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AN AFFORDABLE MISSION TO MARS

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The International space community has declared that our unified long term goal is for a human mission to Mars but major work remains to define how it will be done. In May of 2013, a "Humans to Mars (H2M)" conference was held in Washington DC to discuss the requirements and technology developments necessary to field a human mission to Mars. The authors on this paper all participated in a panel which described potential mission architectures and technology gaps which must be addressed. We will summarize the findings from the H2M conference and attempt to capture some of the key points of discussion and debate.

We will expand on these H2M conference findings to describe a "stepping stone" based approach that charts a path starting at ISS operations today and ultimately leading to a crewed mission to the surface of Mars. Translunar infrastructure and heavy lift capability will be key to this approach and we will show links to other relevant work in this area.

I. MARS AS OUR PRIMARY OBJECTIVE

Mars as a destination for human exploration has captured the imagination of the world for decades. In May 2013, the Explore Mars organization together with the Space Policy Institute hosted a conference at George Washington University to focus on a human mission to Mars. This conference covered all relevant aspects of a human mission to Mars with detailed presentations on many of the key issues.

The authors of this paper participated on a panel which was asked to discuss mission architectures. Some of the key findings for the panel were:

- A human mission to Mars is on the same order of magnitude as the effort it took to build the International Space Station (ISS); a substantial effort but one that is likely affordable in the current budget environment.
- An inclusive, international process should be used to establish the exploration objectives and define the capabilities that are needed to achieve them.
- As with ISS, an international partnership is seen as a key enabling feature of the plan. All partners participating in the plan should be given opportunities to prove their capabilities as part of this "stepping stone" approach.
- Heavy-lift launch capability will be needed in order to provide a reasonable number of assembly flights and thereby a reasonable prospect of success.

The time is now to begin planning in earnest. Figure one shows that the upcoming opportunities in the mid-2030's will be an ideal time to execute a mission so planning must begin soon.

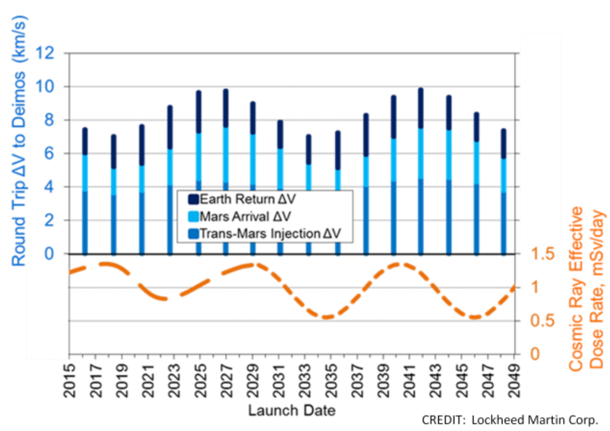

Figure 1 The best opportunity for Mars is approaching

It is important to establish the exploration objectives through an inclusive international process, to define what capabilities are needed, and to develop them through incremental steps in exploration missions. A logical path though exploration missions should efficiently and effectively develop the capabilities, while bringing back significant science discoveries and opening new opportunities on multiple fronts, including commercial. Each mission should be compelling, while demonstrating technologies needed for Mars. It should be readily apparent how each mission contributes to the long term goal of sending human explorers to Mars.

Figure 2 illustrates that there are many different paths that lead to Mars. The lower left of the diagram shows that MPCV (Orion) and SLS are both critical to the Mars mission and much of the variability in the chart relates to the other elements needed for the mission (see section III of this paper for more discussion on this point). A balance must be drawn between incremental testing of new capabilities and the additional cost of capturing peripheral objectives.

II. STEPPING STONES TO MARS

A human mission to Mars will require the development of a set of new capabilities and all of our panelists agreed that steps must be taken to mature and prove out these new capabilities.

