A Research Strategy for Near Earth Asteroid Exploration

Willie Williams
Houston Space Professionals Chapter
National Society of Black Engineers
Houston, TX, USA
wwilliams@nsbe-hsp.org

Marietta Leonard
Houston Space Professionals Chapter
National Society of Black Engineers
Houston, TX, USA
mleonard@nsbe-hsp.org

Abstract - *NASA has announced plans to capture a small asteroid and deliver it to a distant retrograde orbit for scientific study and research. Early studies have also proposed additional missions to send manned spacecraft into deep space to rendezvous with asteroids up to several hundred meters in diameter for expeditions up to a month in duration at the asteroid. A series of research objectives are proposed for a campaign of exploration of Near Earth Asteroids, beginning in lunar vicinity and extending to deep space. Research objectives will include engineering and operations preparations for Mars missions, scientific understanding of asteroids and history of the solar system, and pathfinding for commercial operations.*

Keywords: Near earth asteroid, human spaceflight, exploration, beyond LEO, Cislunar, distant retrograde orbit, planetary defense, NSBE Visions for Human Space Flight Working Group.

1 Introduction

The Space Special Interest Group of the National Society of Black Engineers has commissioned a *Visions for Human Space Flight Working Group* to investigate technical challenges surrounding NASA human space flight and to identify an alternative path for the direction of United States human space flight. Research conducted by working group participants and documented in this paper represents volunteer labor executed on behalf of NSBE, a 501(c)3 nonprofit headquartered in Alexandria, VA. NSBE coordinates the inputs of aerospace industry experts to propose innovative solutions to complex technical challenges facing the United States. This paper, in coordination with six other Working Group papers, collectively encompasses the product of the Working Group's efforts. Recommendations, results, and conclusions in this paper do not reflect NASA policy or programmatic decisions.

1.1 Introduction to Human Exploration of NEAs

Interest in human missions to asteroids has existed for decades, with recent research originating as part of the NASA Constellation Program in a 2006 study of the use of Orion to visit select Near Earth Objects. [4] Following the cancellation of the Constellation Program, these asteroid missions were elevated in priority with additional NASA and industry studies converging on the idea of capturing a small asteroid and bringing it to lunar vicinity instead of sending a crew into deep space. [4] However, if either the understanding of asteroids or the preparation for missions to Mars are serious objectives for human spaceflight, then it is recommended to explore asteroids both within and beyond lunar vicinity.

1.2 Factors Influencing Asteroid Selection

1.2.1 Captured Asteroid

An asteroid selected for capture and retrieval to Cislunar space must be small enough to be transported within anticipated spacecraft capabilities. Current studies suggest an upper limit of 7 meters in diameter and 1,000,000 kg. [4] Safety considerations also point towards a carbonaceous (C-type) asteroid, which is too weak to survive entry through the Earth's atmosphere. [4] If by some error it collided with Earth it would be destroyed in the atmosphere and pose no risk to the surface. Further, both the transfer trajectory and the destination orbit must be one that at no point intersects the orbit of the Earth [4]. Finally, in order to be compatible with research objectives to be described later in this paper, it should not be a rubble pile.

1.2.2 Deep Space Asteroid

Unlike the captured asteroid, a target asteroid for a deep space mission is significantly larger. Ideally, such an asteroid will help prepare for exploration of the Martian moons Phobos and Deimos. However, many near Earth asteroids are smaller than either moon, so it may be necessary to use smaller asteroids as analogs. Deimos is a tri-axial shaped moon measuring 7.5 x 6.1 x 5.2 km [9] and Phobos is a potato shaped moon, measuring 13.4 x 11.2 x 9.2 km [10]. Selected deep space asteroids should be no less than 100 m in diameter in order to provide a large enough test range to practice operations needed for exploration of the Martian moons. An asteroid considered a potential candidate for human exploration is 2008 EV5, an S-type asteroid which measures approximately 450 meters in diameter. [15] C-type, M-type, and S-type asteroids are of interest. Due to constraints imposed by the

Working Group's recommended mission manifest [11] deep space asteroids of interest must be accessible within a 760-day mission, at least 30 days of which must be spent at the asteroid destination.

