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DEEP SPACE MISSIONS: HABITAT AND TRANSPORTATION

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Abstract: The next steps of human exploration in space will depend on the development of deep space exploration capabilities needed to support extensive missions in hostile environments in preparation for a human mission to Mars. Recent works in Europe and the US have established the need for more data on the combined effects of microgravity and radiation on crew members. Also, architecture studies have established the need for improved in-space transportation of non-time critical cargo. Therefore, among the different enabling capabilities, a Deep Space Habitat and a Solar Electric Propulsion (SEP)-based transfer stage may represent the next logical capabilities that should be developed according to an incremental build-up logic.

Together with SLS and Orion, these new capabilities would allow a number of exciting interim missions to be executed in the cis-lunar environment and demonstrate critical capabilities that will be employed for a Mars mission. Aerojet Rocketdyne, NanoRacks and Thales Alenia Space have compared different scenarios' requirements and reviewed possible design solutions for a Deep Space Habitat and SEP Transfer Stage with features for extensibility and augmentation of capabilities.

NASA and its partner national space agencies, including the Italian Space Agency (ASI), have been examining the critical requirements to transition from the current state of operations in human spaceflight – as embodied by the international space station (ISS) – to a more Earth independent mode of operations that will be required for journeys to Mars. This activity is summarized in the Global Exploration Roadmap (GER) which is available at this website:
http://www.nasa.gov/pdf/591067main_GER_2011_small_single.pdf

The general characteristics that have been agreed upon comprise an incremental, stepping stone approach to the eventual flights to Mars. Early missions will focus on testing systems in environments that better simulate the trans-Mars trajectory, such as radiation and micro-gravity. The cislunar region can do a good job in this regard and locations such as the distant retrograde orbit (DRO) about the moon or the Earth-Moon L2 point (EML2) are candidates currently under study. Placing habitats in these locations will allow all systems to be tested with crews visiting periodically. The important thing is they will have the ability to return to Earth if malfunctions in key life support or other mission critical systems occur. Also, it will be possible to upgrade systems and fly iterations on experiments without large costs for the incremental missions. Neither of these is feasible once committed to a trajectory to destinations such as asteroids, the Martian moons or to Mars itself. Before we embark on these missions we must accomplish several shakedown cruises to ensure that the systems required can function as needed on the longer, more distant voyages.

Thales Alenia Space, NanoRacks and Aerojet Rocketdyne have joined together to look at this scenario and compare results from our individual studies. This is a good arrangement because it addresses the need to have international partners involved, while maintaining the ability for each of us to work in the areas best suited to our companies capabilities and interests. It builds on TAS long history of work in habitat design and on Aerojet Rocketdyne's work on in-space transportation concepts. NanoRacks has been pioneering the broader commercial utilization of the ISS and other LEO platforms. Our study attempts to examine the key figures of merit of an early cislunar technology demonstration mission (TDM), the benefits of such a TDM to future human exploration missions, and the enhancements that such a TDM would provide to either lunar missions or an asteroid redirect mission.

Keywords: Exploration, Habitat, Transportation

1. NEED FOR EXTENDED HUMAN STAY CAPABILITY – Evolution from Initial Missions to Mars

Human exploration beyond LEO will require a new system able to survive and to sustain human life in a harsh environment that humans have already experienced in the Apollo era. This time though, the mission duration will be significantly longer and new challenges will be faced. In this section Thales Alenia Space provides its approach for the design of innovative exploration habitats taking advantage of the experience gathered in the ISS program. The Orion Multi-Purpose Crew Vehicle (MPCV) will provide limited duration capability up to about 21 – 28 days in lunar orbit [1]. However, it can perform much longer duration missions if paired with a habitat such as that described here.

1.1. The Proving Ground for Mars Mission Habitats - First Cis-lunar Missions

It may even be possible, using a solar electric propulsion (SEP) tug, to transfer a module from LEO to a cis-lunar orbit after checking it out. These are ideas that we have been considering in the planning of our design and approach. All of these operations can be practiced in LEO using the ISS as a platform prior to the first cis-lunar missions.

