SIMPLE ROADMAP FOR MANNED MARS MISSION

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ABSTRACT

Recent scenarios for human missions to Mars suggest that there are much simpler alternatives to the well-known NASA reference mission. The simplifications are so important that it might be possible to avoid the long and costly preliminary missions to the Moon or to the asteroids that do not help much in the understanding of the difficulties for entry descent and landing on Mars or in the process of in situ resource utilization. If it is desired to determine a realistic roadmap for the first Mars landing, it is important to consider the development costs for new technologies, a number of strategic intermediate missions and a reasonable time frame. The proposed roadmap is based on most simple scenarios and usual recommendations for human rated certifications of space systems. There are two important intermediate missions with two main objectives. The first objective is to qualify the habitable module of the Mars mission for a three years journey in full autonomy and 0-gravity countermeasures. The test can be performed in high Earth orbit with the rotation of several crews. The second objective is to qualify the technologies for aerocapture and then entry, descent and landing on Mars. The test can be performed with a vehicle of the same shape and mass as the one that will be used for the manned Mars mission. Such a vehicle might advantageously be used in the context of a Mars sample return mission. The technologies for the exploitation of Martian resources might be tested at the same time. The roadmap is therefore simple and sustainable.

1. INTRODUCTION

This work is a contribution to a study of the International Academy of Astronautics in which the author is involved. The feasibility of a human mission to Mars has been addressed since the start of the space conquest [5, 11, 12, 13, 14]. Several times, there has been an attempt to determine a possible scenario and a clear roadmap [3, 5]. In front of the difficulties, however, it was established in several reports that there was a very long way before space agencies such as NASA could undertake such a complex mission [1, 4, 7]. In the Augustine report, for instance, while a human mission to Mars is clearly identified as the ultimate goal, it is suggested that other missions should be considered before such as going to asteroids or to the Moon even though these undertakings are of lower significance [1]. Nevertheless, in recent papers, it is claimed that such a mission could be undertaken with sustainable R&D efforts and at reasonable costs without making detours to other celestial bodies [12, 13]. The idea is to optimize the organization of the mission and to reduce the initial mass that has to be sent to LEO by reducing the crew size and the vehicles size to the strict minimum.

2. POSSIBLE SCENARIOS

New scenarios have been recently proposed and others are currently examined by a working group of an IAA (International Academy of Astronautics) study. They are based on a reduction of the crew size to 3 or 4 astronauts, aerocapture for all vehicles and the use of small vehicles for the transit between the Earth and Mars and for the EDL phase (entry, descent and landing) [12, 13]. Some examples are presented below:

- Scenario 1:

  Three vehicles are sent to Mars. The first one includes an ISPP (in situ propellant production) unit with a power plant and backup consumables. The second includes a dual use habitable module that is used for the two interplanetary transits and on the surface of Mars. There are three astronauts inside. The third vehicle is sent to Mars orbit. It includes a wet propulsion system for the return back to Earth. It also includes a small capsule with consumables and spare parts in order to reduce the mass of the ascent vehicle, which is the vehicle with the dual use habitable module.
- Scenario 2:

  This scenario is a light version of Mars semi-direct with only 3 astronauts [14]. Four vehicles are sent to Mars. The first one is a cargo with an ISPP unit and a small ascent vehicle and backup consumables. The second includes a habitable module that is used for the outbound to Mars and on the surface. The third and the fourth vehicle are sent to Mars orbit and should be assembled to form the ERV (Earth return vehicle). The third includes a wet propulsion system for the trans-Earth injection maneuver. The fourth includes the habitable module for the inbound leg of the mission. At the end of the stay on Mars, the ERV is joined in Mars orbit by the ascent vehicle.
- Scenario 3:

  The 2-4-2 scenario has been recently published [13]. It is based on a reduction of the crew to only two astronauts per vehicle and on the entire duplication of the mission as it was proposed by Von Braun [11]. There are therefore two astronauts in each vehicle, they can form a team of four on the surface and they are two once again for the return. This scenario can be considered a duplication of scenario 1 with a total of 6 vehicles and a smaller crew size per vehicle.

The details of all scenarios have not been published yet. Some uncertainties remain on the exact payload, the risks and the levels of backups, especially for scenario 1 and 2. However, according to our first investigations, though the correctness of the architectures is not demonstrated, one way or the other there is little doubt that it is possible to design an architecture based on the same principles. It is suggested here that the following hypotheses can be made for the first human mission to Mars:

- Chemical propulsion is used for all space vehicles.
- The vehicles are small enough to avoid LEO assembly.
- An aerocapture maneuver has to be undertaken for Mars orbit insertion.
- The entry, descent and landing phase is performed by small vehicles (<32 metric tons payload, EDL and propulsion systems included) with a standard biconic shape and a rigid aeroshell.
- An ISPP unit is used to produce propellant for the ascent vehicle.

