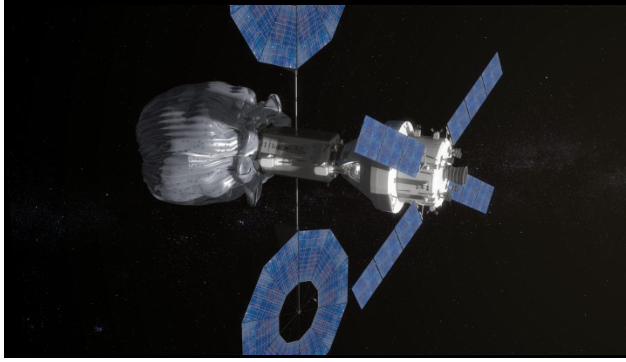
Asteroid Redirect Crewed Mission (ARCM) Reference Concept



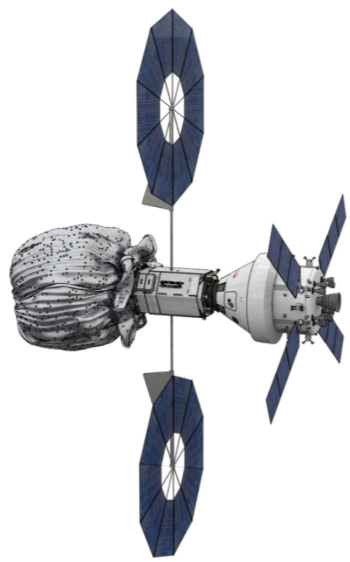
Objectives

Provide the capability for the first-ever human exploration of an asteroid surface in a stable lunar orbit as early as the 2021 timeframe.

- Provide a crewed vehicle to rendezvous with a robotic vehicle and return samples from a captured asteroid to Earth.
    - Demonstrate Space Launch System (SLS) delivery of the Orion crewed vehicle to a stable Earth-Moon orbit.
    - Demonstrate rendezvous and docking of the Orion with a robotic vehicle.
- Provide an extensible architecture that supports human exploration.
    - Develop hardware elements that can be utilized for future human exploration missions.
    - Demonstrate deep space extravehicular activity (EVA) and tools to collect asteroid samples.
- Demonstrate technology needed for humans to explore the solar system.
    - Develop technical capabilities and operations that are necessary “building blocks” for more ambitious human exploration destinations.

Mission Overview

- 2-person crew launched aboard Orion to explore a small asteroid redirected to the Earth-Moon system.
- Rendezvous and dock with a robotic spacecraft known as the Asteroid Redirect Vehicle (ARV) in a Distant Retrograde Orbit (DRO) at an orbital altitude of ~70,000 km above the lunar surface.
- Conduct 2 EVAs to observe, document, and collect samples of the captured asteroid.
- Crew returns with samples to a splashdown off the coast of California.
- Total mission duration of approximately 22 to 25 days.



ASTEROID REDIRECT CREWED MISSION SUMMARY

The Asteroid Redirect Crewed Mission (ARCM) Reference Concept consists of five primary segments of operational activity; launch and early mission operations, Earth departure and distant retrograde orbit (DRO) transit, rendezvous with the Asteroid Redirect Vehicle (ARV) and human exploration operations, DRO departure, and deorbit prep, entry and crew return. The complete crew reference mission will last 22 to 25 days from launch to crew splashdown with the actual mission duration dependent on the launch date and other factors. (See Table 1).

Table 1. ARCM Reference Operational timeline.

Flight Day	Mission Event
1	Launch, Ascent, Trans Lunar Injection
2-6	Outbound Translunar Cruise. Depress cabin to 10.2 psia, suit checkout/EVA dry run, robotic vehicle checkout, rendezvous/docking preparations
7	Lunar Gravity Assist and close approach to moon
7-10	Lunar Gravity Assist to Distant Retrograde Orbit Cruise
10	Rendezvous
11	EVA 1
12	Suit refurbishment, EVA 2 prep
13	EVA 2
14	Contingency margin, Housekeeping, Departure Prep
15	Undock and Departure
15-19	Depart DRO to Lunar Cruise
19	Lunar Gravity Assist maneuver
20-22	Inbound Translunar Cruise, cabin stow, repress cabin to 14.7 psia
22	Entry, crew recovery

Launch and Early Mission Operations

The ARCM reference concept utilizes the Space Launch System (SLS) launch vehicle in the Block 1 configuration for initial ascent to Earth parking orbit. The SLS configuration will use the interim Cryogenic Propulsion Stage (iCPS) to inject the Orion vehicle with a crew of two toward trans-lunar space. This reduced crew size will yield mass and volume savings to accommodate additional hardware to accomplish the crewed mission. Initial analysis of a representative launch epoch has shown that approximately two launch opportunities would exist in a given month where the trajectory, communications coverage, and eclipse constraints are acceptable for conducting the human mission from Orion. Before the Orion departs Earth parking orbit, initial on-orbit checkout operations will occur including but not limited to; communications configuration/checkout, and solar array deploy. These initial operations will occur over the course of the first flight day of the mission.