Another more recent development is the potential to use excess mass capability on the SLS when it is launching the Orion MPCV to a lunar orbit. It now looks possible to place up to 12 t of mass in a co-manifested launch arrangement with Orion into lunar orbit. The dimensions of the co-manifest payload position are approximately the same as the Orion plus service module. This is illustrated in Figure 1. Such a capability would allow for elements of the deep space habitat to be inserted into lunar orbit on the same launch as an Orion capsule.

A habitat in Cis-lunar space can support a variety of exploration missions. Based on actual international plans, elaborated within the GER developed by the ISECG, an orbiting infrastructure in the vicinity of the Moon can support preliminary Human operation beyond LEO, Tele-operations of robotics on the Moon, provide extended capability to an asteroid redirection mission, and strongly support an overall architecture for the lunar surface exploration [2].

Different locations of the Cis-lunar space (EML1, EML2, Low Lunar Orbit or Distant Lunar Orbit) would obviously be more appropriate for the different kinds of missions but all of them could have similar mission duration (less than 30days), similar environments, the same number of crew members, and the same logistics needs. For these considerations, a flexible system design can sustain many different missions. As experience is gained, mission durations can be extended to 60 days, 90 days and finally to 180 days to simulate expected Mars transit times.

As missions progress, a flexible propulsion stage is required to provide transportation of refurbished modules or to serve as a logistics carrier for cargo and supplies. The concept proposed by Aerojet Rocketdyne is perfectly coherent with Thales Alenia Space approach, allowing to move the habitat before human arrival to multiple destination with a low thrust but with very high Isp leading to low propellant consumption and cost reduction.

Fig. 1: SLS Co-manifest capability is a key enabler for deployment of Deep Space Habitats (source: NASA)

2. DEEP SPACE MISSIONS

Initial missions in the cis-lunar environment could rely on simple and small habitats, as they will be visited for relatively short time by the crew transported by Orion, but the evolution to deeper space missions will require a larger habitat to be used as transfer vehicle where the crew can perform its daily activities in a safer and more comfortable way. Deep space missions can concern different targets: typical destinations after Cis-lunar space could be a Near Earth Asteroid (NEA), the moons of Mars or Mars surface. For any of these destinations, the mission duration would reach 6 months as a minimum without the availability of logistic vehicles to re-supply the habitat with resources. It is easily understandable that the strong differences in the mission duration and contingencies for missing re-supply would impose different requirements to the Habitat [3].

2.1. Habitat Systems & Capability

Considering the different mission profiles for the Cis-lunar and of the deep space missions, Thales Alenia Space Italia has conceived an incremental design approach in order to make extensive use of European capabilities in Human Space-flight acquired through participation in the ISS program and to project them as a first step for the development of a Cis-lunar habitat in support of the lunar exploration architecture and, in a second step, to evolve it into a Deep Space Habitat (DSH) able to support extended mission duration without any resupply.

The habitat is based on four key elements:

- A habitable pressurized module (relying on design derived from the ISS's ones)
- A service module (similar to that one of ATV or Orion)
- An airlock (TBD)
- A robotic arm (similar to ISS designs)

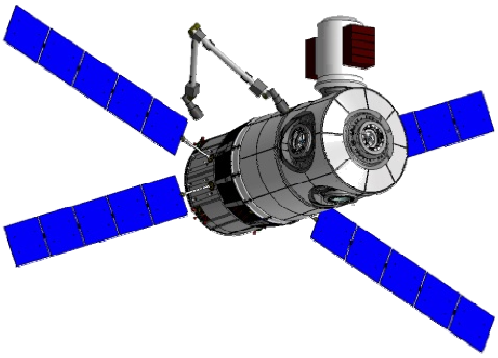

Fig.2: Cis-Lunar Habitat Concept

The core of the habitat can be constituted of a Node-like module (such to provide docking / berthing capabilities to other spacecraft), integrated with an ATV-like service module. These two modules, interconnected and integrated in a single piece, provide main system functions and essential life support elements. The airlock will allow Astronauts to reach the external environment. The multi degree of freedom robotic arm will support berthing operations, the deployment of the habitat itself and extra vehicular activities (EVA) by astronauts.

