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Human exploration of NEA: why and how?

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Abstract. The human exploration of multiple deep space destinations, and among them Near Earth Asteroids (NEA), in view of the final challenge of sending astronauts to Mars, represents a current and consistent study domain. NEAs represent interesting targets, not only for the high level scientific return of such missions, but also for advanced technologies demonstration. Accordingly, the NEA mission described in this paper is conceived as an intermediate step before a human mission to the Red Planet and, in this regard, several technologies required for Mars are implemented, in order to test and validate them in significant environment, but at a closer and easier destination. Another crucial aspect to be considered, when dealing with asteroids, is related to planetary defense: even if the probability of an impact with the Earth is very low, this possibility does actually exist. A human mission as the one described in this paper would represent a chance for the development and test of technologies and techniques to be used for asteroid collision avoidance. The paper starts discussing the main objectives of a NEA mission, highlighting the benefits of the human presence. A reference human mission is then described, in terms of strategy, architecture and concept of operations, with particular attention to NEA collision avoidance issue. In the last part, the idea of exploiting virtual reality in support of the mission definition and execution is discussed.

Key words. Human Space Exploration – Near Earth Asteroid

1. Introduction

The next step in the Human Space Exploration (HSE) is to travel beyond low Earth orbit, and in this regard the major space agencies, industries and academia are performing preliminary high level studies trying to assess the best path to be followed, with the final objective of a human mission to Mars and through human missions to different intermediate destinations (e.g. Near Earth Asteroids). So far, a Near Earth Asteroid (NEA) is considered a very interesting intermediate destination in an increasing path of exploration in view of finally landing astronauts on the Red Planet. Indeed, a human mission to a NEA would provide many benefits in terms of a combination of technology test opportunities, scientific return and possibility to test collision avoidance techniques with planetary defence scopes. As far as human space exploration is concerned, a mission to a NEA offers the possibility to develop, maybe at limited extent, technologies which will be needed for future exploration activities (missions to Mars) and test them in a significant environment but at a closer and easier destination. Another crucial aspect of the asteroids exploration is related to planetary defence. As a matter of fact an impact of an asteroid with the Earth can have catastrophic consequences and therefore it is necessary to take adequate measures to avoid it. Even if the probability of an impact is very low, it does exist and it is necessary to invest on the development and testing of technologies, which can be implemented to avoid the disaster. Thales Alenia Space (TAS-I) has demonstrated its interest in asteroids since many years through several studies and proposals. Hereafter, a list of the most significant works in which TAS-I has been involved is reported.

- **Piazzi Proposal**, Aeritalia, authors: Casacci, Cellino, Zappalà, presented at the Tucson Workshop 1986.
- **Motion for a recommendation on the detection of near-earth objects**, Mr Lorenzi and others, September 1994.
- **Hirads (High Impact Risk Asteroids Detection Satellite)**, Alenia Spazio, 22-23 November 1994.
- **Impact (International Monitoring Programme for Asteroid and Comet Threat) Project**, Alenia Aerospazio, Osservatorio Astronomico di Torino, Regione Piemonte December 1997.
- **SISYPHOS (Spaceguard Integrated System for Potentially Hazardous Objects Survey)**, The Spaceguard Foundation, Osservatorio Astronomico Torino, Alenia Aerospazio, 2000.
- **The Asteroid Hazard, Evaluating and Avoiding the Threat of Asteroid Impacts**, ESA, Regione Piemonte - Settore Protezione Civile, Thales Alenia Space, Osservatorio Astronomico di Torino, Istituto Nazionale di Astrofisica, 2009.
- **NETS (NEO Emergency Technologies and Strategies)**, Proposal in response to the call FP7-SPACE-2011-1/CP-FP, 2011.
- **Marco Polo (asteroid sample return mission)**, Thales Alenia Space, 2011.

According to the international interest in asteroids exploration, TAS-I has supported the study discussed in this paper, which presents a reference human mission to a NEA, starting from the assessment of the mission objectives and describing the mission in terms of strategy and architecture. Particular attention is given to the robotic aspects of the overall missions, especially for what concerns the NEA deflection. In the last part of the paper, the idea of exploiting virtual reality in support of the mission definition and execution is discussed.