Earth Departure and DRO Transit

The necessary delta V for conducting the Earth Departure Maneuver (EDM) will be obtained through the SLS-provided iCPS and the Orion Service Module. Depending on the final selected trajectory, Orion may perform small burns after separation from the iCPS to place the vehicle on a trajectory toward the moon for a Lunar Gravity Assist (LGA) maneuver prior to entering the Earth-Moon DRO. The transit time is estimated at 10 days with crew activities consisting of cabin and extravehicular activity (EVA) preparations, cabin depressurization to 10.2 psia, rendezvous and docking preparations, EVA task ‘dry runs’, potential deep-space science activities and media and outreach events. A detailed timeline assessment will be conducted to determine which activities will be conducted while in transit vice prior to Earth parking orbit departure. An overview of the mission trajectory and transit times is shown in Figure 1. It should be noted that the transit times are approximate. Different launch dates and delta-V allocation strategies impact transit duration resulting in an end-to-end crewed mission duration of between 22 and 25 days. It is anticipated that further analysis and accommodation of different launch dates and contingencies will increase the duration to 25 to 30 days.

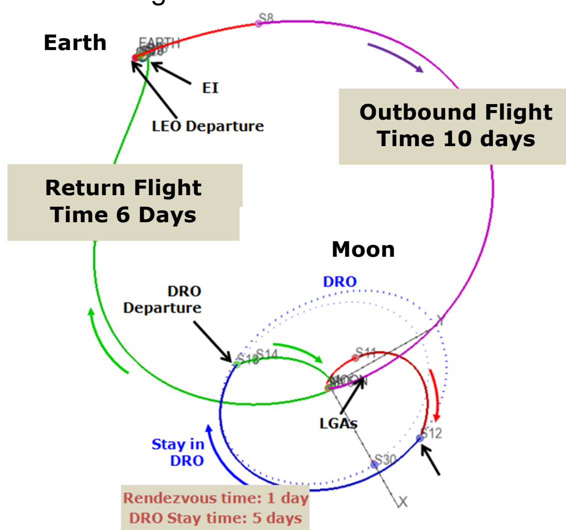


Figure 1. ARCM Reference Concept trajectory overview.

Rendezvous with ARV and Crewed Operations

By the tenth mission day, Orion will reach the DRO insertion point approximately 10 km away from the ARV. The DRO is a highly stable position within translunar space where the ARV can transport the captured asteroid and “park” for long periods of time (years) with minimum trajectory maintenance required. Prior to Orion reaching 5 km from the ARV, the ARV will feather its solar arrays to minimize Orion thruster plume impingement. The ARV will hold its pre-docking attitude throughout the Orion final approach. Prior to Orion contact, the ARV will be moded to free drift via ground command and Orion will transition to free drift at first contact. Orion will then commence with final docking or grapple operations. Docking will utilize an International Docking

System Standard (IDSS) compliant mechanism. Once Orion and the ARV are hard-mated, Orion will maneuver the integrated stack to an operational attitude meeting the constraints of both vehicles and the crew will conduct final preparations for EVA. Grappling would utilize a robotic arm carried on the Orion spacecraft in place of the docking mechanism. Once grappled, the robotic arm would remain active until separation approximately five days later. The robotic arm will actively maintain relative distances between the vehicles. The Orion propulsion system with be used to maintain the integrated stack flight attitude with augmentation from the ARV reaction wheels in some modes of operation.

