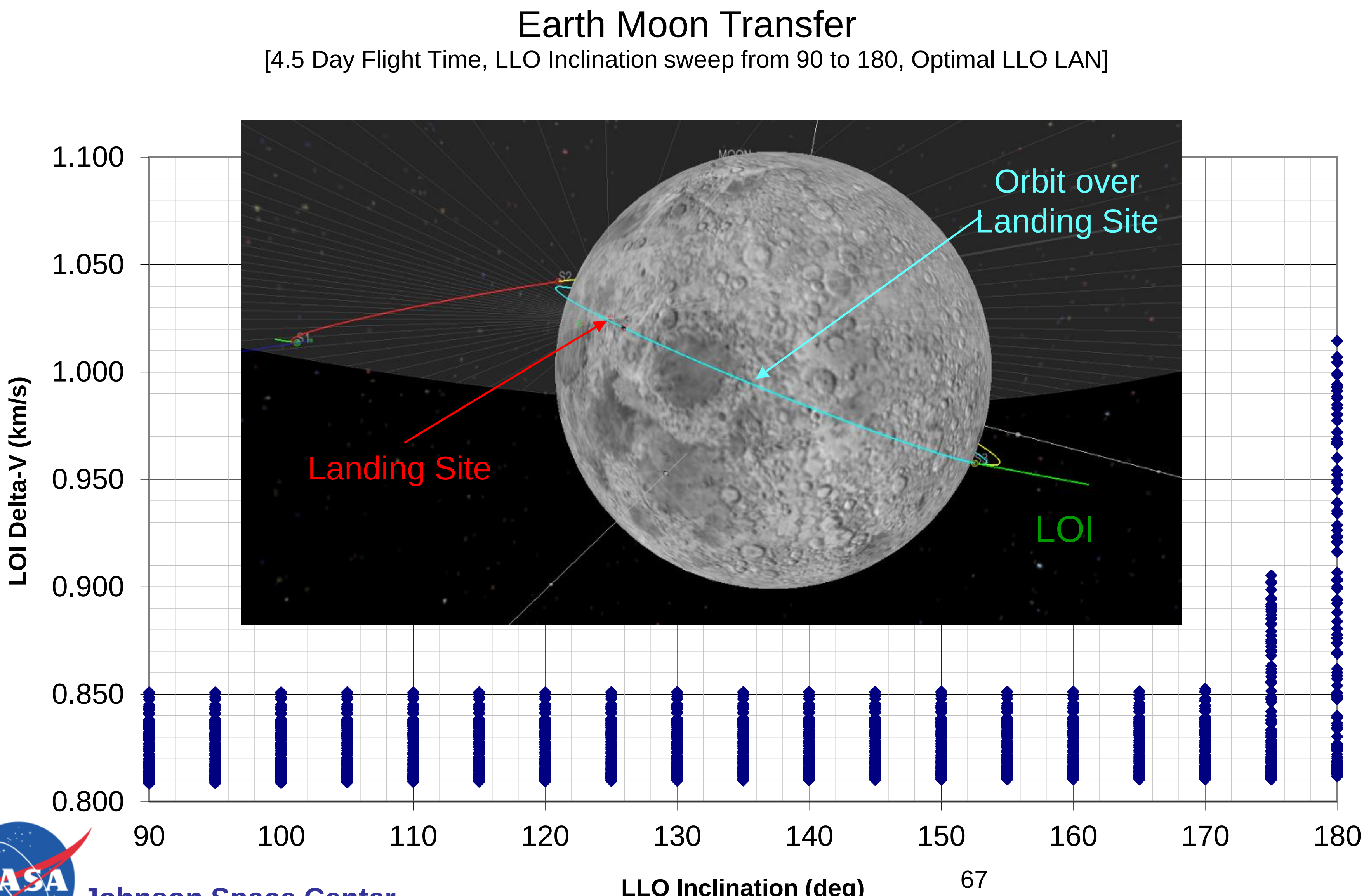
TLI and LOI Performance Scan for 2021 – 3 Ascending and 3 Descending TLI Opportunities per Landing Opportunity at 10° Sun Elevation for 23.4° N, 60.0° W



