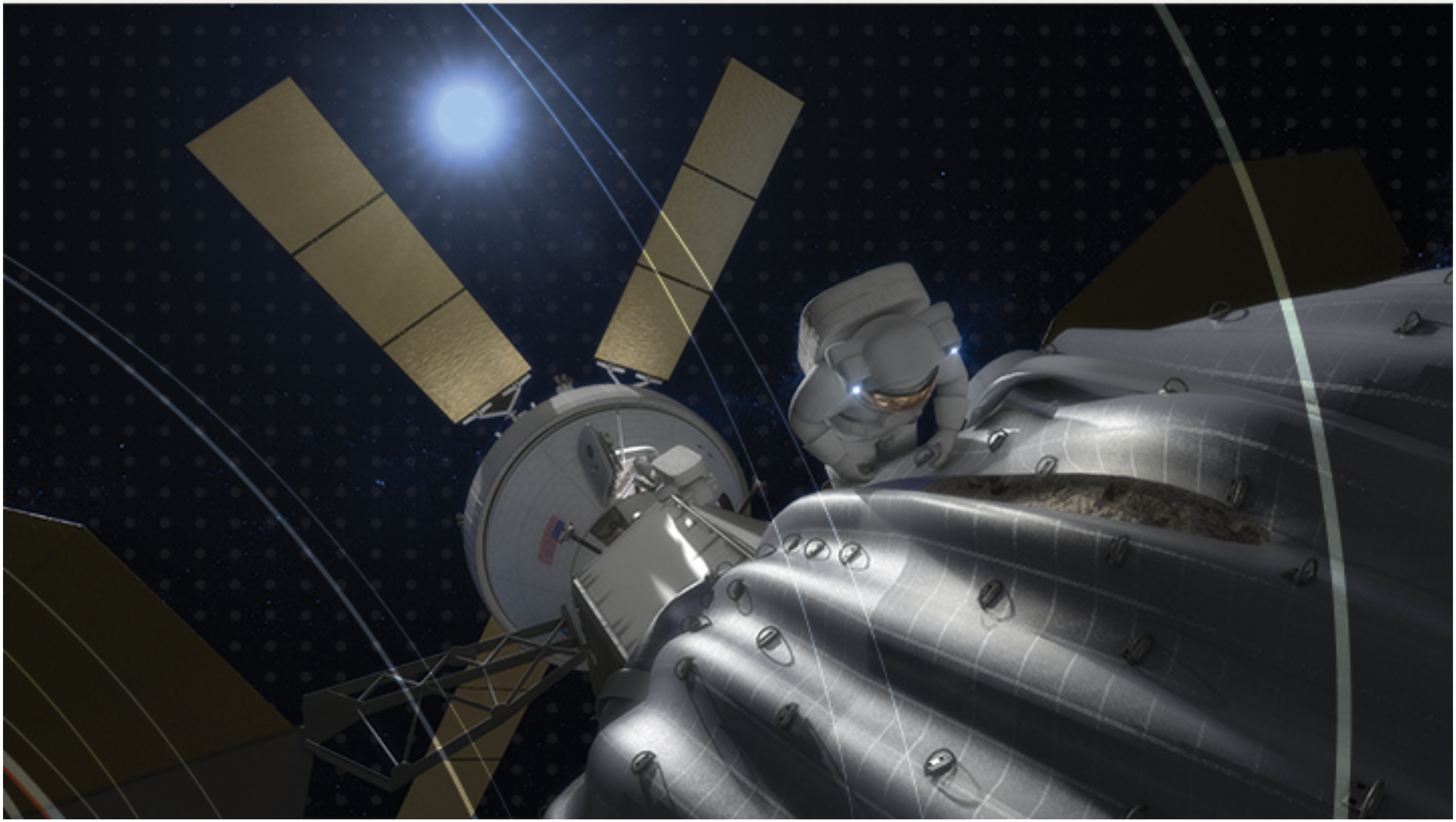
# Asteroid Redirect Mission
# Crewed Mission (ARCM) Concept Study



# Asteroid Redirect Crewed Mission (ARCM)
## Assessment Summary from Mission Formulation Review

- Technical
  - Mission is Feasible – there are no show stoppers identified
  - The design accommodates predicted Orion EM-2 performance with inclusion of Mission Kits
  - There are no significant changes to Orion/SLS Requirements
- Cost
  - The strategy leverages planned Orion exploration capabilities
  - Mission unique costs are limited to EVA tools, GFE to Robotic Mission, and Asteroid Sample Curation
- Schedule
  - Schedule is feasible
  - Mission Kit development leverages efforts in the Advanced Exploration Systems (AES)
  - Asteroid Redirect Robotic Vehicle (ARRV) delivered GFE items drive earliest need dates
- Mission risks are mitigated with appropriate flight testing
  - Employs EM-1/2 flight test strategy
  - Leverages ISS as an Exploration test bed
  - Prior Shuttle Flight test of STORRM Rendezvous and Docking Sensors

**Orion's broad exploration capabilities allow for execution of the Asteroid Retrieval Mission with only minor mission kit additions with a feasible cost/schedule. There are no significant Orion/SLS requirement changes for the Asteroid Mission.**

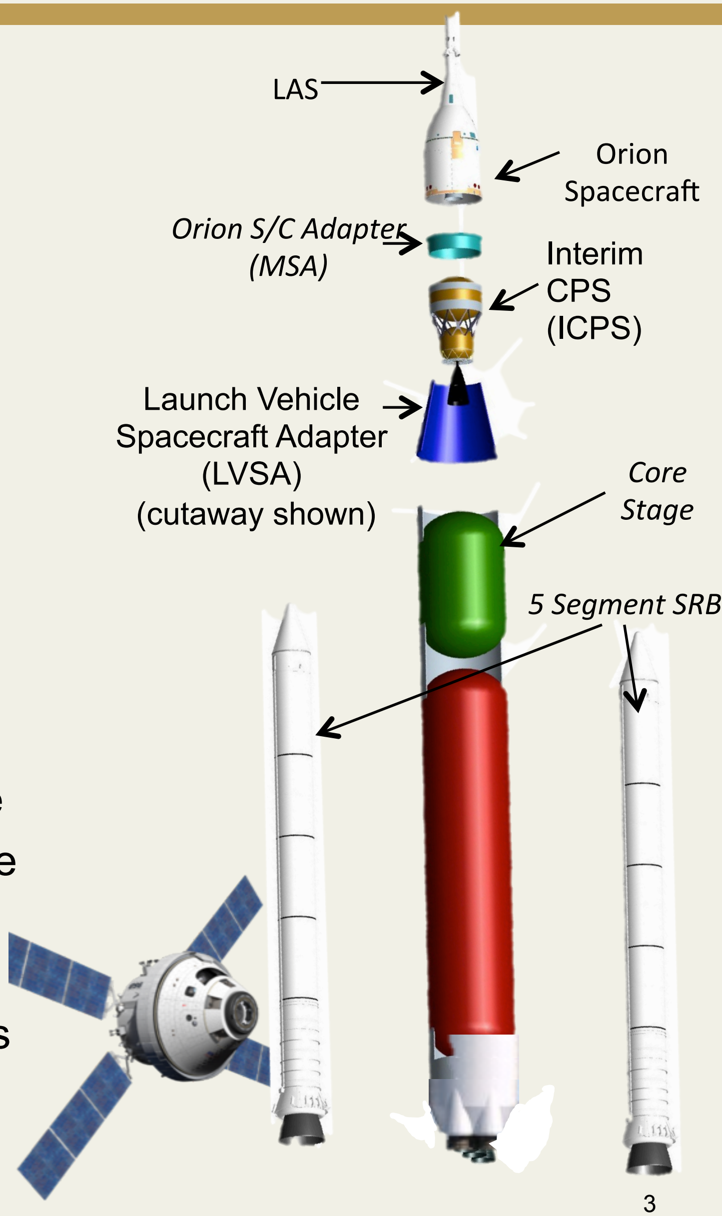
# Mission Objectives/Guiding Principles

Mission Objectives:

Orion will provide capability for crew to rendezvous with Asteroid Redirect Robotic spacecraft; extract asteroid sample; and return sample and crew safely to Earth.