2. NEA exploration rationale

In this section the rationale for an asteroid exploration mission is discussed, highlighting the main objectives of such a mission Viscio & Messidoro (2012). Moreover, the advantages of having astronauts are assessed.

2.1. NEA mission objectives

The mission objectives of a human mission to a NEA can be grouped into three main categories: scientific objectives, planetary defence objectives and technological objectives. In the following sub-sections, they are briefly discussed.

2.1.1. Scientific objectives

The major scientific objectives for a human mission to a NEA are mainly related to research about the origins of life and the history of the solar system, as well as to the study of the asteroid composition for mining purposes and for possible medical applications. Asteroids may contain compounds that were critical to the beginning of life on Earth; moreover initial conditions of our Solar System are similar to those of systems forming around other stars. In this regard a mission to a NEA would provide information about geochemistry, impact history, thermal history, isotope analyses, mineralogy, space weathering, formation ages, thermal inertias, volatile content, and source regions. A more accurate analysis of the asteroid properties could help us determine if there is a possibility of life elsewhere in the Universe. The second point that could be of interest is to better know asteroids and exploit them as source of useful extra-terrestrial resources like:

- water, that can be used to refuel spacecraft for human deep space missions;
- metals, (e.g. Platinum, Nickel, Titanium, Cobalt, and Iron which are present on many asteroids) that can be also exploited to build heat shields for re-entry.

Finally, compounds found on asteroids could have possible medical applications. As a matter of fact, the Murchison meteorite found in Australia contained a rare amino acid, the isovaline, which can be used as analgesic as well as to reduce epileptic seizures; this amino acid and many others could be present in greater quantities on asteroids.

2.1.2. Planetary defence objectives

A mission to an asteroid would also offer the possibility to test different collision avoidance techniques to protect Earth from possible impacts. An impact of a Potential Hazardous Asteroid (PHA) with the Earth can have catastrophic consequences and therefore it is necessary to take adequate measures to avoid it. To avoid the impact of a PHA with Earth, two possible approaches can be followed:

- nudging the object to deviate its trajectory, thus avoiding collision with Earth;
- fragmentation/pulverization of the object.

Several techniques are under study to deviate or fragment an asteroid to avoid collision (see section "4. Planetary Defence"). In this regard a human NEA mission would give the possibility to perform more accurate analyses and characterization of the asteroid, in order to better assess the most appropriate collision avoidance techniques to be applied. Moreover specific devices can be tested on a small scale during a human exploration mission.

2.1.3. Technological objectives

A human mission to a NEA also allows achieving several technological objectives. In this regard the NEA mission can be seen as a test bed for many technologies that are needed to accomplish the human Mars mission (according to the exploration scenario in which it is included). An asteroid mission can be seen as a "rehearsal" of the deep space phase of the future Mars mission. Required technologies can be implemented, maybe at limited extent, thus validating them in an easier mission and guaranteeing a more limited development effort for the accomplishment of the mission to Mars.

2.2. Impact of human presence

The presence of humans would imply many advantages with respect to robotic missions, as briefly discussed hereafter Viscio et al. (2012b), Viscio et al. (2011a). Manned missions are characterized by a good flexibility allowing being more versatile and adapting to unknown environments more easily and quickly than robotics. Indeed, a robotic spacecraft has limited capability for scientific exploration and may not be able to adapt to unforeseen conditions encountered at a particular NEA, as for example happened to Hayabusa spacecraft during its proximity operations at Itokawa asteroid. Astronauts can make on-the-spot value judgments to determine the most effective activities for exploration and intervene and re-plan the actions if necessary in response to any unexpected situation. Visual and tactile abilities of humans would allow them to provide a more thorough description of the asteroid and perform more complex tasks and scientific experiments. Moreover, humans are more mobile and better able to collect samples from different areas of an asteroid. Finally, human presence would ensure a better use of the scientific instruments and avoid errors as instead happened to scientific tools on previous Mars rovers (e.g. seismometers), which were jostled around as the rovers moved about, providing faulty readings. Due to all mentioned reasons the overall scientific return is significantly greater with human presence. Obviously, having humans increases the complexity of the design due to several issues that must be taken into account, as for instance the effects of space radiations and microgravity on the human body, or the psychological effects of such a long permanence in space, which influence the crew sizing and the workload assignment.

