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The Asteroid Redirect Mission and sustainable human exploration ☆

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ABSTRACT

We present the importance of the Asteroid Redirect Mission (ARM) in the context of the Global Exploration Roadmap and NASA's strategy for sustainable human exploration. We also provide status toward baseline of the ARM, including evolution of concept development based on internal NASA analysis and risk reduction, as well as external inputs received. This includes development of mission concept options, key trade studies, and analysis of drivers for both the robotic and crewed mission segments.

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1. Introduction

The Asteroid Redirect Mission will utilize critical exploration technologies and capabilities under development within NASA that enable many future human exploration missions. This work provides the current internal reference concepts for the robotic and crewed missions, including vehicle and system options and trades. Applicability to future deep space human mission is also discussed. The crewed mission in the mid-2020's will include the Space Launch System (SLS) heavy-lift crew launch vehicle; Orion multi-purpose crew vehicle; advanced technologies and systems for rendezvous and extra vehicular activities (EVA); the International Docking System; and crewed/robotic vehicle integrated stack operations [1]. The preceding robotic mission will demonstrate high power, long life solar electric propulsion (SEP) for future deep space exploration cargo delivery and interaction with low gravity, non-cooperative targets [1].

2. Overall mission description

The ARM robotic mission will 'capture' and redirect a cohesive asteroidal mass to a stable, crew-accessible lunar distant retrograde orbit (DRO) [2]. The asteroid mass is primarily dependent upon the capture system's capabilities and orbital mechanics drivers, such as the launch date and velocity change required to rendezvous with the Near Earth Asteroid (NEA) and return the captured material to Earth. One approach, capture option A, for this robotic mission is to rendezvous with a small 4–10 m mean diameter NEA with a mass up to ∼1000 metric tons. The target asteroid will be captured and redirected from its native orbit to a lunar DRO. Capture option B is to rendezvous with a larger NEA (100+ meter diameter) and collect a boulder, typically 2–4 m in

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size, and return the boulder to the same DRO orbit. Both options can demonstrate basic techniques for slow push planetary defense operations.

Once the asteroidal mass is returned to the proper orbit in cis-lunar space, the ARM crewed mission will be launched. The Orion spacecraft serves as the crewed transportation vehicle, habitat, and airlock for the reference mission concept. Potential partnerships may provide for additional capability. In the reference concept, Orion will be launched into cis-lunar space on the SLS, allowing it to rendezvous and dock with the robotic spacecraft to demonstrate early human exploration capabilities including longer duration operations in deep space, rendezvous and proximity operations, life support, and EVA capabilities. Two EVAs, each 4 h in duration, are currently envisioned to explore, select, collect, and secure samples via a variety of sample collection options being examined.

3. Robotic mission concepts and trades

NASA's ARM robotic mission (ARRM) concept includes a conceptual design used for mission pre-formulation and analysis, as well as a number of study contracts to examine additive and alternative concepts [3].

The conceptual design for the spacecraft, Asteroid Redirect Vehicle (ARV) in this work, features a modular design with simple interfaces for ease of design, development, and testing by different organizations. There are three modules notionally shown in Fig. 1: a solar electric module (SEPM), a mission module (MM), and a capture module (CM).

In this conceptual configuration, power and propulsion are provided by the SEPM and the MM provides all of the other spacecraft bus functions. The SEPM and MM are very similar for both mission options. The CM implementation is dependent upon the mission capture option selected, and may include unique hardware and software required for capturing the NEA or boulder. The CM includes the capture system and may include the sensor suite. NASA is investigating the implementation of a common sensor suite for the robotic mission and crewed mission. The sensors will facilitate automated rendezvous and docking/capture (AR&D) for both the robotic and crewed segments. The goal is to eliminate the cost of multiple sensor developments and qualification programs. The proposed sensor suite specification consists of one or more visible wavelength cameras, a three-dimensional Lidar, and a long-wavelength infrared camera for robustness and situational awareness [2].

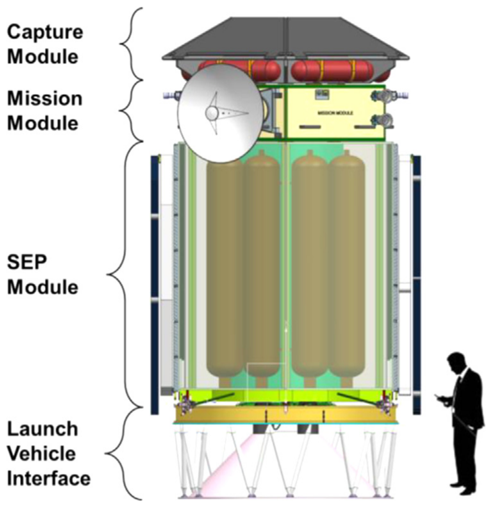

Fig. 1. Asteroid Redirect Vehicle (ARV) modules.

The SEPM provides 50 kW power at the solar arrays for the beginning of the mission and 40 kW into the solar electric propulsion system. This system features significant advances in solar array, thruster, and power processer technology sponsored by NASA's Space Technology Mission Directorate (STMD) to enable a total impulse capability greater than 30 times current deep space and commercial capabilities. The MM is comprised of the avionics, sensors and software required to control the spacecraft during all phases of mission operations.

A number of trade studies have been conducted to arrive at the current conceptual design. Such analyses included studies of the solar electric propulsion elements such as the solar array, thrusters, and power processors. This has led to the working reference of 50 kW solar arrays, and four 12.5 kW magnetically shielded Hall thrusters (three active and one cold spare). A trade study is underway for the primary voltage. We are examining both 300 V and 150 V from the solar array and evaluating the extensibility benefits to future higher power missions vs. development risk and use for other applications.

Another important trade study has been the SEP module structure and tankage. The reference module can carry 10 t of Xe and is scalable up to 16 t to support extensibility to future deep space missions. The thrust level of three Hall thrusters normally operating is 1.5 N at an Isp of 3000 s. Primary considerations have been the type, size, shape, and number of tanks. Examination of a wide range of options yielded a configuration that minimizes tank development cost and risk by using a currently manufactured design of seamless composite overwrapped tank in the approximate size of 0.23 m (30 in.) by 3 m (10 ft) long. The SEPM core structure features a 3 m composite central load carrying cylinder that would support 4–8 tanks depending on the desired load. For the 10 t load five tanks would be used. Nominal dry mass of the spacecraft is about 4500 kg.

3.1. Mission capture options

Capture option A focuses on redirecting an asteroid of up to 10 m mean diameter and 1000 t mass to a stable lunar orbit. NEAs accessible for the mission are, in general, located in very Earth-like orbits in which the velocity change (ΔV) required to redirect it to the desired lunar DRO is less than $\sim$2 km/s. In capture option B, to reach currently known asteroid targets during current potential launch dates, the mission concept is focused on acquiring and returning a 2–4 m mean diameter boulder with the capture system sized to capture a boulder with a mass up to 70 metric tons. Figs. 2 and 3 provide notional depictions of option A and option B, respectively.

For both options, high-power and high specific impulse solar electric propulsion is the key enabling technology