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Human Mission to Asteroids in the Context of Future Space Exploration Studies

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Abstract. The final goal, for the foreseeable future, of the Human Exploration of the Solar System is to land a crew on the Mars Surface (and to bring it back). A wide array of capabilities has to be developed and demonstrated before attempting such a risky endeavor; intermediate steps are therefore needed, also to comply with budget constraints. Human missions to Near Earth Objects (NEOs) and specifically Asteroids (NEAs) are among the most suitable candidates, thanks to high scientific interest, good opportunities for testing technologies and crew operations, and to mature Earth protection capabilities. In the following, a review of existing NEA Human mission concepts is provided and a new one, characterized by the exploitation of Nuclear Thermal Propulsion to reduce overall lift-off mass, is proposed.

Key words. Space Exploration – Near Earth Objects – Near Earth Asteroids – Planetary Protection – NEO Exploration Architecture – Human Spaceflight

1. Introduction

The final goal (for the foreseeable future) of the Human Exploration of the Solar System is to land a crew on the Mars Surface (and to bring it back).

A wide array of capabilities has to be developed and demonstrated before attempting such an endeavor. Budget constraints demand a stepwise and flexible approach to deep space exploration, as resilient as possible to changes in budget, schedule and objectives. However, an intermediate objective of Human Exploration is needed in order to provide inspiration, scientific returns and technical risk mitigation in the mid-term. Human NEO (asteroids, comets) missions are a favored candidate thanks to high scientific interest (e.g. solar system formation, incomplete set of information about NEOs) and because they represent a good test-bench for technologies and crew operations (e.g. deep space habitat, propulsion). Moreover these types of missions are less demanding than Lunar Exploration Architectures, studied as main alternative to Mars mission. Manned spacecrafts to NEOs should be conceived to prepare future human exploration missions to Mars by demonstrating a set of key enabling technologies (e.g. radiation protection, deep-space propulsion, high speed re-entry, in situ resources utilization). Furthermore such a mission would extend the knowledge on psychological and physiological impact of long-term/deep-space mission

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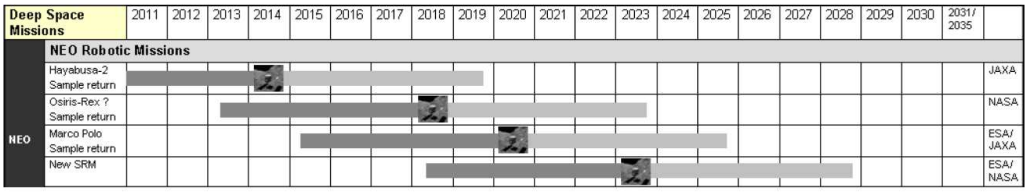


Fig. 1. Planned robotic missions to NEOs

on crew members. Our understanding of the Solar System would be improved, learning more about Near Earth Objects, their structure, composition, identifying also potential sources of resources to be utilized on Earth. Asteroids and comets represent a potential threat for our home planet, therefore a higher attention to NEOs missions, and specifically Asteroids, should help substantially to develop Earth defense techniques for collision avoidance. Also, as the experience with the International Space Station have been teaching for the last decades, a complex human mission is one of the most excellent ways to foster international cooperation and general public involvement in Space Exploration through an ambitious and inspiring program.

2. Role and Benefits of Humans in Space Exploration

A small number of missions have been exploring NEOs for the last years (e.g. Rosetta is in its journey towards a comet), retrieving fundamental knowledge for the understanding of these complex space bodies. All these missions have been unmanned. Future manned missions are supposed to bring several improvements. Actually, astronauts in space can:

- make on-the-spot value judgments to determine the most effective actions
- perform more extensive and in-depth research since they can evaluate what they are collecting
- accomplish more complex tasks and promptly react in case of technical problems
- intervene and re-plan the activities, if necessary, in response to any unexpected situation.