3. NEA mission

3.1. Assumptions

Before proceeding with the description of the mission, some assumptions are discussed. The NEA mission here discussed is part of a larger scenario of human exploration Viscio & Messidoro (2012), Viscio et al. (2012a), Viscio et al. (2012c), Viscio et al. (2012d) having as final target a human exploration mission to Mars and including several deep space destinations that guarantee implementing a gradual approach in the achievement of technological capabilities. Therefore some of the choices that have been made derived from wider considerations at scenario level. The objective of the study was the definition of a conceptual mission to a NEA with the aim of identifying the elements and technologies needed. The first step for the analysis of the mission was the selection of the target asteroid. In this regard, no specific evaluations were performed and the selection was mainly driven by the following assumptions:

- the mission duration shall not exceed 12 months (mission shorter that Mars, but significant deep space permanence time);
- the overall required ΔV shall be maximum about 8.5 km/s (which is assumed as reference value in order to be conservative, even if several less demanding NEAs could be found).

Eventually, the 1999 JU3 asteroid (Hayabusa-2 mission target) was selected as reference target. Some of the major features of this NEA and the associated mission are reported in Table 1. It allows for a human mission in 2033, which is compatible with the HSE scenario in which it is inserted Viscio & Messidoro (2012),Viscio et al. (2012a),Viscio et al. (2012c),Viscio et al. (2012d) with an overall duration not exceeding one year. No detailed analyses have been done for the trajectory and mission definition; however the obtained results can be easily extended to other targets. The crew is assumed to be composed of four astronauts, which is considered the minimum number of crewmembers, in order to accomplish the mission objectives Viscio et al. (2012b),Viscio et al. (2011a).

Finally, for what concerns the propulsion, nuclear thermal propulsion is adopted, according to the high scenario level decisions, which require the implementation of nuclear propulsion, through the intermediate destinations to have it available for the final Mars mission Drake (2009).

3.2. Mission strategy

The strategy to be adopted for the NEA mission has been evaluated considering the necessity to reduce the risks associated with such kind of mission. In this regards a good characterization of the target is mandatory before sending astronauts. According to these considerations, the overall operations of the NEA mission concept are grouped in three main phases, as described hereafter.

The first phase comprises several probe missions to explore and characterize the target asteroid. In this regard, already planned missions have to be taken in consideration (e.g. Hayabusa-2, Osiris-Rex,. . .).

The second phase is represented by a precursor robotic mission to bring to the target NEA specific robotic assets needed for the following human mission. Specifically, elements pre-deployed to the NEA are:

- Multi Mission Space Exploration Vehicle (MMSEV) NASA (2010), which is the vehicle to be used by the astronauts for the NEA proximity/surface activities, including EVA;
- robotic assets to support human exploration activities as well as experiments payloads;
- transponders to support GNC during the manned mission.

The cargo delivery mission shall take place two years before the human mission.

Finally, the last phase is the human exploration phase, that is the crew mission lasting about 350 day and including eight days to be spent in the asteroid proximity, during which exploration activities are to be per-

Table 1. 1999 JU3 Major Features

NEA	Launch Year	ΔV [km/s]	Mission Duration [days]	Size [m]	Re-entry Speed [Km/s]
1999 JU3 (Hayabusa 2 mission target)	2033	- Earth departure: 3.5 - NEA braking: 2.3 - NEA departure: 2.7 - Total: 8.5 km/s	- Outbound flight time: 217 - Stay time: 8 - Inbound flight time: 129 - Total: 354 days	254 – 1134	11.3

formed (Extra Vehicular Activities are envisaged).