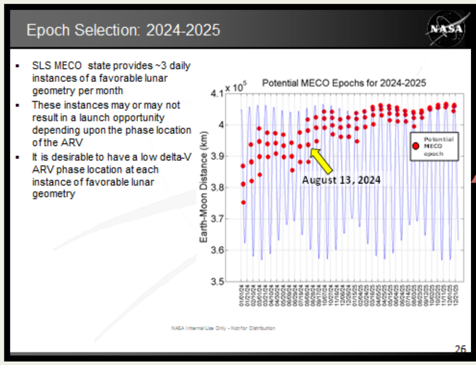
Guiding Principles For Feasibility Study:

- Perform initial sample return mission in two launches:
  (1)Asteroid Redirect Robotic Spacecraft; and
  (2)Orion/SLS with Crew
- Minimize changes to Orion EM-2 Configuration
  - Provide additional Orion mission capability with add-on kits
  - Study based on SLS/Orion Baseline requirements
- Utilize SLS Block I Configuration for Orion launch vehicle
- Affordability is the key consideration in every design trade
- Utilize robotic spacecraft for Extra-Vehicular Activity (EVA) augmentation (e.g. tool stowage, handholds)
- Provide capabilities that enhance future exploration goals



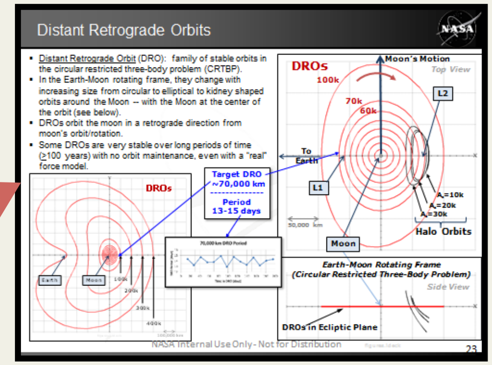
# Mission Design Considerations

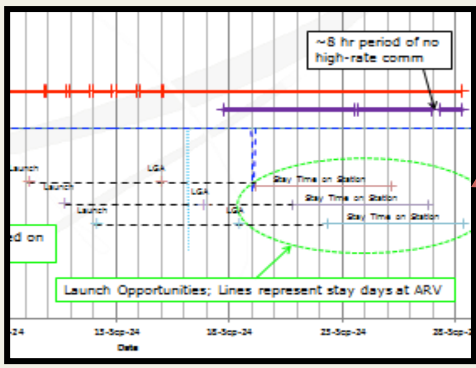
## All constraints currently satisfied for new MFR Reference Mission




**Launch Availability ~2-3 opportunities per month**

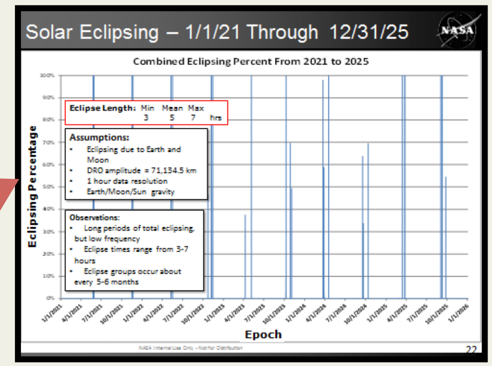
71433km DRO improves launch availability by syncing with Lunar period

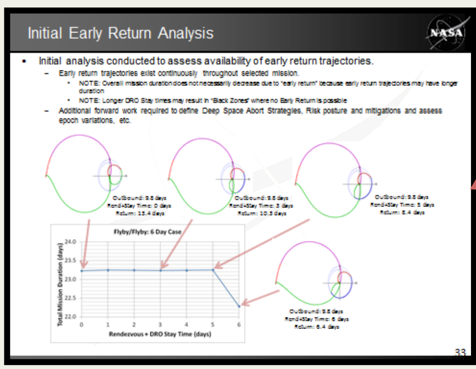



Acceptable Communications Coverage for Orion/ARRV

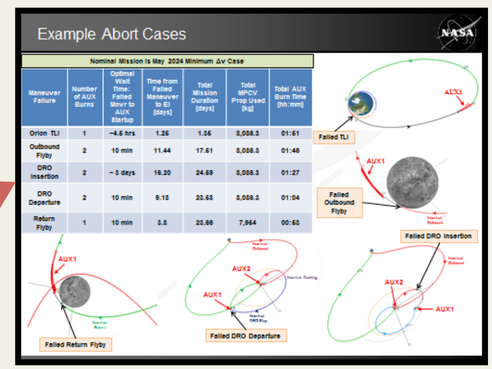
Long Solar Eclipse Periods Manageable for launch availability




Orion Propellant Available for Early Return Throughout Mission

Orion Propellant Allows Auxiliary Thruster Contingency Return



# Asteroid Redirect Crewed Mission "Trade Space"

## All variables interconnected via Mass Impact

- Mass Impact includes both Launch and Abort Landed mass
- Numerous possible solutions available based on combinations of selections
- Individual Packages developed to explain sensitivities on each variable
- Integrated Solutions demonstrate what combinations are feasible

### Mission Design

| | |
|---|---|
| Number of Crew | 2,3,4 crew |
| Mission Duration | 21,22,23 days,… |
| Trajectory | LGA/Direct, LGA/LGA, etc. |
| Number of EVA's | 0,1,2,3 EVA's,… |

### EVA Configuration

| | |
|---|---|
| Suit Selection | MACES, EMU, Explore Suit |
| Life Support Selection | Umbilical, PLSS Variants |
| Tools/Translation Aids | Telescope Booms, etc. |

