Asteroid Crew Segment Mission Lean Development

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NASA Johnson Space Center
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Agenda

- Asteroid Retrieval Mission Overview
- Orion and SLS Baseline Configuration
- Operational Concept Overview
- Trajectory
- Orion Functionality Kits
- Conclusion

Asteroid Redirect Crewed Mission (ARCM) Team

- Multi-center/multi-program team organized for fast turnaround, integrated assessments in concert with JPL/GRC Robotic Team (part-time, as required)
  - GSFC, JPL, JSC, KSC, LaRC, MSFC
  - ISS, Orion, SLS

Core Team

- JSC/Kirk Shireman
- JSC/Steve Stich

- JPL/John Baker
- LaRC/Charlie Cockrell
- JSC/Dennis Davidson
- KSC/Joe Delai
- JSC/Joe Caram
- JSC/John Connolly
- JSC/Kent Joosten
- JSC/Norm Knight
- JSC/Steve Labbe
- JSC/John McCullough
- JSC/Mark McDonald
- MSFC/Jim Reuter
- JSC/Andy Thomas

Analysis Team Members

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- Jonathan Lenius
- Gavin Mendeck

SLS

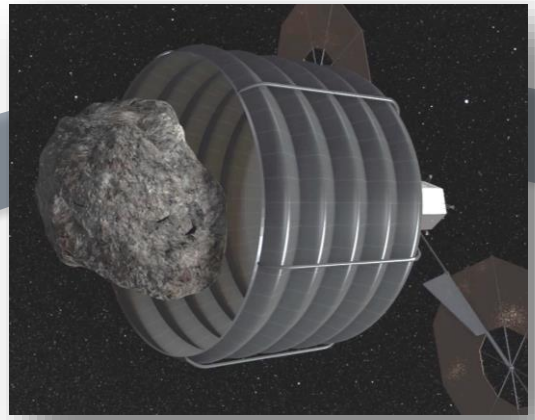
- Steve Creech

ISS

- Eric Schultz

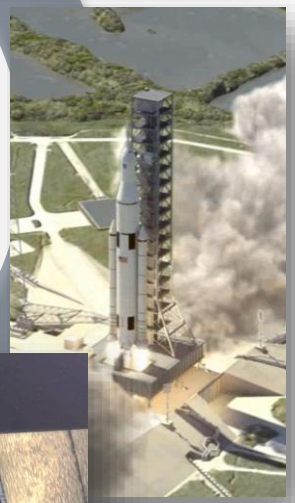
Asteroid Retrieval Mission Overview

Observe / Select



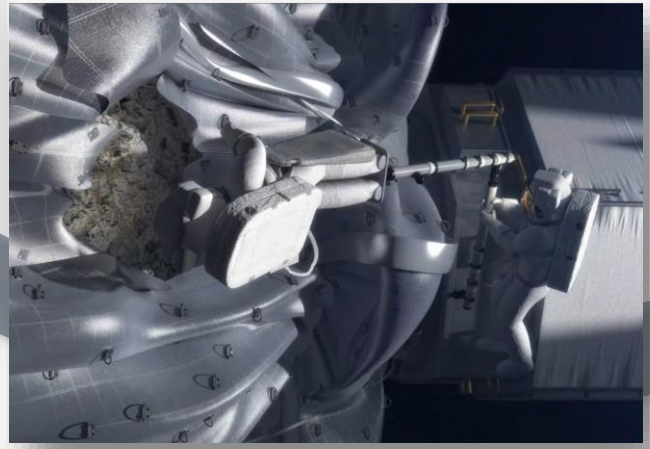
Capture