TLI ΔV vs Lunar Arrival Epoch

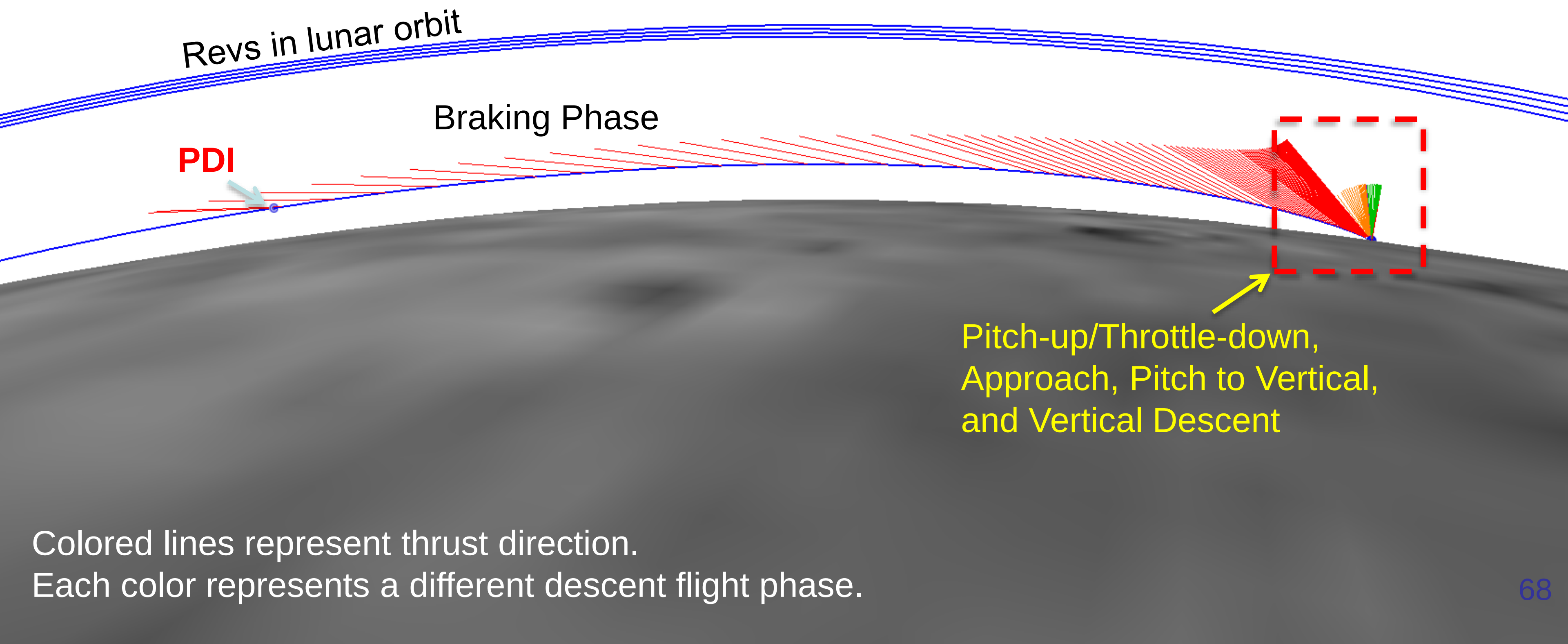


LOI ΔV vs Lunar Arrival Inclination For Selected Arrival Epochs

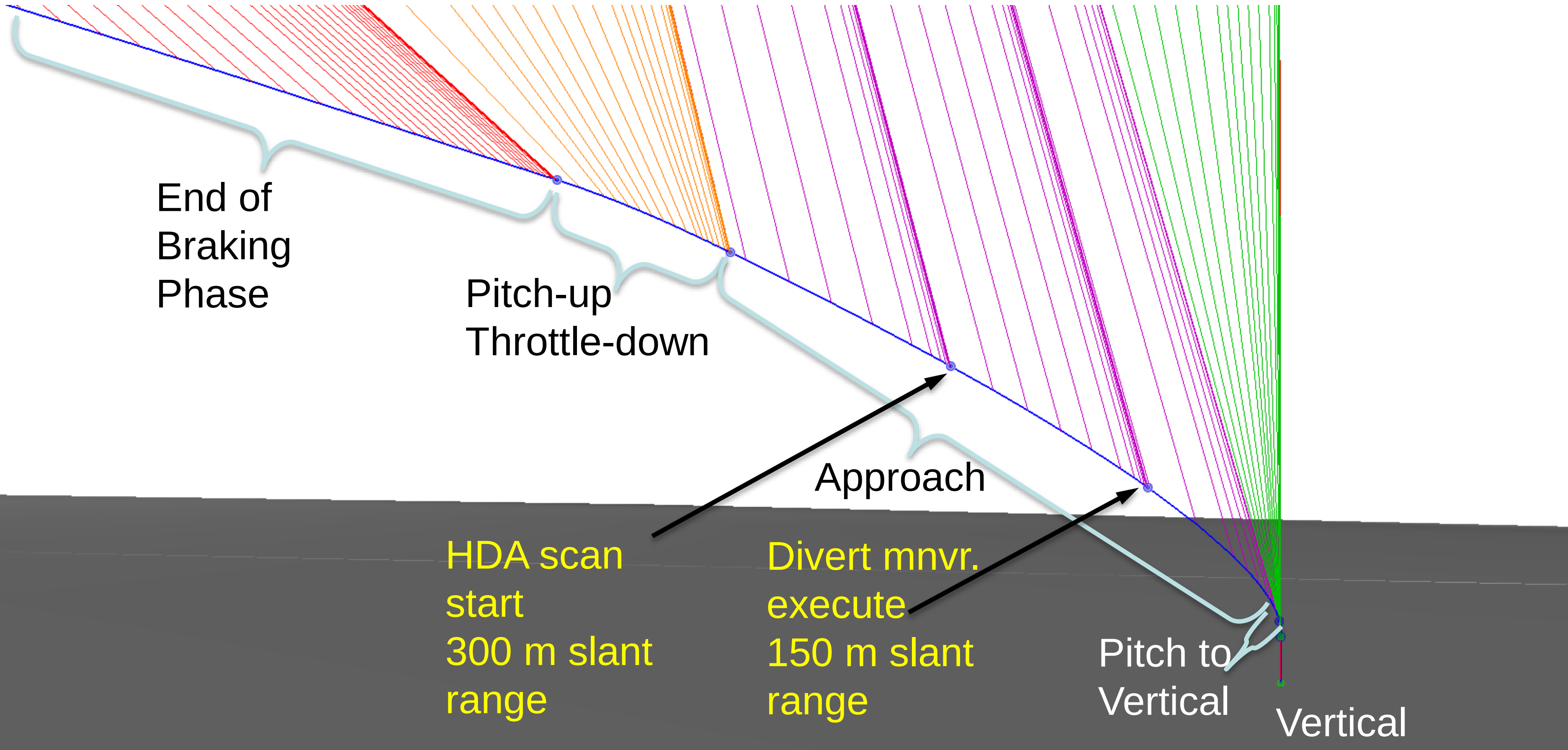


Powered Lunar Descent

- Primary Phases:
  - PDI, braking, pitch-up/throttle-down, approach, pitch to vertical, and vertical descent



Powered Lunar Descent



Colored lines represent thrust direction.
Each color represents a different descent flight
phase

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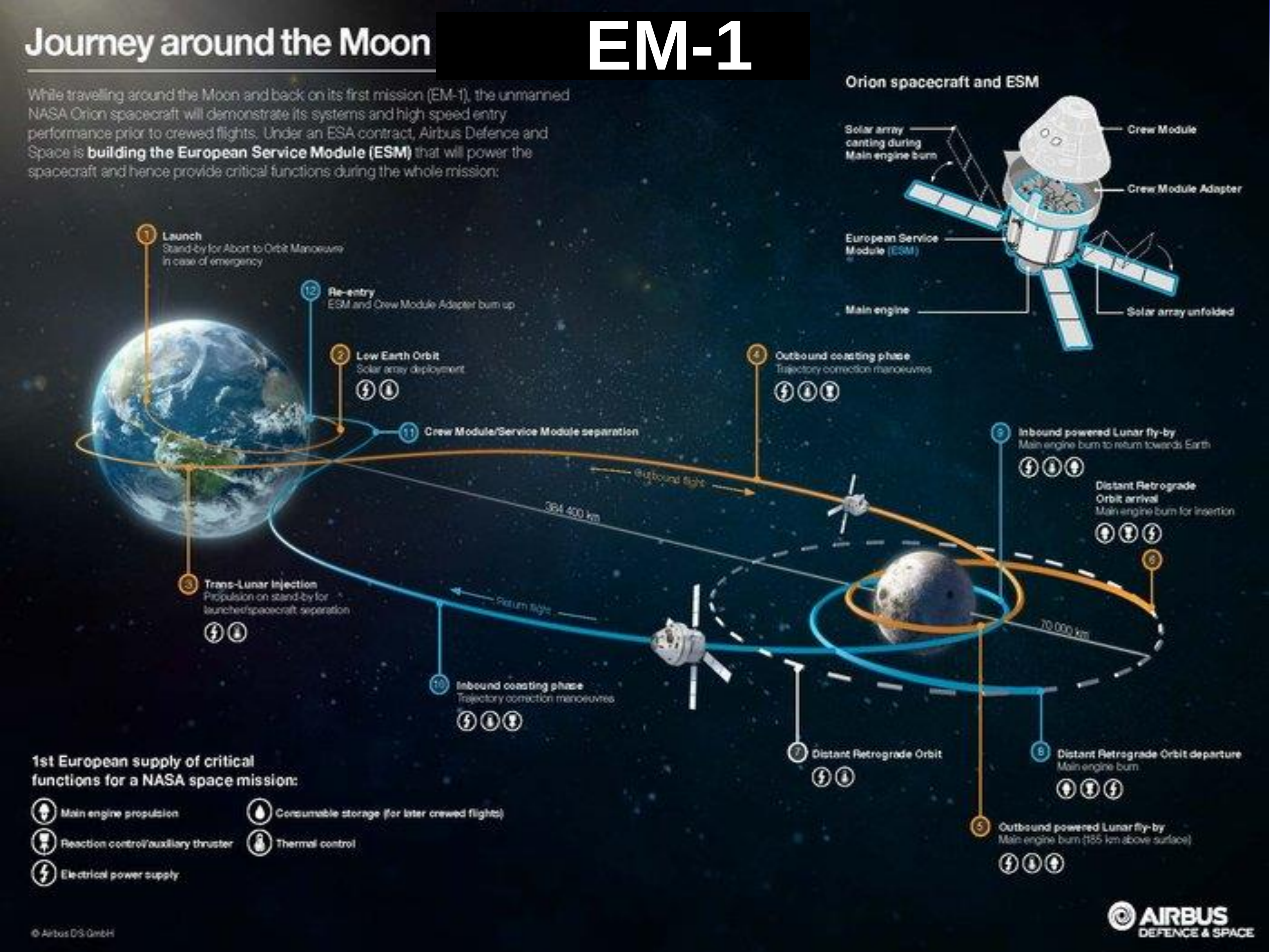
EM-1: Uncrewed Distant Retrograde Orbit 2018

