



# Direct or Not Direct, That is the Criterion

Jean-Marc Salotti

## ► To cite this version:

Jean-Marc Salotti. Direct or Not Direct, That is the Criterion. 73rd International Astronautical Congress (IAC), Sep 2022, Paris, France. hal-03787369

**HAL Id: hal-03787369**

**<https://hal.science/hal-03787369>**

Submitted on 24 Sep 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

IAC-22-A5.IP.5x68223

## Direct or Not Direct, That is the Criterion

Jean-Marc Salotti<sup>a,b,c</sup>

<sup>a</sup> *Bordeaux University, CNRS, Bordeaux INP, IMS, UMR 5218, F-33400, Talence, France, jean-marc.salotti@ensc.fr*

<sup>b</sup> *INRIA, IMS, UMR 5218, F-33400, Talence, France*

<sup>c</sup> *Association Planète Mars, France*

### Abstract

The criteria often put forward for the classification of manned missions to Mars architectures are the planetary configuration known as conjunction or opposition at the time of departure, the duration of the stay on the surface or the type of propulsion for the interplanetary maneuvers, which can be chemical, nuclear thermal, nuclear electric, solar electric or a combination of them. However, another criterion also deserves special attention: the ability of the manned interplanetary spacecraft to also be a lander. This criterion, which has been highlighted by Zubrin in the Mars Direct concept (direct to indicate precisely that the main spacecraft is sent directly from Earth to the Martian surface), seems to have been totally forgotten in the numerous NASA studies, as well as in the ESA study of 2004. An analysis has been carried out to determine the reasons of this omission: Weakness of the state of the art, lack of willingness to explore all-chemical options, as well as the habit of robotic missions, which introduces a methodological bias due to the separation of the payload and space systems teams. Many authors of mission architectures, e.g. Zubrin, Musk, Salotti, have however chosen the direct landing option, at least for the outward leg of the journey, because it has decisive advantages over other options. The advantages are in particular the simplicity of the concept (no complex assembly in low Earth orbit), the ability to implement aerocapture (as the spacecraft is a lander, a heat shield is already included and it is designed to enter the atmosphere), and a significant reduction of the total mass to be sent to low earth orbit (thanks to aerocapture and optimization capabilities). The choice of the direct access to the surface is thus structuring for the whole mission and should be considered at the highest level of the decision tree.

**Keywords:** (maximum 6 keywords)

### Acronyms/Abbreviations

NASA: National Aeronautics and Space Administration  
DRA: Design Reference Architecture (from NASA)  
IMLEO: Initial Mass in Low Earth Orbit

### 1. Introduction

The design of an efficient and appropriate architecture for a human mission to Mars has always been a difficult task [4,5,6,7]. The number of proposals is very high and there is no consensus on the best one. In 1990, Zubrin claimed that the Mars Direct concept with chemical engines was very efficient [15]. In 1998, NASA suggested that nuclear thermal propulsion would provide a clear advantage [3,4], then the same organization and other authors were more in favour of electric propulsion [5,6,7] and while they are still promoting that strategy, Musk or Salotti are claiming that the use of chemical engines is more appropriate [8,9,11]. From the information theory standpoint, there are indeed many parameters and if the problem is set as the search for a minimum in a huge state space, it seems that there are plenty of local minima with strong fluctuations depending on the way the different criteria are considered. It is proposed here to focus on one particular criterion, which is the choice for a direct or indirect trip

to the red planet. A direct trip is defined by the dual use of the spaceship transporting the crew, for the transit between the two planets and also for the stay on the surface. An indirect trip is defined by the use of two different spaceships. The first is used to transport the crew between the two planets. Then, the crew is transferred onto the board of a second spaceship, which is used for landing and supports the crew on the surface. This criterion is rarely cited, but it clearly splits mission to Mars architectures into two distinct families. Section 2, it is proposed to try to understand why the direct option has not been considered by NASA in its different studies and design reference architectures (DRA). Section 3, the benefits of the direct option are analysed with more details. Finally, suggestions are proposed in the conclusion to deepen the analysis.