3. REQUIREMENTS

In human space flight, for safety reasons, the qualification of systems is very strict. In order to achieve the human rated certification, a long list of procedures and tests have to be followed from the design and construction until the integration into the space vehicle [8, 10]. Importantly, at the end of the process, it is required that the systems must be "flight proven" for the exact same configuration and duration as the human mission. These requirements have the following implications:

a. The propulsion systems must be tested with the same payload, the same vehicle configuration and the same environment as the ones expected for the human mission.

b. The habitable modules must be tested with the same life support equipment, the same number of astronauts and the same lifetime requirements without any support from other vehicles.
c. Aerocapture and EDL maneuvers must be tested before with the same shape and size of the vehicle and the same equipment and procedures.
d. ISPP must be tested (deployment and use) in the same environment with the same duration as the one expected for the human mission.
e. The ascent from Mars must be tested before with the same vehicle configuration.
f. Rendezvous in Mars orbit must be tested before with the same constraints.
g. The final Earth atmospheric reentry must be tested with the same heat shield, the same type of vehicle and the same physical constraints (same velocity, same angle of attack, same heat load, etc.).
h. Concerning human factors, tests must be carried out in Martian gravity or in an analog environment to determine physiological impacts and the performance of human systems interactions (for instance living and working with Martian space suits).

These requirements have to be considered for the definition of the roadmap leading to the first human mission to Mars. However, it would be very expensive and unproductive to perform all these tests without any connection to a scientific program. This is especially true for the tests of EDL and ascent maneuvers, which require the landing of a vehicle on Mars [15]. An interesting question is therefore to determine the most promising scientific mission(s) that could address a scientific problem and at the same time provide the appropriate environment to test and qualify important technologies for the first human mission to Mars.

4. MARS SAMPLE RETURN

Requirements a, c, d, e and perhaps also f can be met in one single mission. This mission is MSR (Mars Sample Return). MSR has already been proposed by several space agencies and some work is still carried out on the subject [2, 6, 9]. There are very good scientific reasons to undertake MSR. It would allow us to perform accurate tests in Earth laboratories to determine water concentration, identify salts, potentially toxic particles, carbonates, complex molecules, etc. [9]. Up to now, different mission architectures have been proposed for this mission but they are all based on the use of current launchers and small landers. We believe that this is not a good strategy. MSR might typically become the most important mission in the roadmap of the first human mission to Mars. It would be very valuable to work first on the exact mission architecture of the manned mission and to determine the size, mass and shape of the main landing vehicle. If our assumptions are correct (see section 2 and [13]), such a vehicle could be launched with a single heavy launcher and be sent directly to Mars. As a consequence, if a similar vehicle is used for MSR, it does not add much complexity to the mission. It might even simplify it because the payload would be much higher, in the order of 15 tons [13].

If the same vehicle configuration is used for both types of mission, propulsion systems can be tested and qualified (requirement a). More importantly, EDL, which is often cited as one of the riskiest phase of the mission, can also be tested in the same configuration [13, 15]. ISPP tests can also be performed on Mars. However, it might not be necessary to perform scale one tests with the same duration (hundreds of days) on the red planet. It is indeed possible to partially reproduce the Martian environment and to perform some tests on Earth. The gravity is different and the soil and the dust might have specific properties that might limit the reproduction of the environment. However, only some elements of the equipment might be sensitive to these differences. For instance water electrolysis would work with the same efficiency on Earth and on Mars, provided that the chemical elements are the same. It is also not necessary to test the performance of a large field of photovoltaic cells since the performance of a small number of them would be sufficient to determine the efficiency of any bigger set. The problem is to determine what elements might be sensitive to environmental conditions and to perform intensive tests on Earth with different possible Martian conditions and also on Mars to make sure that an appropriate efficiency is achieved. The idea is to benefit from the Martian environment to undertake whatever experiment is needed to test and qualify ISPP technologies. During the MSR mission, one or several robots will be deployed on the surface in order to collect samples. Then, the samples will have to be sent back to Earth. An ascent vehicle will be used. Ideally, this vehicle would have the same payload and propulsion system as the ascent vehicle of the human mission and it will perform a rendezvous with an Earth return vehicle waiting in Mars orbit. However, it is not possible to follow the same strategy for MSR because it would require at least one other vehicle with a heavy useless payload and the entire mission would be much more complicated. Since a vehicle has to land on Mars with a rather small payload but an important capacity, it is possible to include an ascent vehicle that would be fueled with the help of the ISPP unit for a direct return to Earth. To summarize, the MSR mission would have approximately the following characteristics:

- Payload on Mars: 15 tons
    - power plant (nuclear or solar based, to be discussed): 2 tons
    - ISPP atmospheric unit (exploitation of CO_2): 1 ton
    - ISPP ground unit, including robotic excavators and soil processing plant (exploitation of ground water resources according to NASA method [5, p. 107]): 2 tons
    - robotic collectors(s): 2 tons
    - structure, packaging and deployment devices: 2 tons
    - Earth return vehicle (partially wet): 4 tons
    - Margins: 2 tons
- Aerocapture and EDL systems: 15 tons
- Total payload for TMI (trans-Mars injection maneuver): 30 tons.