2 Scientific Research Objectives

2.1 Geology

Similar to the science strategy of the US Geological Survey [6], geology research of near-Earth asteroids is focused to make a substantial contribution to the well-being of the nation and world through a better understanding of asteroids and their role in the solar system. Applying the USGS scientific strategy to asteroid geology research, NEA missions will in general seek to characterize and interpret the geologic framework of the asteroid through time; discover and characterize any asteroid surface processes; understand and quantify the availability of the asteroid's natural resources; characterize any geologic and environmental hazards to astronauts operating on, inside, or adjacent to the asteroid; and refine technologies and best practices to effectively acquire, analyze, and communicate asteroid data and knowledge.

Asteroid geology research will involve a combination of robotic inspection, EVA field activity, survey from free-flying spacecraft, in-space laboratory analysis, and Earth sample return. Research activities include geological mapping, surveying of topographic features, subsurface mapping, high-resolution stratigraphy, and sample collection and analysis. Geology research may help provide answers to questions concerning the origins of asteroids and will provide better definition of various classifications of asteroids.

A key area of focus is identification of geologic hazards that may pose dangers to visiting spacecraft or astronauts. While especially relevant to rubble-pile type asteroids, there are likely to be geologic hazards on any asteroid, particularly when subjected to mining or propulsive operations.

2.2 Life Science

Life science research is to understand the effect of the microgravity and very low gravity environments (gravity, radiation, atmospheric pressure and composition, etc.) on life processes. This is of scientific interest for any microgravity mission, whether in the vicinity of Earth, asteroids, or other locations in the solar system. Most of our life science knowledge is based on terrestrial environments, with a growing body of knowledge also coming from microgravity environments aboard the International Space Station and to a lesser extent other spacecraft. Very low gravity environments such as those encountered at various asteroids and microgravity environments beyond the Van Allen radiation belts represent significant unknowns. Life science research generally falls within categories of human physiology, animal science, plant science, microbiology, and environmental science.

2.2.1 Human Physiology

Human physiology research includes anthropometry and ergonomics, bone, cardiology, EVA physiology, exercise physiology, neuroscience, nutrition, pharmacotherapeutics and immunology, and behavioral health and performance. [12] The human body takes on an entirely different normal state in space than on earth. All of the human systems and organs perform in a different way in response to the space environment. Data collected from missions to the ISS has been vital in human physiology research. But much more research is needed to determine the effects of extended space trips.

2.2.2 Animal Science

Most animal research is geared toward using analogous animal physiology to extrapolate the effects of microgravity on astronaut health. Mice are among the most commonly used animals in space research. Mice provide the best balance of sample size and ease of storing cages. Mice are often used to study the effect of weightlessness on bone loss. Mice studies are also used to improve osteoporosis drugs Spiders have also been used to study how they build webs and catch flies in microgravity. [8] Other animal studies may include beetles, fruit flies, rats, and avian eggs (Japanese quail).

2.2.3 Plant Science

Plant research will continue to advance human understanding of plant growth in space environments. It is likely that long duration space flight beyond Low Earth Orbit will require use of plants as a necessary accommodation for human habitation. It is of course obvious that plants can recycle carbon dioxide into oxygen and that they can potentially provide a source of food, the latter being of increased interest as some proposed Mars missions exceed current shelf life restrictions for prepackaged food. However, plants are also believed to provide a sense of well-being. This has been observed at the McMurdo Station for research in Antarctica, which is similar to the space station in its isolation and cramped quarters. Scientists there enjoy spending time in the section of the habitat known as the greenhouse. [1] Plant research includes large scale growth of fruits and vegetables for non-critical crew consumption to develop the capability for longer missions that may rely on in-situ food production, as swell as investigative research for plants such as thale cress, rapeseed, and yeast. [12]

2.2.4 Microbiology

Microbiology research is concerned with characterizing the reaction of organisms in the non-terrestrial environmental conditions encountered in spaceflight. Areas of study may include inherent conditions resulting from reduced gravity or closed environments aboard spacecraft. Other environmental factors, such as space vacuum, thermal extremes, solar UV radiation, and the presence of high-velocity micrometeoroids and orbital debris, are typically mitigated by spacecraft design in order to provide internal conditions conducive to sustaining life. However, some research may intentionally expose microorganisms to the harsh external environment or selected parameters of it. [3] Typical research will include studies of bacteria, viruses, and other microbes, as well as plant and animal cells and tissues. [12]