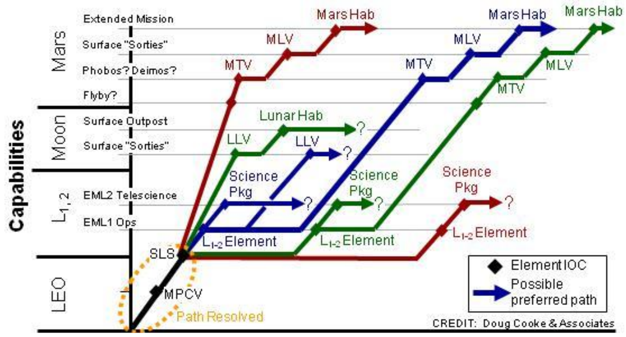

Figure 2 Many options exist for the path to Mars

Figure 3 shows a step-wise plan developed by the European Space Agency which would address this need. This plan was developed as part of the effort to define the Global Exploration Roadmap whose second update has just recently been released[1]. Early crewed missions are augmented with robotic precursor missions to test capabilities and evaluate potential landing sites. These precursor missions are designed to address Strategic Knowledge Gaps (SKGs) which ultimately represent a risk to the human Mars landing objective.

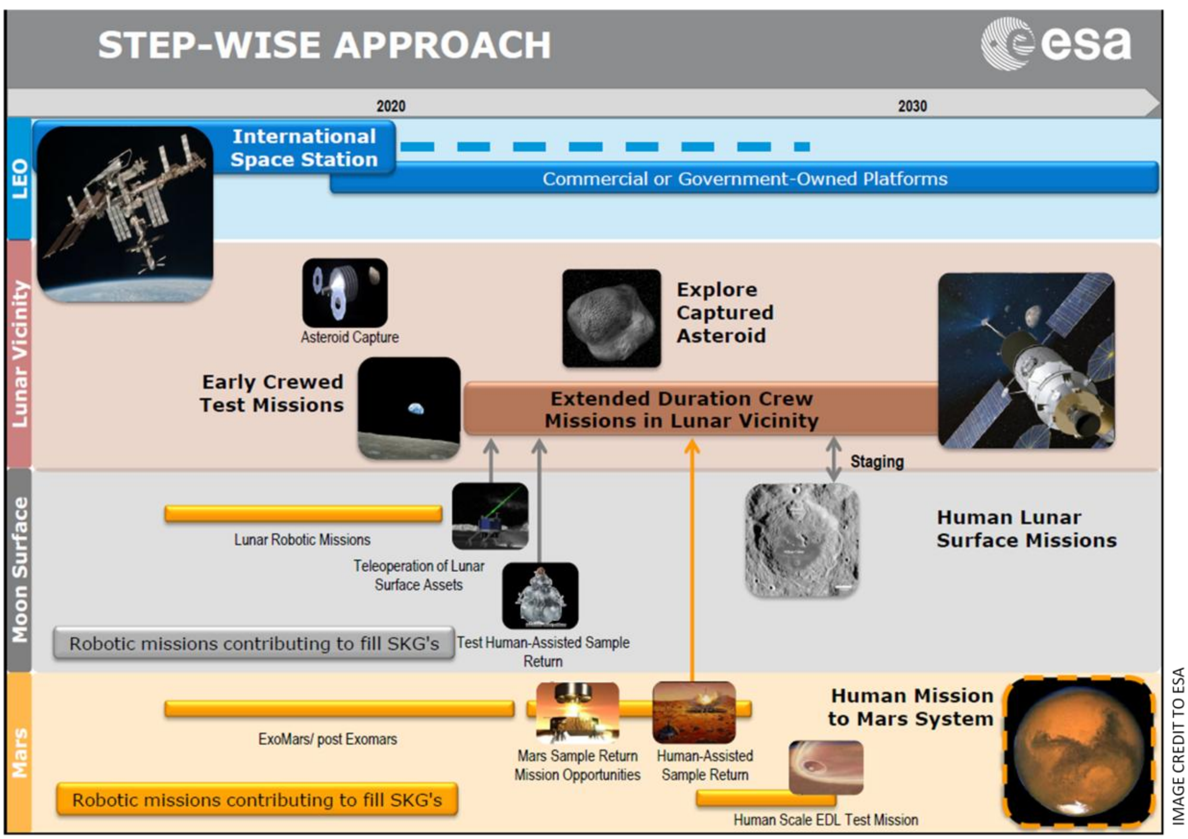

Figure 3 Incremental plan for Mars must focus on mitigating Strategic Knowledge Gaps (SKGs)

Strategic knowledge gaps for human missions to Mars have been studied by various groups, most recently the Mars Exploration Program Analysis Group (MEPAG)[2]. Gaps can be addressed in many ways. For the life support and crew accommodation equipment, the ISS (figure 4) can be used to reduce risk for the Mars mission.