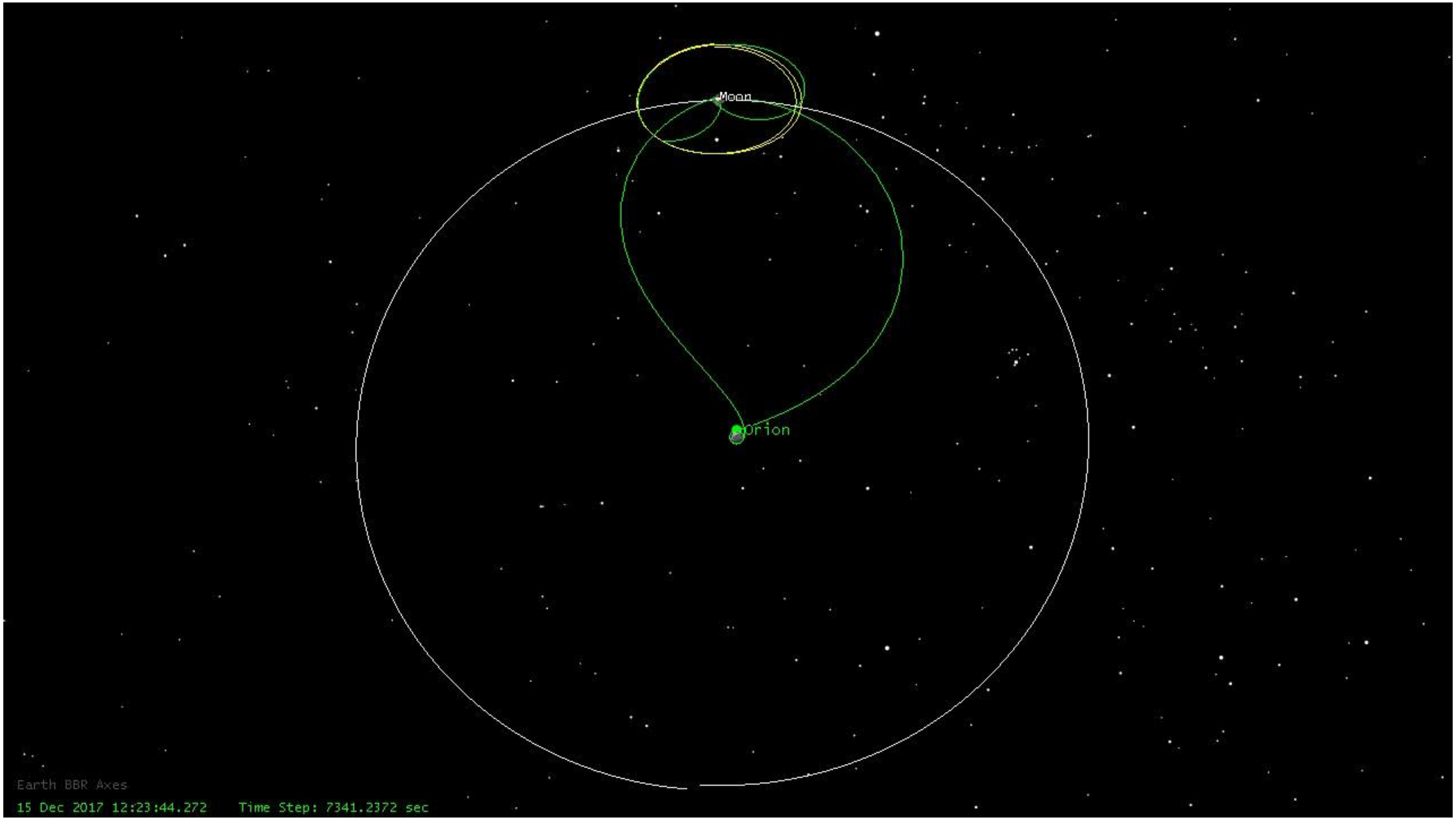
Objectives:
- Demonstrate spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and TPS performance prior to crewed flight

DRM - Uncrewed MPCV
- Lunar capable heat shield
- 4 tank SM with full prop load
- EM-2 systems not included: ECLSS, Crew Systems, LAS Abort Motors (Inert)

Interim Cryogenic Propulsion Stage (ICPS) used to provide TLI burn

EM-1


Journey around the Moon
While travelling around the Moon and back on its first mission (EM-1), the unmanned NASA Orion spacecraft will demonstrate its systems and high speed entry performance prior to crewed flights. Under an ESA contract, Airbus Defence and Space is building the European Service Module (ESM) that will power the spacecraft and hence provide critical functions during the whole mission:
Orion spacecraft and ESM
Solar array canting during Main engine burn
Crew Module
Crew Module Adapter
European Service Module (ESM)
Main engine
Solar array unfolded
1 Launch
Stand-by for Abort to Orbit Manoeuvre in case of emergency
12 Re-entry
ESM and Crew Module Adapter burn up
2 Low Earth Orbit
Solar array deployment
4 Outbound coasting phase
Trajectory correction manoeuvres
11 Crew Module/Service Module separation
9 Inbound powered Lunar fly-by
Main engine burn to return towards Earth
Distant Retrograde Orbit arrival
Main engine burn for insertion
6
Outbound flight
384 400 km
3 Trans-Lunar Injection
Propulsion on stand-by for launcher/spacecraft separation
Return flight
70 000 km
10 Inbound coasting phase
Trajectory correction manoeuvres
7 Distant Retrograde Orbit
8 Distant Retrograde Orbit departure
Main engine burn
5 Outbound powered Lunar fly-by
Main engine burn (185 km above surface)
1st European supply of critical functions for a NASA space mission:
Main engine propulsion
Reaction control/auxiliary thruster
Electrical power supply
Consumable storage (for later crewed flights)
Thermal control
© Airbus DS GmbH
AIRBUS DEFENCE & SPACE

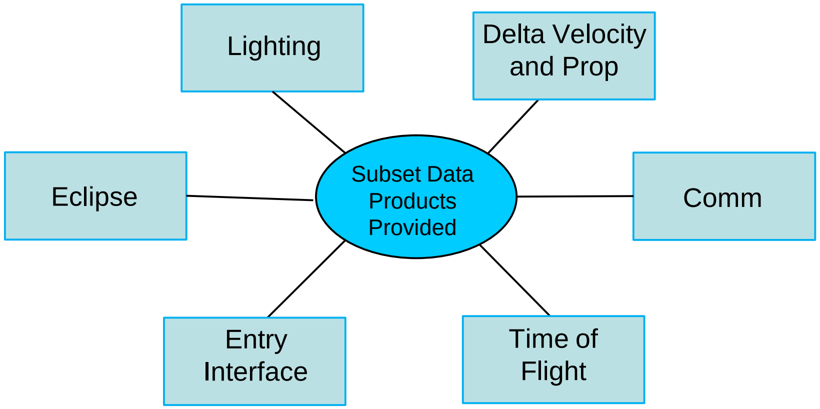

Moon
Orion
Earth BBR Axes
15 Dec 2017 12:23:44.272
Time Step: 7341.2372 sec

Products Provided

Lighting conditions at launch, landing … relative to sunrise/sunset

Performance analysis – delta-V / propellant requirements. Burn durations.