Redirect



Launch

Rendezvous



Explore

Return

Philosophy for the ARCM

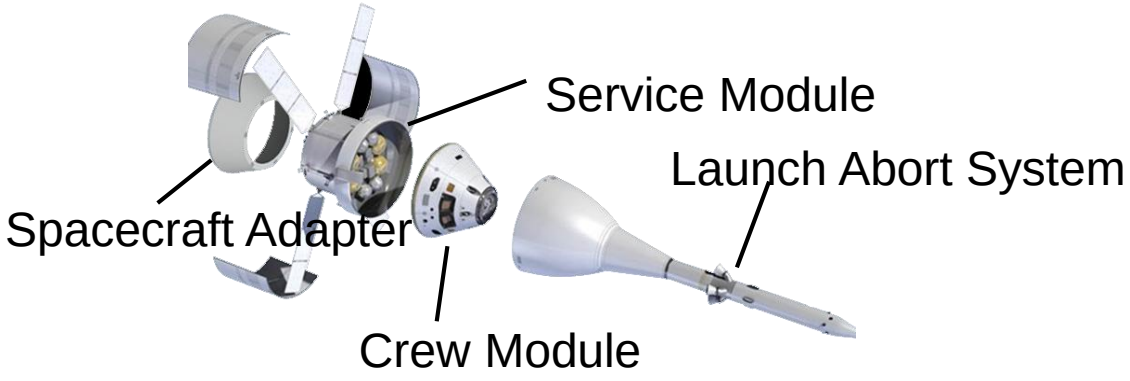
"Do no harm" to Orion Baseline Design

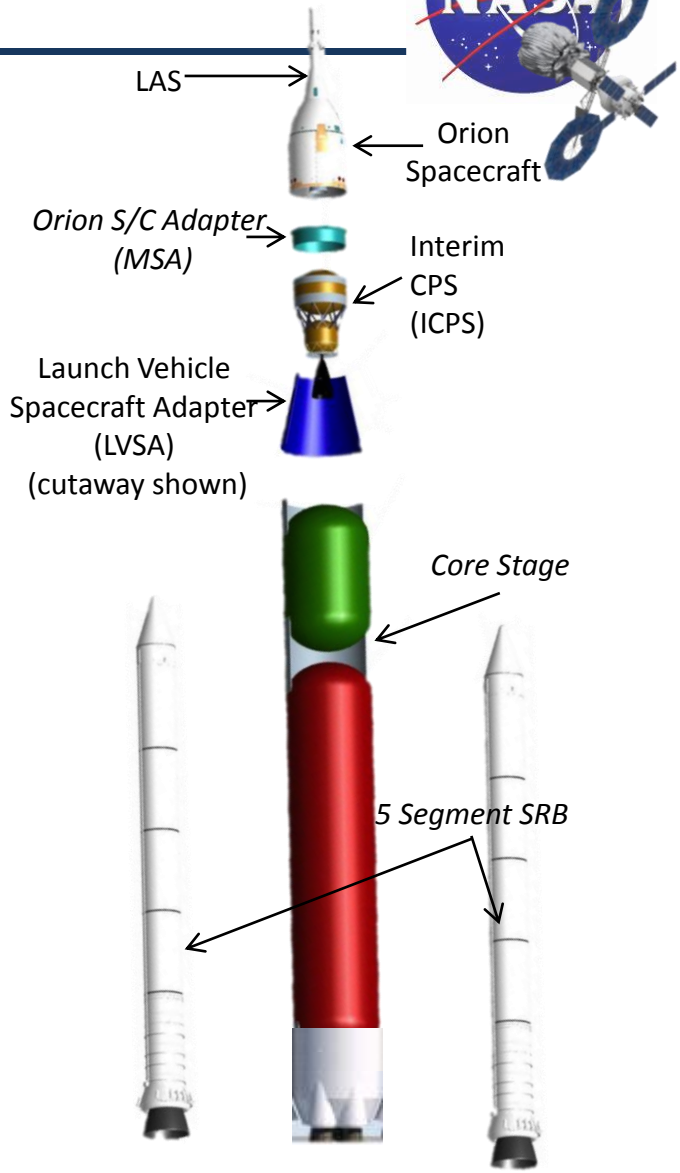
- Minimize delta Orion functionality required to perform ARUM mission
- Minimal changes to the Orion vehicle baseline design (hardware or software)
- Minimize Total Orion Mass Impacts to Orion Launch and Landed Mass Baseline Requirement
- Prefer additional hardware required for the mission to be bolt on kits or logistics requiring minimal Orion modifications.
  - Utilize existing technology investments to minimize kit cost and development time.

Orion and SLS Baseline Configuration

- Utilized Exploration Mission 2 (EM-2)baseline configurations from Orion and SLS Programs for cost, functionality and performance assessments

Crew Size	**Up to 4***
Active Mission Duration	**21.0 days* (req) 10-14 days (DRM)**
EVA	**None**
Rendezvous and Docking	**None**
Abort Capability	**All LAS modes, auto UAS, auto ATO, auto AOA, ground commanded ATO & AOA**
Communications	**Low-Rate (500 kbps)$^{+}$**
Life Support	**ARS and PCS (with flight crew equipment)**
Power	**Solar arrays Li-ion batteries**
SM Propulsion	**ESM - 4 tanks, Shuttle OMS-E**