Robotic precursor missions possibly will anticipate the human missions to prepare the road in terms of scientific knowledge (e.g. asteroid chemical composition), environment characterization (e.g. landing site) and deployment of supporting hardware (e.g. surface infrastructures).

3. Existing Plans and Concepts for NEO Exploration

Today, Space Agencies have plans mostly for robotic exploration missions targeting NEOs, as shown in Fig. 1. NASA, following the outcomes of the Augustine Commission and the new policy issued by the Obama Administration, has scrapped the Constellation Program (that was targeting the Moon) and is developing plans for a Human mission to NEO for the 2030s. In particular, the Human Exploration Framework Team (HEFT) is investigating in depth the possible approaches to a human mission to NEO, with specific focus on required technological developments and their applicability to other missions (e.g. Moon, Mars).

The HEFT prepared two main concepts, based on a crew of 4 astronauts and thirty days of operations on a NEO, both based on a series of multiple launches of the needed elements by means of newly developed HLLVs (Heavy Lift Launch Vehicles). The first, based on Solar Electric Propulsion, is based on three launches with assembly in the Earth-Moon Lagrangian Point 1 (EML1, Earth Moon Lagrangian point 1). Fig. 2 shows an outline of the possible op-

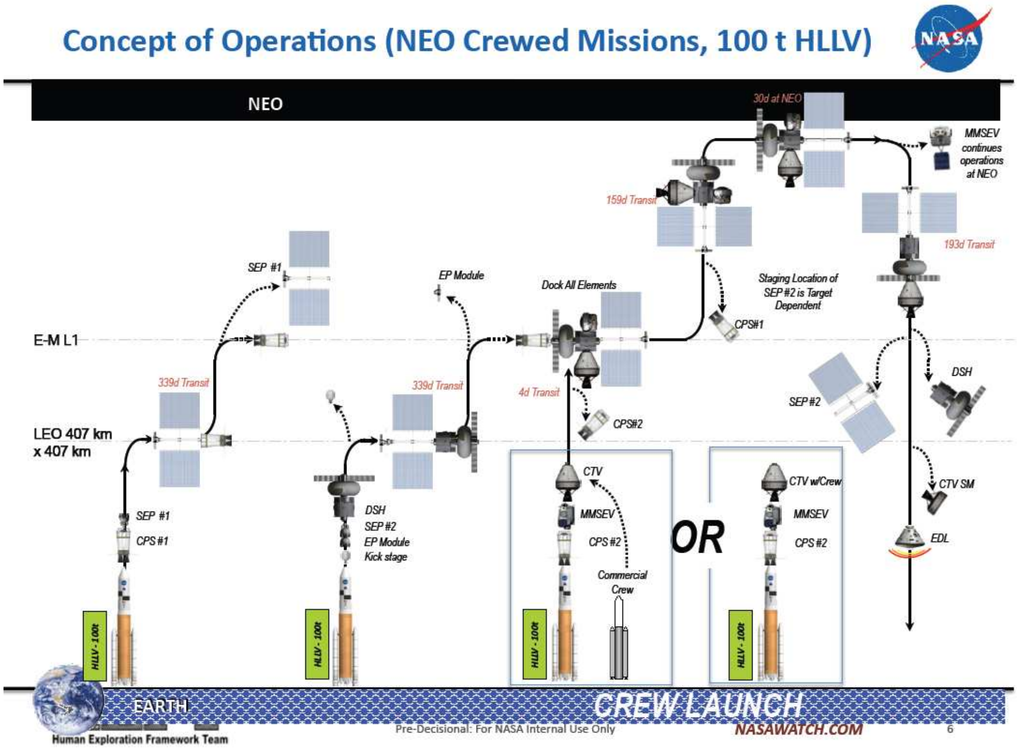


Fig. 2. HEFT Concept 1 (NASA courtesy)

