# Comments On NASA's Journey To Mars (JTM) Document

## 1. Preface

This essay is a personal commentary on a document dated October 2015 and titled "NASA's Journey To Mars: Pioneering Next Steps in Space Exploration". Published by NASA Headquarters as NP-2015-08-2018-HQ, this document is referred to as "JTM" herein. A copy of JTM may be obtained from http://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf (accessed 13 October 2015). The essay author's opinions as an unaffiliated astrodynamics consultant are expressed herein with intent to stimulate further discussion among colleagues and the public of what this author views to be absent, arguable, questionable, unexpected, or unsupported information, strategies, or predictions in JTM.

Commentary on JTM is organized in subsequent paragraphs according to major section-specific themes or concepts running through the document or absent from it. Page *n* references to JTM are therefore not in any ordered numeric sequence and are of the format "p. *n*". External references with respect to JTM are cited in square brackets and detailed in the References section of this essay. Other informal external references appear in footnotes.

## 2. Exploring and Pioneering Mars

A white paper titled "Pioneering Space: NASA's Next Steps on the Path to Mars"[i] and dated 2014 May 29 clearly defines "exploration" and "pioneering" in its fifth paragraph as follows.

> Explorers go with the intent of returning to tell their story and point the way for future forays. Pioneers go with the intent to establish a permanent presence.

With respect to the 2014 white paper's definitions, JTM's "Pioneering Next Steps in Space Exploration" subtitle is nonsense. There is virtually no historic precedent for pioneering to be part of an exploration effort or somehow lead to exploration. History teaches us exploration is a *prerequisite* to pioneering time and time again. How can one pioneer unexplored territory?

Furthermore, to imply NASA does any more than *enable* pioneering off-Earth is inconsistent with the agency's charter as documented in The National Aeronautics and Space Act of 1958[ii]. Nowhere in NASA's charter does the word "pioneer" or any of its derivative forms appear, while "exploration" appears 7 times.

Throughout JTM, the concepts of exploration and pioneering are used in a bewildering interplay that becomes blatantly contradictory at times. For example, in the first paragraph of JTM p. 1, readers are informed: "NASA is leading our nation and our world on a journey to Mars." Later in the paragraph, "journey" is equated with "a historic pioneering endeavor" in which "Unlike Apollo, we will be going to stay." This sounds like Mars pioneering is to be led by NASA in a manner not at all consistent with the agency's charter.

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[i] This publication may be downloaded at http://www.nasa.gov/sites/default/files/files/Pioneering-space-final-052914b.pdf (accessed 13 October 2015).

[ii] Reference http://www.nasa.gov/offices/ogc/about/space_act1.html#POLICY (accessed 13 October 2015).

Later on p. 1, JTM proclaims, "Together with our partners, we will pioneer Mars and answer some of humanity's fundamental questions". One of these questions is "Could it [Mars] be a safe home for humans one day?" On a single page, JTM has NASA sending pioneers to stay on Mars before the agency has determined whether or not Mars is a safe home for humans.

Putting JTM semantics aside for now, suppose NASA really intends to explore Mars with a continuous human presence, as opposed to permanently resident pioneers. This concept would entail crew rotations as on ISS and Antarctic bases. Such rotations require an off-going crew handover to an oncoming crew, a process lasting a few days or weeks in Earth orbit or at the South Pole. Assuming conventional high-thrust propulsion and Earth/Mars transits lasting 240 days, the off-going crew can depart Mars for Earth about 740 days after leaving Earth. Unfortunately, the oncoming crew can't reach Mars much earlier than 1020 days after the off-going crew left Earth. The handover will only be possible if the off-going crew delays its Mars departure by about 780 days, requiring this crew spend a total of about 1760 days (4.8 years) away from Earth. Formidable complications arise from 2 crews spending about 500 days on Mars simultaneously. In addition to humans spending an inordinate time away from Earth in hostile environments, consumables logistics to Mars become all the more burdensome.