### Orion Functionality

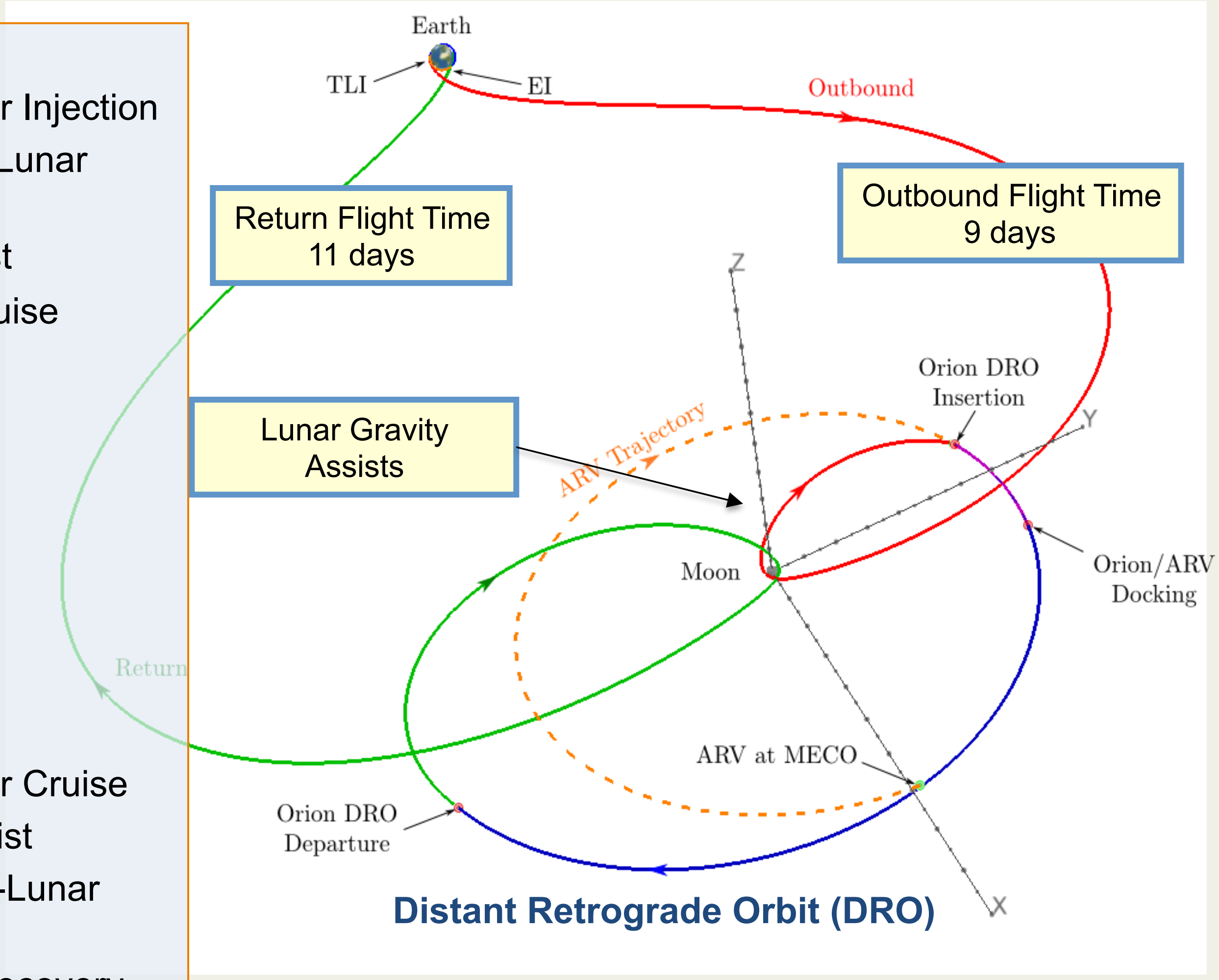
| | |
|---|---|
| Attachment Trades | Docking, Grappling, etc |
| AR&D Sensors | Add Required Capability |
| Sample Curation | Amount, Thermal Provisions |
| Robotic Science | Standalone Robot Sampling |

### Mass Impact Mitigation

- Propellant Offload
- Reduce Number of Crew
- Orion Functionality Allocation
- ARRV Functionality Allocation
- Functionality Launched Separately
- Trajectory Design

# Reference Trajectory: Earliest Mission for 2009BD

- Outbound
  - Flight Day 1 – Launch/Trans Lunar Injection
  - Flight Day 1-7 – Outbound Trans-Lunar Cruise
  - Flight Day 7 – Lunar Gravity Assist
  - Flight Day 7-9 – Lunar to DRO Cruise
- Joint Operations
  - Flight Day 9-10 – Rendezvous
  - Flight Day 11 – EVA #1
  - Flight Day 12 – EVA #2 Prep
  - Flight Day 13 – EVA #2
  - Flight Day 14 – Departure Prep
  - Flight Day 15 – Departure
- Inbound
  - Flight Day 15 – 20 – DRO to Lunar Cruise
  - Flight Day 20 – Lunar Gravity Assist
  - Flight Day 20-26 – Inbound Trans-Lunar Cruise
  - Flight Day 26 – Earth Entry and Recovery




Mission Duration and timing of specific events will vary slightly based on launch date

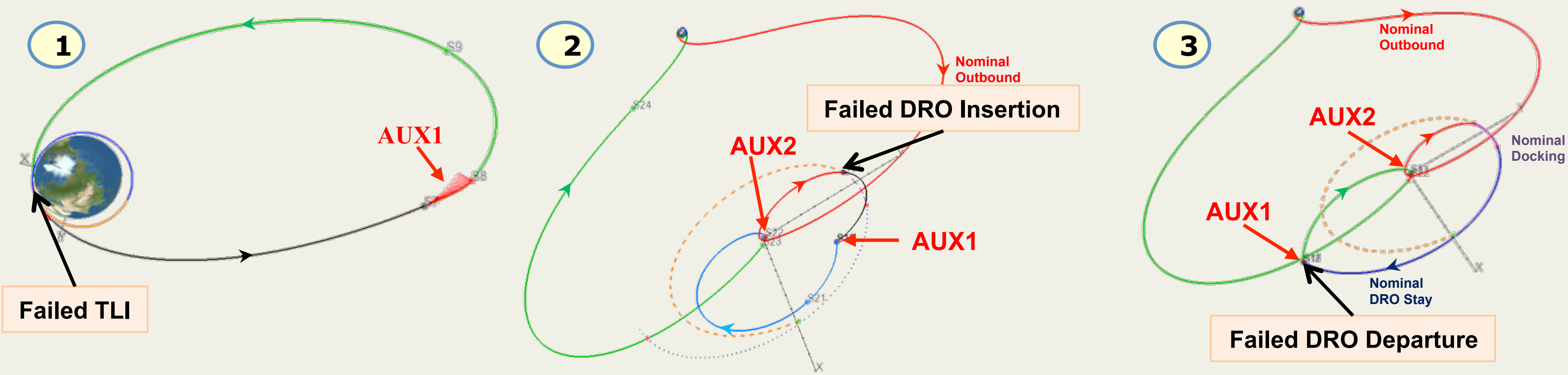
# Contingency Trajectory Planning

| MFR Reference Mission: May 2024, Min-ΔV | | |
|---|---|---|
| Maneuver Failure | Number of Aux Burns | Total Mission Duration [days] |
| Orion TLI | 1 | (1) 1.36 |
| Outbound Flyby | 2 | 17.57 |
| DRO Insertion | 2 | (2) 26.69 |
| DRO Departure | 2 | (3) 23.61 |
| Return Flyby | 1 | 23.66 |

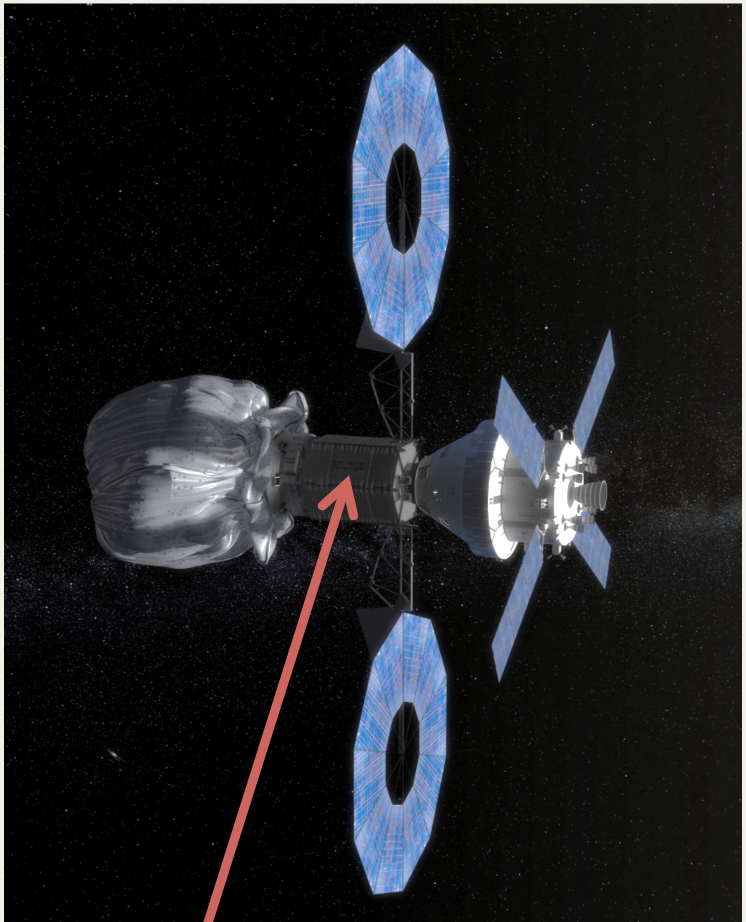
All usable Orion Propellant Utilized in Abort Cases to minimize return duration