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

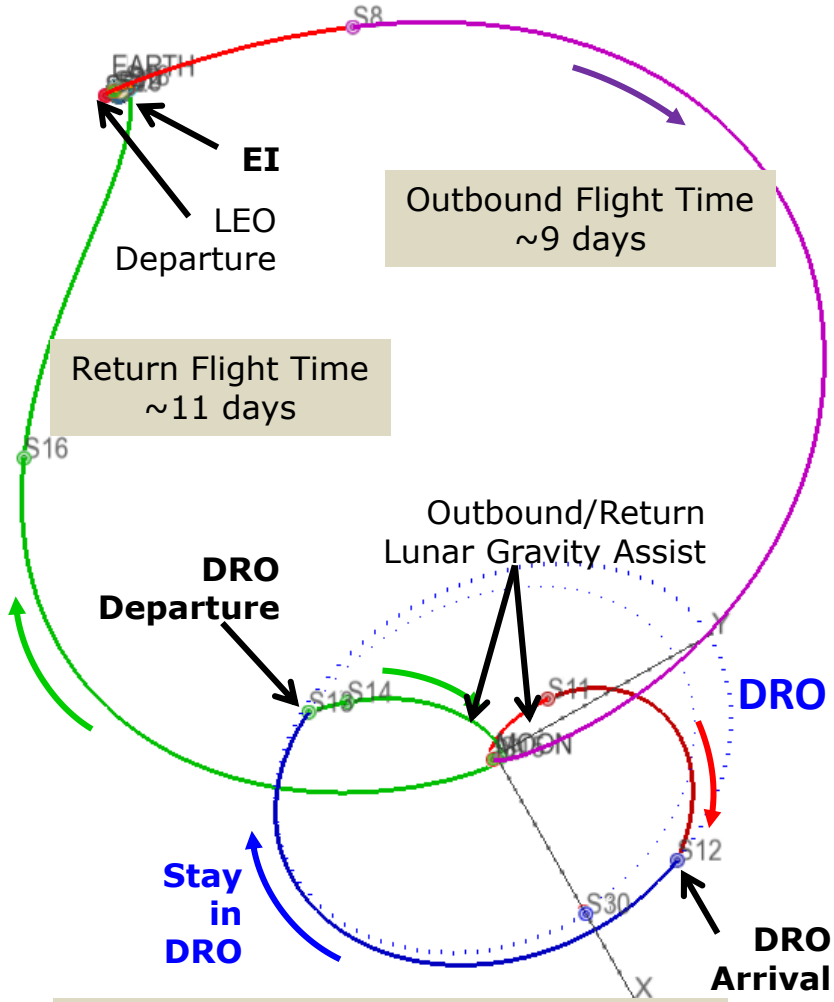
- Mission Design
  - Number of Crew — 2,3,4 crew
  - Mission Duration — 21,22,23 days,…
  - Trajectory — LGA/Direct, LGA/LGA, etc.
  - Number of EVA's — 0,1,2,3 EVA's,…

- 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
  - ARV Functionality Allocation
  - Functionality Launched Separately
  - Trajectory Design

Nominal ARCM Mission Concept Overview



Outbound Flight Time: 8 days, 9 hours
Return Flight Time: 11 days, 6 hours
Rendezvous time: 1 day
DRO Stay time: 5 days
Total Mission Duration: 25.65 days

- MECO Epoch: 2024-Aug-13 22:28:05TDB
- Entry velocity: 10.99 km/s

- Outbound
  - Flight Day 1 – Launch/TLI
  - 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 – Suit Refurbishment, EVA #2 Prep
  - Flight Day 13 – EVA #2
  - Flight Day 14 – Contingency / Departure Prep
  - Flight Day 15 – Departure
- Inbound
  - Flight Day 15 – DRO to Lunar Cruse
  - 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 event will varying slightly based on epoch variation.

Mission Design & Trajectory Trades

- Key constraints for crewed mission:
  - Orion/SLS performance capabilities ΔV, mission duration/consumables, etc.
  - Operations Planning Constraints: Launch availability, communications coverage, solar eclipses, etc.