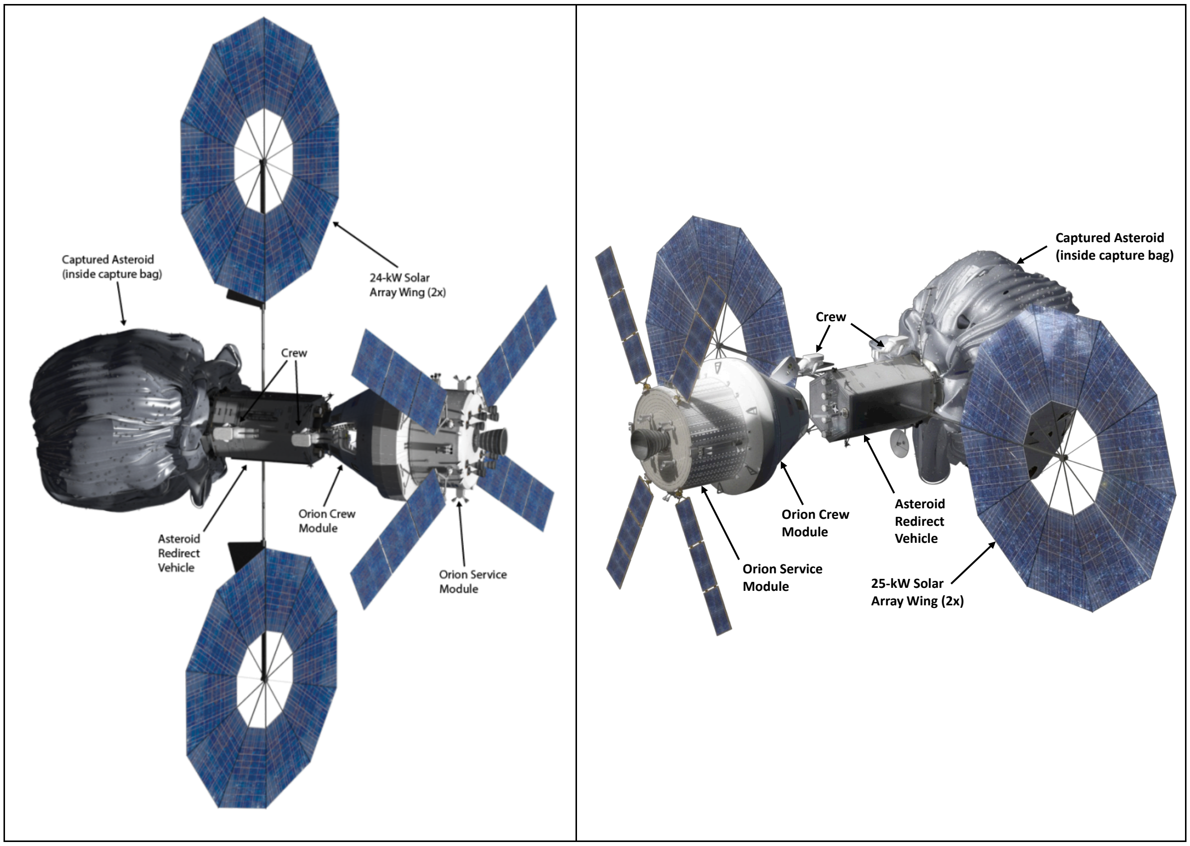


Figure 2. ARCM Docked and Grappled Configuration.

Orion and the ARV will be docked in DRO for approximately five days with Orion undocking on the 5th day (~Flight Day 15) (see Figure 2 for docked configuration). Over the course of the docked period, two 2-person 4-hour EVAs will be conducted utilizing lightweight exploration space suits with a day between EVAs spent reconfiguring/servicing the suits. This servicing and checkout of the suits will recharge suit consumables, clean the suit interior, replace biomedical sensors, and allow checkout of Portable Life Support System (PLSS) components in preparation for the second EVA. After suit donning, in-suit prebreathe, and a cabin depressurization to vacuum, the crew will commence EVA by exiting Orion and translating across a boom installed between the Orion hatch and the ARV (See Figure 3).

Figure 3. EVA crew on boom translation path from Orion to ARV.

The crew will translate along the ARV using the preinstalled handrails to the ARV EVA toolbox and capture bag. The EVA crew will utilize additional booms and EVA tools to access the captured asteroid to collect samples. (See Figure 4).