- Examined failure of Service Module (SM) Main Engine throughout mission as part of trajectory planning
- Orion SM contains substantial additional propellant above the nominal mission requirement and 30 days of crew consumables (O2, N2, food, etc.)
- Assessment concluded that Auxiliary Thrusters could complete the mission should SM Main engine fail although mission duration may be longer than nominal mission

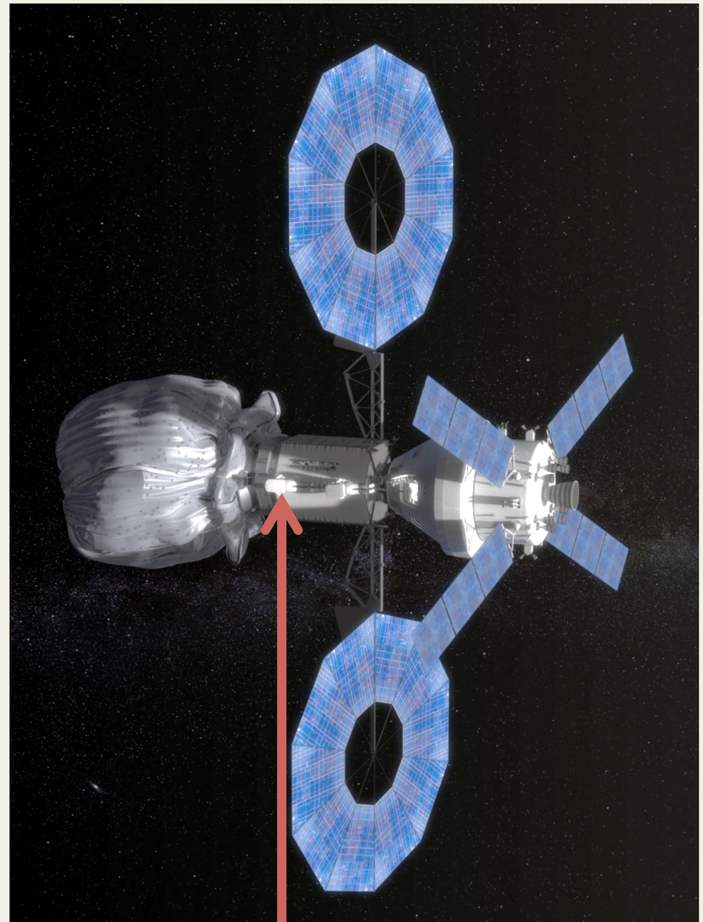
Example Failed Maneuvers followed by Auxiliary Engine Maneuvers



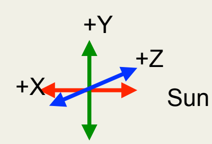
# Assessment of Integrated Flight Attitude



Solar Inertial Attitude



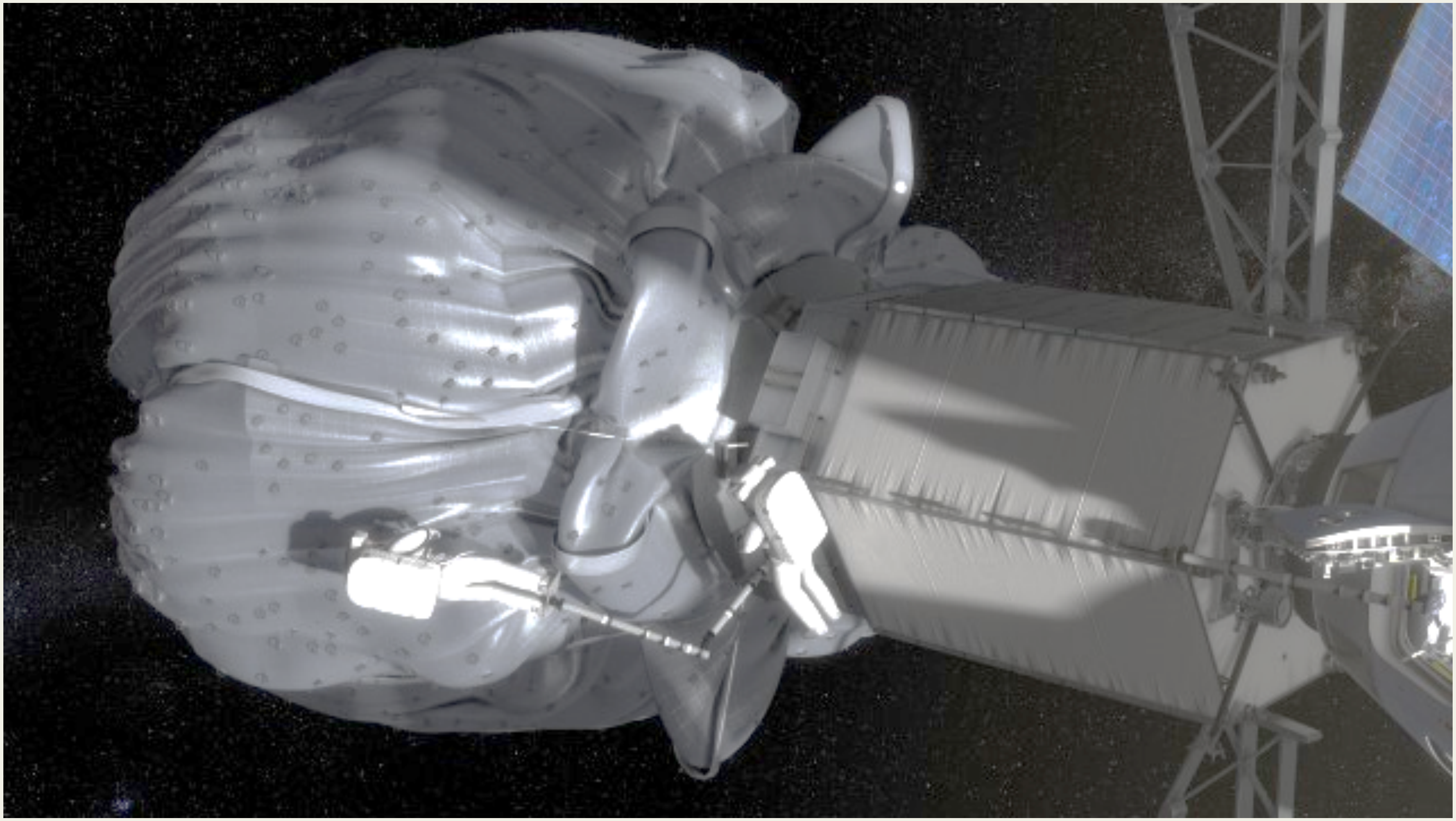
EVA Biased Attitude




- Extensive shading in unbiased solar inertial attitude
- Biasing attitude allows for adequate EVA lighting and thermal conditions
- Orion required to maneuver integrated vehicle to EVA attitude