Earth, Moon shadowing



Line of sight communications / dropouts. Field of view (to satellites, ground stations)

Entry targeting analysis

Mission duration. Flight segment durations.

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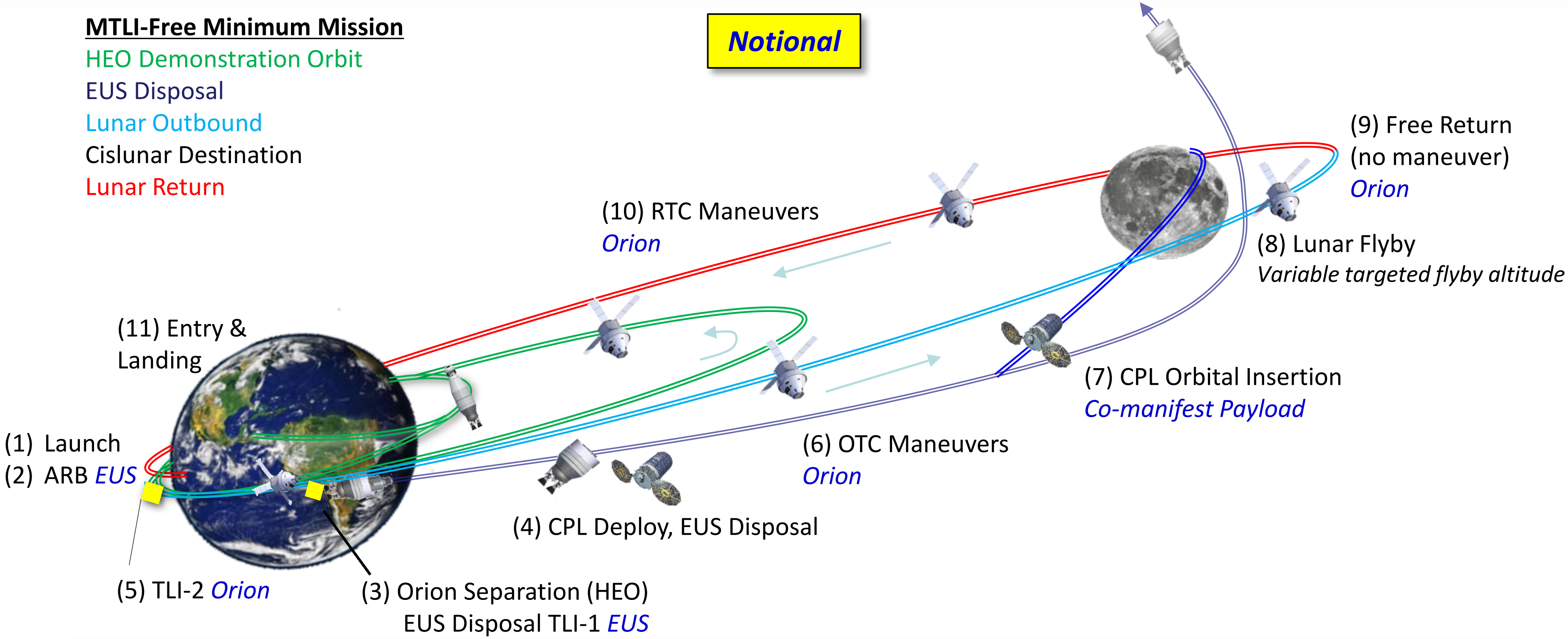
  - EM-2
  - Other
- Proposed support profile

EM-2



1-2) LEO parking orbit, orbit checkout, and EUS “TLI”-ARB demonstration

3-4) Orion separates after majority of EUS TLI burn, achieves safe sep distance, EUS completes TLI-1 with disposal maneuver & deploys CPL

5) Orion flight test system characterization occurs in HEO, TLI-2 performed by Orion, initial mission duration fixed by target altitude

6) Option available to increase mission duration TLI-2 OTC-1 with fly-by altitude raise

7) CPL performs completely independent mission, non-critical path to mission success

8-9) Free return flyby, no Orion critical maneuvers required

10-11) Nominal mission return and cis-lunar entry velocity targeting San Diego vicinity

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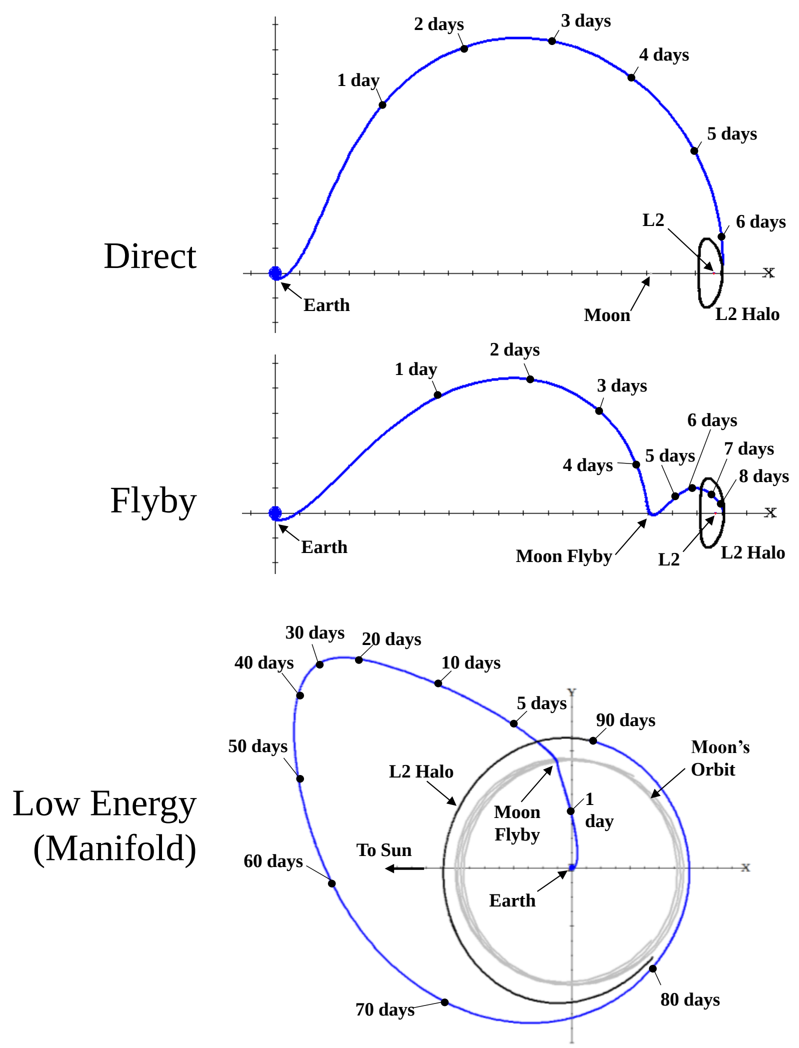
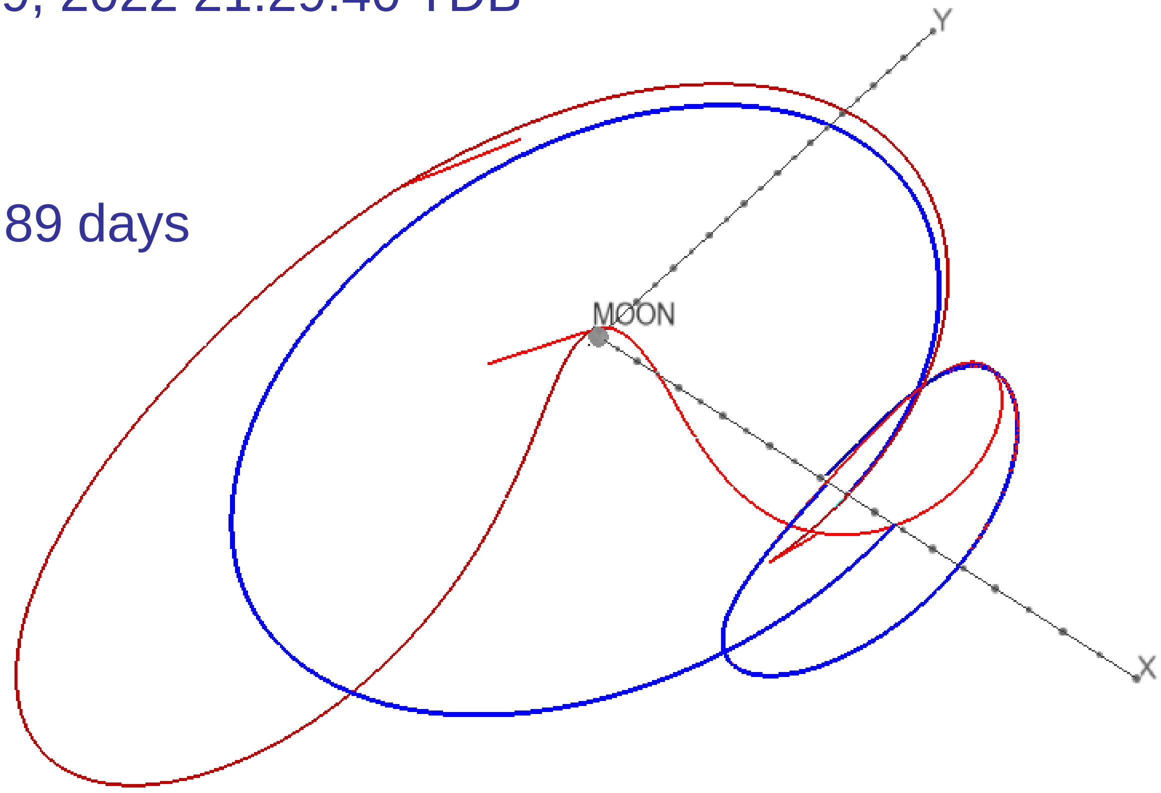
Transfer Options to EM-L2



