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Roadmap to a human Mars mission

Jean-Marc Salotti [a,b,*], Richard Heidmann [b]

[a] IMS laboratory, CNRS, IPB, Université de Bordeaux, France
[b] Association Planète Mars, France

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ABSTRACT

We propose a new roadmap for the preparation of the first human mission to Mars. This proposal is based on the work of ISECG and several recent recommendations on human Mars mission architectures. A table is proposed to compare the possible benefits of different preparatory missions. Particular attention is paid to the possibility of qualifying important systems thanks to a heavy Mars sample return mission. It is shown that this mission is mandatory for the qualification of Mars aerocapture at scale-1, EDL systems at scale 1 and Mars ascent. Moreover, it is a good opportunity to test many other systems, such as the heavy launcher and the transportation systems for the trips beyond LEO. These tests were not mentioned in the last ISECG report. This strategy is facilitated in the case of the simplified Mars mission scenarios that have recently been presented because it is suggested that relatively small vehicles with small crew sizes are used in order to optimize the payload mass fraction of the landing vehicles and to avoid the LEO assembly. An important finding of the study is that a human mission to the surface of the Moon is not required for the qualification of the systems of a human mission to Mars. Since affordability is a key criterion, two important missions are proposed in the roadmap. The first is a heavy Mars sample return mission and the second is a manned mission to a high Earth orbit or eventually to the vicinity of the Moon. It is shown that both missions are complementary and sufficient to qualify all the critical systems of the Mars mission.

1. Introduction

Numerous scenarios have been proposed for human missions to Mars but there is currently no consensus on the best one [4,6,8,16,17,18,20,26]. The most detailed scenario is the NASA reference mission, but it is also known for its complexity [6]. According to the NASA study, there is a long list of technologies that have to be developed and matured before the first mission can be undertaken. An important problem is to determine an appropriate roadmap to prepare the Mars mission [1]. An international group, ISECG, is working on the future of space exploration [5,9,10]. Based on the strategies of the main space agencies, the ultimate goal is to send humans to Mars. With this long term objective, ISECG proposed a possible roadmap with a list of technologies and capabilities that could be developed for the implementation of several missions to intermediate destinations such as the Moon, deep space and near-Earth asteroids [10]. However, this roadmap is not clearly justified for several reasons:

- First of all, there is still no consensus on the final scenario of the manned Mars mission. If the scenario is not clearly defined, the list of technologies that have to be developed may be underestimated and there is also the risk that several technological developments

* Corresponding author.
E-mail addresses: jean-marc.salotti@ensc.fr (J.-M. Salotti), heidmann.r@orange.fr (R. Heidmann).

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proposed in the roadmap would be useless for the final Mars mission.
- Second, there is a technological gap between the main intermediate missions (Moon and asteroids) and the Mars mission. This gap is represented by a dashed line in the graph of the ISECG roadmap with no clear indication of the number of precursor missions and their difficulty. For instance, the tests of the EDL (Entry, Descent and Landing) systems for heavy vehicles might require several complex Mars missions. How many of them and at what costs? Is this an opportunity to send robots and return samples? To test nuclear thermal rockets? To test ISRU (in situ Resource Utilization)? In addition, since these missions are absolutely necessary, is it possible to undertake complementary tests such that the missions to the Moon and to the asteroids are no longer required?

It is worth noting that other roadmaps proposed in the literature have the same drawbacks [7,25]. A mission to Mars is set as the final goal but the justifications of the intermediate missions are not clear. For instance, it is assumed that the qualification of a lunar ascent vehicle would be very useful for the qualification of a Mars ascent vehicle [10,25]. This assumption is not obvious. The vehicles will not have the same payload, the gravitational field is very different, and the power of the engines will be different, as will the amount of propellant or thermal and atmospheric constraints. All in all, the tests of an ascent vehicle launched from the surface of the Earth might provide more valuable data than the tests from the surface of the Moon.

Another interesting preparatory mission is a Mars flyby as is proposed for instance by Dennis Tito [26]. It is an important step before a mission to the surface but if the roadmap had to be optimized in terms of costs, time, or risks, it is not clear whether this would be preferable to a mission to a near Earth object (NEO), a mission to a lunar orbit or to a Lagrangian point. Psychologically and politically, for the public and decision makers, it might well be more appropriate to undertake a Mars flyby but this does not provide clear technological advantages over other destinations and it has not been highlighted in the ISECG roadmap.

Fundamentally, as the human mission to the red planet is not well defined, the ISECG approach is technology and capability driven while a goal driven approach could be more efficient as was the case for the Apollo program. This new approach is presented in this paper. In Section 2, the most important elements of a class of human mission to Mars scenarios are presented. These scenarios are simpler, less expensive and probably more reliable than the NASA reference mission. These elements are used to draw up and discuss the list of new technologies and systems that would have to be developed. Based on this list, two important intermediate missions are proposed in order to qualify most systems:

- A heavy Mars sample return mission.
- A manned high Earth orbit mission.

These two missions are described and discussed in Sections 3 and 4.

2. Critical elements and possible missions

2.1. Analysis of the NASA reference mission

The NASA reference mission is well known for its complexity [6]. In the NASA report itself, it is clearly stated that there is a methodological problem because of the numerous risks that have to be considered and reduced to acceptable levels. The main risks are linked to the entry, descent and landing phase (EDL), the long and complex assembly of giant spaceships in low Earth orbit and the use of nuclear thermal engines for which the technology readiness level (TRL) is low. This methodological problem has been highlighted in several studies showing that there are other options allowing important reductions of the risks [19,20,21,22]. The main idea is to downscale the entire mission by means of several simplifications [21]:

- The crew can be reduced to 3 or 4 astronauts.
- Provided that the mass and volume of the interplanetary vehicles are reduced, an aerocapture maneuver can be carried out for the Mars orbit insertion.
- Provided that the payload mass is lower than a threshold, the landing vehicles can have a standard capsule shape with rigid heat shields or small IADs [3,18,21]. Importantly, it has been shown in a recent study that if a crew of six is chosen, the best option in terms of mass and complexity is to split the crew into two crews of three and to land with small vehicles rather than bigger ones [21]. The hypothesis of the capsule shape is therefore valid for a large class of Mars mission scenarios.
- The interplanetary vehicles can be sent to Mars after simple (or eventually no) assembly in low Earth orbit and the use of chemical propulsion systems [19,21].

These strategic choices allow the use of the technologies and systems with the highest TRL, thus reducing the complexity of the possible scenarios, the risks and the development costs at the same time.

2.2. Critical elements of the human Mars mission

The scope of this paper is not to determine the details of the human Mars mission but to lay out the most important elements that can be shared by a class of scenarios respecting the recommendations presented in the previous section (see also [19]).

According to the ISECG study, the critical elements are [10]:

1. Beyond low-Earth orbit crew transportation
2. Heavy lift launch
3. Autonomous crew operations
4. Deep space staging operations
5. Mars ascent
6. Space radiation protection/shielding
7. Life support and habitation systems
8. Entry, descent and landing systems