HUMAN EXPEDITION TO A NEAR EARTH ASTEROID: REFERENCE MISSION AND TECHNOLOGIES

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The human exploration of multiple space destinations (e.g Cis-lunar, NEAs), in view of the final challenge of sending astronauts to Mars, represents a current and consistent study domain especially in terms of its possible scenarios and mission architectures assessments, as proved by the numerous on- going activities on this topic, overall the Global Exploration Roadmap work. After proposing a flexible path scenario, a detailed characterization of a Design Reference Missions (DRM) to one of the intermediate destinations represents a necessity in order to evaluate the feasibility and affordability of human space exploration missions, specifically in terms of enabling technological capabilities. A human expedition to a NEA, milestone also of the GER 'Asteroid Next' scenario, is considered the mission that would offer a large suite of benefits in terms of scientific return, operational experience and familiarity on human deep space missions, test of technologies and assessment of human factors for future long-duration expeditions (including planetary bodies), evaluation of In- Situ Resource Utilization (ISRU) and, more specifically, opportunity to test asteroid collision avoidance techniques. In the proposed paper a DRM of a human expedition to a NEA is characterized in terms of strategy, missions, architectures, space system elements and technologies. Several options have been considered at the different levels of the reference mission design, and trade-offs among them have been carried out. Within the paper the different traded options, as well as the final results, for the most relevant and crucial aspects of the mission (e.g. ΔV, Mission Duration, Crew, Operations...) are reported, in order to justify and support the major study choices. Once the space system elements have been identified, an overview of the critical technological areas, sub-areas and the specific enabling key technologies that, at the status of the art, require deeper studies, developments and assessments, is illustrated. The proposed DRM to a NEA would represent a milestone in human space exploration, the result of a detailed and justified process of scenario and strategies evaluation, and the starting point for the characterization of the elements subsystems and the required technologies developments. The final goal is to perform multiple destinations deep space human exploration missions in the next few decades, achieving the globally shared mission objectives and incrementally prepare the path towards the first human mission to Mars.

I. INTRODUCTION

Human Space Exploration (HSE) is facing nowadays a key moment in its definition and strategic long term (next 30 years) planning activities. All the major space agencies, industries and academia are performing preliminary high level studies trying to determine the best path to draw and follow, mainly through human missions to different intermediate destinations in order to obtain the maximum benefits in the short term and incrementally demonstrate capabilities needed for a final crew mission to Mars at the end of the 2030 decade.

On the specific domain the current main reference study is the Global Exploration Roadmap whose latest version identifies two alternative paths to follow, "Asteroid Next" and "Moon Next", providing a general preliminary description of the strategy to be followed; both of the options foresee a human mission to a NEA only with a different assigned priority level.

In the framework of a research activity involving the System Engineering groups of both Politecnico di Torino (Italy) and MIT (USA) with the support of Thales Alenia Space-Italy as industrial partner (MITOR 2012 project), a study on Human Space Exploration, from the definition of a scenario to the identification of the enabling technologies was performed.

One of the most significant results was the confirmation of the benefits deriving from a single human mission to a NEA in terms of a combination of technology test opportunities, scientific return and possibility to test collision avoidance techniques with planetary defence scopes.

The current paper, after an overview of the overall scenario as analysed and proposed in the MITOR project 2012, focuses on the NEA human mission concept, which represents one of 6 intermediate destinations concepts to be developed.

A Design Reference Mission (DRM) is proposed including considerations on the general strategy, missions (including precursors and cargos), space system elements and architectures. Moreover the most critical technological areas, sub-areas and key-enabling technologies are identified and mapped on the implemented elements according to their applicability.

II. HUMAN SPACE EXPLORATION SCENARIO

A 30 years-term human space exploration scenario (until the end of the 2030 decade) shall foresee a final flagship human mission to Mars as the final goal. By studying, investigating and analysing all the technical aspects related to the human mission to the Red Planet, an incremental scenario in terms of capabilities demonstration and achievement through several interesting intermediate destinations human missions can be identified.

The technical stepwise approach on the exploration scenario can be implemented at the preliminary design level of the strategies, missions, architectures, elements and technologies applied to the intermediate destinations mission concepts.

II.I Human Mission to Mars

A unique and perfect architecture for a feasible human mission to Mars does not exist. The preliminary design and identification of a strategy passes through the definition and evaluation of several high-level key-decisions whose options can lead to significantly different architectures.

Among the 5 most recent studies on a preliminary design of a human mission to Mars, including the last version of the Mars Direct [2009] and the ESA CDF HMM study [2004], the NASA DRA 5.0 [2009] was selected as the reference one. The major mission attributes and high-level key decisions are reported in table I.