Co-manifest opportunities on the SLS could launch nodes and individual modules. Larger modules and other elements could be delivered from LEO via transfer using SEP transportation modules. Aggregation and assembly operations would benefit from the knowledge base gained on ISS.

The system, conceived to be able to interface with any vehicle with common berthing system such as Orion, cargo/storage logistic vehicles, reusable lunar ascent vehicles, can be also further enhanced, especially in the longest mission scenarios, by inflatable structures, conceived to provide additional habitable volume for the crew (i.e. working and social area)and for storage. The inflatables could also offer additional protection from radiation thanks to their construction material like Kevlar and plastic that typically perform better than the aluminium utilized in the rigid modules.

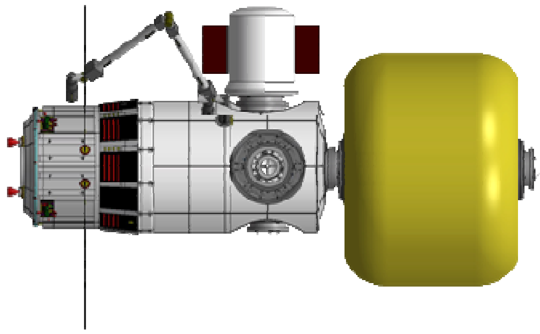

Fig.3: Cis-Lunar Habitat Concept with extended habitable volume

2.2. Solar Electric Propulsion Module

Solar Electric Propulsion (SEP) has seen renewed interest for Mars missions in the past few years as many architecture studies began to focus on addressing the cost of mounting a campaign of human missions. Under constraints of limited funding, a solution that both reduces development cost and risk (the so called non-recurring engineering or NRE) and also results in a lower mission life cycle cost or sustained cost is the most desired. Of the many technologies available for advanced in-space propulsion, SEP is the one that most nearly hits that target. For the NRE portion, this is true because SEP has benefitted from investments made in industry that have resulted in commonplace application of SEP at the 2 – 5 kW power level on diverse military and communications satellites. The remaining work to achieve SEP vehicles at a higher power level can strongly leverage that investment and the many lessons learned. SEP also makes a great deal of sense for long-term cost reductions when the architecture selected separates crew and cargo delivery. By using SEP in the primary role for cargo transport, the amount of mass that must be transported to Mars by cryogenic chemical propulsion can be reduced to approximately 15% of the overall mass required for a given mission. For the remaining 85% of the mass, the transfer propellant can be reduced dramatically by using SEP at an Isp of 3000 sec versus cryogenic chemical propulsion at an Isp of 450 sec. Previous studies have shown the tremendous potential for cost savings of this approach [5].

For these Mars cargo missions, the likely power level of a SEP cargo vehicle will be in the range of 100 – 300 kW. [6] However, the system can be proven at power levels much more in line with other applications, such as Earth orbital transfer. For these applications, SEP tug concepts of approximately 30 – 40 kW are under study. A design of a SEPM for these types of missions has been the focus of on-going IRAD activities at Aerojet Rocketdyne for the past several years. Target missions include: delivery of multiple satellites from launcher drop-off orbits to their final orbits, satellite servicing, and debris remediation. A notional SEP tug design is shown in Figure 4.

The notional configuration is a module comprising four 12.5 kW Hall thrusters, a set of propellant tanks that hold the xenon load required for the mission, thermal control and attitude control subsystems, and the powertrain for the electric propulsion system, including the advanced technology solar arrays and the power management and distribution for both the high power and housekeeping buses.