Initial 185x185 km LEO Altitude					
Mission Type	Flight Time (days)	Earth Departure C3 (km^2/s^2)	LEO Departure ΔV (m/s)	L2 Halo Arrival + Flyby ΔV (m/s)	Total ΔV (m/s)
Direct	6.3	-1.685	3151	967	4118
Lunary Flyby	8.4	-2.083	3133	294	3427
Manifold	89.6	-1.991	3195	0	3246

Results
EML2H to DRO

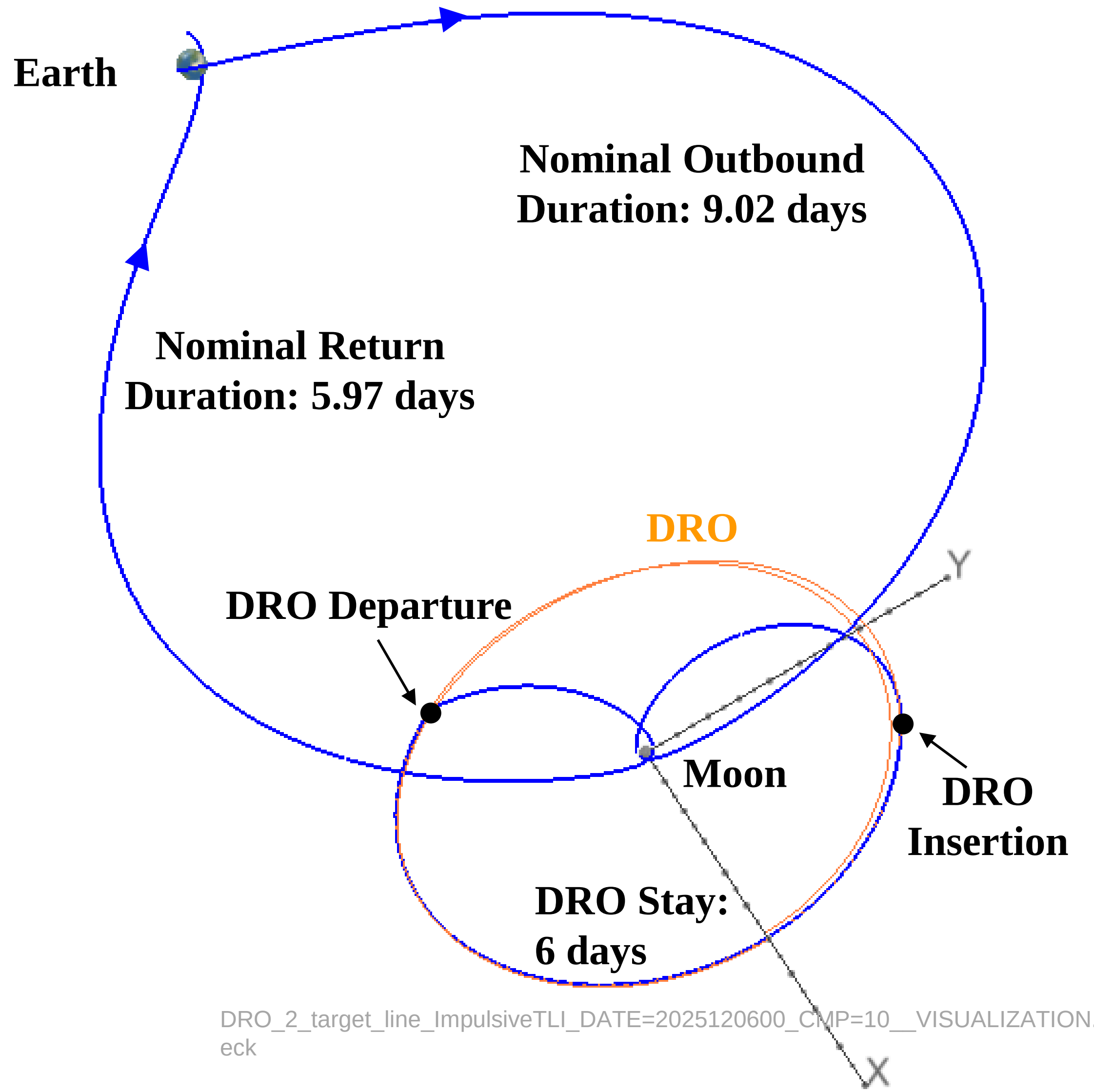
- 3-impulse transfer (flyby, midcourse, and insertion)
- Departure epoch: Nov 29, 2022 21:29:40 TDB
- Halo A_z: 2,000 km
- Total Δv: 126.7 m/s
- Total Transfer Time: 37.89 days