erations. The second concept, based on chemical propulsion, is based on six launches (five cryo stages) with assembly in Low Earth Orbit (LEO). Fig. 3 shows an outline of the possible operations. Fig. 4 shows a comparison between the two concepts. The first one includes a higher number of elements due to the electric propulsion, which is a new technology that can be usable for other missions (e.g. cargo to Mars). Furthermore, it includes the necessity to have new operations for assembly in EML1 (e.g. remote control). The second concept consists of a lower number of elements, but the propulsion technology may not be reused for Mars and has a complex assembly sequence in LEO. Another concept for a “basic”, low budget and shorter Near Earth Asteroid (NEA) mission, during the most favorable orbital alignment, is the Lockheed Martins “Plymouth Rock”, based on a simpler and lower lift-off mass architecture with two docked Orion spacecrafts as Habitat (and a smaller crew of 2), LEO-NEA cryo-transfer, rendez-vous w/o docking at the asteroid. Main concerns of this concept can be identified in the limited scientific return (short surface operations, only five days, duration at NEA) and low crew comfort (particularly during NEA-LEO transfer). Fig. 5 The proposed destinations are asteroid 2008 HU4 (6-10 mt in diameter, at an encounter distance of 4 million km) and asteroid 2008 EA 9 (similar dimensions, 12 million km).

4. Thales Alenia Space Preliminary Proposal of a NEA Mission Concept

In the frame of European Scenarios Studies for Human Spaceflight & Exploration (HS&E), Thales Alenia Space Italia (TAS-I) is currently performing investigations on possible Human

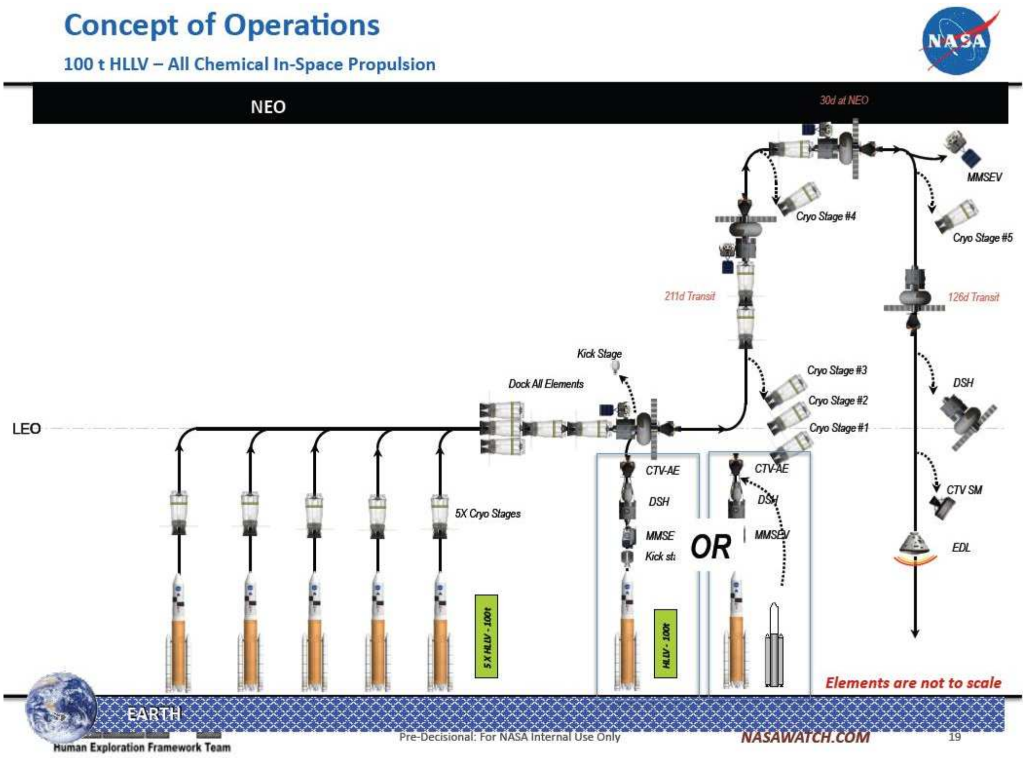


Fig. 3. HEFT Concept 2 (NASA courtesy)

Fig. 4. Comparison between HEFT Concepts

Missions to Deep Space, with specific focus on human NEA Missions as preparatory steps to Mars.