3.3. Mission architectures

According to the strategy just discussed, two specific types of missions were analysed:

- Unmanned Cargo Delivery Mission, which refers to the unmanned mission for the delivery of the cargo to the asteroid;
- Crew Mission, which represents the actual human exploration mission.

For these missions, two different architectures were derived, requiring several elements. The two missions rely on four types of launchers:

- Unmanned Space Launch System (SLS), with 70MT payload capability in LEO;
- Unmanned Space Launch System (SLS), with 100MT payload capability in LEO;
- Unmanned Space Launch System (SLS), with 130MT payload capability in LEO;
- Atlas 5 Men-rated, with 28MT payload capability in LEO.

The mission profile of the cargo delivery mission, which should take place in 2031 Viscio & Messidoro (2012),Viscio et al. (2012a),Viscio et al. (2012c),Viscio et al. (2012d) is schematically shown in Fig. 1. Please note that the ΔVs considered for the robotic mission are the same ones of the NEA mission (further investigation shall be carried out for the definition of the robotic mission).

The cargo pre-deployed at the NEA includes the MMSEV and additional robotic assets, and its overall mass is considered to be 10MT. The overall spacecraft is composed of a Small Nuclear Thermal Rocket (SNTR), a small LH2 tank and the payload (depicted as the blue box in the figure), which includes the MMSEV and other robotic assets (e.g. transponders, support structures, etc.). The spacecraft is assembled on ground and launched to LEO by means of a Space Launch System with 70MT payload capability. The SNTR provides the first ignition ($\Delta V1$=3500m/s) to inject the spacecraft into the NEA transfer orbit. This manoeuvre is performed using the propellant stored in the in-line tank. The SNTR is also in charge of providing the ΔV required to insert the spacecraft in the NEA parking orbit (ΔV=2300 m/s). At this point the nuclear stage is expended and the robotic assets are released at the NEA waiting for the crew to arrive. Since the propellant of the SNTR has to be stored for several months of travel, an active thermal control system must be included in the SNTR design in order to face the boil-off issue. This is clearly not necessary for the in-line tank, since the stored propellant is used at the beginning of the mission.

The second architecture that was analysed refers to the human mission (see Fig. 2). The human mission will take place in 2033 and will last approximately one year with a crew of four

