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An efficient approach for Mars Sample Return using emerging commercial capabilities

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ABSTRACT

Mars Sample Return is the highest priority science mission for the next decade as recommended by the 2011 Decadal Survey of Planetary Science (Squyres, 2011 [1]). This article presents the results of a feasibility study for a Mars Sample Return mission that efficiently uses emerging commercial capabilities expected to be available in the near future. The motivation of our study was the recognition that emerging commercial capabilities might be used to perform Mars Sample Return with an Earth-direct architecture, and that this may offer a desirable simpler and lower cost approach. The objective of the study was to determine whether these capabilities can be used to optimize the number of mission systems and launches required to return the samples, with the goal of achieving the desired simplicity.

All of the major element required for the Mars Sample Return mission are described. Mission system elements were analyzed with either direct techniques or by using parametric mass estimating relationships. The analysis shows the feasibility of a complete and closed Mars Sample Return mission design based on the following scenario: A SpaceX Falcon Heavy launch vehicle places a modified version of a SpaceX Dragon capsule, referred to as “Red Dragon”, onto a Trans Mars Injection trajectory. The capsule carries all the hardware needed to return to Earth Orbit samples collected by a prior mission, such as the planned NASA Mars 2020 sample collection rover. The payload includes a fully fueled Mars Ascent Vehicle; a fueled Earth Return Vehicle, support equipment, and a mechanism to transfer samples from the sample cache system onboard the rover to the Earth Return Vehicle. The Red Dragon descends to land on the surface of Mars using Supersonic Retropropulsion. After collected samples are transferred to the Earth Return Vehicle, the single-stage Mars Ascent Vehicle launches the Earth Return Vehicle from the surface of Mars to a Mars phasing orbit. After a brief phasing period, the Earth Return Vehicle performs a Trans Earth Injection burn. Once near Earth, the Earth Return Vehicle performs Earth and lunar swing-bys and is placed into a Lunar Trailing Orbit-an Earth orbit, at lunar distance. A retrieval mission then performs a rendezvous with the Earth Return Vehicle, retrieves the sample container, and breaks the chain of contact with Mars by transferring the sample into a sterile and secure container. With the sample contained, the retrieving spacecraft makes a controlled Earth re-entry preventing any unintended release of Martian materials into the Earth’s biosphere. The mission can start in any one of three Earth to Mars launch opportunities, beginning in 2022.

1. Introduction

1.1. Mars Sample Return

Mars Sample Return (MSR) has been identified as the highest priority planetary science mission in the 2011 Decadal Survey of Planetary Science, the guiding document for the United States Planetary Science Program [1]. MSR has been studied extensively within the last three decades and several mission designs have been proposed [2–6]. Those earlier mission designs have been large and complex, with many elements and systems, and multiple launches, implying a high cost. This article reports on a study that examined the use of an emerging suite of commercial capabilities to reduce the number of elements, systems, and launches and therefore the mission complexity compared to the previous approaches [2–6]. A description of emerging commercial capability is provided in Section 1.2.

Mars Sample Return is intrinsically a complex mission as it requires Entry Descent and Landing (EDL) through atmosphere and onto the surface; surface mobility to collect the samples; a

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rocket powered Mars Ascent Vehicle (MAV) capable of launching the samples into space from the Martian surface; transportation of the sample back to the vicinity of Earth; and EDL of the sample at Earth in a controlled manner to minimize the risk of planetary back contamination at Earth. The 2011 Decadal Survey [1] is supported by a mission architecture [2–4] that involves three Mars launches, carrying 14 mission elements. We refer to this architecture as the "Decadal Survey architecture". This Decadal Survey architecture includes the following:

- Launch vehicles

– Three Atlas V or Falcon 9 class launch vehicles.

- Mission elements

– Two cruise stages.
– Two entry vehicles.
– Two sky cranes.
– Two differently designed, rovers.
– One orbiter.
– One Earth Return Vehicle (ERV).
– One Earth Entry Vehicle (EEV).
– One Mars Ascent Vehicle (MAV).
– One thermal protection "igloo" for the MAV.
– One landing pallet for the MAV and fetch rover.