2.2.5 NEA Material for Radiation Shielding

There are significant health risks associated with exposing humans to radiation in space for long periods of time. Human exposure to greater than 1 Sievert (Sv) of radiation will suffer a variety of serious illnesses including leucopenia and other immune system-impairing conditions. [7] A radiation dose greater than 8 Sv will be fatal to humans within days, as they succumb to organ failure and severe burns. [7] An Astronaut on board a spacecraft exposed to a solar flare or CME of sufficient intensity without protective shielding could potentially be killed.

NASA defines acceptable risk from radiation to be a “limit of 3% fatal cancer risk at a 95% confidence level”. [14] However, as noted above, there are significant other health hazards beyond cancer. A limited amount of data exists to compare the radiation exposure in space to the radiation exposure on earth. The data obtained from the exploration of NEAs will be important to study the effects of radiation for future long term missions. Additionally, NEA expeditions will permit the study of the use of asteroid material for radiation shielding. It is cost-prohibitive to launch significant masses of material into space to provide desirable levels of radiation shielding. If such shielding can be obtained from asteroids, it may enable deep space missions that may otherwise be incapable of meeting NASA acceptable radiation risk levels.

2.3 Astronomy

2.3.1 Extra-Solar Astronomy

It is likely that as a consequence of orbital motion, each deep space mission will be to a different asteroid. This creates a valuable opportunity to place telescopes on each asteroid visited, effectively creating a network of telescopes. These telescopes can be used independently, or in a coordinated fashion with other telescopes (e.g. via interferometry) to image extra-solar objects, potentially aiding in a search for terrestrial planets.

2.3.2 Earth and Lunar Observation

In addition to looking out into the galaxy, NEA-based telescopes can also look back at Earth and the Moon. Observation of Earth from such a significant distance may help to refine techniques used in planetary exploration to search for signs of life. Lunar observations from a NEA placed in a DRO can provide a unique perspective for imaging locations on the Moon inaccessible from terrestrial telescopes and can provide mission support to ongoing surface expeditions.

2.3.3 Other Celestial Bodies in the Solar System

NEA-based telescopes may also be used to image a variety of other targets within the solar system. This may include asteroid or comet detection, tracking of robotic or manned spacecraft, or studies of other planets.

3 Commercial Research Objectives

3.1 Materials Extraction

One of the primary anticipated commercial uses for asteroids is the harvesting of natural resources contained within the asteroid. Materials might include resources such as hydrogen, oxygen, iron, nickel, cobalt, platinum-group metals, gallium, germanium, selenium, or tellurium. [4] Companies such as Planetary Resources and Deep Space Industries have already formed in anticipation of opportunities to mine NEAs. Both Cislunar and Deep Space NEA expeditions will include test objectives to validate or refine hardware and techniques for extracting materials of interest from asteroids. It is hoped that asteroid resource extraction can become cost effective and provide access to resources not readily available on earth.

3.2 Shielding Fabrication

Two options exist for using asteroids as a resource for shielding. The first is to fabricate shielding material from asteroid mass. This may involve fabricating bricks or other shaped structures, which would then be installed inside (or surrounding) the spacecraft to be shielded. The second option is only valid for large (relative to the spacecraft) asteroids and involves excavating sufficient material to create a hangar sufficient for a spacecraft to maneuver inside the asteroid and use the asteroid’s remaining thickness itself as a shield.

4 Engineering Research

4.1.1 Asteroid Stress Carrying Capability

A key engineering research objective is determination of the stress carrying capabilities of visited asteroids, both the small asteroid delivered to cislunar space and the larger asteroids visited on deep space expeditions. This has implications for both commercial utilization of asteroid resources and for planetary defense deflection of potentially hazardous asteroids. Understanding the stress carrying capability will enable designers to develop safe asteroid handling techniques and to optimize the mass and volume of capture systems used to mate physical structures (space stations, deflection engines, etc.) with asteroids.