5. Thales Alenia Space Preliminary Proposal of a NEA Mission Concept

A first basic NEA mission concept, hereby presented, has been preliminarily developed, posing the basis for further activities aimed to refine the design of the involved architectural Elements and to assess the associated technological needs, risks, and costs. TAS-I mission concept is exploiting results of the SEEDS[1] 5 project work, whose theme for the year 2010 was the study of a mission for humAn Exploration of a Near Earth Asteroid (AENEA).

The considered mission is to transfer 4 crew members to the target NEA and back to Earth. The target NEA is not selected, but the candidates will have to present the following characteristics:

- encounter distance to allow a round trip of about 180 days
- size greater than 50 mt
- slow/simple rotation
- reachable by Robotic Precursor Mission(s) at least 3 years earlier than the planned manned mission.

The crew members mission is to perform a set of Extra Vehicular Activities (EVA) on the NEO surface, so to perform in-situ scientific investigations, to collect samples of the NEO soil and to test technologies on the NEO surface (e.g. ISRU, Earth Protection). An additional mission requirement is to employ technologies applicable to future exploration missions (in particular, Human Mars mission) to the maximum feasible extent. Fig. 6 shows the mission architecture elements identified for the space segment.

The mission includes two high-lift launches and the assembly at 800 km altitude. This higher than usual orbit is forced by the utilization of a Transfer Stage based on Nuclear Thermal Engine technology. Should problem arise during the assembly phase, a high altitude (low decay) orbit provides sufficient time to reach the system and solve the issue before the system re-enters into the atmosphere. The habitat module is outfitted at post-ISS orbit. Fig. 7

For what concerns the surface operations, the spacecraft is not planned to land on NEA surface, but to remain at a safe distance with astronauts getting closer. Current mission concept includes the utilization of Manned Maneuvering Units (MMUs) to perform operations on the NEA surface by the astronauts. NASA HEFT concepts include the utilization of a, so called, Multi Mission Space Exploration Vehicle (MMSEV). The MMU approach is currently preferred for its mass benefit, but further dedicated investigations are needed to consolidate the choice. Alternatively, if the NEA is sufficiently large and solid, the entire spacecraft, or part of it, could land on its surface.

Surface Operations in EVA include: collection of samples (also sub-surface via drilling), deployment and operation of scientific payloads, photos and videos recording

6. NEO Hazards Mitigation

TAS-I considers a manned mission to a NEO as a fundamental step in the establishment of an Earth Protection Systems, to assess the risk posed by NEOs and to study multiple strategies and technologies for countering the hazard of objects colliding Earth.Fig. 8

A manned mission should be included in a wider project, where three main research and experimental development branches are envisaged in order to prepare humanity to defend its home planet from a potential collision threat:

- Science: to study the NEOs, e.g. orbits, composition, natural dynamics and the be-

[1] SEEDS is an International Post Graduate Master Course in SpacE Exploration and Development Systems organized by three European Universities, Politecnico di Torino (Italy), ISAE Toulouse (France) and Univesitt Bremen (Germany), and supported/endorsed by several sponsors and institutions (including Thales Alenia Space).