In the first mission [2], a sample collection rover lands using the same "sky crane" landing system as the Curiosity Rover. The second mission [3] sends a Mars orbiter with an ERV and an EEV to Mars. The combined spacecraft wait in Mars orbit to perform the end steps of the third mission. The third mission [4] begins by dispatching a MAV and a fetch rover to be landed on Mars. The fetch rover drives to where the cache was left by the sample collection rover, picks them up and delivers them to the MAV. The fetch process takes up to six months and a traverse of up to 12 km. The MAV then delivers the sample canister, with minimal spacecraft support functions, into Mars Orbit. The waiting Mars orbiter performs a Mars Orbit Rendezvous with the sample canister, and captures it with a basket. The sample canister is them placed in into a sterile container housed within the EEV. The ERV carries the propulsion system to send the EEV from Mars orbit back to Earth. Near Earth, the ERV releases the EEV where it performs a passive EDL while safely containing the sample.

In addition to the previous MSR mission studies mentioned earlier, [2–6], other prior work has questioned the use of Mars Orbit rendezvous and suggested that a direct to Earth approach be considered [7,8]. In particular, in [7], it is suggested that in order to break out of the much used box defined by legacy mission approaches, the development of alternative systems would be required. The emerging commercial capabilities of Red Dragon and the Falcon Heavy, can meet this need.

It is to be noted that although the Decadal Survey architecture was not approved as a whole due to cost concerns, the Mars 2020 rover will be tasked with performing sample collection functions in addition to the primary science mission. This startup of MSR activities was actually assumed by the worked described in this article.

The motivation of our study was the recognition that emerging commercial capabilities might be used to perform MSR with an Earth-direct architecture, and that this may offer a simpler and lower cost approach. We examined whether a suitably modified SpaceX Dragon capsule, referred to as a "Red Dragon" could perform the cruise, entry, descent, and landing functions in place of a dedicated cruise stage, an aeroshell, a sky crane, and a landed platform as used in the Decadal Survey architecture [2–4]. We evaluated the landed mass capability of a Red Dragon to determine that it allows a MAV-ERV stack with the capability of launching the sample directly towards earth, without the need for Mars orbit operations.

This article presents a new MSR architecture based on the emerging capabilities under development by SpaceX. We refer to this new MSR architecture as the "Red Dragon MSR architecture". The original sampling intent of the planetary science community is preserved in the Red Dragon MSR architecture. We show that it is possible to take advantage of the Mars 2020 sample collection rover that has already started development. In keeping with the desire to lower the complexity and cost of the MSR program, we assumed that the Mars 2020 rover could be used to deliver the samples to the sample return vehicles. The Red Dragon MSR architecture was analyzed as starting in any one of three consecutive Earth to Mars launch opportunities, beginning in 2022. The 2022 opportunity is the preferred option since the shortest mission extension, approximately of 12 months, will be required for the 2020 rover. The Red Dragon MSR architecture covers a complete mission with all required elements. Mass closure is achieved when it is shown that the mass of elements needed to perform the Earth direct mission fit within the mass that can be landed on Mars.

1.2. Emerging commercial capabilities

The use of the capabilities that have been emerging from recent commercial space activities is key to the Red Dragon MSR architecture. The use of fewer elements makes this architecture an efficient approach. SpaceX is used as an example but there are others that are attempting to reduce the cost of spaceflight as well. There is no endorsement of any particular commercial organization by NASA. There is also no endorsement of this work by any particular commercial organization.

SpaceX is a much different type of organization than the aerospace industry has seen in the past. They operate in a more efficient manner than the aerospace industry or large customers such as NASA.

Within a time period just under a decade, the Dragon capsule and Falcon 9 launch vehicle have emerged as a commercial source of cargo delivery services to the International Space Station (ISS) to fill the gap left by the retirement of the Space Shuttle. Commercial, in this sense, refers to the fact that NASA can now contract for cargo delivery services to ISS. A similar approach will be used for human missions to the ISS. Both capabilities are implementations of U.S. Space Exploration policy as administered by the NASA Commercial Crew and Cargo Program Office (C3PO) [9,10]. The Red Dragon MSR architecture described in this article is built on this commercial premise.

1.3. Article overview

We first describe the MSR Concept of Operations (ConOps) in Section 2, from Earth launch until return of the recovered samples to Earth. In Section 3, the methodology used to perform the study, including data sources; major engineering tools, and internal checks is provided. Appendix A provides a summary of key data assumptions. Section 4 provides information related to the design and operation of the Red Dragon MSR architecture elements. A description of the interfaces between the Red Dragon MSR architecture and the Mars 2020 rover is provided in Section 5. Planetary Protection issues are addressed in Section 6. In Section 7, a discussion of the results and related topics is included. Section 8 is the conclusion while Section 9 recommends potential future work.