4.2 Planetary Defense

Various methods for protecting Earth from asteroids have been proposed and debated. [2] A key area of proposed research in the area of planetary defense from the threat of asteroids involves the concept of using continuous propulsion to change the course of an asteroid in a potentially hazardous orbit. Obviously the greater the power of the continuous thrust system the more effective this method can be, which has implications to the design of the Power, Thermal, and Propulsion (PTP) spacecraft. [11] (A PTP is not the only possible solution for altering the course of an asteroid – solar sails, explosions, and thermal coatings are but a few of many other proposed methods, but this architecture will focus on applying common technologies to multiple challenges and no other missions within this architecture can make use of solar sails or other proposed asteroid redirection methods.)

Asteroid mission research will involve developing and testing mechanisms for anchoring or attaching to an asteroid, particularly attaching some sort of mounting platform to which a PTP can dock. The most common asteroids are C and S-types and research will focus on attaching to these asteroids, with one mission devoted to M-type asteroids. Rubble piles will be of less interest than solid bodies because rubble piles are less likely to survive atmospheric entry and are therefore less of a planetary threat.

4.3 Pathfinding for Mars Exploration

4.3.1 Transit Cruise Habitability

The transit to Mars is unprecedented in human space exploration. An intermediate step before committing humans to a Mars destination is a transit to a NEA beyond the orbit of the Moon. Transits to NEAs will be used to validate habitability capabilities of the Microgravity Habitat (MH) [11] and ensure that the design is sufficient to commit humans to transfer to Mars.

4.3.2 Phobos and Deimos Exploration

Both Martian moons are similar to D-type asteroids [13] and there is some debate as to whether they originated as material ejected from Mars or if they are actually captured asteroids themselves. [13] In any event, deep space excursions to NEAs larger than those that can be captured and delivered to DRO can serve as intermediate precursors to prepare NASA for human exploration of the moons of Mars.

5 Research Accommodation in a Proposed NEA Architecture

The NSBE Visions for Human Space Flight Working Group recommends a total of ten NEA missions in parallel with lunar and Mars expeditions. [11] The NEA missions are shown extracted from the recommended mission manifest in Table 1.

Table 1. Recommended NEA Missions

Year	Mission (includes transit times)
2025	21-Day NEA Expedition at DRO
2026	45-Day NEA Expedition at DRO
2027	45-Day NEA Expedition at DRO
2028	45-Day NEA Expedition at DRO
2029	45-Day NEA Expedition at DRO
2030	730-Day NEA Expedition in Deep Space
2033	860-Day Mars Dry Run at Lunar/DRO/NEA
2034	730-Day NEA Expedition in Deep Space
2038	730-Day NEA Expedition in Deep Space
2042	730-Day NEA Expedition in Deep Space

5.1 DRO NEA Test Mission

The first NEA mission will launch in 2025 with a crew of two to the captured asteroid that has been robotically towed to a distant retrograde orbit (DRO) in lunar vicinity. The mission is a total of 21 days, including MPCV transit times to and from DRO. The crew time at MPCV will be focused on geology and asteroid stress carrying capability research.

5.2 DRO NEA Expedition 1

In 2026, after the NEA Orbital Spacecraft (NOS) [11] has been deployed to the captured asteroid, MPCV will deliver four crew for a 45-day mission, including at least 30 days at the NEA. This mission will continue and expand geology and stress research and add life science and astronomy research.

5.3 DRO NEA Expedition 2

MPCV will launch the next four-person crew to the NOS in 2027 for the second 45-day mission, also including at least 30 days at the NEA. In addition to the research conducted in Expedition 1, the crew will also test asteroid anchoring and attachment techniques and large scale excavation from the asteroid.

5.4 DRO NEA Expedition 3

The third DRO expedition will launch to the NOS in 2028, repeating the same crew size and mission duration. This mission will continue the previous research and incorporate shielding fabrication activities. Returned samples from this mission will include extracted materials and fabricated shield material.

5.5 DRO NEA Expedition 4

The fourth DRO expedition to the NOS in 2029 will give the life science community a large enough sample size to give validity to human research objectives. It will continue research from previous expeditions and will also serve as a dry run for the deep space NEA expeditions.