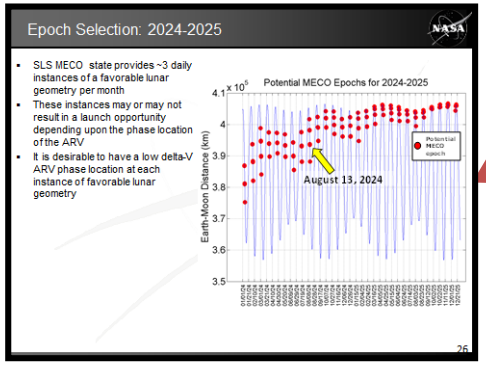
- Two areas of trades:
  - Staging Orbits:
    - High Earth Orbit (HEO)
    - EM-L2/EM-L2 Halo
    - Distant Retrograde Orbit (DRO)
  - Trajectory Optimizations:
    - LGA Outbound/Inbound
    - Direct Outbound/Inbound
    - Minimum-Duration (Feasibility Reference)
    - Minimum-DV (MFR Reference)

	HEO	EM-L2/Halo	DRO
Propellant - ΔV cost	Low	Moderate	Moderate
Orbit Maintenance	High	Moderate	None
Orbit stability	Low	Low	High
Risk of asteroid Earth entry	High	Low	Low

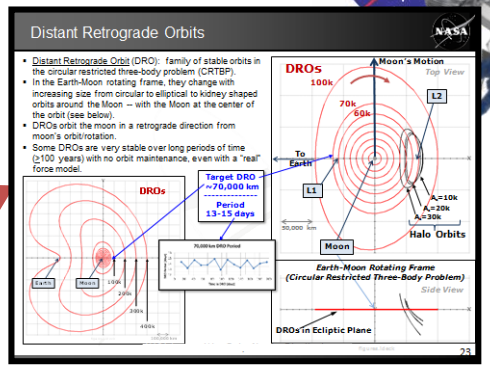
	Min-Duration	Min-ΔV
Delta-V cost	1200 m/s	1010 m/s
Number of crew	2	2
Number of days	22	26
Meets Orion/SLS GLOM/TLI control mass	Yes	No
Accommodates Orion mass threats	No	Yes
Accommodates main engine failure	No	Yes

Destination/Trajectory Selected: DRO/Minimum-ΔV/LGA Inbound and Outbound
26-day mission; Accommodates Orion mass threats and main engine failure
Exceeds Orion/SLS GLOM/TLI control mass requirements
SLS cannot perform complete TLI; Orion SM used to finish TLI maneuver

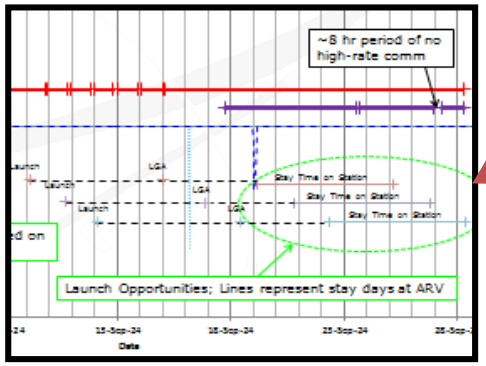
Mission Design Considerations



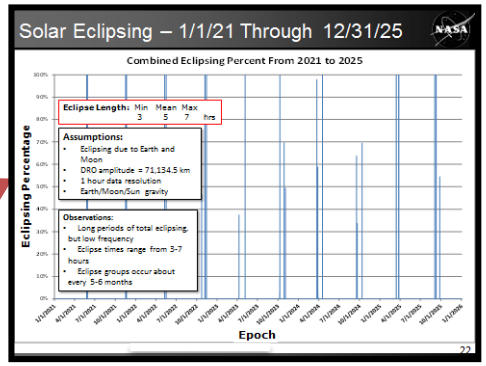
Launch Availability
~2-3 opportunities per month



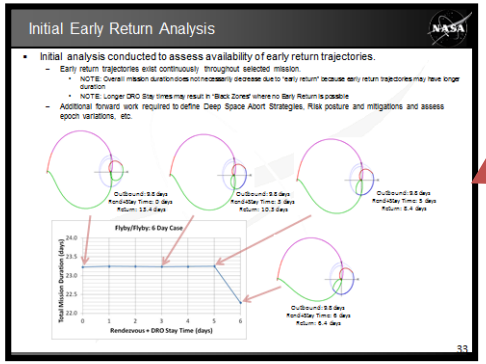
Selection of 71433km DRO improves Launch Availability by syncing with Lunar period



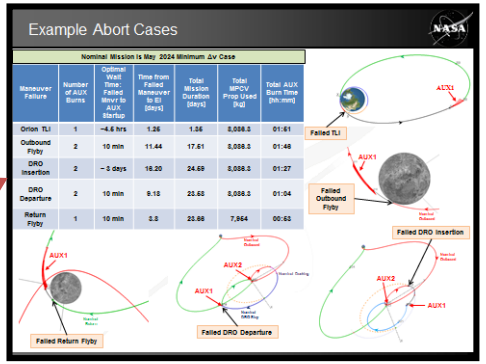
Initial Communications Coverage for Orion/ARV indicate acceptable coverage periods