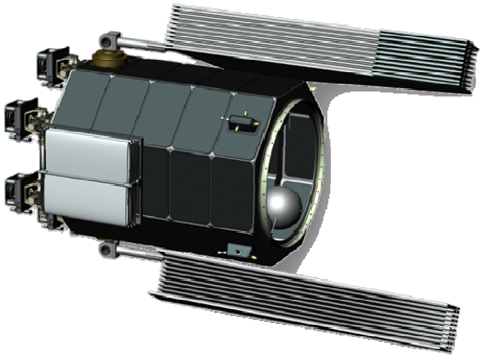

Fig. 4: Notional 30kW SEP Module Design

2.3. Deep Space Habitat Logistics

Previous mission analysis results from Aerojet Rocketdyne studies have shown that it is possible to transfer cargo modules from the ISS to the Earth-moon L1/L2 points using a 27 kW SEPM. The table shown in Figure 5 provides the details of these analyses. The basis for this study was utilization of the ISS and its already existing cargo spacecraft (Cygnus, Dragon, and MPLM) as the staging ground for logistics resupply of a lunar DSH. Further analysis performed for the Waypoint studies showed that by utilizing the launcher to inject into higher energy orbits (beyond LEO), it was possible to reduce trip time by a factor of 2 – 3 at the expense of reduced payload mass delivered. This analysis, which looked at SEPM power levels of 9 kW, 18 kW, and 27 kW is summarized in Figure 6.

Initial Wet Mass at ISS (kg)	Payload mass (kg)	Xenon mass (kg)	Trip Time (years)
5000	2500	1500	0.7
10000	5800	3000	1.4
15000	9000	4500	2.15
20000	12300	6000	2.9

Fig. 5: Details of deployment and resupply of Deep Space Habitat using SEP cargo modules

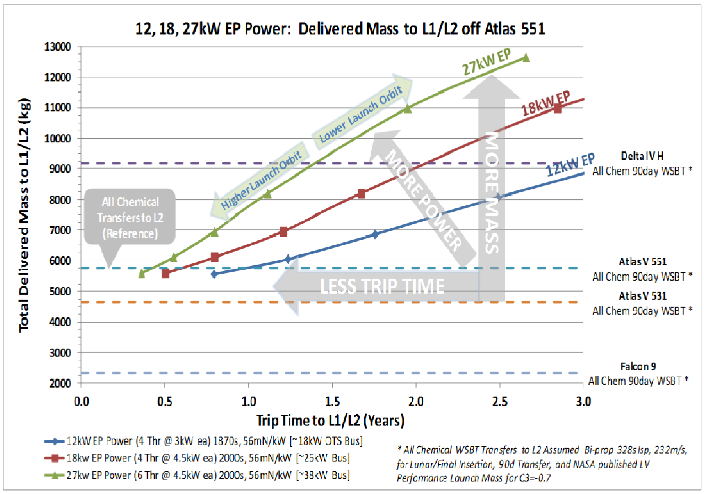

Fig. 6: Summary Trade Space for Logistics of Deep Space Habitat

High power solar arrays and EP thrusters, now under development by NASA STMD, open up the possibility of SEPM power levels much higher than these previous studies. Assuming a power level of 50 kW (possible with advanced arrays in a single module) the trip times shown in the above table can be cut by a factor of two. This, coupled with the launch capabilities of the SLS, provides the ability to routinely access and affordably support the DSH in cis-lunar space.

2.4. Integration of SEPM and Habitat

The interface to the payload or mission module is simple because the SEP tug is designed to perform one function – transportation. There will be minimal data and only a small amount of power transferred across the interface. By eliminating high power, data, and fluid coupling across the interface to the payload, we can make the SEP tug extremely versatile. Users need only conform to a mechanical interface and a standard low voltage power and data bus interface. The thrusters can be operated at less than nominal power and can also be modulated by shutting off 1, 2 or even 3 thrusters to operate on lower system power levels. Keeping the habitat and the SEP modules separate and functional either together or apart allows reuse of the SEPM and, perhaps more importantly, extensibility of the SEPM and the habitat modules to future missions.

3. ASTEROID REDIRECT MISSION and NASA's EVOLVABLE MARS CAMPAIGN

In April 2013 the White House and NASA announced the Asteroid Redirect Mission (ARM) program as the next step for Human Space Exploration after the International Space Station (ISS) [7].