Beside a large set of more advantageous technical, risk and cost aspects related to the feasibility of the mission, the main reasons why it was decided to rely on the NASA DRA 5.0, were:

- the level of completeness of the work with detailed considerations also on elements, subsystems and technologies,
- the accuracy of the analysis supporting main trade-offs decisions and of justifications where only a qualitative assessment was performed.

Attributes/Key-decisions	Value
Timeframe	2035-2040
Mission duration	5 years
Mission type	Conjunction
Cargo pre-deployment	Yes
Mars Capture Method	Cargo: Aerocapture Crew: Propulsive
ISRU	Yes – LOX for ascent
In-space propulsion	Nuclear Thermal
Number of crew members	6 – all on surface
Surface exploration strategy	Commuter
Total IMLEO Mass	328 mT
Total Launches	9
Crew Mission Durations - days	
LEO	5
Outbound Cruise	174
Mars Orbit	20
Mars Surface	539
Inbound Cruise	201
Total – Deep Space	395
Total - Mission	939

Table I: NASA DRA 5.0 Mission attributes and key decisions

The NASA DRA 5.0 foresees 2 cargo missions to Mars in 2037. The first one will pre-deploy assets on the surface, specifically power plants, mobility, utility and communications elements, ISRU plan and the Mars Ascent Vehicle (MAV). The second mission will insert into a 1-sol Mars orbit the manned lander and surface habitat, carrying also pressurized rovers for additional surface mobility capabilities.

The crew mission is planned to start 2 years after the cargo mission arrival at Mars and the confirmation that all the LOX propellant needed for the ascent is produced and stored in the MAV tanks.

The crew will perform the LEO assembly, the outbound transfer, the Mars orbit insertion, the transfer to the manned lander, the Mars entry, descent and landing, the surface staying, the ascent, the rendezvous with the main orbiting S/C, the inbound transfer and finally the Earth direct re-entry.

In order to accomplish all these phases and the required functions a total 28 different elements, belonging to transportation, surface and in-space categories, are estimated to be required by NASA engineers with their specific concepts of operations, design drivers, functions to be accomplished and technologies to be implemented.