Figure 4 ISS serves as a testbed for critical technology

Subsystem equipment can also be tested on ISS, but ultimately, human experience in the deep space environment is needed. Initial missions with the Orion and SLS will allow short duration exposure for crews to deep space but longer duration missions representative of a trip to Mars will require a habitat. Recent analysis has suggested that a habitat-based gateway in translunar space would be helpful as an assembly node for Mars and for many other missions as well[3].

An asteroid retrieval mission could play a useful role in preparing for a Mars mission. One of the key technologies needed for Mars is a high power solar electric propulsion (SEP) system. Current designs for the asteroid retrieval mission feature a "first generation" SEP system which could form the foundation of the larger SEP systems needed for Mars.

Mars sample return (MSR) is one of the highest priorities of the Science Mission Directorate at NASA. It was also one of the top priorities in the National Academies Decadal Survey which has been used by NASA for planning guidance[4]. As a stepping stone to Mars, the MSR mission could provide valuable information about the Martian atmosphere, weather, geology, and potential landing sites. It could even act as a subscale prototype for the larger human rated entry, descent, and landing system.

A lunar landing could also be on the path to Mars. The Moon could be used as a testbed for the surface systems and lander propulsion systems which will ultimately be needed for Mars. The delta velocity requirement for the Mars ascent vehicle is about 5000 meters/second; very close to what would be needed for a reusable lunar lander[5].

Finally, the moons of Mars itself would provide an excellent stepping stone to the surface[6]. As a "shake-down" cruise before landing, a mission to Deimos or Phobos would test all of the systems except those needed to get to the surface and back. This test would provide confidence for the in-space transportations and crew habitat systems[7].

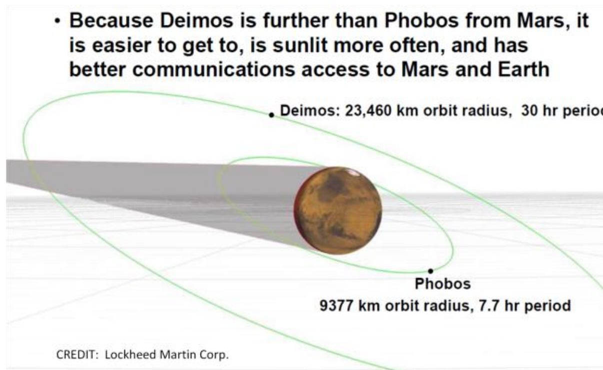

Figure 5 The Mars moon of Deimos would be an ideal precursor mission

The authors believe that an inclusive international process must be used to define the capabilities needed for Mars and also the steps that must be taken to get there. While it's possible that not all of the steps described in the previous section will be required to prepare for Mars, many of them will. An international planning process should be used to coordinate the effort and ensure that resources are being most efficiently employed.

III. AN AFFORDABLE MISSION CONCEPT

The final section of this paper will focus on a conceptual framework for an affordable Mars mission system. The intent of this section is not to advocate for any particular elements, but instead to provide a reference for the types of systems needed to accomplish the Mars mission. As was discussed earlier in this paper, an inclusive and comprehensive international commitment, similar to the agreement made for ISS, would allow this next great chapter in human exploration to be written.

There are six basic elements of a Mars mission system (figure 6). Two of the six elements are currently funded for development and the other four represent improvements or scaled-up versions of systems that are operational today.