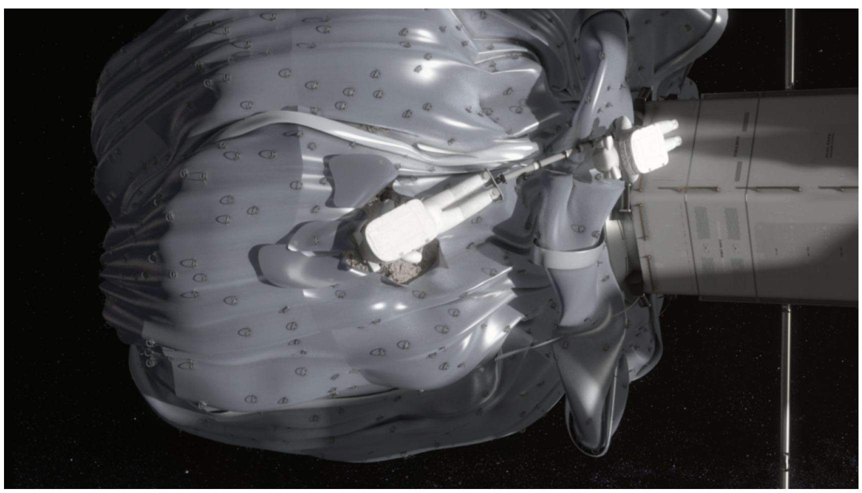


Figure 4. Sample Collection from Boom.

Throughout the EVAs, the crew will interact with Johnson Space Center's Mission Control Center (MCC) over a 3 to 4 second round-trip communications delay. The duration of each EVA is assumed to be dependent upon crew fatigue with the lightweight exploration space suit and not consumables, and may be extended if crew evaluations show fatigue to be less of a factor than anticipated. Upon completion of the EVAs, samples of the asteroid will be labeled and contained within a sample return container for return to Earth in Orion. The EVA crew will stow tools and translation aids on the ARV for use by future crews and then ingress Orion for cabin repressurization, suit doffing, and preparations for undocking from the ARV and return.

A day after the final EVA will be reserved as contingency margin, generic Orion /ARV housekeeping, lower priority science and outreach activities, and preparation for ARV departure. EVA capability will be maintained in the event of a contingency during undocking operations. On the day of undocking, the integrated stack will be commanded into free drift until physical separation is achieved. As during rendezvous and docking operations, range and range rate information will be collected until vehicles are no longer operating in proximity. The ARV will then be configured for extended quiescent operations until a new Orion, commercial or international vehicle visits.

DRO Departure

After Orion undocks from the ARV, the crew will enter a 6 day return from the DRO including a LGA. During this journey, the crew will complete potential deep-space science activities, media and outreach events, and cabin reconfiguration for return and reentry including repressurization of the cabin to 14.7 psia.

Deorbit Prep and Crew Return

The returning Orion crew will complete deorbit to a targeted skip entry with splashdown off the coast of California. Collected asteroid samples will be transported to the Sample Curation Facility at Johnson Space Center for processing, study, and analysis in an inert environment.

ARCM Mission Functionality Kits

While the Orion configuration utilized for the ARCM mission includes full crew life support systems capable of supporting a 21 day mission for four crewmembers, it cannot support EVA operations. By reducing the crew compliment from four to two, additional internal stowage and mass capability can be realized, extending Orion capability beyond 21 days. This will also allow for the installation of ARCM Mission Functionality Kits (MFK's) which will extend the capability of Orion to support the ARCM mission. The fundamental design guideline with the MFK's is to minimize changes to the Orion baseline and ground support equipment, and make those changes self-contained to the kits themselves. A total of nine kits are proposed to extend MPCV capabilities for the ARCM mission (see Table 2).

Table 2. Summary of required Mission Functionality Kits (MFK).

Mission Functionality Kit (MFK)	Kit Summary
Lightweight Exploration Space Suits	Providing improved mobility and reduced crew fatigue supporting 4-hour ARCM EVA operations.
EVA Servicing Kit	Provides PLSS recharge & servicing to support ARCM EVAs.
EVA Tool Kit	Provides tools for nominal and contingency operations supporting translation, sample collection, and other ARCM EVA activities.
EVA Communication Kit	Provides voice and data (suit telemetry & video) communication between Orion and the EVA crew.
EVA Repress Kit	Provides consumables and interfaces for Orion cabin repress following ARUM EVA's.
Sample Container Kit	Provides collection and containment bags for preserving asteroid samples for Earth return and later analysis.
Relative Navigation Kit	Provides sensors for rendezvous, proximity operations, and docking of Orion to ARV.
Docking or Grapple Kit	Provides IDSS compliant docking mechanism or grapple fixture plus robotic arm for mating of Orion to ARV.
Robotic Augmentation Payload Option	Notionally would provide robotic assistance (free flyer and/or attached robotic device) for EVA support and augmentation.

Interfaces

Key elements of this mission include the ARV, Orion, SLS vehicles, the Deep Space Network (DSN) for communications, Launch and Ground Operations, Crew Mission Operations, and ARV Mission Operations Centers, the asteroid itself, and the sample recovery mechanism. Interfaces between each of these core elements will be taken into consideration throughout ARCM design.