As shown in Figure 7, NASA's ARM program consists in an Asteroid Redirect Robotic Mission (ARRM) first, and then in an Asteroid Redirect Crew Mission (ARCM) [8]. NASA plans to begin the ARRM launching the Asteroid Redirect Vehicle (ARV) in 2020, so that the first ARCM can take place in 2024-2025 [9].

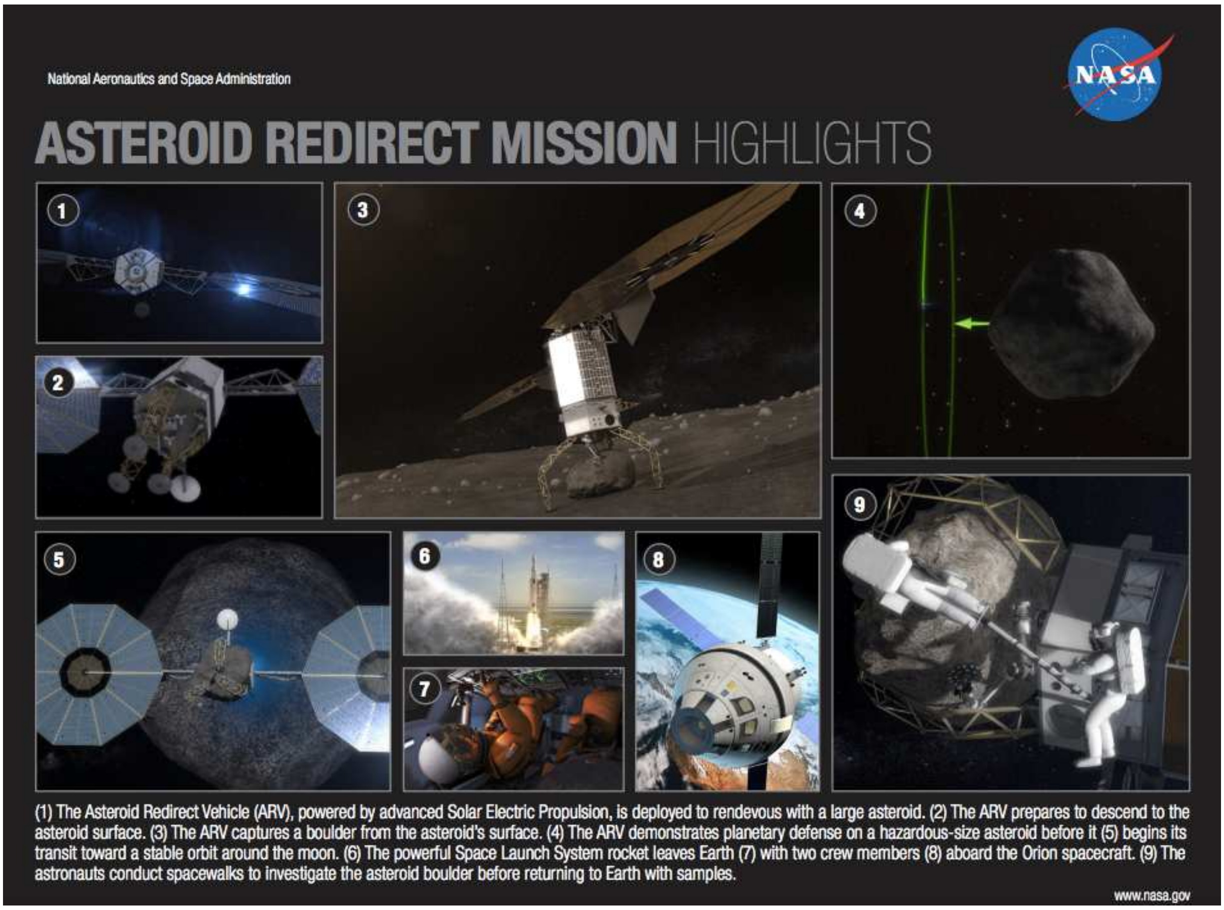

Fig. 7: Asteroid Redirect Mission Highlights (source: NASA)

NASA’s reference plan is for the first ARCM to encompass 26-28 days, including 5 days in the stable lunar Distant Retrograde Orbit (DRO) for Orion rendezvous and docking with the ARV and attached asteroid mass and the astronauts’ Extra- Vehicular Activity (EVA). The Orion spacecraft is designed to support four crew on 21-day missions beyond low Earth orbit and does not support EVA. Reducing the crew size from four to two provides additional internal stowage and mass capability. This recovered volume allows for the addition of ARCM mission kits which will extend the capability of the Orion to support the ARCM flight [10].