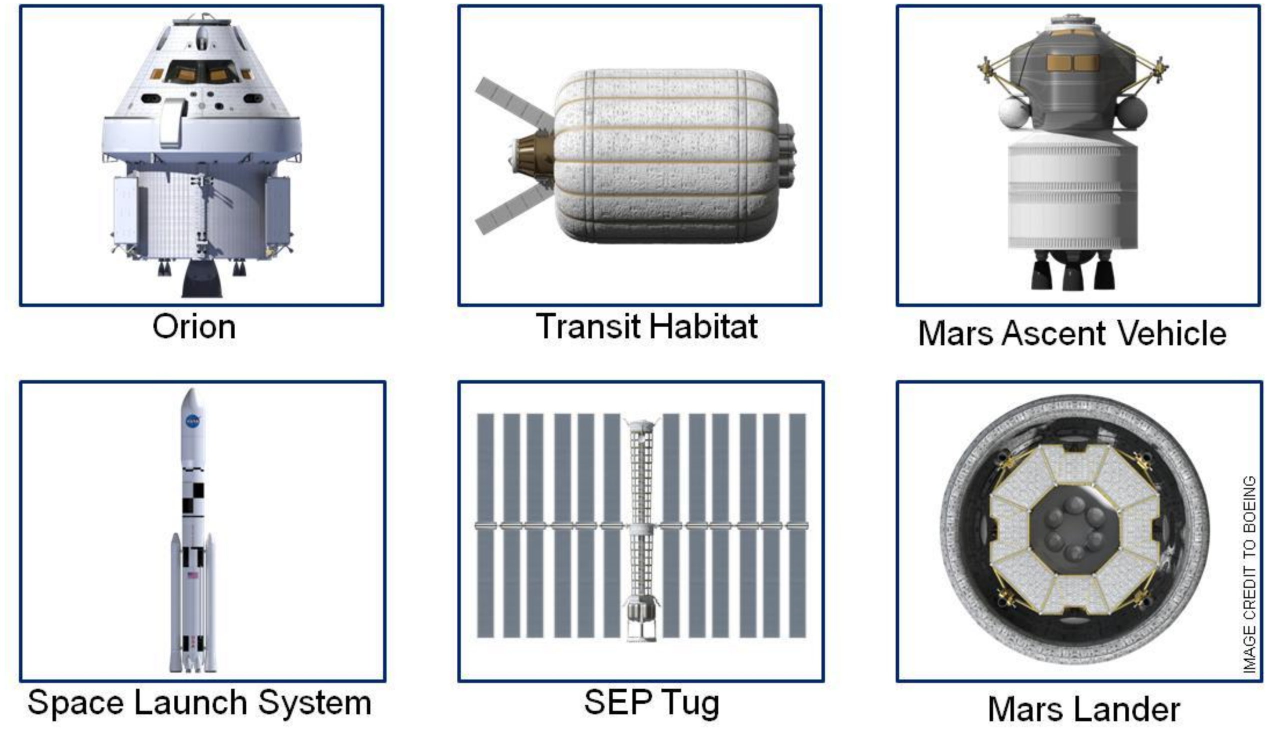

Figure 6 Six basic elements needed to complete the manned mission to Mars

Orion

The Orion program is already well underway with a significant flight test planned for next year. The Orion capsule will protect the crew through one of the most dangerous legs of the journey: the transit through the Earth's atmosphere.

Space Launch System (SLS)

The SLS provides heavy lift capability for both the crew and cargo. As shown in figure 7, the SLS will ultimately deliver Saturn V class lift performance. Even at this size, five or six launches of the SLS will be needed for the complete Mars mission.

Transit Habitat

The trip between Earth and Mars will take about seven months each way. During this period, the crew will need adequate living space and room for their food and supplies. The job of the TransHab is to provide this capability. It will also provide exercise equipment and a radiation storm shelter to keep the crew healthy on their journey. The TransHab mass is about 25 tons when loaded for the trip and each is reusable for multiple missions when restocked.

Solar Electric Propulsion (SEP) Tug

The SEP tug is used to ferry the crew and cargo between the Earth and Mars. The solar arrays provide a whopping 1500 KW of power at one AU. The tug has thirty nested Hall thrusters, each rated at 50KW. The propellant is krypton and the tank capacity is 45 tons. Each end of the tug has an international standard docking interface. Like the TransHab, the tug is completely reusable for multiple Mars missions once refueled.