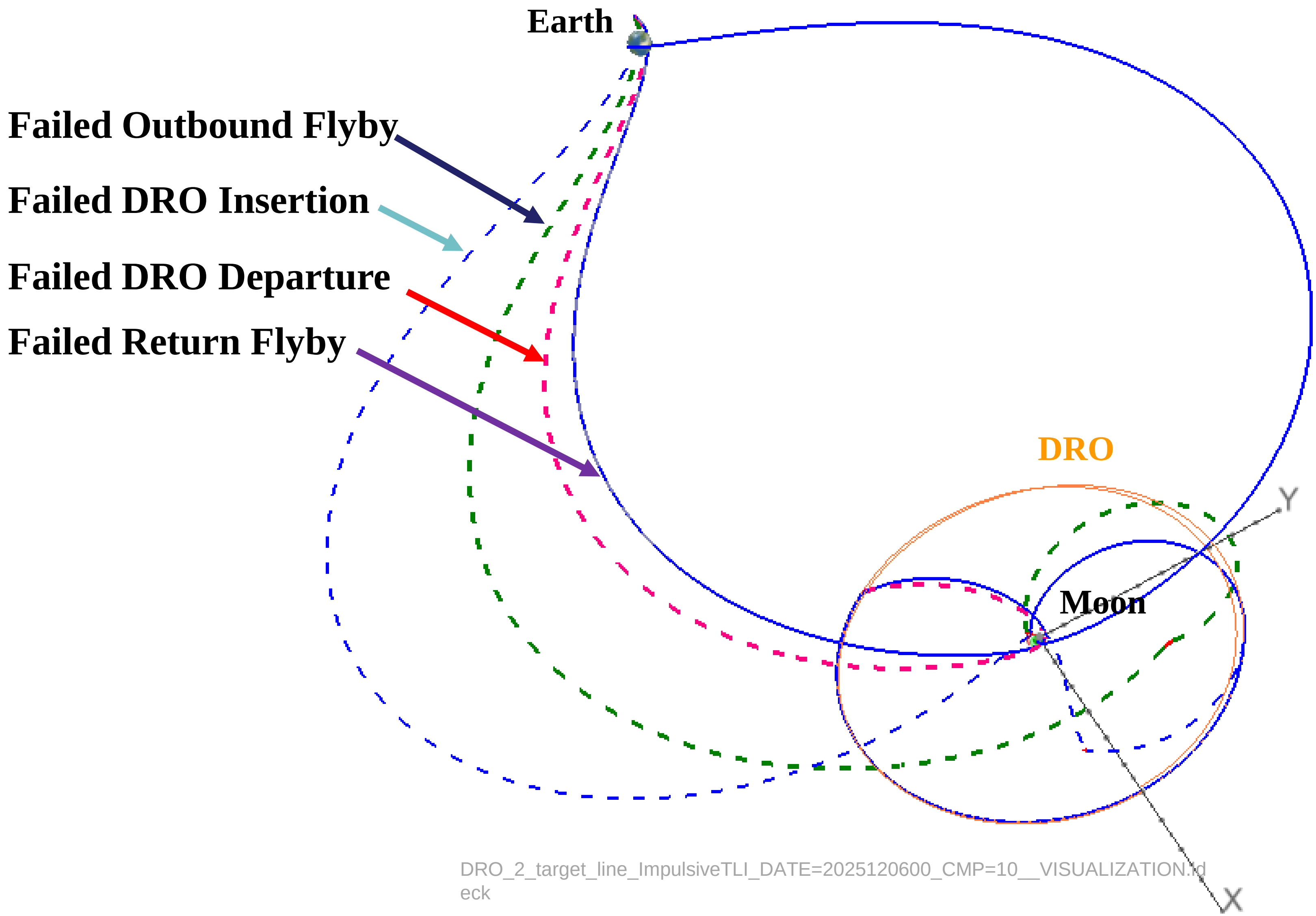
06/10/2015

Results
LEO to DRO- Nominal

- Departure epoch: Nov 28, 2025
- Departure C3 = -2.089 km^2/s^2
- Total Orion ΔV: 892.7 m/s
- Total Orion Prop: 7,885 kg
- Total Nominal Mission Duration: 21 days
- All Aborts Possible Within 21 days.