Avoid flying when Orion would experience long Solar Eclipse



Allow for adequate ΔV for Early Return Constraints



Allow for Auxiliary Thruster Contingency Return Cases

Additional Orion Functionality

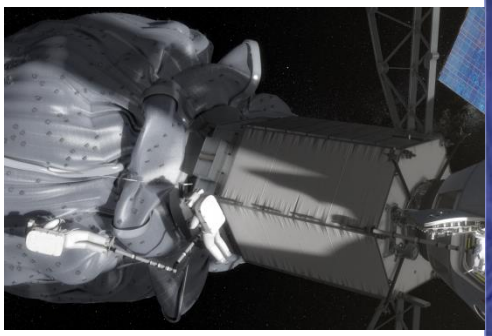
Using the Orion EM-2 configuration as the reference baseline: Any additional capability required for the mission would be treated as add-on-kits

- Additional functionality required for ARCM Mission
  - In order to take full advantage of the Asteroid, Crew members would need to perform EVAs to collect samples.
  - In order to mate the ARV and Orion, Rendezvous and Docking functions need to be added.

- Scaling the crew number and mission duration to meet mission objectives to 2 crew 30 day mission duration allowed EM2 Crew and equipment mass to be traded for additional capability
  - Removed
    - 2 Crew
    - 2 Suits
    - 2 Seats
    - 24 days of Food
    - 24 days of Cloths and crew preference items

Suit and EVA Mission Kits

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

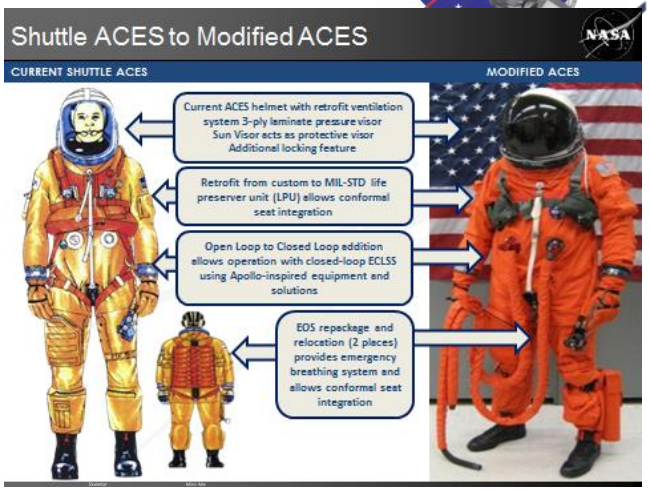


EVA Servicing and Recharge	EVA Tools, Translation Aids & Sample Container Kit	EVA Communications	Cabin Repress Kit
Equipment necessary for multiple EVAs including recharge for PLSS water and oxygen, crew equipment, etc.	Standard and specialized tools to complete mission objectives	Repackaged PLSS radio 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

Space Suit Options

- The following suits were considered for ARCM:
  - Shuttle ACES
  - Modified ACES (MACES)
  - EMU
  - Exploration Suit (Z-series)

EMU



MACES

Z-Suit

Suit	Per Crew Mass (lb/kg)	Accounted for in Orion Mass?	Suit Design Focus	Applicability for dual use?
Shuttle ACES (full gear)	~90/41	No	Launch/Entry Survival	--
Modified ACES (Orion Baseline less umbilical)	~35/15.9	Yes	Launch/Entry Survival	Minor mods for EVA-capable prototyped
EMU**	~140/64	No	Microgravity Mobility	Not appropriate for launch and entry
Exploration Suit**(Z-series)	~140/64	No	Planetary Mobility	Not appropriate for launch and entry