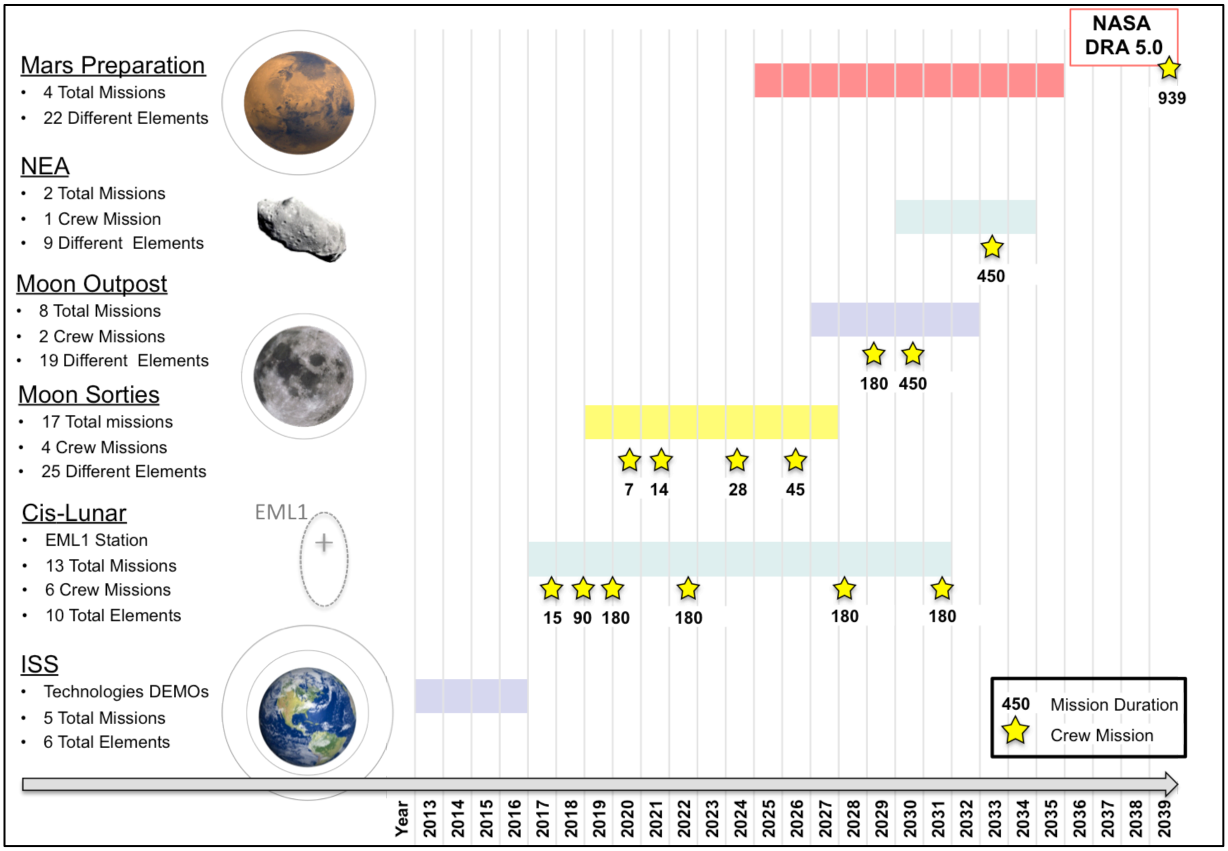


Figure 1: MITOR Project 2012 HSE Scenario

II.II Human Missions to Intermediate Destinations

The spectrum of interesting destinations and relevant concepts for intermediate human missions on the path towards Mars is extremely wide. Lots of them were considered but a down-selection to an acceptable number was done, according to technical considerations on opportunities to demonstrate capabilities needed to Mars through the implementation of similar strategies, missions, architectures, elements and technologies.

Others besides capabilities demonstration interests (for example scientific or planetary defence) were also addressed at the moment of the selection, but with a less influence on the overall ranking process.

Other main drivers were:

- to prefer closer to Earth and “easier” destination concepts,
- to prefer concepts that foresee reusable elements where feasible,
- to prefer coupled concepts (e.g. Moon Sorties with the support of a Cis-lunar infrastructure),
- to select no more than one concept for each destination.

At the end 6 intermediate destinations with their corresponding concepts were selected. In Fig. 1 the whole Human Space Explorations Scenario within a feasible timeline is reported with all the destinations and some major features of the proposed missions.

In this paper the NEA concept is investigated in more details and a Design Reference Mission (DRM) for a human visiting is proposed.

For more details on the other destinations concepts in terms of objectives, strategies, missions, elements, architectures and technologies refer to the MITOR Project 2012 report that is going to be available in September 2012.

III. NEA MISSION

III.I NEA Mission Objectives

A human mission to a NEA will have several mission objectives that can be divided into three main categories: scientific objectives, planetary defence objectives and technological objectives. In the following, they are briefly discussed.

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, the study of the asteroid composition for mining purpose as well as for possible medical applications.

Asteroids may have 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 to 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 in order to mine them and get:

- water, that can be used to refuel spacecraft fort 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, a meteor found in Australia contained an amino acid, the isovaline, which reduces epileptic seizures; this amino acid and many others could be present in greater quantities on asteroids.

Planetary Defence Objectives

The planetary defence objectives refer to avoid the impact of a Potentially Hazardous Asteroid (PHA) with Earth, which can have catastrophic consequences. This can be achieved mainly in two ways:

- by nudging the object out of collision course with Earth,
- by Fragmentation/Pulverization of the object.

Several techniques are under study to deviate or fragment an asteroid to avoid collision. In this regard a human NEA mission would give the possibility to perform more accurate analysis 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.

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 to be implemented in the human mission to Mars (according to the exploration scenario in which it is included). More details are provided in the following sections (in particular see section *"III.IX Critical Technological Areas"*).

III.II Benefits of human presence

Several benefits derive from having humans in a NEA mission. In particular the most significant ones are briefly described hereafter.

Humans adapt to unknown environments more easily and quickly than robotics and would be able to better use scientific instruments.

Visual and tactile abilities of humans would allow them to provide a more thorough description of the asteroid. Moreover, humans are more mobile and better able to collect samples from different areas of an asteroid.

Scientific tools on previous Mars rovers (ex. seismometers) were jostled around as the rovers moved about, providing faulty readings. Human presence would ensure the proper placement and orientation of instruments.

Due to all the mentioned reasons the overall, scientific return is significantly greater with human presence.

III.III Assumptions and High-level key decisions

The definition and characterization of the NEA mission architecture are based on some assumptions and high-level key decisions, which represent the starting point of the performed analyses.

No specific evaluations were performed in order to select the best target NEA and the 1999 JU3[*] was taken as reference. This asteroid allows for a human mission in 2033, which is compatible with the HSE scenario in which it is inserted, with an overall duration not exceeding 1 year.

In terms of ΔV, this reference asteroid requires an overall ΔV of 8.5km/s. It is worth to underline that different less demanding NEAs could be selected, but assuming this value as reference allowed for a more conservative analysis.

The high-level key decisions that were considered, for defining the NEA mission architectures referred mainly to the mission duration, the number of crewmembers and the propulsion to be adopted. For the duration the 1 year option was selected (which is also guaranteed by the reference NEA) since this is representative of the Deep Space part of the human mission to Mars.