Near the end of p. 1, JTM concludes, "There are challenges to pioneering Mars, but we know they are solvable." In the context of NASA's vintage 2014 definition of "pioneering", this remark borders on hubris and would benefit from a healthy dose of respect for "unknown unknowns" in human space flight (HSF) and off-Earth adaptability. Pioneering Mars entails humans living out their lives there to successfully reproduce and raise viable progeny. But NASA has no data on human adaptation to life on Mars, particularly effects of 38% Earth gravity on reproduction, gestation, development, productivity, and longevity. With a rotating habitat or centrifuge in low Earth orbit (LEO), at least some data on these effects could be obtained at less expense and risk before humans attempt to live on Mars. Yet NASA has no plans to study human adaptability to 38% Earth gravity before landing humans on Mars, presumably to spend about 500 days there and about 980 days away from Earth. Ignorance about living on Mars is truly profound. There is no guarantee humans can overcome millions to billions of years evolving in Earth gravity and adapt to being permanent residents on Mars.

The LEO-based centrifuge advocated to study human adaptation to Mars gravity might also serve to develop a "gravity prescription" for extended periods in which a crew would otherwise experience microgravity. On JTM p. 32, a litany of degenerative conditions from crew exposure to microgravity is cited, together with complex and time-consuming techniques to study and mitigate those conditions aboard ISS. Many mitigation techniques impart side effects whose interactions produce still more degenerative conditions. Would an onboard centrifuge not offer prospects for a more straightforward remedy to debilitating effects from microgravity while requiring less time from the crew? Why is an onboard crew centrifuge absent from ISS and JTM planning?

## 3. "Commercial" Partnerships

The concept of off-Earth commercial partnerships currently in widespread use by NASA and others in aerospace is misleading[iii]. According to U.S. Space Policy [1, p. 10]:

> The term "commercial," for the purposes of this policy, refers to space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential nongovernmental customers.

Private sector firms SpaceX and Orbital ATK are routinely said to be providing "commercial cargo" logistics to ISS, while SpaceX and Boeing are on paths to provide "commercial crew" logistics to ISS later this decade. Although these firms do indeed have the capacity to offer space station logistics services to nongovernmental customers, the fact is such customers do not yet exist and foreseeing any off-Earth nongovernmental logistics customers requires optimistic speculation. Even by NASA's own definition of "commercial space"[iv], private sector firms with ISS logistics contracts have business models in which "Government is only customer" or "Government is anchor tenant". Only when these models evolve to "Government is one of many customers" will NASA actually consider private sector firms to be truly commercial.

Given this background, the JTM statement on p. 3 is difficult to reconcile: "NASA's efforts build upon the proven international and commercial partnerships at the core of the ISS." Besides their non-commercial nature, these commercial ISS logistics partnerships are far from *proven*. Both "commercial cargo" providers suffered launch failures in the 2014-2015 time frame and subsequently stood down from flight operations supporting ISS for many months. No "commercial crew" launches have yet been attempted. To be *proven*, a partner needs to tally an uninterrupted series of successful ISS missions approaching 100 or more. It is dubious such tallies will even be possible before ISS planned retirement and disposal circa 2024. Given the immature LEO logistics services being provided to ISS by so-called commercial partners, a credible and substantive role in human logistics to Mars by these private sector firms is anything but proven.

## 4. The Journey's Three Phases

As detailed on p. 7, JTM's three phases are Earth Reliant (in LEO), Proving Ground (in cislunar space), and Earth Independent (to the vicinity of Mars and on its surface). This multi-phase concept is appropriate in managing risk as present-day HSF experience in LEO is evolved to progressively greater distances from Earth. But the scope of each phase suffers from key omissions in JTM. Risk management and JTM integrity suffer as a consequence.

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[iii] The verb "mislead" is sometimes associated with intent to deceive. In reading this essay, no such intent is to be inferred. Use of "mislead" and its derivative forms in this essay simply means JTM readers are likely being given a wrong idea or impression. Discerning JTM's intent is beyond the scope of this essay.

[iv] Reference the plot and associative narrative at http://www.nasa.gov/offices/oct/partnership/comm_space/ (accessed 14 October 2015).