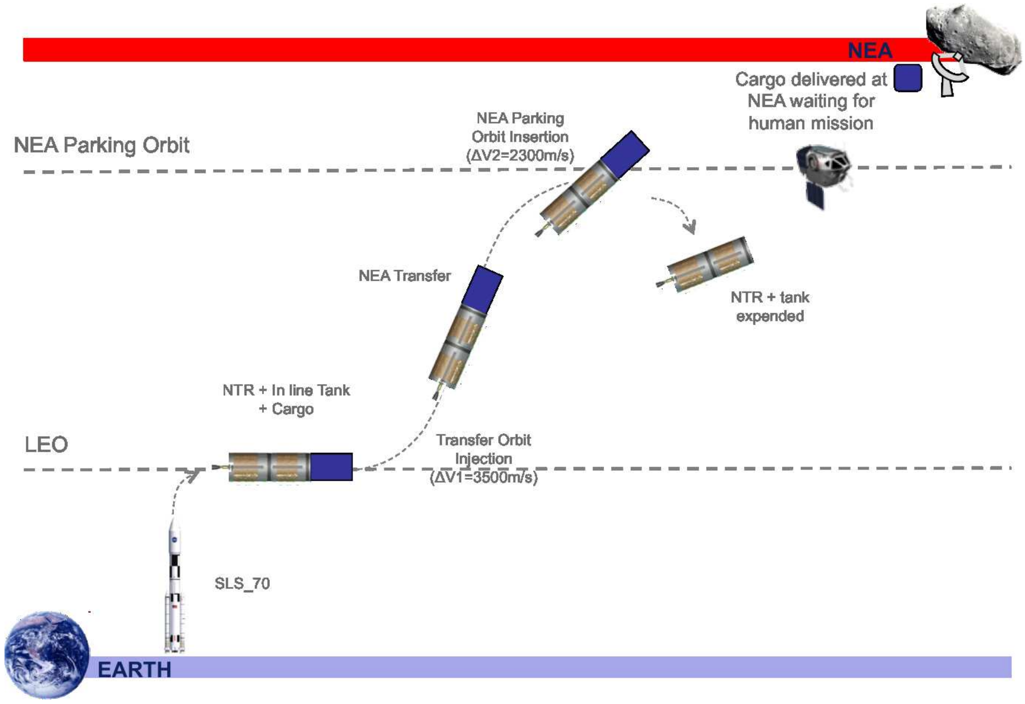

Fig. 1. Cargo pre-deployment mission

astronauts Viscio & Messidoro (2012),Viscio et al. (2012a),Viscio et al. (2012c),Viscio et al. (2012d).

The spacecraft is composed of the Long Term NTR, the drop tank, the Deep Space Habitat (DSH), the Crew Exploration Vehicle (CEV) and CEV-Service Module (CEV-SM). It is assembled in LEO where the various elements are brought by means of three launches:

- one SLS of 100MT capability, which delivers in LEO the NTR,
- one SLS of 130MT capability, which brings in orbit the DSH and the drop tank,
- one Atlas 5 - Men rated, for the CEV and CEV-SM launch with the crew.

The DSH is launched already attached to the drop tank; moreover a space tug is attached to the DSH to support the RvD manoeuvres for the spacecraft assembly. When the docking between the NTR and the DSH and drop tank assembly is completed the space tug is expended. The last RvD manoeuvre is finally needed to dock with the CEV - CEV-SM assembly. At this point the spacecraft is completely assembled and the mission can start. After the system checkout, the NTR provides the first ignition (ΔV=3500 m/s) to insert the spacecraft in the transfer trajectory. The propellant necessary for this manoeuvre is stored in the drop tank, which after the burn is expended. After 217 days of travel, the NTR will provide the second ΔV (ΔV=2300 m/s) to insert the spacecraft into the NEA parking orbit. Eight days will be spent in the NEA proximity and the exploration activities will be carried out by means of the MMSEV. In particular, when the spacecraft is in the asteroid parking orbit, the MMSEV approaches and docks on the radial docking port of the DSH rigid part, allowing the transfer of two astronauts. Then the MMSEV undocks from the DSH and approaches the asteroid to observe and analyse its surface, as well as to perform EVAs. Several EVAs are envisioned to be performed and the MMSEV shall be capable to perform multiple RvD with the DSH