30 tons is within the launching capabilities of a heavy launcher like the Space Launch System actually developed by NASA. More importantly, this is approximately the expected mass of the vehicles that will be sent to Mars in the context of a human mission. This mission could help a lot for the qualification of the propulsion systems (requirement a), for aerocapture and EDL systems and procedures (requirement c), for the tests of ISPP (requirement d) and for the launch from Mars (requirement e) though in this case the configuration of the vehicle would probably be very different (small payload for a direct return in the first case and an important payload with a Mars orbit rendezvous in the second). Last but not least, it is also possible to test the Mars orbit rendezvous during the Mars sample return mission. The solution is simply to leave a microsatellite in Mars orbit before landing and to proceed to a symbolic rendezvous with it before the TEI maneuver at the end of the mission.

5. HIGH EARTH ORBIT MISSION

Life support systems on board the ISS have been tested and qualified for long stays in space. However, the systems are not optimized for the minimization of the mass for a 2.5-years mission to Mars and the autonomy is rather limited [16]. At least once a year, there is a mission to resupply the station with consumables and life support elements. In addition, the habitable modules are not organized for a long mission in deep space with a specific architecture, specific devices for microgravity counter measures (a small centrifuge or a rotation of two modules to simulate gravity), water walls for radiation protections, etc. All in all, the ISS cannot provide an appropriate environment for the qualification of the habitable module that will be used for a human mission to Mars. In order to prepare the mission, it is necessary to design, build and test the habitable module in space with the same lifetime requirements [8]. In Earth orbit, the advantage is to be able to abort the mission at any time in case of an emergency. A possible option is to perform a test in LEO. However, since we also need to test the reentry systems (requirement g), a more interesting option is to perform the tests in HEO (High Earth Orbit). Two habitable modules can be sent there by means of two heavy launchers of the same class as the one that is going to be used for a Mars mission. The modules would stay at least 2.5 years in orbit with the exact same configuration as the one expected for the 2.5 years mission to the red planet plus the necessary service module for a return to Earth. An important role of this mission could be to test microgravity counter measures and at the same time to simulate the Martian gravity (requirement h) by means of a rotation of the two modules the one around the other (see Figure 1).

Figure 1: The two habitats are linked with a cable and rotate the one around the other to simulate the Martian gravity.

For safety reasons, as for the ISS, in case of an emergency, it should be possible to use the service module and to come back to Earth in less than a day. In addition, the transhipment of a crew into the second habitable module also provides a backup solution.

A crew of the same size as the one expected for the Mars mission must live in the habitable module. However, for a total duration of 3-years in HEO, a rotation of several crews is preferable. The multiplicity of the crews enables a multiple testing of two important maneuvers:

- The rendezvous with another vehicle, which could ideally resemble the Mars ascent vehicle.
- The high velocity atmospheric reentry of capsules. Earth reentry technologies already have a good TRL. However, no capsule has ever entered the Earth atmosphere with the expected velocity for a return from a Mars journey. These tests might advantageously be used to optimize the mass of the heat shield and improve the control of the descent. Entry from HEO is easier than entry from deep space. However, the difference is not very important and if necessary, the capsule can be accelerated to obtain the same physical constraints.

In addition, HEO would be a good place for radiation measurements with different shielding materials in preparation for the manned mission. Because of the Van Allen belts, such measurements are not possible in LEO. The rotation of the crews would limit the exposition to radiations.

To conclude, a 2.5-years (or even more) HEO manned mission with a duplication of the habitable module of the Mars mission could advantageously be implemented in the roadmap of the first human mission to Mars. It would help a lot in the qualifications of the systems and procedures, especially for points a, b, g and h.

6. CONCLUSION

Two important space missions have been proposed for the preparation of the first human mission to Mars. The first is a revisited scenario of Mars sample return and the second in a 3-years HEO manned mission. These two missions are complementary and provide the appropriate conditions for the tests and qualifications of the top 7 most complicated procedures and systems that will be used in a human mission to Mars. Before these missions can be undertaken, it is necessary to define the Mars mission with great details, so that the vehicles can be duplicated and integrated in the specifications of the two missions. Beside these missions, a lot of work is also needed on Earth to design and test the propulsion systems, the vehicles, the space suits, to select and train the astronauts, etc. However, only two important space missions might be sufficient for the qualification of the main systems. It is not necessary to implement a mission to the asteroids or to the Moon. Obviously, it is also possible to wait for the development and qualification of nuclear based propulsion systems, bio-regenerative life support systems, giant inflatable heat shields and perhaps formidable robots that could build an entire Martian base using in situ resources to prepare the arrival of a colony. However, though such objectives could clearly be included somewhere in the global roadmap of the conquest of space, the sustainability of the space program also has to be considered. The cost is probably the main reason why a human mission to Mars has not been implemented yet. The proposed roadmap is clearly an attempt to simplify and reduce the costs of the first human mission to Mars without compromising with robustness and safety.

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