The duration of the ARCM could be extended up to 60 days by deploying a small habitat module in lunar orbit prior to launch of the crewed mission. The habitat module would first dock with the ARV, and then Orion would dock with the habitat module. NASA is developing concepts for an Exploration Augmentation Module (EAM) that would provide more consumables for life support, a larger habitation volume, docking ports, and an EVA airlock. The EAM may allow the ARM crew size to be increased to four astronauts. The EAM could also be used to test capabilities needed for a long-duration Mars transit habitat [11].

The EAM that Aerojet Rocketdyne - NanoRacks and Thales Alenia Space are proposing, that can be called also In-Space Habitat, can be seen as a key element in what NASA is calling the Journey to Mars (Figure 8).

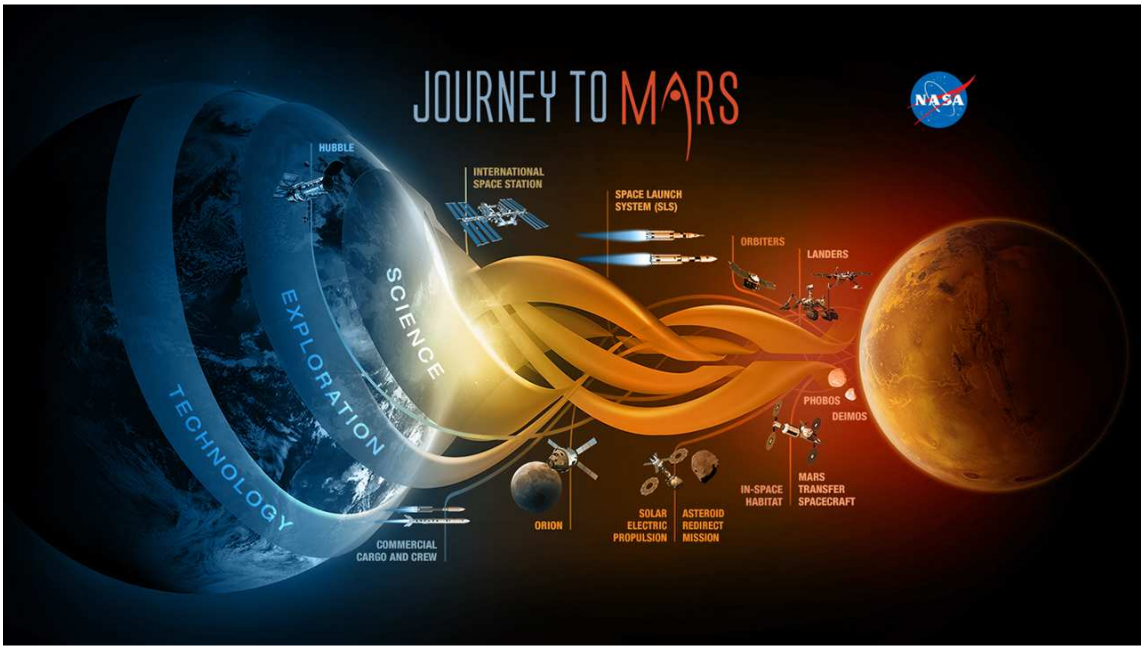

Fig. 8: NASA's Journey to Mars (source: NASA)

As shown in Figure 9, ARM and the cis-lunar space are part of the Proving Ground of the Evolvable Mars Campaign, where technology and operations will be tested in order to later become Earth Independent and have crewed exploration of the Mars neighbourhood: first Phobos, and then the surface of Mars.