The second decision was about the crew size: 4 was evaluated as the minimum required number of crewmembers in order to accomplish the mission objectives.

For what concerns the propulsion to be used, Nuclear Thermal Propulsion was selected according to considerations about the scenario in which it is included and the philosophy behind its development.

[*] This asteroid is the target selected for the Hayabusa 2 mission.

In particular, since the reference NASA DRA 5.0 mission to Mars implements nuclear propulsion, it was decided to use this type of propulsion also for the NEA mission to make this mission as much as possible representative of the Mars one and in order to minimize the technological development effort for the Mars mission.

Moreover, the NEA mission is one step of a scenario in which previous missions are already envisioned to implement nuclear propulsion and therefore this technology shall be available for the time of the expedition to the asteroid.

III.IV Mission Strategy

A human mission to a NEA is a quite challenging mission and for this reason it is necessary to adopt an adequate strategy, which allows to best minimize the risks. According to that, having a good knowledge and characterization of the target is fundamental to achieve the mission objectives.

The strategy to be adopted for such kind of mission foresees a first phase in which a campaign of probe missions shall be performed. These missions are necessary in order to explore several possible candidate targets and among them select the most interesting one for the human mission.

The second phase of the mission strategy will be represented by a precursor robotic mission that shall be envisioned to pre-deploy at the target asteroid robotic assets needed for the human one.

Finally the last phase will be represented by the actual human exploration mission.

III.V Mission Types and List

Three main mission types were identified and are briefly described hereafter.

The first type of mission refers to the "Precursor Robotic Missions", which include several probe missions needed to explore and characterize the target NEA prior to the human exploration. In the present work no specific evaluations have been performed about the probe missions, but already planned missions are considered as starting point (e.g. Hayabusa 2).

The second type of mission is the "Cargo Delivery Mission", which is the unmanned mission envisioned for the pre-deployment of the cargo at NEA. In particular this mission will bring at the NEA the Multi Mission Space Exploration Vehicle (MMSEV) and additional robotics assets needed to support human missions (e.g. transponders, supporting surface structures,…)

The third type of mission is referred to as "Crew Mission", that is the actual human exploration mission.

The analyses presented in the paper were performed taking as reference a specific NEA, even though no specific trade-offs or evaluations were carried out to select a particular target. The chosen reference NEA allows having conservative assessment; as a matter of fact a quite high ΔV (about 8.5 km/s) is required and the overall mission duration is about one year. Moreover the reference asteroid allows for a human mission in 2033, which is accordance with the HSE scenario in which it shall be included.

The cargo delivery mission is planned to take place two years before the human one.

The architectures as well as the needed elements for the two missions were analysed and are described in the following sections.

III.VI Mission Elements

Several elements were identified as necessary to accomplish the NEA missions. Hereafter a brief description of the elements and their main features is reported.

The cargo delivery mission will implement the following elements:

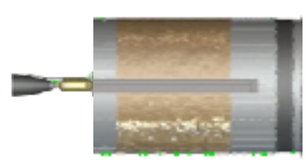
- Small Nuclear Thermal Rocket,
- Small LH2 tank,
- Multi Missions Space Exploration Vehicle (MMSEV),

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 nuclear rocket implementing one NERVA engine able to provide a thrust of 111kN (see Fig.2). 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 and moreover multi-ignitions capability is required. The small NTR adopted in the mission has a maximum propellant loading capability up to 24 MT[†], but in the NEA cargo deployment mission it is used not completely loaded, but with 9MT of liquid hydrogen.



[†] This value was the results of specific evaluations performed within the scenario study and derives from the need of implementing this element even in different missions.

Fig.2: Small Nuclear Thermal Rocket

For the cargo deployment, the SMTR is coupled with an in-line small LH2 tank (see Fig.3). This tank will carry 22MT of fuel, which is needed to provide the NEA transfer orbit injection.

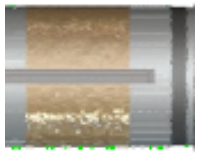


Fig.3: Small LH2 tank

The Multi Mission Space Exploration Vehicle (MMSEV) 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) [Ref.2].

Fig.4: Multi Missions Space Exploration Vehicle

The MMSEV will allow astronauts to perform EVAs and explore the NEA surface. The EVAs can be performed by means of suitports that are integrated on the MMSEV.

For the human mission the transportation system still implements nuclear propulsion. In this case the nuclear stage is different from the SNTR since the requirements are different. In this regard the used stage, referred to as Long Term Nuclear Thermal Rocket (NTR), has 3 engines providing 111kN thrust each, similar to what required by the NASA DRA 5.0 human mission to Mars. The NTR is loaded with 63 tons of propellant.