### 2. NASA disregard the Direct to surface option

#### 2.1 Design Reference Architectures methodology

NASA teams have a great expertise in all fields of astronautics [4,5,6]. For the design of a mission to Mars, numerous NASA experts are generally solicited, each one to provide a technical analysis on a particular problem and the criteria for decision making. An important issue is to address multidisciplinary problems in an efficient way. In the design of a mission to Mars,

there are indeed many complex questions that require a trade-off taking different viewpoints into consideration. For example, the number of crew should be addressed by experts in human factors, experts in life support, as well as experts in almost all spaceship elements that are strongly impacted by this choice, such as designers of the Mars ascent vehicle, designers of the entry, descent and landing systems and even designers of the overall mission architecture [10]. The choice of the propulsion system for the interplanetary trip also requires a multidisciplinary analysis. For example, if electric propulsion powered by huge solar panels is chosen, there is an impact on the duration of the trip and therefore on consumables for life support. In addition, there is an impact on the Earth orbit departure and on the choice of aerocapture/no aerocapture to reach the Mars orbit. The overall architecture is therefore strongly impacted. In order to address these multidisciplinary problems, NASA tried to elaborate a decision tree with the most important parameters and to determine the impact of each structural choice. The method seems appropriate. However, there are several important critical issues:

- How to determine the list of the most important parameters?
- How to split the problem into subproblems without making implicit and unjustified early choices?
- How to assess each choice and make comparisons without methodological biases?

These issues are discussed in the next sections.

## 2.2 Propulsion systems bias

It is very difficult to list the most important parameters before a detailed analysis. NASA identified several of them but without clear justification, based on the expertise of astronautical engineers and the objective of IMLEO reduction [5]:

- Conjunction / Opposition class of mission (position of planets at departure)
- Predeploy vs all up
- Aerocapture / propulsive Mars orbit insertion
- In situ resource utilization or not
- Type of propulsion system for interplanetary transportation

The last parameter is probably the most complex. The best NASA engineers have been solicited from the beginning in order to improve the efficiency of propulsion systems, reduce the overall mass that has to be sent to space and simplify the architecture of human missions to Mars. As the specific impulse of the propulsion system is a key parameter, several strategical choices have been proposed. The first is the use of nuclear thermal rockets (NTR) [3,4]. Obviously, as it would be complex and risky to land a huge nuclear reactor on the surface, the direct to surface option has not been proposed in this scenario. The second is the use of

huge solar panels to supply electricity to ion thrusters [5,6,13]. Electric propulsion allows important gains for the specific impulse but at the expense of lift capacities. As an important lift is required for landing, there is a good reason to avoid the direct to surface option for this scenario. In addition, huge solar panels would be destroyed during the descent. Similar reasons exist if a nuclear reactor is used for electric propulsion. As a result, the direct to surface option is not investigated for the scenarios based on other systems than chemical engines for interplanetary transportation and it is justified. A methodological bias comes into place, however, if comparisons are made with a scenario based on chemical propulsion and if the direct to surface option is not examined for that scenario. This is what happened.

## 2.3 Bias from robotic missions' experience

Numerous NASA robots have been sent to the red planet. Obviously, an important experience has been gained in the design and implementation of such missions and they certainly provided a methodological and organizational framework for the design of human missions. However, it could also be the source of a cognitive bias. It is indeed well-known that the design of a robotic mission is split into two parts held by two different teams (or two groups of teams). The first team is in charge of the scientific payload (the robot and its instruments) and the second is in charge of the transportation of the payload to the red planet. Both teams cooperate at the beginning to determine the maximum mass and volume but once they agreed upon these constraints, they generally work separately and do not interfere in the critical choices that the other team has to make. As a consequence, the same organization is expected for a human mission and the team in charge of interplanetary transportation does not expect a close collaboration with the team in charge of the payload (life support systems, number of crew, etc.). The problem is that there are very important choices that concern both teams for several reasons:

- For a given space vehicle, the mass of consumables increases with the number of days spent by the crew onboard that vehicle. The impact is very different if the same vehicle is used for the outbound and inbound leg of the journey, if different vehicles are used or if the interplanetary vehicle is used for landing.
- There is a possible impact on the size and capacity of the launcher, as well on the requirement for a complex LEO assembly, and therefore on the total cost and organization of the mission [12].