Mars Ascent Vehicle (MAV)

When the crew has completed their mission on the surface, they use the MAV to launch back into Mars orbit. The MAV is a three stage LOX/Methane vehicle. The first two stages are used in conjunction with the SEP tug as a "kick stage" which reduces the transit time for the crew. For the first mission, the MAV is landed full of fuel so that the crew can abort to orbit if necessary. For subsequent missions, in-situ fuel production can be used as confidence is gained in those systems. The MAV weighs 30 tons fully loaded.

Mars Lander

The Mars lander is perhaps the most challenging element of the six. Like the MAV, it uses LOX/Methane for terminal landing but it also uses a Hypersonic Inflatable Aerodynamic Decelerator (HIAD). The lander is configured so that it can carry two different payloads: the MAV or a surface habitat. The surface habitat is a special version of the TransHab which is configured to deploy from the lander.

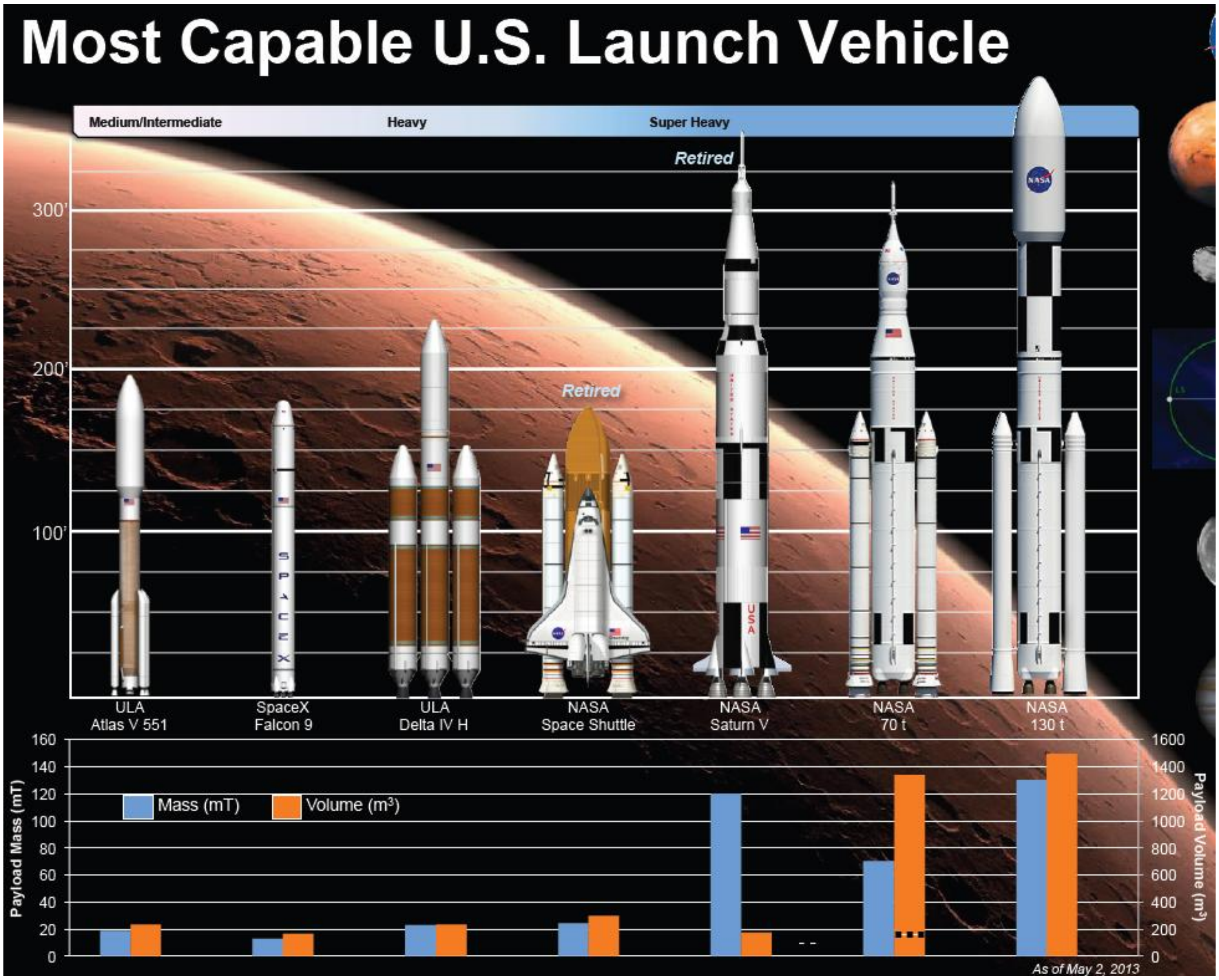

Figure 7 NASA's Space Launch System (SLS) provides the heavy lift needed for Mars

To illustrate how these six elements could be used to accomplish a Mars mission we will briefly describe the sequence of events. The first element launch is shown in figure 8. The SLS is used to launch the first SEP tug and the cargo lander with the surface habitat to low earth orbit. This payload is about 125 tons and it will use the full capability of the SLS.

Figure 8 First Mars elements launched on SLS

The SEP tug is activated and used to deploy the lander out to the translunar assembly site. The assembly site, or Gateway, is used as a location where all of the assets needed for the mission can be accumulated and made ready for the trip to Mars. The second SLS launch deploys the TransHab and the return kick stage directly to the Gateway. All four elements of the cargo mission leave for Mars when the departure window opens. The cargo trip takes ~500 days because only the SEP tug is used to power the trip. The return kick stage will stay in Mars orbit waiting to be used for the crew return. When the cargo mission reaches Mars, the SEP tug is used to spiral down to 5000Km altitude for the cargo lander entry. The lander uses its HIAD (see figure 10) to decelerate the vehicle for landing. The purpose of the cargo lander is to install the surface habitat which will contain all the supplies the crew needs for their year-long stay that will come when the next window opens.