Fig.5: Long Term Nuclear Thermal Rocket

This stage is coupled with a drop tank (see Fig.6), similar to that foreseen for the 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.

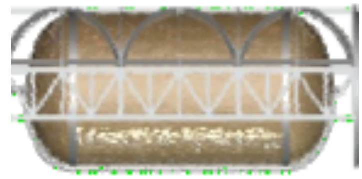


Fig. 6: Drop Tank

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 crew during the travel to the asteroid and back to Earth. The DSH is design to support 4 crewmembers for a mission lasting up to 1 year. Its overall mass amounts to about 28MT, including the resources and crew systems. A schematic overview of the module is shown in Fig.7 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. [Ref.3]

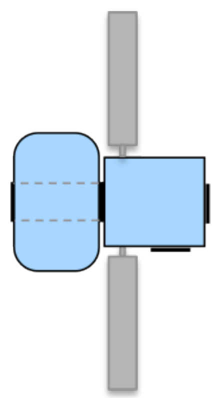


Fig. 7: Deep Space Habitat

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 evaluations, reference masses of 9MT and 11MT were assumed for the CEV and CEV-SM respectively.

Fig. 8: Crew Exploration Vehicle

Fig. 9: 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 can be done through CEV depressurization.

III.VII Architectures

In this section the architectures for both the cargo pre-deployment and the crew mission will be described.

The Robotic mission will take place in 2031 to bring at the NEA the MMSEV and additional robotics assets. The overall mass of the cargo to be deployed at the NEA amounts to 10MT.

The mission profile is schematically described in Fig.10. The ΔVs considered for the robotic mission are the same ones of the NEA mission. Further analyses should be performed to implement a less demanding robotic mission.

The overall spacecraft is composed of a SNTR, a small LH2 tank and the payload (depicted as the blue box in the figure), which includes the MMSEV and other robotics assets. The spacecraft is assembled on ground and launched to LEO by means of a Space Launch System with 70MT payload capability in LEO.

The SNTR provides the first ignition (ΔV1=3500m/s) to inject the spacecraft into the NEA transfer orbit. This manoeuvre is performed by 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 robotics assets are released at the NEA waiting for the crew mission.

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 here stored propellant is used at the beginning of the mission.