A close collaboration is therefore required between the two teams but they are not used to it. As a result, if the direct to Mars option is not considered in the first step of the analysis, it is not expected to be considered later. And this is what happened in NASA studies.

#### 2.4 Bias from poor literature review

Zubrin proposed the Mars Direct concept in 1990 [15]. NASA experts had the opportunity to discuss with him. One of the most important issue was the launch of the heavy return vehicle from the Martian surface. In order to overcome the difficulty, Zubrin proposed later the semi-direct concept, in which the return is split into two steps, coming back to Mars orbit with a Mars ascent vehicle and junction with another vehicle dedicated to the return to Earth [16]. The outbound leg, however, remained unchanged, direct to the surface. Surprisingly, the direct and the semi-direct options were not considered in the technical studies describing the NASA Design Reference Missions in 1998, 2009 and 2014 [4,5,6]. It is a pity that these studies were full of technical details in all domains, but very poor in citations and analysis of several previous works. It is therefore not surprising that the direct to surface option was discarded by NASA.

## 2. Benefits of the direct to surface option

### 2.1 Simplicity

In order to minimize the costs of the mission, Zubrin, Musk or Salotti tried to find the simplest architectures [8,9,11,15,16]. When Zubrin called his concept “Direct”, he wanted to highlight the simplicity of his proposal, arguing that there was no need to organize a rendezvous in Mars orbit for a transfer of the crew onto another vehicle for landing. In addition, he suggested that the crewed interplanetary vehicle could be the payload of a single heavy launcher, and there was therefore no need for a complex LEO assembly. In NASA reference missions, a LEO assembly is required for a heavy manned vehicle because it is used for the outbound and inbound legs of the mission, while in Mars Direct or Mars Semi-direct, as two different vehicles are used, the mass of consumables is shared between them as well as the mass of propellant. As Zubrin’s proposal was based on the existence of a hypothetical heavy launcher and the mass budget was approximate, the feasibility of the concept could be doubtful. However, the feasibility of the direct to surface option was confirmed in 2016 with the revisited Mars semi-direct scenario based on the use of SLS launchers and NASA data [11].

Though the detailed mass budget of the Space X scenario has not been given, the simplicity of the concept is remarkable. The same space vehicle is used for the transit to the red planet, for landing and for the return to Earth. The feasibility is still uncertain, but if it works, it would outperform by far all NASA reference missions in terms of costs.

### 2.2 Aerocapture

The aerocapture technique allows a spacecraft to go through the upper layers of the Martian atmosphere to brake down and access to Mars orbit without propellant

consumption (or very little, just for circularization) [1,14]. An aerocapture manoeuvre requires a very accurate trajectory, the control of the attitude, a heat shield and thermal control systems. These constraints are very strong and cannot be respected in all cases. For example, if other modules or huge solar panels are hanging on the side of a spacecraft, the shielding is almost impossible and the control of the attitude would be overly complex (see Fig. 1). Aerocapture is therefore possible and efficient only if the space vehicle is compact and simple. As a result, aerocapture is not possible or not efficient with the vehicles proposed in NASA reference missions, while it is the logical way to go in Mars Direct architectures. Importantly, aerocapture allows important mass savings for Mars orbit insertion (or direct entry). The delta V for Mars orbit insertion depends on numerous parameters. As it is generally expected to reach a low Mars orbit before starting the entry and descent phase, the delta V is on the order of 2 km/s and it can be much more if a fast transit is implemented. The mass of a propulsion system for such a delta V would represent approximately 50% of the total mass of the interplanetary vehicle. Aerocapture systems could represent half of that. In addition, as the vehicle already includes the heat shield and thermal systems required for the descent, the supplementary mass would be much smaller, on the order of 10% if the dual use is optimized (heat shield with adaptable size for instance). All in all, the direct to surface option allows an efficient implementation of aerocapture, which in turn allows important mass savings.