The cargo mission provides a good test for most of the major elements that the crew will need for landing.

Departure windows for Mars open about every 25 months so while the cargo mission is en-route to Mars, the human mission is being prepared.

The human mission starts in much the same way as the cargo mission, with the launch of the SEP tug and the MAV lander. The launch of the second TransHab and kick stage to the Gateway follows. All the elements for the crew mission are assembled at the Gateway and the Expedition crew is the last to launch. Figure 9 shows the crew arriving at the Gateway for their trip to Mars.

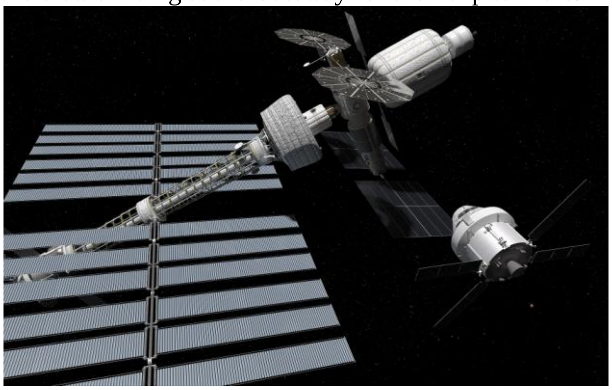

Figure 9 Mars cargo elements staged at the translunar gateway

The translunar Gateway provides a small measure of infrastructure which is used to support assembly, store fuel, and respond to contingencies. The Gateway allows NASA and the partner agencies with some measure of operational flexibility to resolve off-nominal situations and ensure readiness before the final mission commitment at the trans-Mars injection (TMI) burn. Once the TMI maneuver is performed, the crew is committed to at least a two year expedition.

The crew Mars transfer spacecraft is equipped with a kick stage to help boost the transfer performance. For comparison, while the cargo transfer to Mars takes ~515 days for the trip to Mars, the crew transfer is ~256 days or roughly half. This is due in part to the fact that the crew transfer spacecraft is about 25 tons lighter than the cargo spacecraft but it is also due to the use of the kickstage. SEP technology, when used in conjunction storable chemical kickstages can produce transit times that are competitive with nuclear propulsion options. When departing from translunar space, an Earth fly-by departure trajectory can be used to help accelerate the spacecraft if a kickstage is available.