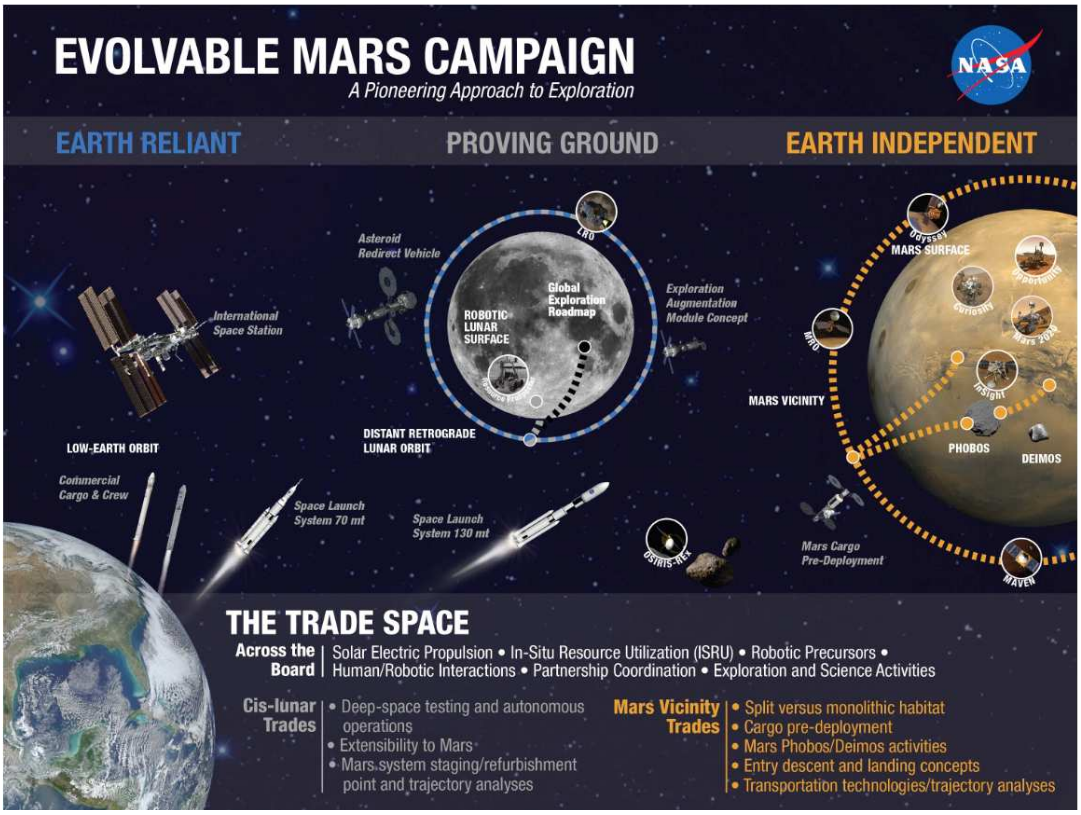

Fig. 9: Summary of the Evolvable Mars Campaign (source: NASA) [12]

The EAM in DRO can be also used as an outpost for crewed exploration of the Lunar surface, as for example ESA has shown interest in landing European astronauts on the Moon.

The DRO will be an aggregation point for Mars habitation systems. As shown in Figure 10, NASA plans to use the DRO as a gateway to deep space. Indeed, the DRO provides a stable environment and ease of access for testing Proving Ground capabilities, and it allows for Mars transit vehicle build-up and checkout in the deep-space environment prior to crew departure. Returning from Mars, the crew will return to Earth in Orion and the Mars Transit Habitat will return to the staging point in cis-lunar space for refurbishment for future missions.

