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Utilizing in-situ resources and 3D printing structures for a manned Mars mission

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ABSTRACT

This paper presents a manned Mars mission, which is based on the use of in-situ resources for the fabrication of structures. First, it provides an overview of the two-phase mission. In phase one, robotic construction units prepare a functional base for phase-two human habitation. Then, it describes a set of prospective structures that can be created utilizing additive manufacturing (commonly known as 3D printing) techniques and in situ materials. Next, the technological advancements required to allow this type of mission are considered and their feasibility is discussed. Specific focus is given to the topics of basalt 3D printing and the maintenance of the pressure environment. The process of the construction of the base is also discussed. Finally the proposed approach is analyzed through comparison to prior missions, before concluding.

1. Introduction

Mars has excited humanity for some time. The prospective benefits, as Ehlmann, et al. note [1], from Martian exploration are significant. Robotic exploration (e.g., [2]) of the planet has enthralled individuals around the globe while collecting preliminary information required to support the development of Mars mission concepts for human exploration. This paper presents one such concept which is based on reducing mission launch and deep space transfer mass and volume requirements via the fabrication of most of the base structures from in-situ resources. This mission concept is not intended as an initial human mission to Mars, but instead as a longer term and larger scale successor mission once several initial missions have been completed.

This mission concept requires technical advancement in several areas beyond those typically required for Martian missions. Specifically, this work requires advancement in the development of basalt additive manufacturing (commonly known as 3D printing) technology and analysis of the produced basalt structures' permeability, ability to maintain a pressurized environment suitable for human habitation and radiation blocking properties. Several approaches which could be utilized, depending on the capabilities of the basalt structures, are considered.

The proposed mission consists of two high-level components. First, an unmanned preparation mission would be sent to build the requisite infrastructure required to support human life. With this infrastructure deployed and validated, a second mission would then be readied for launch. This second mission would carry multiple astronauts to Mars to inhabit the structures built by the robotic assembly vehicles from the first mission.

Several key mission elements are required to sustain life. Key among these are power, water, food, air and waste processing. Power for this mission could potentially be

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provided in several ways, such as a wireless microwave power system that will stay in orbit and project generated power to a receiving array on the surface (see [3]) – reducing the amount of mass that must be landed – or a solar array on the surface. Water will be brought with the astronauts, reclaimed from waste and generated from in situ materials. Initial food as well as various non-producible items will be brought from Earth. Most food for the mission, however, will be grown in an in situ hydroponics facility. This production could conceivably be mechanized. Air will be brought with the robotic mission and the astronaut-carrying mission, recycled in situ and generated from in situ materials. Waste processing and reclamation will utilize techniques that have been extensively demonstrated in prior space missions (e.g., [4]).

Upon the landing of the first unmanned mission, the spacecraft will be unloaded and prepared for the first phase of printing. Components of the main dome will be printed at this point of the mission. Once the main dome is completed, a basalt 3D printer will be constructed within. This printer will create the living dome structures. These structures will be extracted from the main dome and assembled together to create a base.

This paper continues with an overview of prior work in numerous areas. Following this, the base and its structures are detailed. Then, basalt 3D printing is considered. Next, pressurization strategies are discussed. Finally, the paper discusses the base construction process, before concluding.

2. Background

Mars has been an exploration target for humanity and, more specifically, NASA for a long time. The creation of any space mission inherently brings together prior work from multiple disciplines. The design of a Martian base presented herein is no different. This section provides an overview of relevant prior work in several areas.

2.1. Martian missions

Key to any Martian mission is transportation. Travel to Mars takes approximately 180 days [5], with several mission durations [6] – including indefinite – possible. In [7], the use of an orbit that intersects with the Earth's and Mars' orbit every 2.5 years is proposed for carrying astronauts and supplies onboard a cyclic orbiting station. Zubrin [5] proposed a “Mars Direct” plan under which an un-manned module would be launched as a precursor to begin converting the Martian atmosphere into rocket fuel, followed by a manned mission. The Mars One concept [8] – which also utilizes robotic precursors – is for a one-way mission. This would be followed by additional manned missions. Other proposals have included a two-craft/two-crew-per-craft mission which would collect in situ resources for its return [9] and a mission concept for a 920–980 day venture (with 420–570 days on Mars) utilizing electric propulsion [10]. Hoffman and Kaplan [11] and Drake, Hoffman and Beaty [12] have developed NASA Martian reference missions.

Much like placing an object into orbit, landing an object safely on Mars is complex and expensive. Various methods have been developed, including drogue chutes, parachutes [5], and retropropulsion [13]. However, numerous entry, descent and landing (EDL) challenges [14] still must be overcome to allow landing of the 20–80 t mass levels projected [14,15] for human Martian missions. While technologies used for prior robotic missions could be used for human missions, Christian, et al. [16] suggest that this may be “insufficient”. Korzun, et al. [15] proposed an EDL solution for 20 t of landed, while Steinfeldt, et al. [17] proffer the possibility of a solution for up to 37.3 t of landed mass. For many Mars missions, a primary payload is landed, while a communications satellite continues in orbit to relay communications [18].

2.2. Astronaut needs

Astronauts require temperature-controlled and pressurized dwellings and workspaces, breathable air, food, water and other resources. They also require protection from radiation exposure. Finally, astronaut space needs are discussed.

The Martian atmosphere has a pressure of approximately 0.6% of the Earth [19]; clearly, direct exposure to which would cause numerous issues [20]. The planet's temperature, while varying by the season and day cycle, averages -65 °C [19], compared to the Earth's average of 15 °C [21]. This limited atmosphere is comprised of 95% CO_2 [19], making it unsuitable for breathing, even at higher pressures.

Numerous Martian resources can be utilized, however. The soil is well-suited for growing different vegetables [22] and could be fertilized to grow other foods using, for example, a fertilizer derived from the soil's sulfur. Martian soil also contains 1% water which can be extracted via heating [23]. The soil can be used to make concrete [23] and it contains numerous other metal-oxides [23]. It also serves as a basalt supply. Water can be harvested from underground areas through wells [24] and is also present in the northern and southern cap areas [25]. In addition to use, it can also be split into components: the Hydrogen could be used for fuel or to synthesis methane, a fuel that can be used for a rocket [26] and other purposes. The atmosphere can be harvested via electrolysis. The CO_2 can be split into CO and O and the oxygen used in the pressurized air mixture while the CO is used as a fuel or to synthesize other fuels [5].

Mars presents a significant challenge to short and long duration exploration, as well as to later prospective settlement. Radiation protection is required, due to Mars having a minimal magnetosphere to protect the planet from sources such cosmic rays and solar radiation [27]. An astronaut on Mars quickly surpasses the US Nuclear Regulatory Commission's 5 rem annual safe exposure limit (see [28]) – potentially in as little as 30 days [29]. NASA's radiation limits are somewhat higher. Currently, NASA allows exposure of 25 rems over 30 days or 50 rems annually [30]. Both limits refer to the blood forming organs and higher exposure limits exist for the skin and eyes. This yearly limit could be exceeded in 10 months [29]. The potentially significant negative effects of excess radiation exposure and uncertainties about its prediction are discussed in [31].