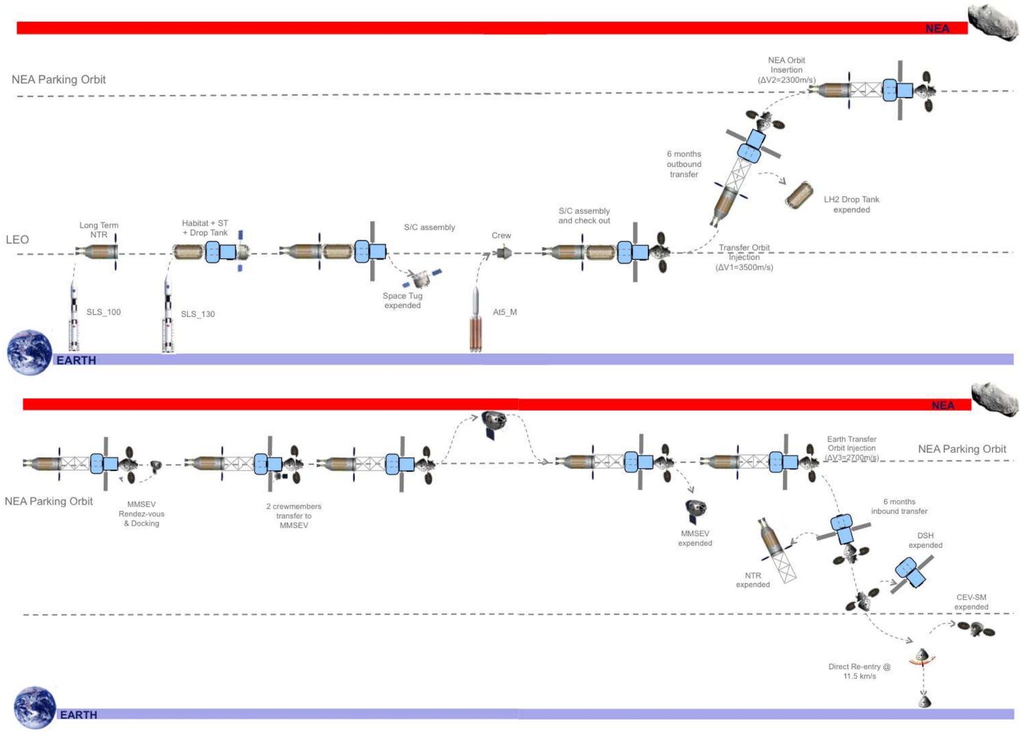

Fig. 2. NEA human mission profile

during the NEA proximity operations phase. After eight days, the MMSEV is released and the spacecraft begins its trip back to Earth. The NTR is expended after having provided the last ΔV (ΔV=2700 m/s) to insert the spacecraft into the Earth transfer orbit. The mission ends with a direct re-entry of the CEV in the Earths atmosphere after 129 days of travel.

3.4. Elements summary

In this section a summary and a brief description of the elements necessary to accomplish the NEA missions, introduced in the previous section, is reported. The cargo delivery mission will include the following elements:

- Small Nuclear Thermal Rocket;
- Small LH2 tank;
- Multi Missions Space Exploration Vehicle (MMSEV);

while for the human mission the following elements will be needed:

- Long Term Nuclear Thermal Rocket;
- LH2 Drop Tank;
- Deep Space Habitat (DSH);
- Crew Exploration Vehicle (CEV);
- CEV-Service Module (CEV-SM).

The Small Nuclear Thermal Rocket (SNTR) is a nuclear rocket implementing one NERVA-type engine Drake (2009) able to provide a thrust of 111kN (see Fig. 3). This stage is used to inject the spacecraft into the transfer orbit towards the NEA and to brake into the NEA parking orbit. The specific impulse provided by this type of engine is Isp=900s; moreover multi-ignitions capability is required. The small NTR adopted in the mission has a maximum propellant loading capability up to 24 MT[1], but in the NEA cargo

[1] This value was the results of specific evaluations performed within the scenario study and de-

deployment mission it is used not completely loaded, but with 9MT of liquid hydrogen.

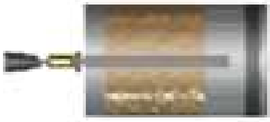

Fig. 3. Small Nuclear Thermal Rocket

For the cargo deployment, the SNTR is coupled with an in-line small liquid hydrogen (LH2) tank (see Fig. 4). This tank will carry 22MT of fuel, which is needed to provide the NEA transfer orbit injection.

Fig. 4. Small LH2 Tank

It must be noticed that the propellant mass estimations for these two just mentioned elements were performed assuming for the robotic mission the same ΔV values as those of the human mission (see Table 1). Further analyses shall be done to review this assumption and implement a less demanding robotic mission.

The Multi Mission Space Exploration Vehicle (MMSEV) (see Fig. 5) is the element that will be used for the NEA proximity operations. No specific evaluations were performed for this element, but the NASA concept was taken as reference (reference mass ≈7MT) NASA (2010). The MMSEV will allow astronauts to perform EVAs and explore the NEA surface. The EVAs will be performed through suitports, which are integrated on the vehicle.

For the human mission the transportation system implements nuclear propulsion as well. In this case the nuclear stage is different from

rives from the need of implementing this element even in different missions

Fig. 5. Multi Mission Space Exploration Vehicle

the SNTR, since the requirements are different. In this regard the used stage, referred to as Long Term Nuclear Thermal Rocket (NTR) (see Fig. 6), has three engines providing 111kN thrust each, similar to what is required by NASA DRA 5.0 human mission to Mars Drake (2009). The NTR is loaded with 63MT of propellant.