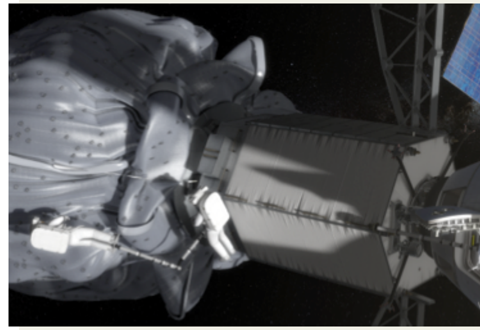
# Extravehicular Activity (EVA) Details

- Orion-based EVA with two Crewmembers
- Two EVAs + One Contingency
- Short Duration (~4 hours)



# Suit and EVA Mission Kits

## Four kits were identified to enable Orion Capsule-Based EVA capability



| EVA Servicing and Recharge | EVA Tools, Translation Aids & Sample Container Kit | EVA Communications | Cabin Repress Kit |
|---|---|---|---|
| Equipment necessary for multiple EVAs including recharge for PLSS water and oxygen, crew equipment, etc. | Standard and specialized tools to complete mission objectives | Repackaged PLSS radio that allows relay communication between EVA crew and ground | Provides enriched air for multiple repressurizations of the cabin without using Orion resources |
| Based on ISS and Shuttle equipment | Leverage current ISS, heritage Apollo and analog tools; Evaluate prototype designs in NBL | Utilizes common radio design currently being developed for AES PLSS | Based on ISS tanks; Plan to mature concept in work |

Assumes GFE Development for EVA support kits

# MACES Capsule-Based EVA Development Plan

***Leveraging existing AES, Orion and ISS investments***

Summer 2013 → Fall 2013 → Early 2014

| NBL/MACES Integration | Incremental Refinement | Capability Demonstration | |
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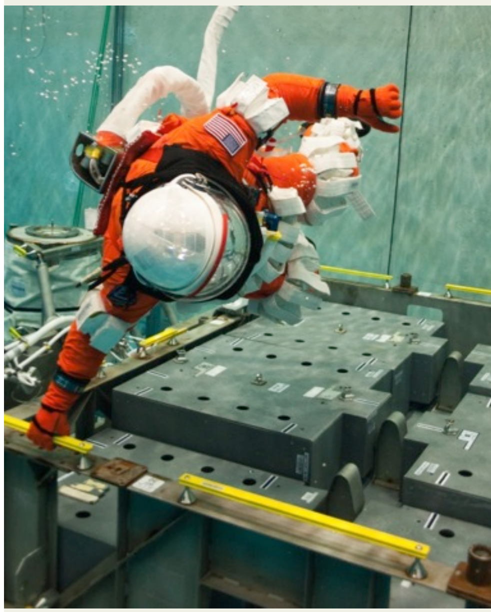
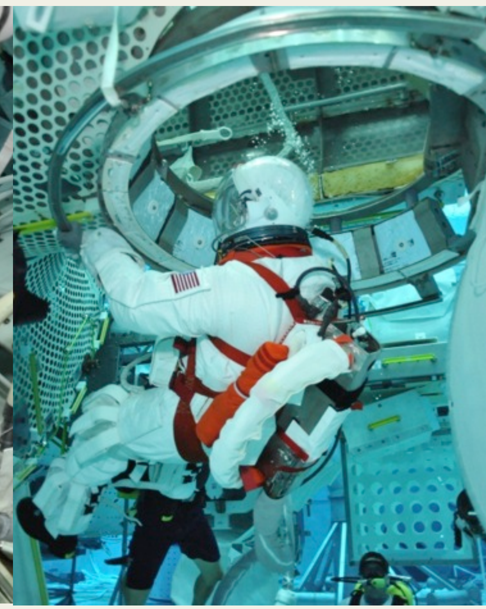
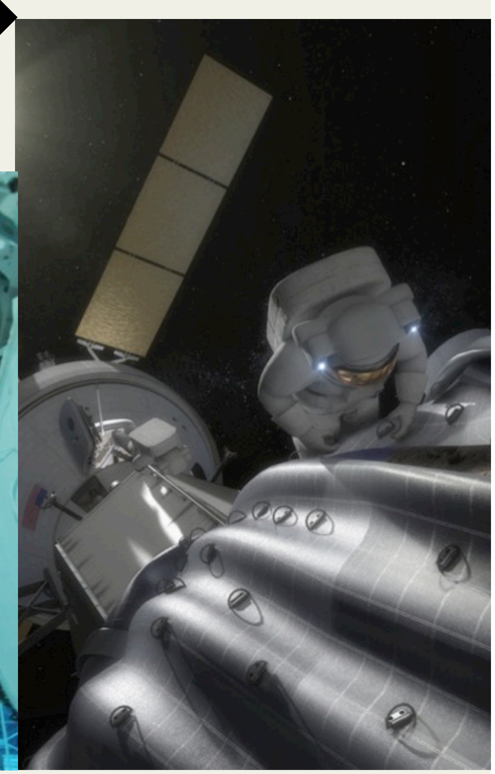
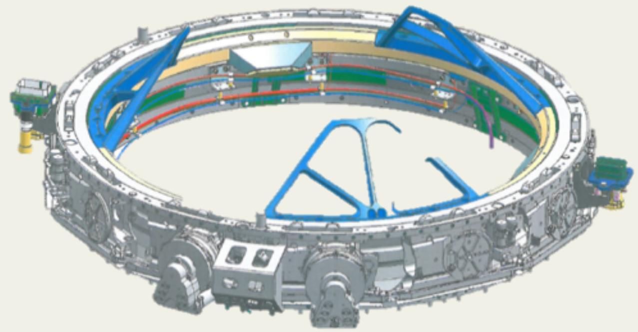
|  |  |  |  |
| Suit: Baseline Orion MACES<br><br>Tasks:<br>NBL Facility Integration<br>NBL Weigh-Out<br>Length: 2 hours | Suit: Baseline Orion MACES & enhanced MACES<br><br>Tasks:<br>Standard tool interfaces<br>ISS Standard Tasks<br>Length: Increasing to 4 hours | Suit: Baseline Orion MACES & enhanced MACES<br><br>Tasks:<br>Standard and Prototype Tools<br>Mission Representative Tasks<br>Length: 4 hours | Full Mission Profile Test by end of 2014 |

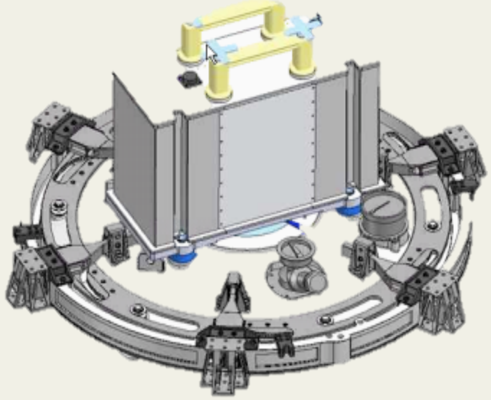
# Mission Kit Concept Enables Affordable Crewed Mission

- Docking System- Leverages International Space Station development of International Docking System Standard