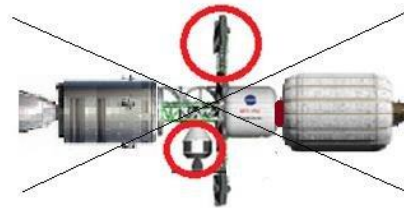


Fig. 1. Complex spaceships with docking ports hanging on the side are not appropriate for aerocapture.

## 3. Conclusion

The direct to surface option has not been considered by NASA, while it is clearly structuring mission architectures, potentially allowing huge mass savings. As NASA made comparisons with other scenarios based on chemical propulsion but clearly not optimized, the conclusion of these reports is biased and not trustworthy. An obvious recommendation for all mission to Mars designers is to consider the direct to surface option in any new study, especially for fair comparisons with scenarios based on chemical propulsion.

## References

- [1] R.D. Braun and R.M. Manning, Mars Entry, Descent and Landing Challenges, *Journal of Spacecraft and Rockets*, Vol. 44 (2), 310–323, Mar-Apr, 2007.
- [2] L. Bessone and D. Vennemann, CDF Study Report, Human Missions to Mars, Overall Architecture Assessment, CDF-20(A), ESA report, February 2004.
- [3] Borowski, S.K., et al., Nuclear Thermal Propulsion (NTPS). Wiley Online Library, 2010.
- [4] NASA Report EX13-98-036, "Reference Mission Version 3.0, Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study", June 1998.
- [5] G. Drake ed., Mars Architecture Steering Group, 1st Addendum of the Human Exploration of Mars, Design Reference Architecture 5.0, NASA Johnson Space Center, 2009.
- [6] G. Drake ed., Mars Architecture Steering Group, 2nd Addendum of the Human Exploration of Mars, Design Reference Architecture 5.0, NASA Johnson Space Center, 2014.
- [7] G. Genta and J.M. Salotti (ed.), Global Human Mars System Missions Exploration, Goals, Requirements and Technologies, *Cosmic Study of the International Academy of Astronautics*, January 2016.
- [8] E. Musk, Making Life Multiplanetary, Space X document, transcript of the talk presented at the 68th International Astronautical Congress, Adelaide, Australia, September 28th, 2017.
- [9] J.M. Salotti, Revised Scenario for Human Missions to Mars, *Acta Astronautica*, vol. 81, p. 273-287, 2012.
- [10] J.M. Salotti, R. Heidmann and E. Suhir, Crew Size Impact on the Design, Risks and Cost of a Human Mission to Mars, *Proceedings of the IEEE Aerospace Conference*, Big Sky, Montana (USA), pp. 1-9, March 2014.
- [11] J.M. Salotti, Robust, affordable, semi-direct Mars mission, *Acta Astronautica*, Volume 127, October–November, pages 235–248, 2016.
- [12] J.-M. Salotti, Launcher size optimization for a crewed Mars mission, *Acta Astronautica*, Volume 191, Pages 235-244, 2022
- [13] T.D. Schmidt, W. Seboldt and M. Auweter-Kurtz, Flexible piloted Mars mission using continuous electric propulsion, *Journal of Spacecraft and Rockets*, vol. 43 (6), 2006.
- [14] B. Steinfeldt, J. Theisinger, A. Korzun, I. Clark, M. Grant, and R. Braun, High Mass Mars Entry, Descent, and Landing, Architecture Assessment, *Proc. of the AIAA Space 2009 Conference and Exposition*, AIAA 2009-6684, Pasadena, CA, 14-17 September 2009.
- [15] R. Zubrin and D. A. Baker, Mars Direct: Humans to the Red Planet by 1999, *pro-ceedings of the 41st Congress of the International Astronautical Federation*, 1990.
- [16] R. Zubrin and D. Weaver, Practical Methods for Near-Term Piloted Mars Missions, AIAA 93-2089 AIAA/SAE 29th Joint Propulsion Conference, Monterey CA, 1993.