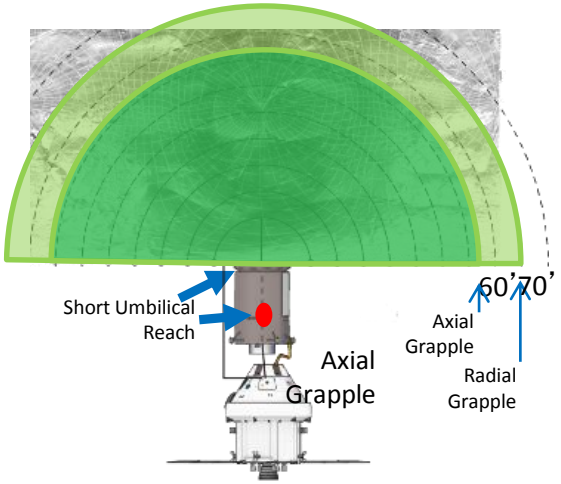
Modified ACES suit selected:
Orion launch/entry suit; mass is already accounted for in Orion baseline
Minimal EVA-capability with minor mods being tested to increase EVA capability

Life Support System Options

- The following Life Support options were considered for ARCM:
  - Short Umbilical Closed-loop
  - Long Umbilical Open loop
  - EMU PLSS
  - Exploration PLSS

EMU-PLSS

Umbilical EVA



Umbilical Reach

Exploration PLSS

Life Support Option	Applicability to Future Exploration Missions	Mass Impact for 2 EVA crew (lb/kg)	Applicability to Asteroid Redirect Mission
Short EVA Umbilical (28' Closed Loop)	No	--	Won't support mission due to short length Orion modifications would be required due to fan size
Long EVA Umbilical (100' Open Loop)	**No**	**784/356**	**Could support asteroid mission** **Supplemental O2 tank required to support metabolic load** **Boost pump would be required for water cooling**
EMU PLSS	In use on ISS	--	Suit integration effort would be significant Designed for hard upper torso vs. MACES soft upper torso
Exploration PLSS	**Currently under development**	**585/265**	**Could support asteroid retrieval mission**

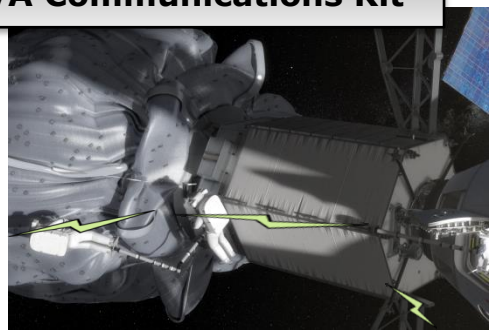
Exploration–PLSS selected: LOWEST mass option;
Leverages recent technology development efforts; Benefit to Orion, ISS, and future Exploration Missions

Additional Orion Kits

Orion EVA Repress Kit

- ARUM mission needs auxiliary gas to repress the cabin following Nominal EVAs
  - Orion carries sufficient nitrogen to repress cabin for contingency EVA only.
- A high pressure gas tank stores enriched air at the required mixture to perform the repressurizations to 10.2 psia (70 kPa)

EVA Communications Kit



- Common radio hardware used in Orion, ARV and EVA PLSS.
  - Repackaged PLSS radio that allows relay communication between EVA crew and ground
  - Orion version of kit interfaces with the Orion power and serial data interface.

Sample Container Kit

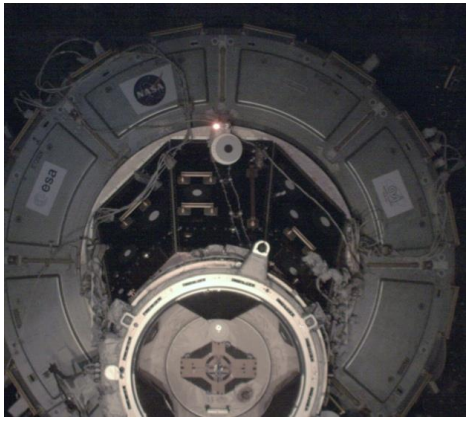
- Multiple containers used for sample collection and storage
  - Based on Apollo and Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) white papers.