- Relative Navigation Sensor Kit based on Space Shuttle Flight Tested Orion Sensors

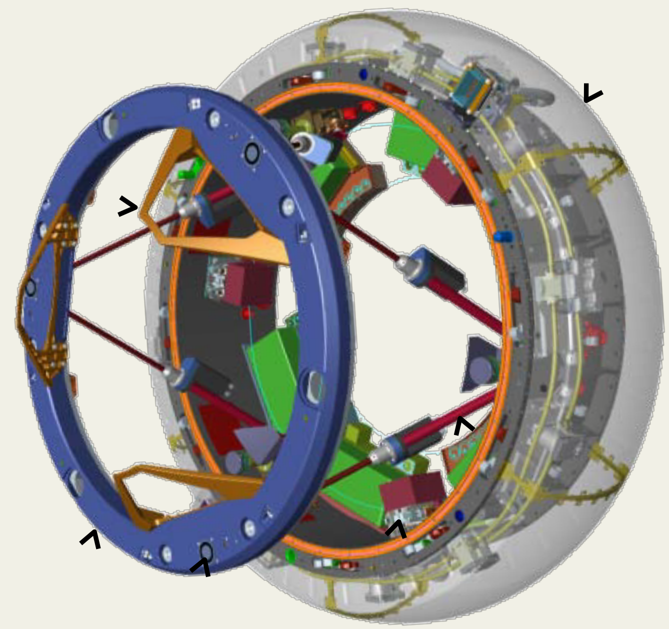
**Robotic Spacecraft Passive Half of Docking Mechanism**



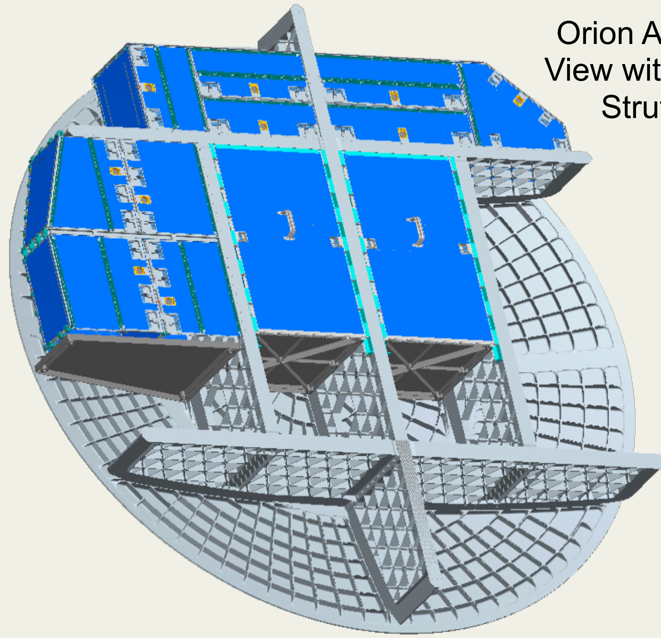


**Relative Navigation Sensor Kit**

**Orion Active Half of Docking Mechanism (extended)**

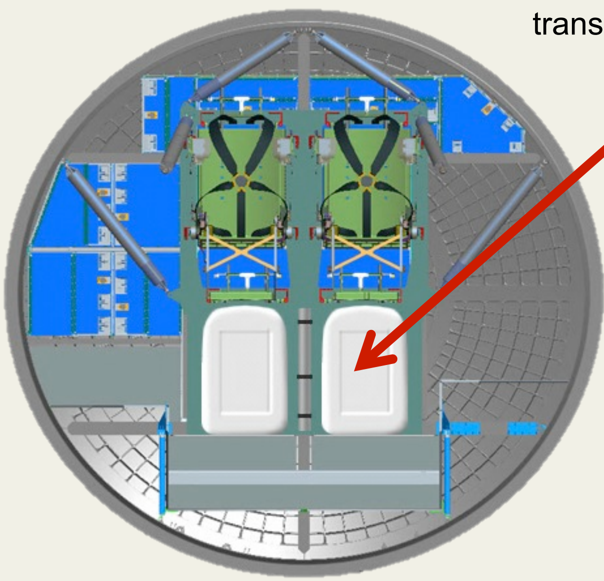


# Mission Kit Stowage



Orion AFT Bay Lockers View with All Seats and Struts removed

View with Seats; PLSS & translation boom Stowage

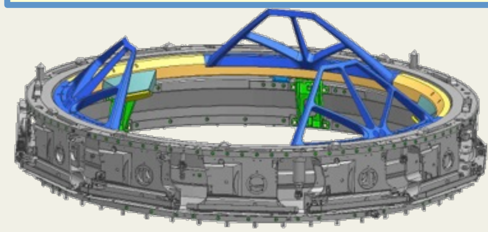


- Exploration PLSS backpacks and EVA translation boom stowed on unused Orion seat structure.
- Orion aft bay lockers stow smaller items (sample container, AR&D Sensors during launch, consumables)
- EVA Repress Tank stowed in the AFT bay
  - EVA accessible valve and plumbing is routed to the cabin for crew use

**Analysis shows sufficient stowage exists to accommodate ARCM Mission Kit**

# Accommodations for Crewed Mission (Docking)

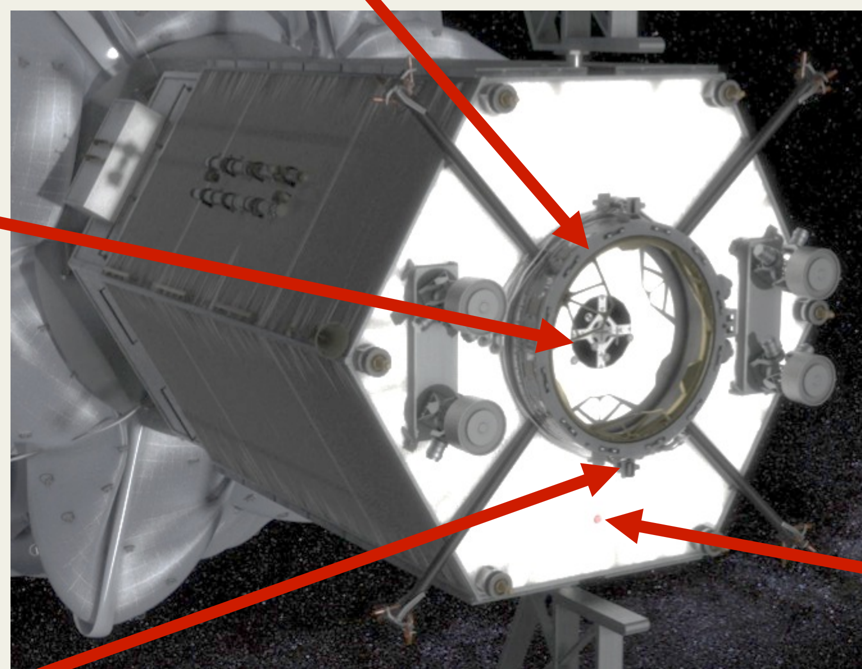
- Identified minimum ARRV hardware to accommodate Orion communication, docking using International Docking System Standard (IDSS) and extensibility



**Docking Mechanism**
- IDSS-compatible, passive side

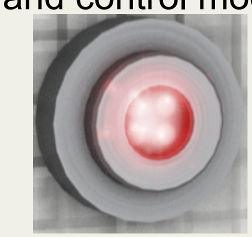
**Vehicle-to-Vehicle Comm**
- Orion compatible low-rate S-band with transponder