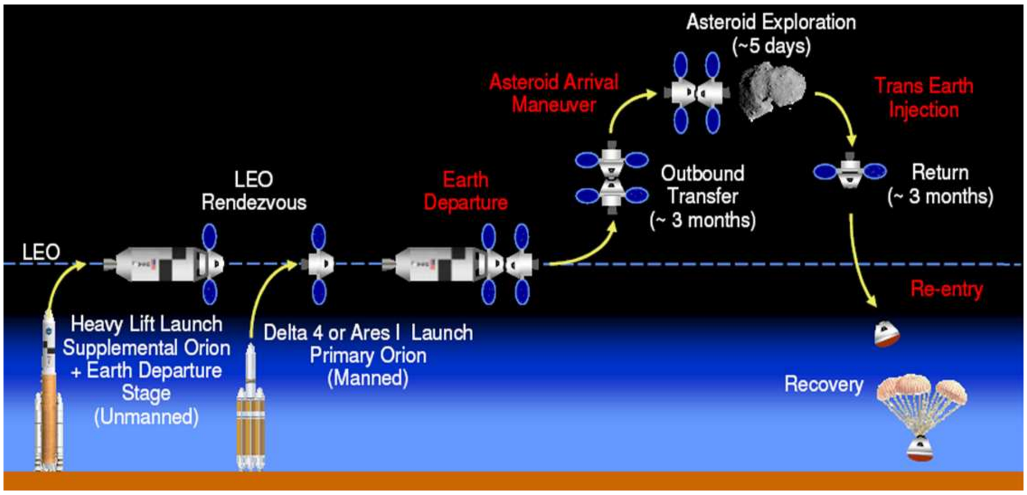


Fig. 5. Lockheed Martin Plymouth Rock concept (Lockheed Martin Courtesy)

Fig. 6. Mission Architecture Elements

havior of the body subject to external forces, to understand the "threat"

– Strategy: to study the feasibility of flexible space architectures to respond to several types of hazards, in accordance with NEO nature and adopted technology
– Technology: to study and validate the key technologies necessary to deflect an asteroid, including performance of experimental tests and preparation of breadboards in support of the integrated simulations of mission and strategies.

While a manned mission is hardly feasible for the actual mitigation mission, especially in the near term, it may be an essential milestone in the experimentation and development