Automated Rendezvous and Docking (AR&D) Kit

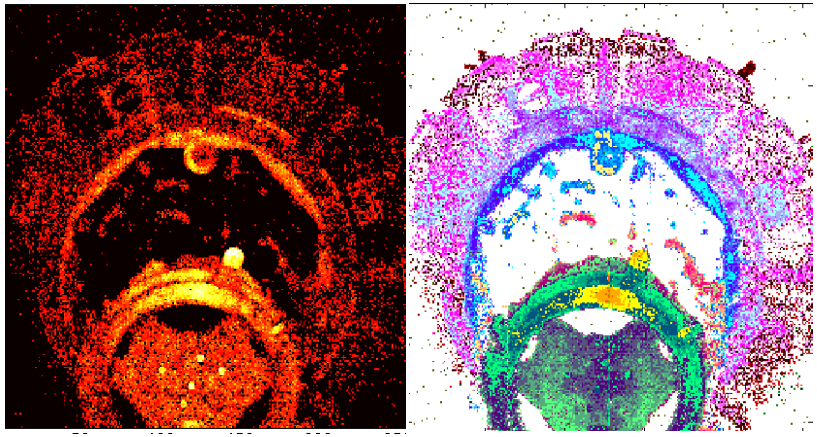
- Use Agency wide Common AR&D Sensors based on STORM DTO packaged to fit the Orion Crew Module.
  - Leverage Multi-Center investments in Synergistic AR&D solutions
  - AR&D solution common among multiple projects including Orion, ARV and Satellite Servicing missions.
- Orion S-Band transponders on both Orion and ARV provide initial Range/Range rate to assure crew timeline constraints are satisfied.
- Requires Orion Software development to integrate sensors into navigation system.

Prototype Sensor Package

STORRM Camera Image



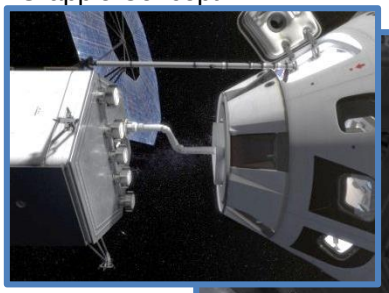
STORRM LIDAR Images

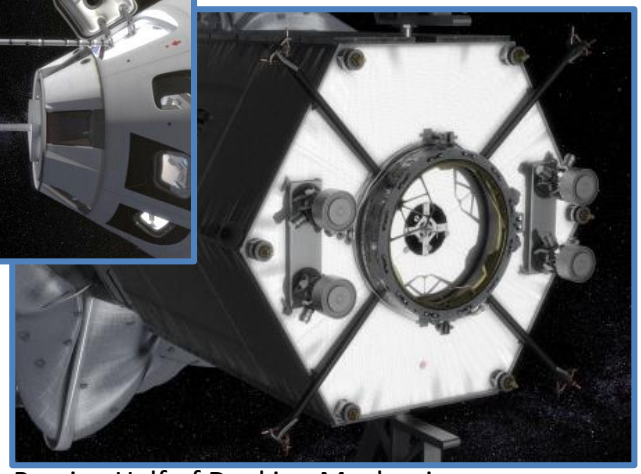


Orion to ARV Attach Options

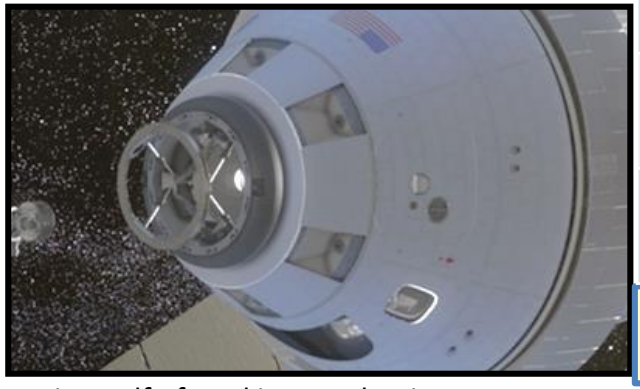
- Options considered for Orion-ARV Attach:
  - Grapple – multiple locations studied
  - Docking – multiple locations studied
  - Tether – not feasible