Fig. 6. Long Term Nuclear Thermal Rocket

This stage is coupled with a drop tank (see Fig. 7), analogous to the one foreseen for NASA DRA 5.0 mission, which is meant to carry the propellant needed to provide the first burn (≈77MT), that is to put the overall spacecraft into the NEA transfer trajectory. After the ignition the drop tank is expended.

Differently from the NTR which needs an active thermal control for the fuel management (boil-off issue), due to its longer operative life, the drop tank will not be equipped with this kind of thermal control, since it is used only for the first burn.

A Deep Space Habitat (DSH) is another fundamental element, to host and support the

Fig. 7. Drop Tank

crew during the travel to the asteroid and back to Earth Viscio et al. (2012e). The DSH is design to support four crewmembers for a mission lasting up to one year. Its overall mass amounts to about 28MT, including the resources and crew systems[2]. A schematic overview of the module is shown in Fig. 8 in its nominal configuration. It is composed of a rigid part, with one radial and 2 axial docking ports, and an inflatable part, mainly introduced for habitability reasons Viscio et al. (2012e). The radial port is needed for the docking with the MMSEV once in proximity of the asteroid, to allow the astronauts to move in the vehicle and start the surface exploration activities.

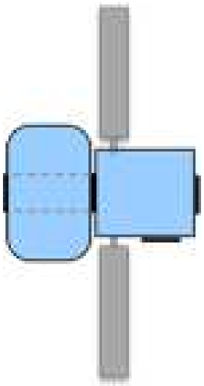

Fig. 8. Deep Space Habitat

The last two elements needed for the human mission are the Crew Exploration Vehicle (CEV) and its Service Module (CEV-SM). These two elements are mainly needed for the last phase of the mission. They were not investigated in details, and for the present study estimations, reference masses of 9MT and 11MT were assumed for the CEV and CEV-SM, respectively.

Fig. 9. Crew Exploration Vehicle

Fig. 10. CEV - Service Module

It is worth noticing that the need to perform EVAs during the deep-space flight in case of any contingency situation shall be taken into consideration, and this is assumed to be done through CEV depressurization.

4. Planetary defence

As already introduced the issue of planetary defence is very important and actual topic to be addressed to find an answer to the question "What should be done in case of NEA Hazard?"

The first step is to understand the threat, that is identifying potentially hazardous objects and characterizing them. In this regard, remote observations are an essential part of any credible system of mitigation of the NEO hazard, allowing the discovery of objects on likely collision paths with the Earth, based on available observations. Then, the physical characterization of the objects is fundamental in order to understand and identify which are the most suitable techniques to be adopted for deviating them. As a matter of fact, several different methods can be adopted, which may be

[2] This value was obtained using as reference the study described in Viscio et al. (2011b),Viscio (2013), readapting it to this specific case.

more or less applicable and efficient depending on the objects composition, as well as on the available warning time.

A brief overview of the mostly considered methods is reported hereafter Beckey (2009), Di Martino et al. (2009). First of all, two categories can be identified depending on the time available for deflection, that are slow push/pull techniques and impulsive techniques. Belonging to the first category are the following techniques:

- **Tug Boat**, which foresees the RvD of a propulsion-equipped S/C with the NEO, attaching to its surface, and pushing it gently along its velocity vector.
- **Gravity Tractor**, that consists in hovering a S/C near the asteroid by constant thrusting; the S/C exerts an attraction force on the asteroid, causing a change in the NEA velocity.
- **Laser Ablation**, that is based on the use of a sufficiently intense laser projection system to illuminate the NEA, causing surface ablation and plasma ejection, whose reaction forces result in a velocity change.
- **Solar Photon Pressure**, that exploit the solar photon pressure to effect the NEA velocity change; this can be achieved in different ways, e.g. by painting with a highly absorptive coating or using large reflectors in space.
- **Mass Driver**, that envisages having one or more S/C docked to the NEA to impart a velocity change, by ejecting chunks of the NEOs own mass to cause reaction forces

Among the impulsive techniques, the most significant ones are:

- **Kinetic Impact**, to directly alter NEA momentum by colliding a sufficiently high-impact velocity S/C with the asteroid.
- **Nuclear deflection techniques**, which can rely on the detonation of nuclear devices at or near (stand-off) the NEA surface, or deeply buried under the surface.