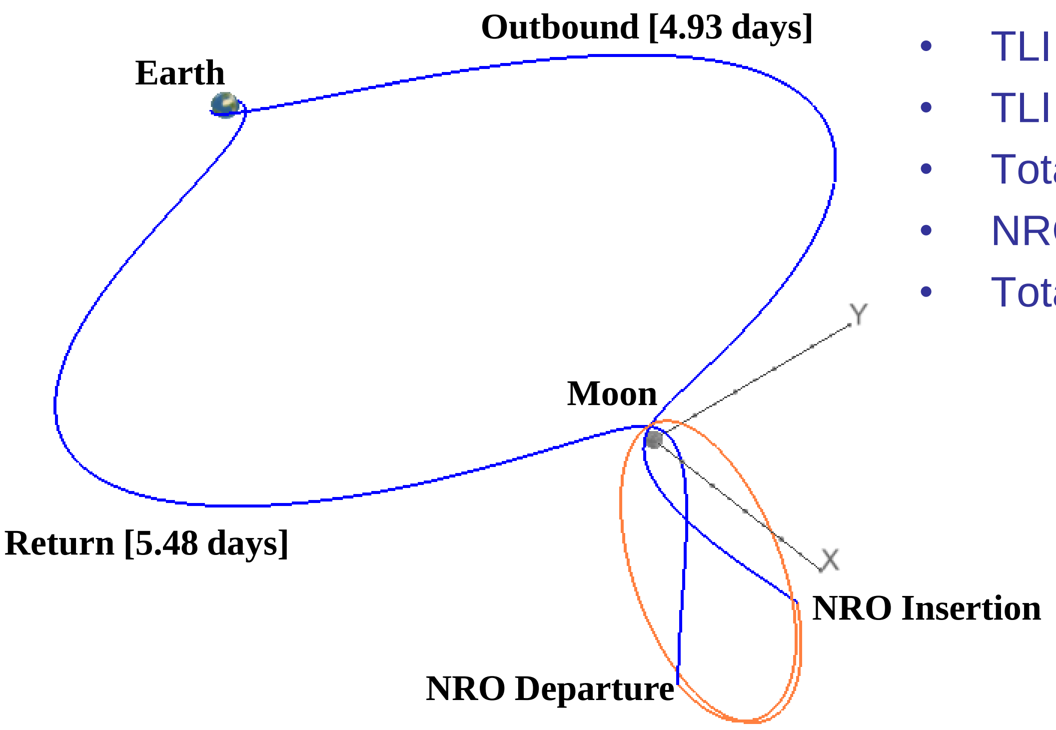


LEO to DRO- Abort



DRO_2_target_line_ImpulsiveTLI_DATE=2025120600_CMP=10__VISUALIZATION.ldeck

Results
LEO to NRO - Nominal



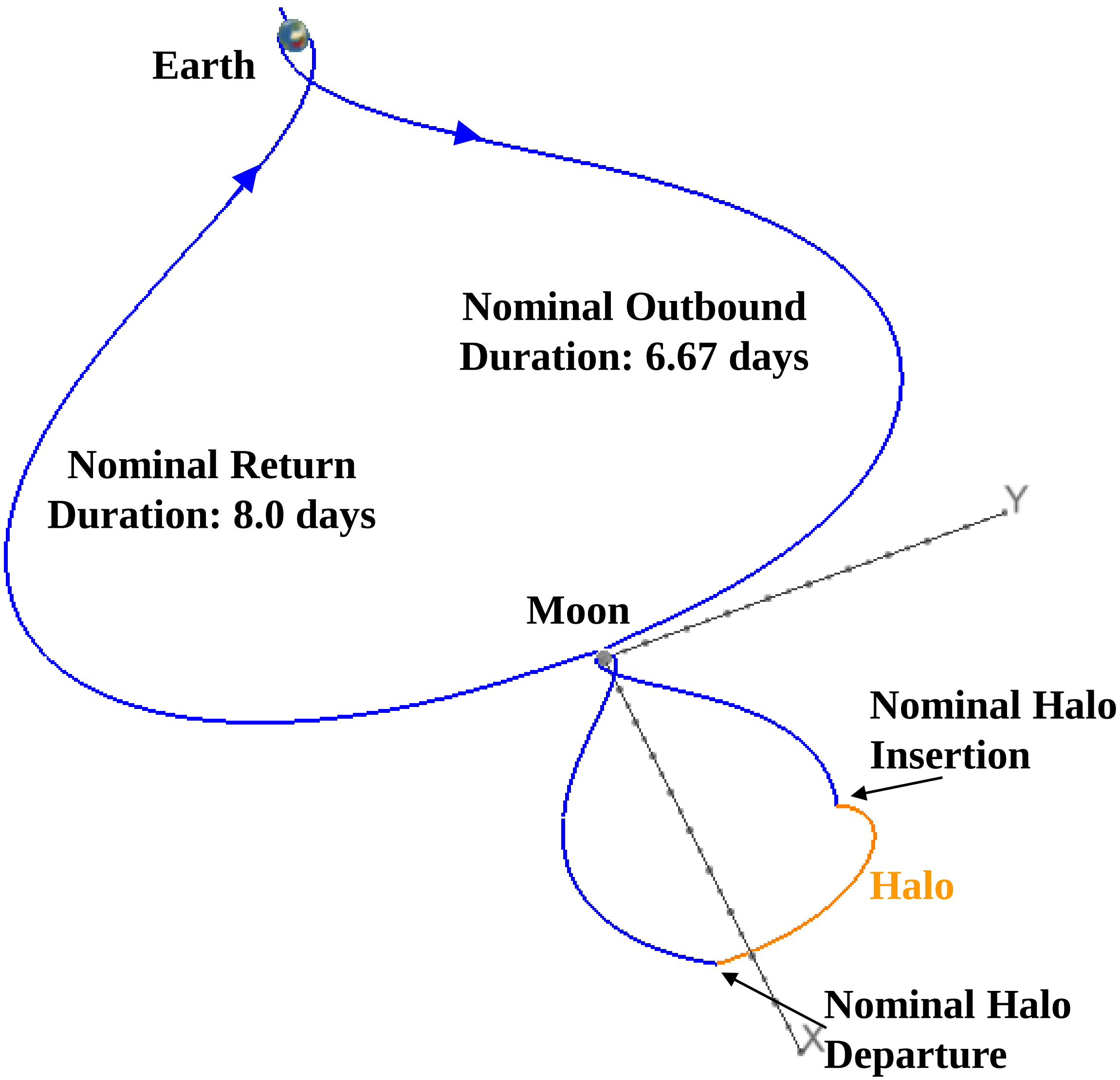
- TLI epoch: 1-Dec 2025 10:14:45 TDB
- TLI C_3: -2.155 km/s
- Total Mission Duration: 21.00 days
- NRO Stay Time: 10.57 days
- Total Orion Prop: 7431.6 kg

Outbound Flyby: 213 m/s
NRO Insertion: 206 m/s
NRO Departure: 205 m/s
Return Flyby: 199 m/s

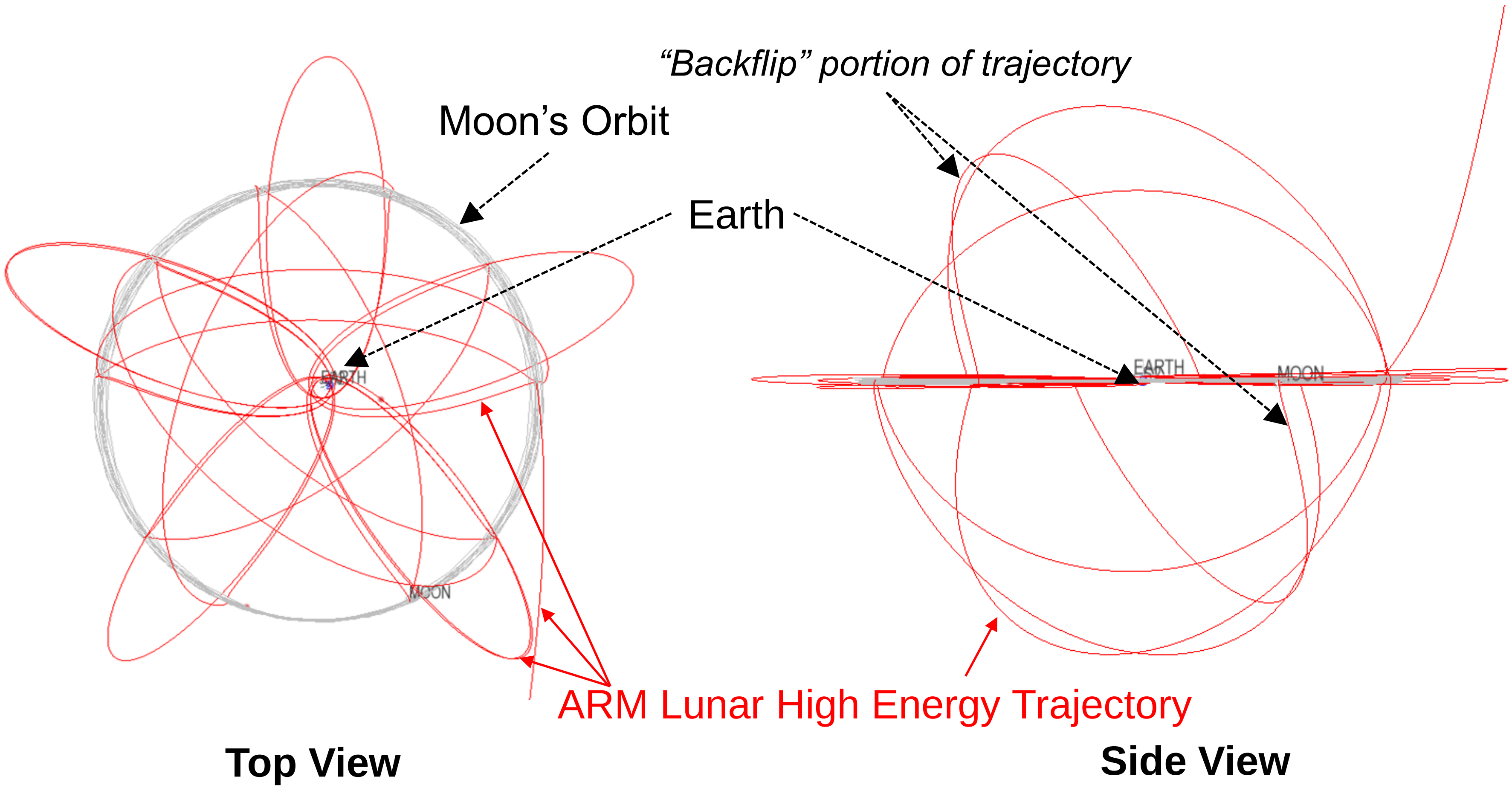
NRO_2_target_line_Impulsive_CMP=10.ideck

Results
LEO to EML2H - Nominal

- Departure epoch: Dec 8, 2025
- Departure C3 = -1.896 km^2/s^2
- Halo A_z = 2,638 km (period ≈ 13.5 days)
- Total Orion Δv: 697.6 m/s
- Total Orion Prop: 6,469 kg
- Total time in EML2H vicinity: 6 days
- Total Nominal Mission Duration: 20.66 days
- All Aborts Possible Within 21 days.