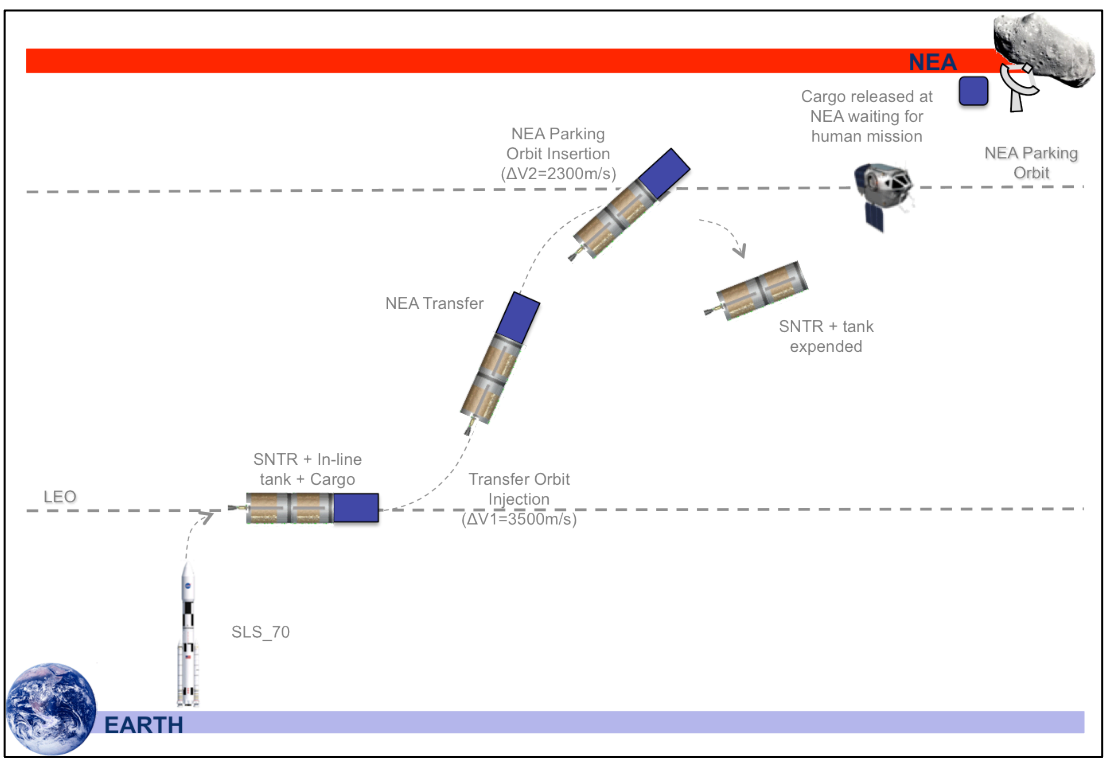


Fig. 10: Cargo pre-deployment mission

The second architecture that was analysed refers to the human mission (see Fig.11). The human mission will take place in 2033 and will last approximately 1 year with a crew of four astronauts. The spacecraft is composed of the Long Term NTR, the drop tank, the DSH, the CEV and 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. After the docking between the NTR and the DSH and drop tank assembly is completed the space tug is expended.

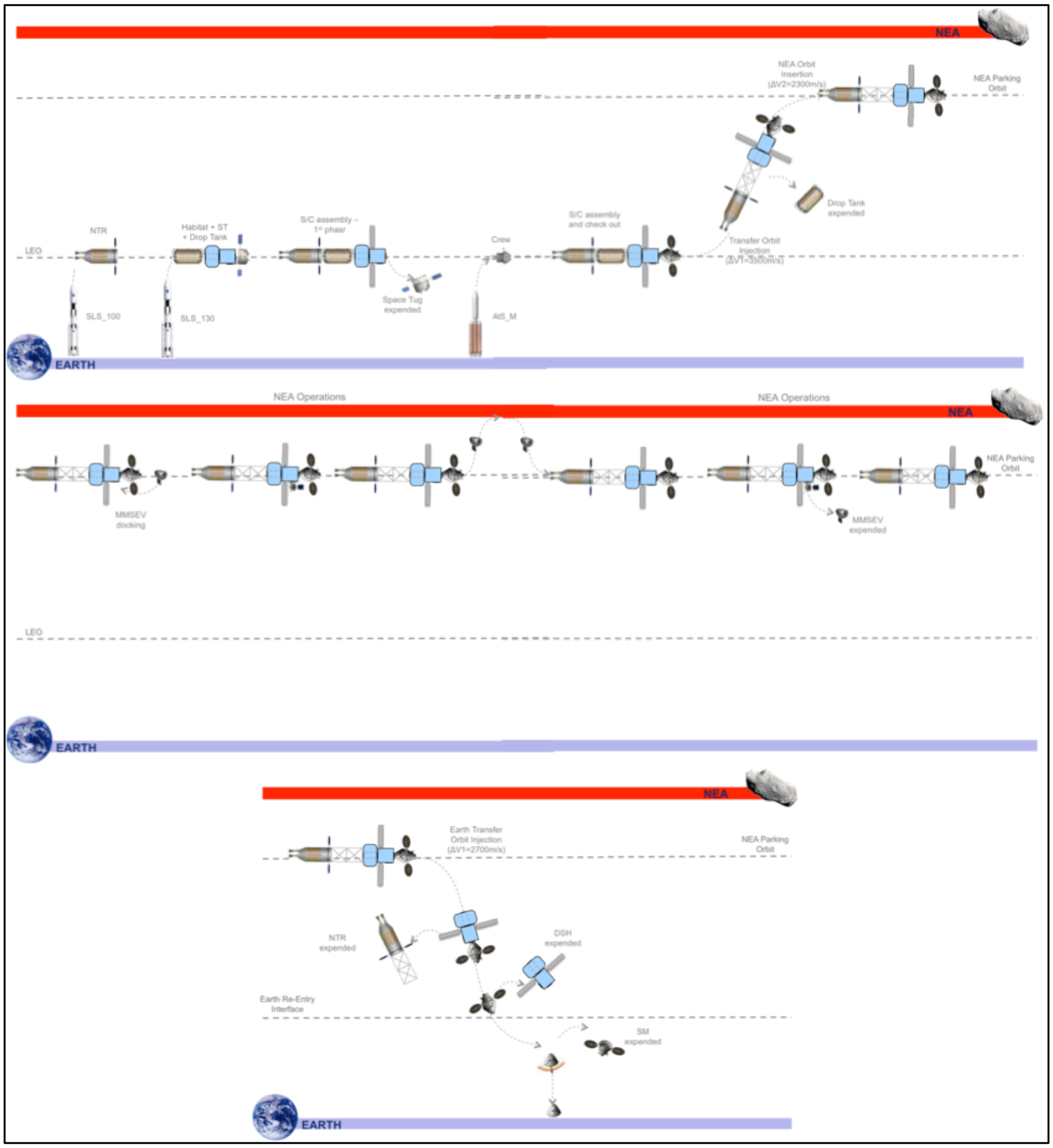


Fig.11: NEA human mission profile

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. 8 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 during the NEA proximity operations phase.