**Docking Target**
- Augmented with features for relative navigation sensors
- Visual cues for crew monitoring



**Reflectors**
- Tracked by the LIDAR during rendezvous and docking

**LED Status Lights**
- Indicate the state of the ARRV systems, inhibits and control mode



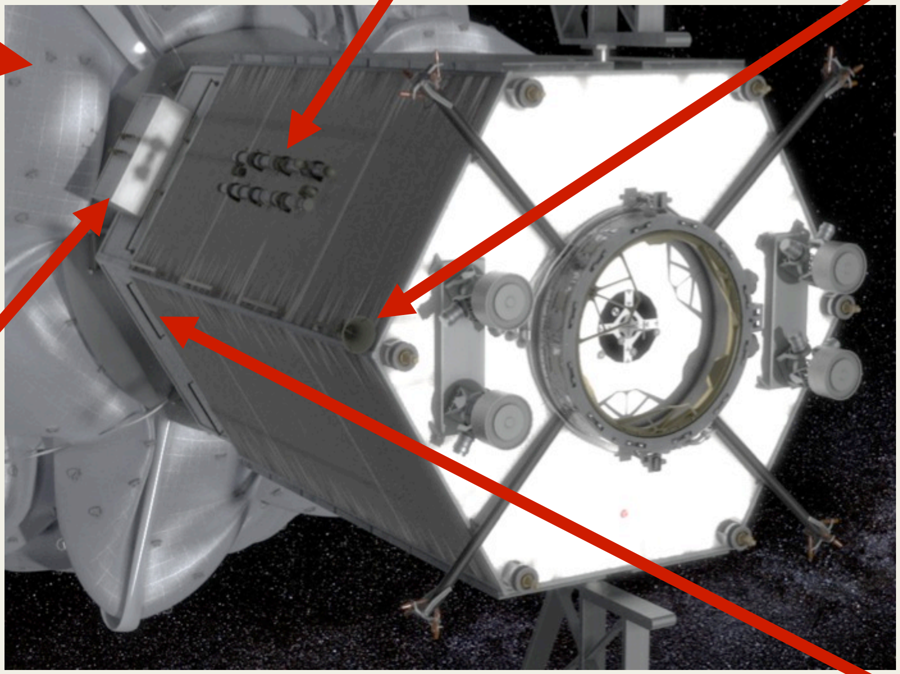
**Power and Data Transfer**
- Transfer through connectors already part of the docking mechanism design; Supports extensibility

# Accommodations for Crewed Mission (EVA)

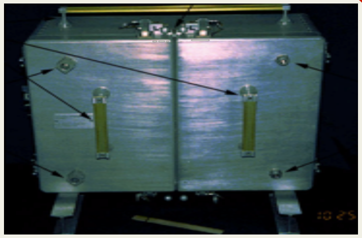
**Extra Vehicular Activity (EVA) Translation Booms**
- Translation Booms for Asteroid EVA

**EVA Translation Attach Hardware**
- Circumference of Mission Module at base of Capture System and ARV-Orion Interface

**EVA Tether Points**
- Hand-over-hand translation
- Temporary tool restraint
- Management of loose fabric folds



**Hand Rails**
- Translation path to capture bag
- Ring of hand rails near capture bag

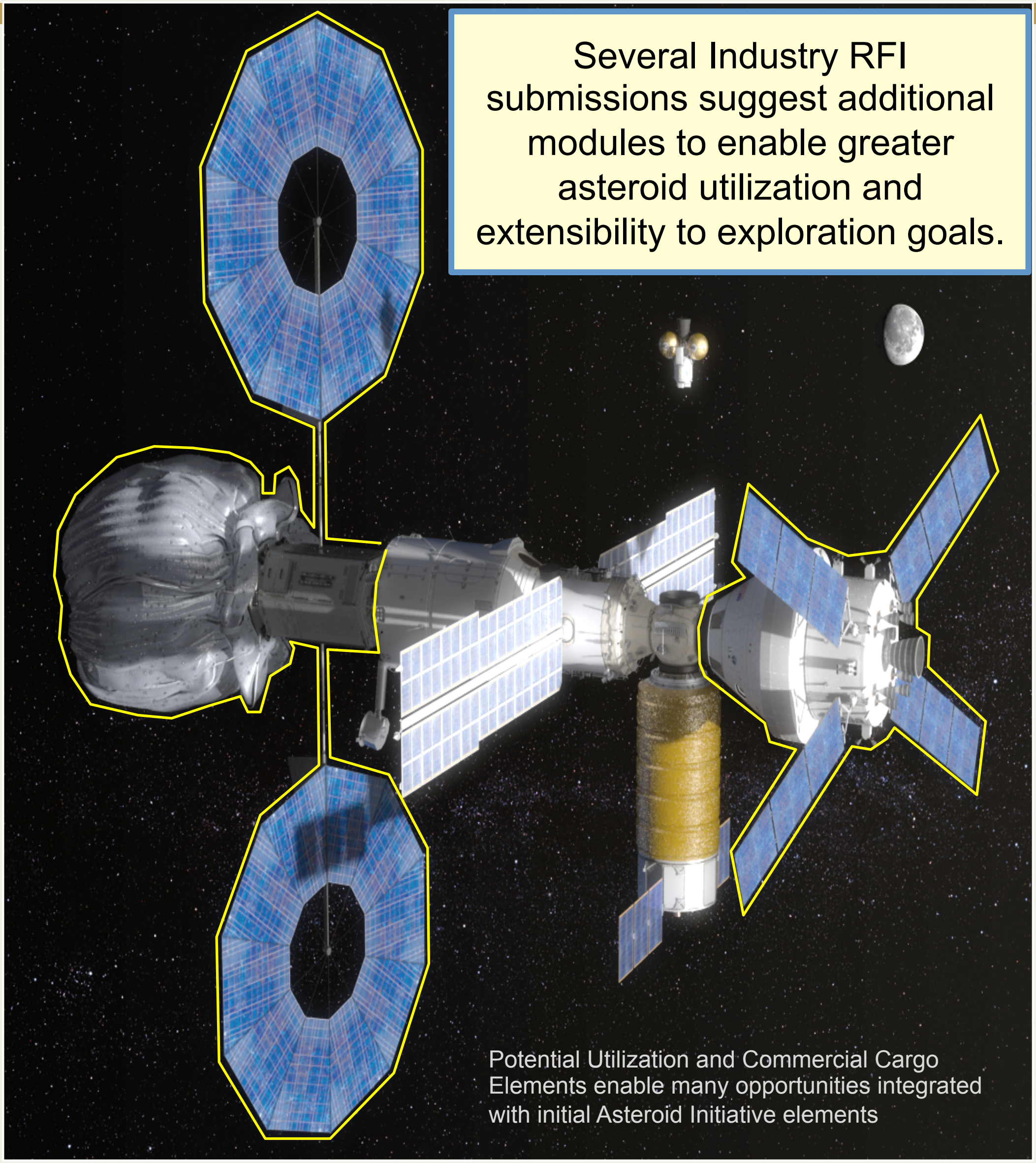


**Pre-positioned EVA Tool Box**
- Tool box stores 85 kg tools

# Further Utilization Enables Broader Participation to Achieve Exploration Goals

- Many possible opportunities for further utilization of the Asteroid
  - Testing of anchoring techniques
  - In-situ Resource Utilization (ISRU) Demonstration
  - Additional Asteroid Sample Collection
  - Lunar and Mars sample return
  - Scientific Experiments
  - Many other possibilities
- Realization of these opportunities requires additional payload delivery resources
  - Extending Commercial opportunities beyond low Earth orbit
  - Opportunity for International Partner Contributions
- Addition of utilization elements provide:
  - Extended crewed mission duration and additional EVA capability
  - Enhance crew safety with more robust systems and infrastructure

Several Industry RFI submissions suggest additional modules to enable greater asteroid utilization and extensibility to exploration goals.