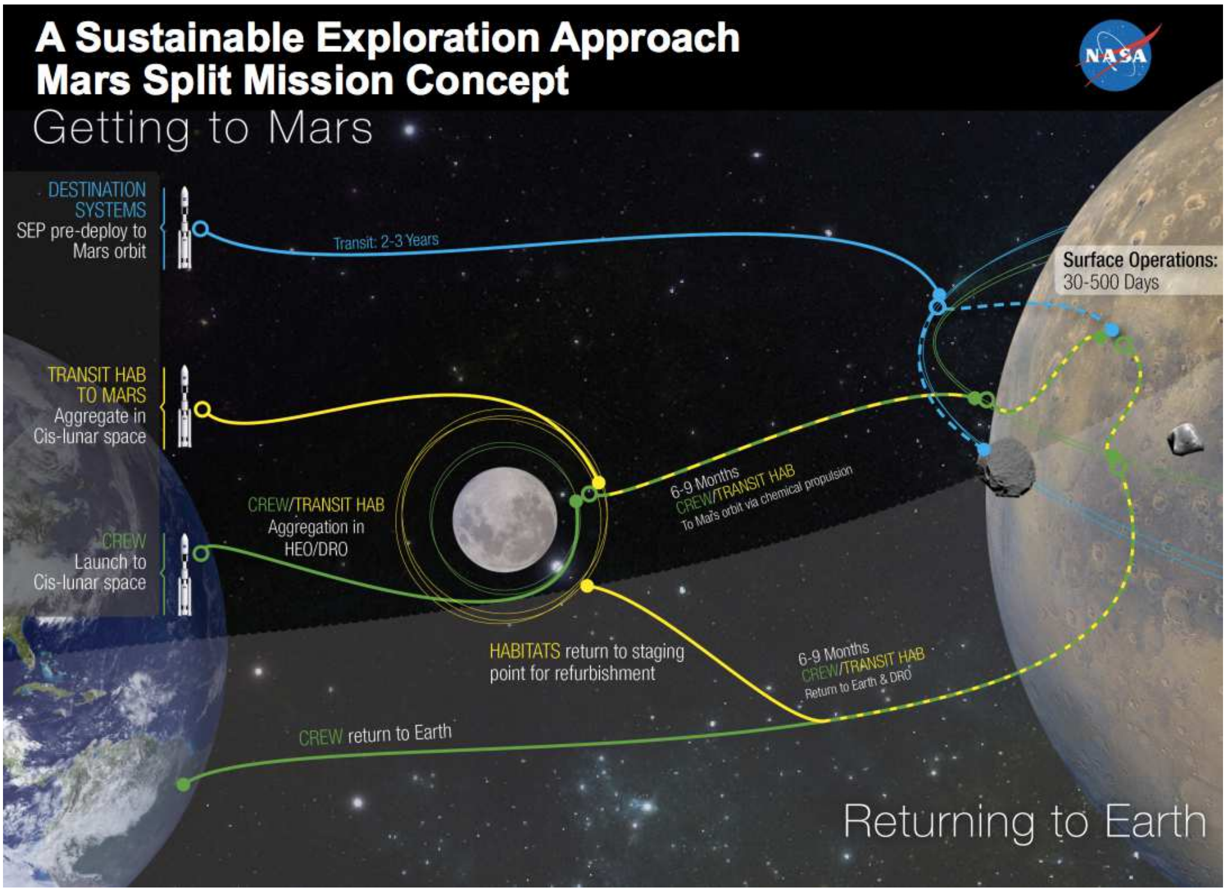

Fig. 10: Getting to Mars (source: NASA) [12]

4. CONCLUSIONS

Deep Space Habitats will play a key role in the future of Human Space Exploration, starting with ARM and cis-lunar space and continuing with deep space and the Mars neighbourhood.

An incremental design approach, by making extensive use of heritage and capabilities from ISS and passing from a first step of a simpler habitat to host visiting crew for limited time (still relying on logistic supply) to a next step evolving into a Deep Space Habitat able to support extended mission duration without resupply, would likely be the most affordable and reliable approach.

The utilization of an advanced transportation system based on Solar Electric Power (SEP) allows a simple way to interface with the mission module, as the limitation in the set of data and amount of power transferred across the interface can make the SEP tug extremely versatile.

Building on their heritage and experience, Aerojet Rocketdyne - NanoRacks and Thales Alenia Space believe that together they could be well positioned to provide the habitat and the tug to space agencies, both to NASA and ESA, thus posing the basis for the build-up of key elements of the future international cooperation on the pathway to human spaceflight and exploration.

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