Another idea can be that of using a space tug, maybe developed for other initial objectives (e.g. the space tug envisaged for the S/C assembly on orbit); the tug can be deployed at a PHA and used to deviate it exploiting one of the slow push/pull techniques, e.g. the tug boat or the laser ablation method.

Within the human NEA mission described in the previous sections, astronauts can provide support for the test and validation of technologies for the asteroid deflection. For a capabilities demonstration mission a mock-up payload would be used and mitigation methods could be tested to determine their effectiveness. Astronauts can provide onsite supervision of surface operations and, moreover, a joint human-robotic mission could survey an asteroid to characterize the surface composition and orbital trajectory. Surface operations include installation of explosive devices in the subsurface and mass drivers/advanced propulsion systems on the surface of the asteroid. To accomplish these tasks, astronauts must demonstrate the ability to drill and dock/grapple onto an asteroid in a low gravity environment.

5. Virtual and augmented reality

Virtual and Augmented Reality (VR&AR) can be used in support of mission definition and execution. In particular, VR&AR can be a useful means for simulating:

- NEA proximity crew operations, including the docking/grappling of the MMSEV on the NEA surface; such a tool can be a good support for the astronauts training!
- potential hazardous asteroid deflection in order to evaluate the effectiveness of different strategies according to the typology of NEA.

Detailed models for the mission building blocks and technologies, as well as asteroids and orbital models will be needed.

6. Conclusions

The paper has presented a human mission to a Near Earth Asteroid, which is the result of a wider study aimed at evaluating a scenario for the exploration of multiple targets, eventually arriving on the surface of Mars. Asteroids are very interesting targets in the path for exploration, since they provide significant opportunities for testing and validating technologies needed to accomplish more and more challenging missions through the solar system. Besides the scientific interest and technological testing opportunities offered by a NEA mission, very important issue is planetary defence. Indeed, it is necessary to investigate and test possible collision avoidance techniques, in order to be ready to face any dangerous situation.

The main focus of the paper was the description of a reference human mission to a NEA in terms of general strategy, missions, space system elements and architectures. Within the paper, the importance of coupling the human mission with dedicated robotic missions has been underlined, to better characterize the object and to pre-deploy specific cargo in the proximity/on the surface of the asteroid. This is fundamental in order to reduce and limit the risks associated to the human expedition.

The robotic aspects are also strictly related to the planetary defence objectives, since it is very important to test and validate methods and technologies for asteroid deflection to be ready to use them in case of real emergency.

In the last part of the paper, the possibility to exploit Virtual and Augmented Reality has been discussed, in support of mission definition and execution. Future work shall be devoted to this aspect.

7. Acronyms

AR - Augmented Reality
CEV - Crew Exploration Vehicle
CEV-SM - CEV Service Module
DRA - Design Reference Architecture
DSH - Deep Space Habitat
EVA - Extra Vehicular Activity
GNC - Guidance Navigation and Control
HSE - Human Space Exploration
ISRU - In Situ Resources Utilization
LEO - Low Earth Orbit
LH2 - Liquid Hydrogen
MMSEV - Multi Mission Space Exploration Vehicle
MT - Mega Tons
NEA - Near Earth Asteroid
NEO - Near Earth Object
NERVA - Nuclear Engine for Rocket Vehicle Applications
NTR - Nuclear Thermal Rocket
PHA - Potentially Hazardous Asteroid
RvD - Rendezvous and Docking
S/C - Spacecraft
SLS - Space Launch System
SM - Service Module
SNTR - Small Nuclear Thermal Rocket
VR - Virtual Reality

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