After the 8 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 Earth's atmosphere after 129 days of travel.

III.VIII Manifest

In this section a summary of the sequence of missions and the associated needed elements is reported.

Fig.12 shows the three main phases of the NEA exploration.

The first phase is foreseen between 2014 and 2029 and will be characterized by several probe missions. In this regards there are already planned missions in this timeframe, as for instance Hayabusa 2, Osiris Rex, etc.

The second phase is the precursor robotic mission for the cargo pre-deployment, which is planned in 2031, that is two years before the manned mission. For this mission one launcher is required (SLS of 70MT capability in LEO). The elements required are grouped in two categories: the transfer elements and the NEA elements. As transfer elements a SNTR and small LH2 tank are required for the robotic mission. Finally, the element to be brought at the NEA is the MMSEV, which also includes the suitports.

For what concerns the NEA human mission, three launchers are necessary: two cargo (SLS of 100MT and of 130MT capability in LEO) and one manned launcher (Atlas 5 – men rated). The transfer elements are the Long Term NTR and the Drop Tank, while the other needed elements are the DSH, the CEV and the CEV-SM.

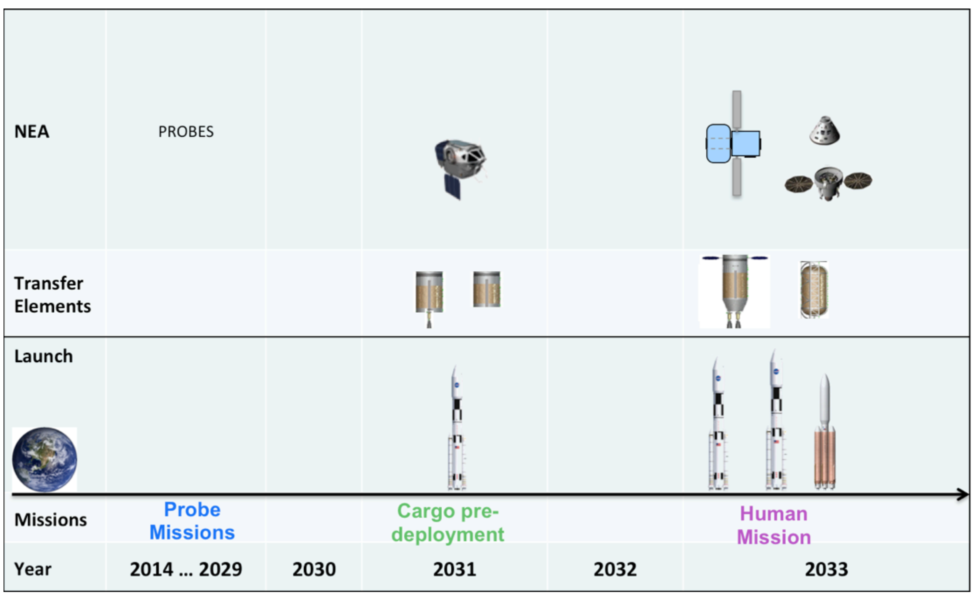


Fig.12: Manifest

III.IX Critical Technological Areas

All the 9 elements, part of the NEA human mission concept, shall implement several sub-systems that are able to perform different functions. Sub-systems are formed by components that can be represented also in terms of one or usually more implemented technologies.

The technologies can be grouped in Technological Areas (TAs) that can have a prefect correspondence to the subsystems. In the MITOR 2012 Project, 11 Technological Areas were defined grouping all the innovative, promising and not-yet qualified technologies applicable to the Human Space Exploration.

A first analysis was to assess the critical technological areas for the 9 elements implemented in the NEA human mission concept. Results are reported in Table II.

Label	Technological Areas/Sub-Areas	Elements								
		SNTR	NTR	Small LH2 Tank	LH2 Drop Tank	CEV	CEV-SM	MM SEV	DSH	Suit Ports
TA.1	Structure & Mechanisms									
	Structure		X	X					X	
	Mechanisms					X		X	X	X
TA.2	Power									
	Power Generation	X	X	X					X	
	Power Distribution and Mgmt	X	X	X					X	
	Energy Storage						X	X	X	X
TA.3	Thermal									
	Thermal Control					X		X	X	X
	Thermal Protection					X				
	Cryogenic Systems	X	X	X	X					
TA.4	Robotics & Automation									
	Sensing & Perception		X			X	X	X		X
	Mobility, Support & Anchoring							X		
	Manipulation & Capture							X		
	Human-Machine Interface							X	X	
	Cognition									
	Autonomy	X	X			X		X	X	
TA.5	Avionics									
	Avionics					X		X	X	
TA.6	Communications									
	Communications							X	X	
TA.7	Attitude & GNC									
	Attitude							X		
	Guidance & Navigation							X		
	Control								X	
TA.8	Life Support									
	Air Management								X	
	Water Management								X	
	Waste Management								X	
	Food Management								X	
	Hybrid Processes									
TA.9	Propulsion									
	Chemical						X			
	Electrical									
	Nuclear Thermal	X	X							
	Electromagnetic									
TA.10	Environment, Humans & Safety									
	Radiation Protection	X	X					X	X	
	Reduced Gravity								X	
	Dust Mitigation							X		
	Habitability							X	X	
	EVA									X
	Crew Health								X	
	Fire Detection & Suppression					X		X	X	X
TA.11	Atmospheric Descent&Landing									
	Atmospheric Descent									
	Landing									