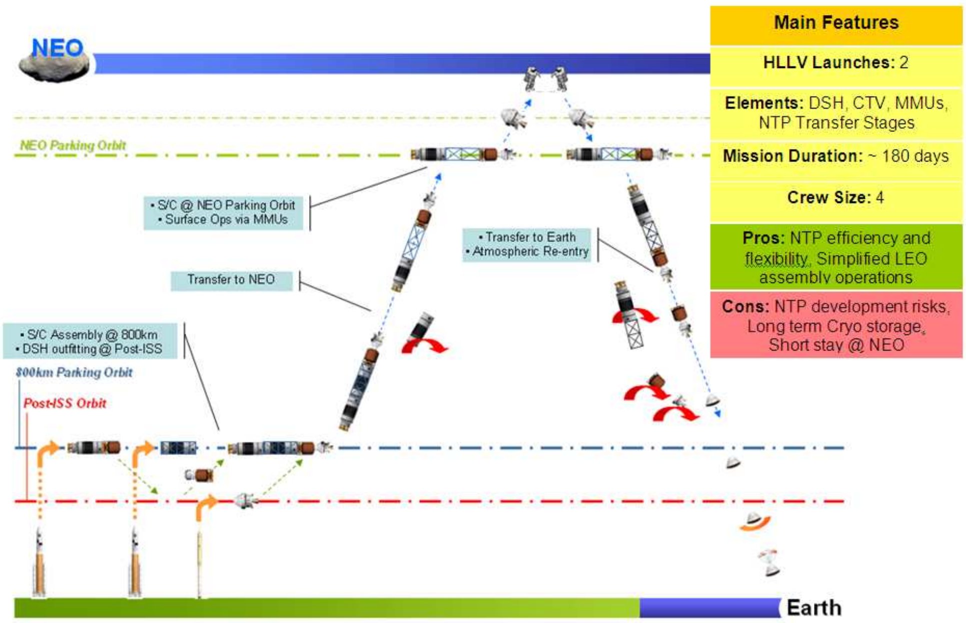


Fig. 7. Mission Outline

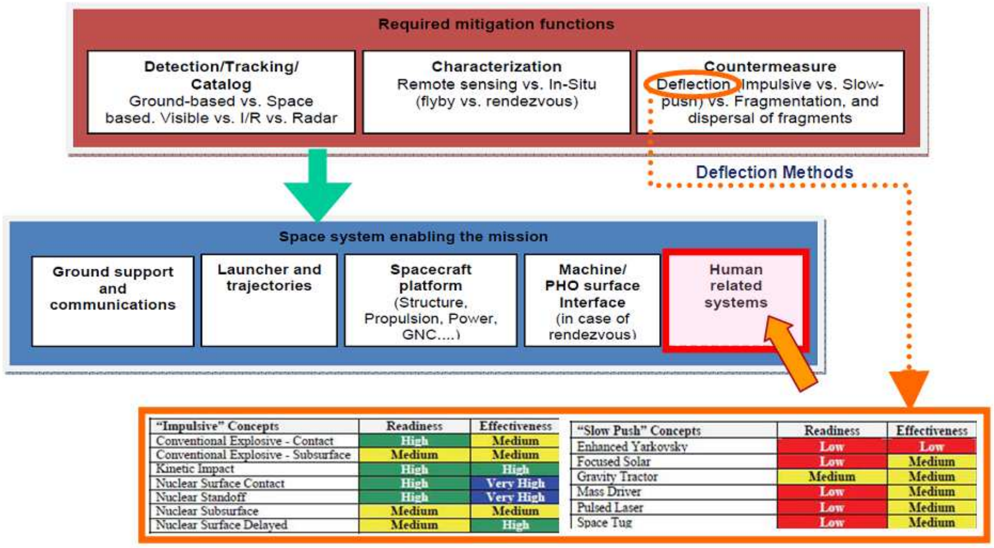
Fig. 8. Options for Surface Operations

of technologies for risk mitigation, including in the exploration objectives also the research and developments to increase the readiness and effectiveness of possible technologies, as shown in Fig. 8

7. Conclusions

Human NEO Missions are currently a "thot topic"in Space Exploration, as a key preparatory step towards future Human Mars Mission, being more affordable, with a limited number of elements to be developed in comparison to Moon Surface Exploration Architecture. Such long term Deep Space mission is also considered as an effective test bench to test technologies and operations in view of future exploration, but also for possible future needs in Planetary Defense. Many benefits are derived from this mission, first of all for the possible significant scientific and technological discoveries and improvements. Furthermore the challenging and inspirational endeavor would be able to foster international cooperation and attract public interest, with a higher participation with respect to a robotic mission.

Many advantages support the choice of a human mission. Humans are required to advance space fairing capabilities in preparation to Mars and their ingenuity and flexibility can significantly enhance scientific return and Earth Protection capabilities demonstra-



"Impulsive" Concepts	Readiness	Effectiveness
Conventional Explosive - Contact	High	Medium
Conventional Explosive - Subsurface	Medium	Medium
Kinetic Impact	High	High
Nuclear Surface Contact	High	Very High
Nuclear Standoff	High	Very High
Nuclear Subsurface	Medium	Medium
Nuclear Surface Delayed	Medium	High

"Slow Push" Concepts	Readiness	Effectiveness
Enhanced Yarkovsky	Low	Low
Focused Solar	Low	Medium
Gravity Tractor	Medium	Medium
Mass Driver	Low	Medium
Pulsed Laser	Low	Medium
Space Tug	Low	Medium

Fig. 9. NEO Hazard Risk Mitigation through effective space systems

tion. Capability to deal with the unforeseen, particularly relevant in the NEO environment (e.g. Spin rate, complex gravity field, geological heterogeneity) is a unique human characteristic. A crew member is also able to optimize in place choices for data acquisition (i.e. samples, images, long term payloads location).

Last but not least, if no human is there, there is no real "Exploration".

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