Grapple Concept





Passive Half of Docking Mechanism



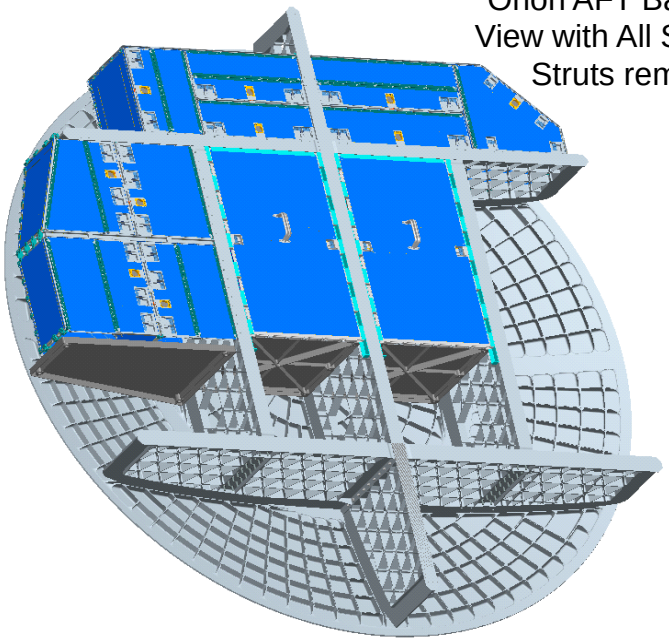
Active Half of Docking Mechanism

	Grappling	Docking
Mass impact to Orion/ARV (kg)	115.0/13.6	341.0/114.0
Mass Threat	High; Additional mass required for mated stack loads	Low
Cost Threat	High; New development item	Low; under contract
Implementation on aft end of ARV bus	Unknown due to requirement to actively handle stack loads	Yes
Short-Term Support		
ARCM Integrated Stack Attitude Control	Known issues/risks; more effort required to resolve	Allows Orion to maneuver the integrated Orion/ARV stack with its thrusters
Docking Loads/Effects on Stack	Minimal	Slewing of stack away from docked attitude, corrected by Orion RCS
Extensibility Support		Planned Comm. Crew Use
Supports Permanent Attachment of Additional Elements	No	Yes
Power Transfer	Requires EVA umbilicals and additional inhibits/complexity due to amount of power transfer	Addressed via connectors built in to docking mechanism
Data Transfer	Requires EVA umbilicals	Addressed via connectors built in to docking mechanism

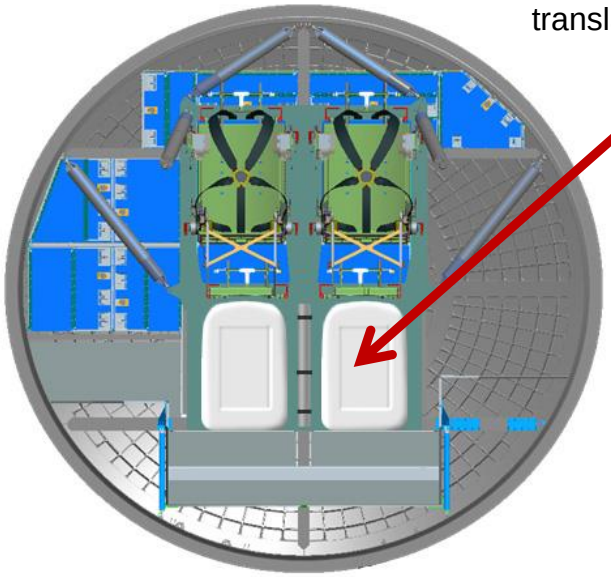
Docking Selected; Robotic & Crewed Mission Teams Concur
Low cost/mass risk; enables integrated stack control & extensibility

Mission Kit Stowage

View with Seats; PLSS & translation boom Stowage



Orion AFT Bay Lockers View with All Seats and Struts removed



- Exploration PLSS backpacks and EVA translation boom stowed on unused the 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

Integrated Mass Impacts

Gross Lift Off Mass (GLOM)		
Category	**Mass Impact (kg)**	**Mass Impact (lb)**
Reduce Crew, Equipment, Consumables to 2 crew, 30 days	-333	-734
Add EVA Kits	+379	+835
Add Docking Kit	+429	+946
Add Relative Navigation Kit	+44	+97
Orion Propellant Offload	0	0
Total Net Impact	+519	+1144

Abort Landed Mass		
Category	**Mass Impact (kg)**	**Mass Impact (lb)**
Total Net Impact	+90	+199

Nominal Landed Mass		
Category	**Mass Impact (kg)**	**Mass Impact (lb)**
Total Net Impact	+40	+88
Includes 10kg/22lb samples		

Trajectory Analysis utilized Orion SM to augment the Trans Lunar Injection (TLI) burn accommodating the additional GLOM mass of the ARCM mission.

Continuing to coordinate with ESD/Orion/SLS for ongoing Landed Mass analyses

Conclusion

- Asteroid Retrieval Crewed Mission requires a minimum set of Key Capabilities compared in the context of the baseline EM-1/2 Orion and SLS capabilities.
  - Life Support & Human Systems Capabilities
    - Orion ECLSS Capability (2 crew/~30 days/Open Loop)
    - Human Interface and Support Systems for ~30 day mission
  - Mission Kit Capabilities
    - Automated Rendezvous System
    - Docking System
    - Deep Space EVA Capability

- Something about minimizing the impact to the Orion and SLS development schedules and funding
- Leveraging existing technology development efforts to develop the kits adds functionality to Orion while minimizing cost and mass impact.