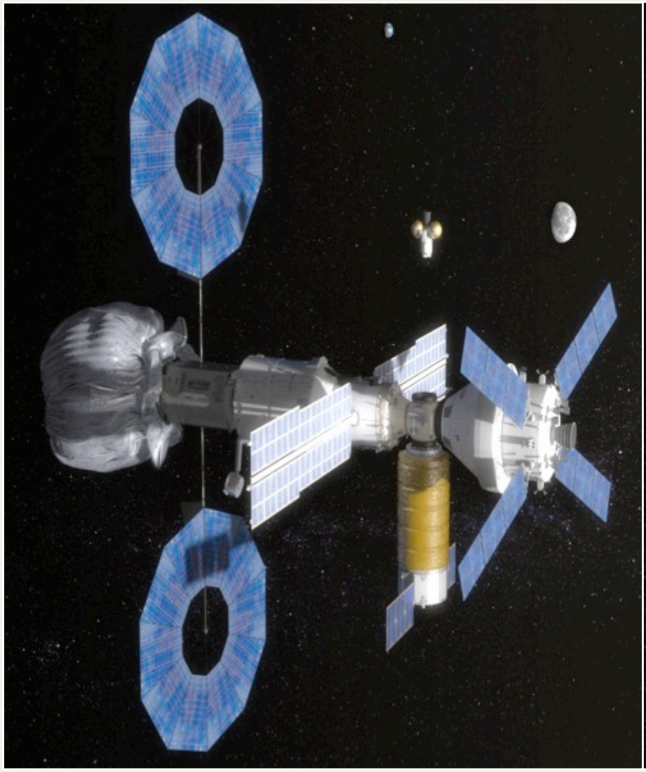


Potential Utilization and Commercial Cargo Elements enable many opportunities integrated with initial Asteroid Initiative elements

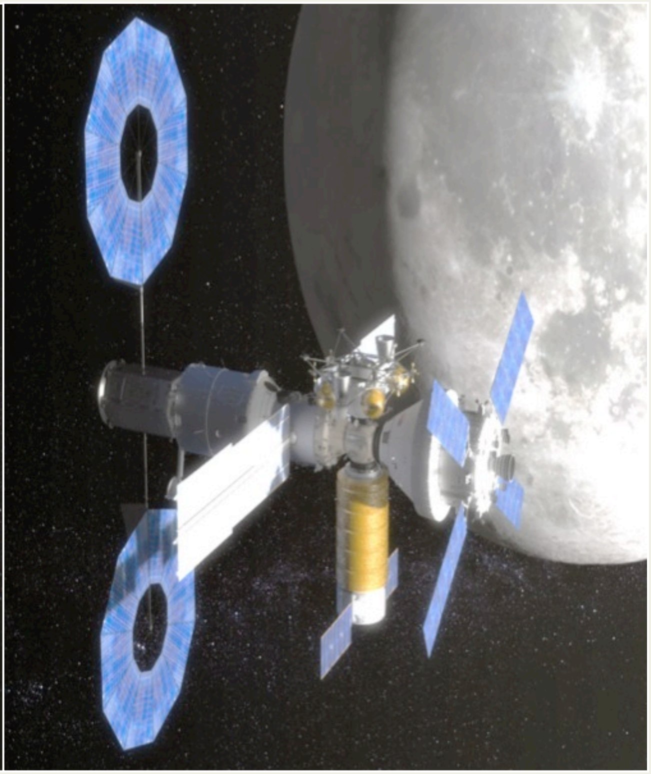
Moon size in image not to scale

Initial Asteroid Initiative Elements

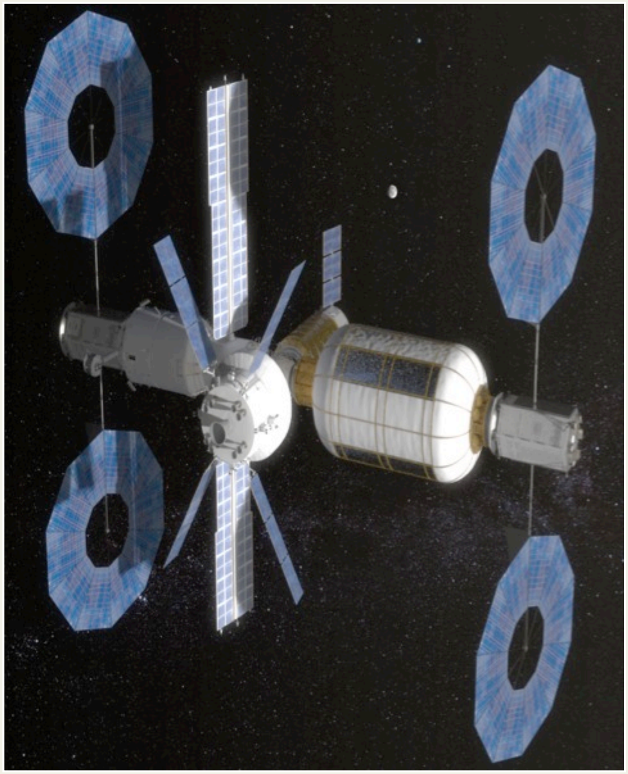
# Asteroid Redirect Mission builds upon Orion/SLS to Enable Global Exploration Roadmap



Asteroid Exploitation Missions



Lunar Surface Missions



Deep Space Missions

# First Steps to Mars and Other Destinations

| Sequence \ Mission | Current ISS Mission | Asteroid Redirect Mission | Long Stay In Deep Space | Humans to Mars Orbit | Humans to Surface, Short Stay | Humans to Surface, Long Stay |
|---|---|---|---|---|---|---|
| In Situ Resource Utilization & Surface Power | | | | | | X |
| Surface Habitat | | | | | | X |
| Entry Descent Landing, Human Lander | | | | | X | X |
| Aero-capture | | | | X | X | X |
| Advanced Cryogenic Upper Stage | | | | X | X | X |
| Solar Electric Propulsion for Cargo | | X | X | X | X | X |
| Deep Space Guidance Navigation and Control | | X | X | X | X | X |
| Crew Operations beyond LEO (Orion) | | X | X | X | X | X |
| Crew Return from Beyond LEO – High Speed Entry (Orion) | | X | X | X | X | X |
| Heavy Lift Beyond LEO (SLS) | | X | X | X | X | X |
| Deep Space Habitat | * → | → | X | X | X | X |
| High Reliability Life Support | * → | → | X | X | X | X |
| Autonomous Assembly | * → | → | X | X | X | X |

# Benefits of Asteroid Redirect Mission

- **Provides challenging near term missions for human exploration to provide foundational capabilities for deep space exploration**
  - SLS and Orion initial capabilities for deep space
  - Navigation and piloting operations of deep space vehicles for human missions
  - Mission Kits for in-space assembly (EVA, Docking and Rendezvous)
  - Life support and deep space habitability
  - Complex ground and space operations, and sampling of small objects
- **Exercises collaboration between human and robotic missions of exploration**
- **Furthers science and technology**
  - Enhanced small bodies observation and characterization
  - Advanced solar electric propulsion
  - Asteroid sample return - but this is not a science mission
- **Strong commercial application**
  - Advanced solar electric propulsion
- **Planetary defense interests (testing of deflection techniques)**
- **Future utilization of in space resources**