Table II: Elements Critical Technological Areas

Moreover each critical technological area includes several technologies that shall be developed in order to be ready for space qualification and implementation in the elements. The most critical ones and applicable to the NEA human mission concept are listed below:

TA.1
Advanced Deployable Structures
Multifunctional Structures
Flexible Pressurized Inflatable Structures
In-space Docking Mechanisms (IBDM)
Low-g Sampling Mechanism
Advanced Separation Mechanism

TA.2
Flexible Solar Arrays
Dynamic Conversion Fission Reactor
Advanced PCU
Advanced Batteries
Regenerative Fuel Cells

TA.3
Advanced Heat Exchanger
Two-Phases Heat Transfer Circuit
Advanced Fusible Heat Sinks
High Density Carbon Phenolic
PICA
LBO-ZBO Concepts
Cryocoolers
Cryogenic Fuel Transfer Components

TA.4
Stereo Vision – 3D Cameras
LIDAR
Advanced Manipulators & Robotic Arms
Immersed/Advanced Reality

TA.5
Radiation Hardened Multi-core Processor
Advanced Atomic Clocks

TA.6
High Data Rate X/Ka-bands
Wireless Communications
Laser Communications
6-m High Gain Antenna
Advanced Transceivers
Advanced SDR
Deep Space Network

TA.7
Terrain Trackers
Relative Guidance (RG) Algorithm
Hazards Detection & Avoidance (HDA) Algorithm

TA.8
Air Regeneration Systems (e.g ARES)
Regenerative TCC Systems
Brine-dewatering
Lyophilisation

TA.9
Pressure-fed Storable NTO/MMH 33.5 kN
Nuclear Thermal Engine 111 kN

TA.10
Advanced Shielding Materials
Advanced Shielding Concepts (e.g. Water Bags)
Internal Centrifuge
Dust Mitigation Techniques (e.g. Lotus Coatings)
Suitport
Advanced Suits
Advanced PLSS

IV. CONCLUSIONS

The paper has presented the results obtained in the frame of the MITOR 2012 project, which is developed as collaboration between Politecnico di Torino and Massachusetts Institute of Technology (MIT).

The main focus of the paper was the description of a Design Reference Mission (DRM) to a NEA in terms of general strategy, missions, space system elements and architectures. Moreover an overview of the most critical technological areas, sub-areas and key-enabling technologies and of how they are mapped on the elements depending on their applicability has been discussed.

The architectures derived for the NEA missions are inserted in global exploration scenario studied within the MITOR 2012 project as well. According to the scenario and the current space exploration plans they seem to be feasible in terms of elements to be developed as well as of launchers required. As a matter of fact, the mission here described shall take place starting in 2031 and will rely on SLS launchers, which should be available according to the plans.

Further investigation shall be performed to select the proper NEA target. Moreover, more accurate evaluations should be objective of a second iteration to better assess the technologies implementation in the mission elements.

V. LIST OF ACRONYMS

CEV – Crew Exploration Vehicle
CEV-SM – CEV Service Module
DRA – Design Reference Architecture
DRM – Design Reference Mission
DSH – Deep Space Habitat
EML – Earth-Moon Lagrangian Point
EVA – Extra Vehicular Activity

IBDM – International Berthing and Docking Mechanism
LBO – Low Boil Off
LEO – Low Earth Orbit
LH2 – Liquid Hydrogen
LOX – Liquid Oxygen
MMSEV – Multi Mission Space Exploration Vehicle
MT – Mega Tons
NEA – Near Earth Asteroid
NTR – Nuclear Thermal Rocket
PLSS – Portable Life Support System
RvD – Rendezvous and Docking
SLS – Space Launch System
SM – Service Module
SNTR – Small Nuclear Thermal Rocket
ZBO – Zero Boil Off

XI. REFERENCES

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Ref. 3: M.A. Viscio, F. Fenoglio, "Exploration Research Habitat Concept", SD-RP-AI-0735, TAS-I, 2011