5.6 Deep Space NEA Expedition 1

In 2030, MPCV will deliver four astronauts to the Deep Space Vehicle (DSV) [11] for a 730-day mission. In addition to the research performed at the DRO NEA, habitability research will also be conducted during the cruise phase. The mission will be to a C-type NEA and at the destination will evaluate asteroid stress carrying capabilities and validate anchoring/attachment techniques designed for C-type asteroids, effectively simulating the placement of multiple propulsion modules on a large, Earth-threatening asteroid. Scientific equipment left behind at the asteroid will include telescopes for imaging from the unique vantage point of the asteroid.

5.7 Mars Simulation (Lunar/DRO NEA)

In 2033, a lunar crew will conduct a full simulation of a Mars expedition. This will involve launching from Earth in a MPCV, but instead of traveling to lunar orbit, it will deliver the crew to DRO where they will dock with a Mars Transfer Vehicle (MTV) [11]. The crew will spend six months aboard the MTV, simulating the Mars outbound transfer while it conducts a six-month orbital phasing to rendezvous with the captured asteroid. There, the crew will conduct 30 days of MS/PS excursion operations to the captured NEA to conduct a dry run of exploration of Phobos and Deimos. The crew will then depart to the lunar surface for a 470-day surface mission, simulating a Mars surface expedition. Finally, the crew will return to the MTV and conduct a six-month phasing departure to separate the MTV from the captured asteroid, simulating the inbound return leg, prior to departing the MTV for Earth.

5.8 Unmanned Transport to LEO

With the completion of research objectives for the smaller captured NEA in DRO, it will be possible to position the asteroid for long-term commercial utilization. For this purpose, it will be more efficient to use the propulsive capabilities of the NOS [11] to deliver the asteroid to low earth orbit than to launch commercial missions to Cislunar space. Previous research has shown that it is possible to deliver a NEA to the International Space Station. [5] Whether the host facility is indeed the ISS, or a Bigelow space station, or other orbital facility, a LEO environment will enable commercial providers to deliver industrial-scale equipment and associated crews to make full use of asteroid resources. Additional scientific research will likely also be conducted from the orbital facility. Should all commercial value of the asteroid be exhausted, it is small enough to burn up in the atmosphere during entry, but will nonetheless be targeted for reentry over a remote section of ocean where no threat is posed to human populations.

5.9 Deep Space NEA Expedition 2

The Deep Space NEA Expedition 2 will begin in 2034. It is essentially a repeat of the 2030 mission, but will test anchoring and attachment for an S-type asteroid instead.

5.10 Deep Space NEA Expedition 3

Expedition 3 will launch in 2038. This 730-day mission will perform the same mission as the prior deep space NEA missions, with an M-type asteroid selected for testing anchoring and attachment.

5.11 Deep Space NEA Expedition 4

The fourth expedition will launch in 2042. Also a 730-day mission, it will travel to a C or S-type NEA measuring at least 200 meters in diameter in a non-hazardous trajectory and will attach a number of separately deployed PTPs to the asteroid. The objective will be to change the course of a large, but non-hazardous NEA from one safe trajectory to another. The PTPs will be activated after crew departure.

6 Conclusions

This paper and numerous other asteroid studies collectively serve to vector a diverse assembly of thought processes to plan a coordinated vision for future scientific and commercial human space flight ventures. Whether those ventures are focused on asteroids, the Moon, Mars, or a combination of these destinations, research from initial asteroid missions can serve to develop technologies to enable these future explorations.

Specific to the architecture recommended by the NSBE Visions for Human Space Flight Working Group, the set of research objectives detailed in this paper provide pathfinding activities for many of the nascent commercial asteroid ventures that have come into existence in recent years. They also address many of the risks inherent to human Mars exploration and help to lower the risk profile faced by the crew. Early research objectives even support crews involved in a return to the lunar surface.

An enormous amount of knowledge and capabilities can be gained from near earth asteroid exploration. Travel to and study of these near earth objects will help develop our technologies to take humans back to the Moon, Mars and beyond.

