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An independent assessment of the technical feasibility of the Mars One mission plan – Updated analysis ☆

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ABSTRACT

In recent years, the Mars One program has gained significant publicity for its plans to colonize the red planet. Beginning in 2025, the program plans to land four people on Mars every 26 months via a series of one-way missions, using exclusively existing technology. This one-way approach has frequently been cited as a key enabler of accelerating the first crewed landing on Mars. While the Mars One program has received considerable attention, little has been published in the technical literature regarding the formulation of its mission architecture. In light of this, we perform an independent analysis of the technical feasibility of the Mars One mission plan, focusing on the architecture of the life support and in-situ resource utilization (ISRU) systems, and their impact on sparing and space logistics. To perform this analysis, we adopt an iterative analysis approach in which we model and simulate the mission architecture, assess its feasibility, implement any applicable modifications while attempting to remain within the constraints set forth by Mars One, and then resimulate and reanalyze the revised version of the mission architecture. Where required information regarding the Mars One mission architecture is not available, we assume numerical values derived from standard spaceflight design handbooks and documents. Through four iterations of this process, our analysis finds that the Mars One mission plan, as publicly described, is not feasible. This conclusion is obtained from analyses based on mission assumptions derived from and constrained by statements made by Mars One, and is the result of the following findings: (1) several technologies including ISRU, life support, and entry, descent, and landing (EDL) are not currently "existing, validated and available" as claimed by Mars One; (2) the crop growth area described by Mars One is insufficient to feed their crew; (3) increasing the crop growth area to provide sufficient food for the crew leads to atmospheric imbalances that requires a prohibitively large ISRU atmospheric processor or a notably different system architecture to manage; and (4) at least 13 Falcon Heavy launches are needed to deliver a portion of the required equipment to the Martian surface, a value that is at least double that planned by Mars One for the same mission phase. Most importantly, we find that the one-way nature of the Mars One mission, coupled with its plans to increase its crew population every 26 months, causes the operating costs of the program to grow continually over time. This is due to the fact that maintaining a growing colony on the Martian surface incurs increasing equipment and spare parts resupply requirements and hence launch costs over time. Based on published launch vehicle and lander estimates, our analysis finds that by the launch of the fifth crew, the cost associated with launching a portion of all required equipment and spares is approximately equal to half of the total NASA FY2015 budget – and this cost will grow when other critical systems outside the

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scope of this analysis are included. To mitigate these costs and bring the plan closer towards feasibility, we recommend a number of mission architecture modifications and technology development efforts be implemented before the initiation of any Mars settlement campaign. These include the further development of EDL, life support, and ISRU technologies, as well as additive manufacturing technology that utilizes ISRU-derived Martian feedstock as a potential means to address the growing cost of resupply.

1. Introduction

In mid-2012, the Mars One program was announced with the aim of building the first human settlement on the surface of Mars. Following a series of precursor missions to demonstrate and deploy key technologies, the first crewed mission would depart Earth in 2024, sending four people on a one-way journey to the surface of Mars. Following this initial mission, additional four-person crews would be sent to Mars at every subsequent launch opportunity to expand the extraterrestrial colony.

While this program has received significant publicity, little has been published in the technical literature on the formulation of this mission architecture. Moreover, common arguments for the mission's feasibility based on its exclusive use of existing technologies [1] conflict with the widely published capabilities and limitations of the current suite of validated human spaceflight technologies.

As the Mars One mission plan represents a departure from the traditional approach of initial sortie missions followed by later long-duration missions, there are many uncertainties in the mission design that need to be addressed prior to its implementation. Long-term colonization efforts on Mars present new logistical challenges, and rely on several technologies that are at a low Technology Readiness Level (TRL) [2,3].

In light of these observations, this paper aims to:

(1) Objectively assess the feasibility of the Mars One mission plan based on statements made by Mars One and the technical information that the organization has made publicly available;
(2) When applicable, provide recommendations for the stated Mars One mission architecture and operational strategy. We note that in some instances, the implementation of a recommendation requires the relaxation of one or more of the constraints imposed by statements and assumptions made by Mars One. When this is the case, recommendations are made with the intent of improving the Mars One mission architecture while minimizing the number of Mars One-specified constraints that are violated; and
(3) Highlight areas in which focused technology development can better enable future Mars settlement efforts in general.

With regards to items (2) and (3) listed above, we emphasize that this analysis does not attempt to design the Mars One mission architecture. Rather, recommendations are suggested and analyzed to extend the scope of this feasibility analysis to less-constrained variants of the Mars One architecture.

We perform this analysis by first compiling statements and assumptions publicly made by Mars One to model and simulate their baseline mission plan. When insufficient data is available from Mars One sources, we use data from standard aerospace handbooks and data sources, such as the NASA Human Integration Design Handbook [4] and the NASA Baseline Values and Assumptions Document (BVAD) [5]. After analyzing the results of the baseline Mars One mission simulation, we assess its feasibility, and if applicable, make recommendations to the mission architecture based on the considerations listed earlier. These recommendations are then implemented into a modified system architecture and the process of simulating, analyzing, providing recommendations based on an intermediate feasibility assessment, and performing an updated analysis with an updated architecture is repeated. We continue to iterate through this analysis cycle until we find that either: (1) the mission requires the development of new technologies whose capabilities are so uncertain that their performance and lifecycle properties cannot yet be confidently predicted; and/or (2) the lifecycle cost of the program does not reach a steady state and is hence unsustainable.

Finally, we note that the first version of this analysis was originally reported in a paper presented at the 65th International Astronautical Congress [6],[1]. This paper presents an update to this original analysis that incorporates:

1. A refined crop growth model that captures crop death due to insufficient CO_2 concentration within the crop growth environment;
2. An updated intermodule atmospheric exchange model;
3. An updated Atmospheric Processor model;
4. A refined Sparing module that accounts for commonality in spare parts across multiple crews;
5. A longer campaign time horizon of ten crews to the surface of Mars, as compared to the five crews considered in the previous analysis; and
6. A first order power and thermal system analysis to compare the system level impacts of different strategies for providing food to the crew.

While these updates have led to some changes in the quantitative results of each of the areas studied, this updated analysis finds that the overall results and conclusions presented in the original paper remain unchanged.

[1] Available at: http://bit.ly/mitM1.