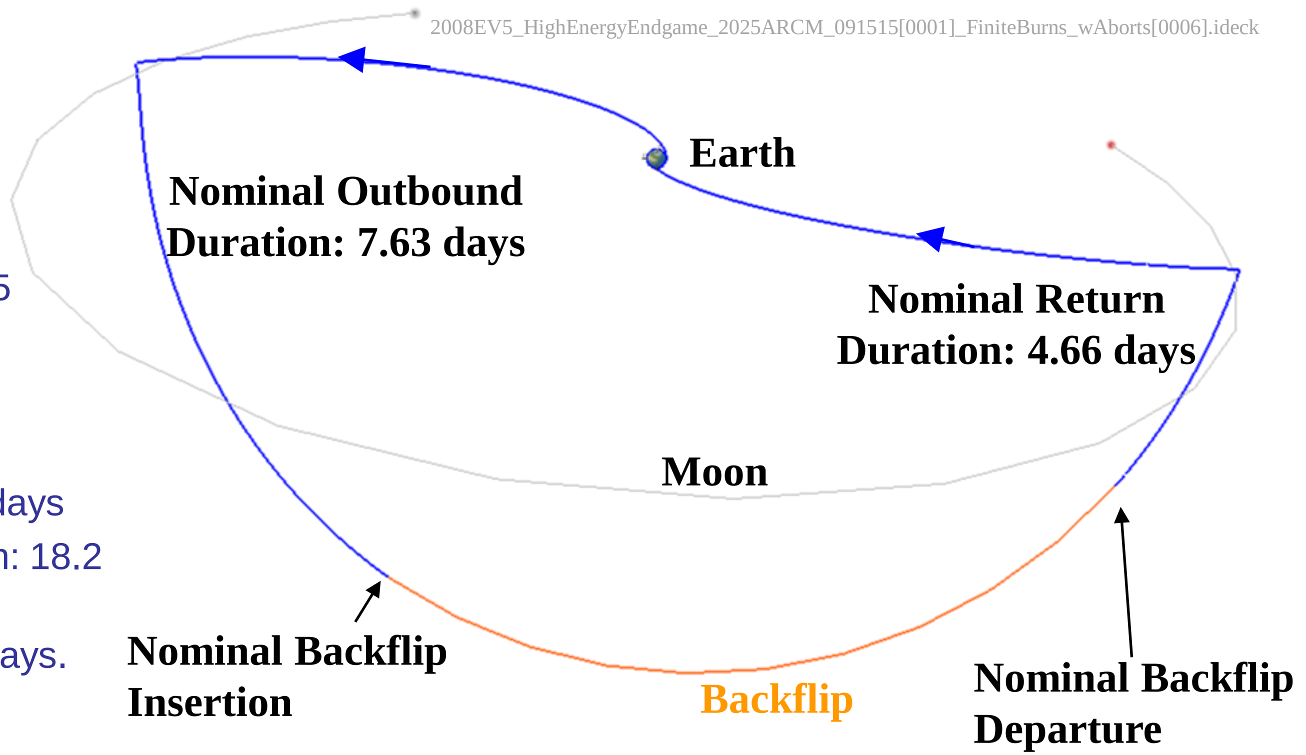


High Energy Trajectory



Results
LEO to High Energy - Nominal

- Departure epoch: Nov 25, 2025
- Departure C3 = -1.740 km^2/s^2
- Total Orion Δv: 131.4 m/s
- Total Orion Prop: 1,512.9 kg
- Total time in lunar backflip: 6 days
- Total Nominal Mission Duration: 18.2 days
- All Aborts Possible Within 21 days.



BACKUP

The Road to GN&C

Conceptual Timeline

HQ Directive for new mission

Level 0 Requirements

Mission Design

Interconnected Tasks

Trades Studies – Vehicle performance and sizing

Preliminary GN&C algorithm development

Refined trades

GN&C algorithm development for onboard / autonomy

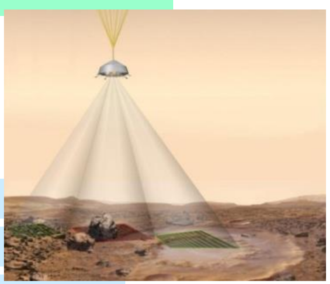
Flight

Post-flight

Previous Projects Support & Studies

Earth Ascent / Entry

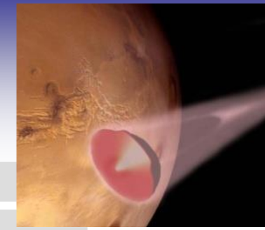
- Space Shuttle / Orbiter
- Shuttle II
- Liquid Fly Back Booster (LFBB)
- Heavy Lift Launch Vehicle (HLLV)
- Shuttle C Cargo Element (SCE)
- Crew Logistics Vehicle (CLV)
- Personal Launch System (PLS)
- Reuseable Launch Vehicles (RLVs)
- X-38 (Phoenix, V131, V132, V131r, V201
- Parafoil Systems Tests
- Crew Rescue Vehicle (CRV/ACRV)
- 2nd Generation Launch Vehicle
- Space Launch Initiative (SLI)
- Columbia Investigation
- Orbital Space Plane (OSP)
- Shuttle Return To Flight (RTF)



Earth Orbit

- LifeSat Satellite
- Hubble Refurbishment
- Wakeshield Experiment
- Orbital Transfer Vehicle (OTV)
- Orbital Maneuvering Vehicle (OMV)
- Aeroassist Flight Experiment (AFE)
- Shuttle Flight Experiments
- Space Station Freedom (SSF)
- International Space Station (ISS/ISSA)

Exploration: Moon Specific



- Apollo
- Interlune One
- First Lunar Outpost (FLO)
- Lunar Transfer Vehicle (LTV)
- Lunar Excursion Vehicle (LEV)
- Lunar Scout
- Common Lunar Lander (CLL)
- Lunar Ice Discorver Mission
- Reusable Lunar Lander
- Human Lunar Return (HLR)
- Lunar Gateway Station

Exploration: Mars Specific

- Mars Transfer Vehicle (MTV)
- Mars Excursion Vehicle (MEV)
- Pathfinder X
- Mars Combo Lander
- Mars Precision Landing
- Mars on a Shoe String (MOSS)
- Mars Global Surveyor Team
- Mars Sample Return (MSR) Direct
- Mars 3 Magnum Mission
- Mars Rover Sample Return (MRSR)
- Mars ISRU Sample Return (MISR)
- Mars Sample Return (MSR) Split Mission
- Mars 2001/03/05/07/09 (Phoenix)
- Mars Science Laboratory (MSL) 2009

Exploration: General Application

- Human Spaceflight Chapter
- Low Thrust Trajectories
- NEP Architecture
- Artifical Gravity
- Formatioin Flying Team
- Next Decadal Planning Team
- TransHab Module
- HEDS /Exploration Blueprint
- NASA Exploration Team
- Planetary Aerocapture
- New Exploration Vision