Acknowledgment

The authors would like to acknowledge the work of other members of the NSBE Visions for Human Space Flight Working Group and their contributions to an integrated rationale for human space exploration and development. Additionally, the authors would like to acknowledge the work of the Keck Institute and various other study teams within and beyond NASA who have pioneered mission concepts for human missions to asteroids.

References

[1] Barbara Patterson, Why Study Plants in Space? International Space Station Feature, NASA Ames Research Center, November 2012, URL: http://www.nasa.gov/mission_pages/station/research/news/plants_in_space.html.

[2] Bong Wie, Ian Carnelli, Mariella Graziano, and Brent Barbee (Session Chairs), Session 4: Mitigation Techniques & Missions, 2013 International Academy of Astronautics Planetary Defense Conference, Flagstaff, Arizona, April 15-19, 2013.

[3] Gerda Horneck, David M. Klaus, and Rocco L. Mancinelli, Space Microbiology, Microbiology and Molecular Biology Reviews, Vol. 74, No. 1, pp. 121-156, March 2010, URL: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2832349/pdf/0016-09.pdf.

[4] John Brophy, Fed Culick, and Louis Friedman, "Asteroid Retrieval Feasibility Study," Keck Institute for Space Studies, April 2, 2012.

[5] John Brophy, Robert Gerhman, Damon Landau, Don Yeomans, James Polk, ChrisPorter, Willie Williams, Carton Allen, Erik Asphaug, *Asteroid Return Mission Feasibility Study Final Report for the 2010 NASA Innovation Fund*, Internal Document, Jet Propulsion Laboratory, Pasadena, CA, 2010.

[6] Linda C.S. Gundersen, Jayne Belnap, Martin Goldhaber, Arthur Goldstein, Peter J. Haeussler, S.E. Ingebritsen, John W. Jones, Geoffrey S. Plumlee, E. Robert Thieler, Robert S. Thompson, and Judith M. Back, *Geology for a Changing World 2010–2020: Implementing the U.S. Geological Survey Science Strategy*, US Department of the Interior, US Geological Survey Circular 1369, 2011.

[7] Marc Green, Justin Hess, Tom Lacroix, Jordan Marchetto, Erik McCaffrey, Erik Scougal and Mayer Humi, "Near Earth Asteroids:The Celestial Chariots," Worcester Polytechnic Institute, Worcester, MA, June 14, 2013, URL: http://arxiv.org/pdf/1306.3118.pdf.

[8] Mark Betancourt, On the Orbiting of Species, Air & Space Smithsonian, October 2011, URL: http://www.airspacemag.com/space-exploration/Animals-in-Space.html.

[9] Phil Davis, *Deimos: Facts & Figures*, Solar System Exploration, NASA, URL: http://solarsystem.nasa.gov/planets/profile.cfm?Object=Mar_Deimos&Display=Facts&System=Metric.

[10] Phil Davis, *Phobos: Facts & Figures*, Solar System Exploration, NASA, URL: http://solarsystem.nasa.gov/planets/profile.cfm?Object=Mar_Phobos&Display=Facts&System=Metric.

[11] Robert Howard, "A Comprehensive Human Spaceflight Architecture for Exploration Beyond Low Earth Orbit," Proc. 2014 NSBE Aerospace Systems Conference, Los Angeles, CA, Jan. 22-25, 2014.

[12] Robert Howard, "Research Objectives for a Lunar Outpost Architecture with Extended Range Rover Capability," Proc. 2014 NSBE Aerospace Systems Conference, Los Angeles, CA, January 22-25, 2014.

[13] Scott L. Murchie, Andrew S. Rivkin, Joseph Veverka, Peter C. Thomas, and Nancy L. Chabot, "The Scientific Rationale for Robotic Exploration of Phobos and Deimos," John Hopkins University Applied Physics Laboratory, 2009.

[14] Team Voyager's Mission Proposal: Vault-1, Caltech Space Challenge, Keck Institute for Space Studies, September 16, 2011, URL: http://www.kiss.caltech.edu/study/space-challenge/Voyager_Final_Report.pdf.

[15] Viorel Badescu (Ed), *Asteroids: Prospective Energy and Material Resources*, Springer Heidelberg, New York, 2013.