With the exception of the shorter transit time, the crew transfer to Mars looks very similar to the cargo transfer that preceded it. Once at Mars, the SEP stage will spiral down to 5000Km altitude to release the crew lander. This relatively low altitude helps to reduce the entry velocity that the lander must accommodate. Figure 10 shows an artist's representation of the crew lander entry during the HIAD deployment. Supersonic retro-propulsion is used along with the HIAD to slow the spacecraft down for terminal landing. The landed mass for both the crew and cargo lander is ~40 tons.

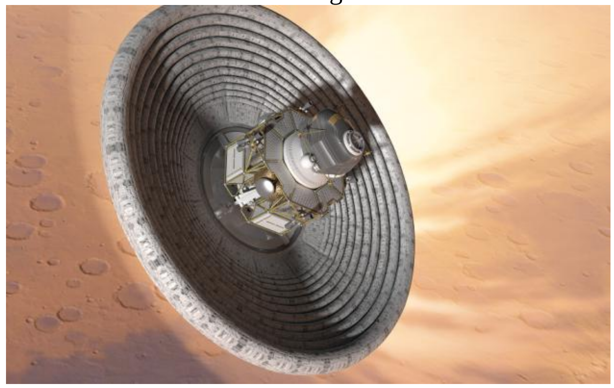

Figure 10 Lander during Mars atmospheric entry

The crew must land fairly close to the habitat if they are going to stay on the surface for their full duration mission. Since the crew will have rovers, this means within 10-20 kilometers. The Mars Curiosity mission was able to land within 3 Km of its target so it seems reasonable that the crew will be able to do this. If, for some reason, they land too far away from the habitat, they will only be able to stay for about a week and will need to abort to orbit where they would wait for the return window to open.

Assuming all goes well with the landing, the crew would secure the MAV and transfer over to the habitat for their 450 day surface stay. Once their surface mission is complete, they use the MAV to launch back to Mars orbit. Figure 11 shows the crew rendezvous with the SEP tug which has been configured for the trip home.

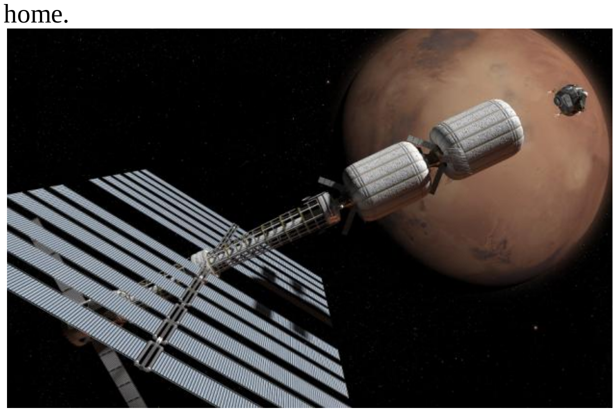

Figure 11 Crew rendezvous on the trip home to Earth

The MAV is a three stage vehicle with the crew cabin acting as the third stage. The concept MAV that we have been evaluating is sized to launch the crew to a 17,000 Km altitude circular orbit. This orbit was selected as the parking orbit for the SEP tugs because it is stationary relative to the landing site which will allow the SEP tugs to act as a communications relay and perhaps even a power source for the surface assets.

Once the return window opens, the trip back to Earth for the crew lasts 205 days. The SEP tugs and TransHabs are parked at the Gateway where they can be refueled and prepared for the next trip and the crew returns to Earth in Orion.

IV. CONCLUSION

The release of the Global Exploration Roadmap (GER) has made clear that our unified long term goal is for a human mission to Mars[1]. A "Humans to Mars (H2M)" conference was held to discuss the requirements and technology developments necessary to make this goal a reality. The authors on this paper all participated in a panel which described potential mission architectures and technology gaps which must be addressed. We have summarized the findings from the panel and described a conceptual architecture which could be used to achieve the objective at a reasonable cost and in a reasonable timeframe.

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