On JTM p. 7, all cited Earth Reliant activity is aboard ISS. As mentioned previously, NASA has no data on human adaptation to the effects of 38% Earth gravity experienced on the surface of Mars. There are no NASA plans to research these effects aboard ISS or elsewhere before humans land on Mars using a "conjunction" mission profile requiring they remain there for about 500 days [2, p. 22]. Such a "sink or swim" strategy is irresponsible and unethical. At some point before humans land on Mars during a credible JTM effort, it should be incumbent on NASA to demonstrate human adaptation to simulated Mars gravity in LEO using a rotating habitat or onboard centrifuge. If this experiment goes awry, its human subjects are hours from home as opposed to being on the surface of Mars with months to reach Earth gravity again.

Also on JTM p. 7, the Proving Ground phase is described as "a deep space environment that allows crews to return to Earth in a matter of days." This statement is misleading because departing some cislunar orbits for Earth is not possible at some times. Lunar distant retrograde orbits associated with NASA's Asteroid Redirect Crew Mission (ARCM) and periodic orbits about the Moon's cislunar and trans-lunar libration points have periods of about 2 weeks. Current Orion performance limitations permit Earth returns to be initiated only on a certain few days during such two-week orbits. Consequently, mission aborts may require 10 days or more to achieve Earth return from cislunar space if circumstances are poorly timed. The actual transit to Earth may only require "a matter of days", but that transit cannot be initiated at an arbitrary time.

The Earth Independent phase, as introduced on JTM p. 7, is described by a poorly supported statement: "With humans on Mars, we will be able to advance science and technology in ways only dreamed of with current robotic explorers." No JTM rationale is provided explaining why humans on the surface of Mars are best enabled to advance science and technology. What more can humans on Mars do as opposed to humans exploring at other interplanetary destinations including near-Earth asteroids (NEAs) and the moons of Mars? Tacit acceptance of Mars as the 21st Century's preeminent HSF destination is based on little more than a century of science fiction literature and poorly informed research at the dawn of The Space Age[v].

Perhaps justifying humans on Mars is beyond JTM's scope. Nevertheless, absence of this justification does not excuse JTM's failure to recognize NEAs in their native heliocentric orbits as necessary "stepping stone" destinations for HSF to Mars. The only mention of NEAs as HSF destinations by JTM is on p. 7 in association with the Proving Ground phase's ARCM. Consequently, a chasm of increased risk to HSF is opened by JTM's abrupt jump from cislunar space to Mars orbit or the surface of Mars. Missions to NEAs could incrementally bridge this gap[vi]. As if to underscore this omission, the three-phase schematic on JTM p. 8 completely omits NEAs.

The "Proving Ground Objectives" table on JTM p. 17 also suffers from omission of missions to NEAs in interplanetary space. With only one NEA sample, it is misleading to imply ARCM addresses the "*In-Situ* Resource Utilization" (ISRU) objective to "Understand the nature and distribution of volatiles and extraction techniques, and decide on their potential use in the human

[v] Reference http://www.lpi.usra.edu/sbag/meetings/jun2015/presentations/Adamo.pdf (accessed 18 October 2015).
[vi] Reference http://www.lpi.usra.edu/sbag/science/NHATS_Accessible_NEAs_Summary.png (accessed 18 October 2015).

exploration architecture." The ISRU objective can only be fully addressed by a comprehensive survey of representative NEAs in their native heliocentric orbits.

On JTM p. 18, "Proving Ground missions, including the launch of [Space Launch System] SLS and Orion" are associated with "a robust launch services capability" being developed by NASA. Unfortunately, the only facility capable of launching SLS is Launch Complex 39B (LC-39B). After the Apollo 7 mission in October 1968, U.S. HSF launches had been possible from two facilities: LC-39A and LC-39B. Damage to one facility would not long delay a subsequent launch from the other facility. Furthermore, two facilities enabled invoking a Launch On Need (LON) strategy whenever warranted. With LON, launch of a potential rescue mission could be prepared at one facility in parallel with an actual launch from the other facility. If the actual launch led to a nominal mission, the rescue mission was repurposed to become the next actual launch. Prospects for these robust capabilities were lost with respect to SLS launches when NASA signed a 20-year lease of LC-39A to private sector firm SpaceX on 14 April 2014[vii]. It therefore appears Proving Ground missions will enjoy less U.S. HSF launch capability robustness than had been available since 1968.

A LON-enabled rescue capability ought to be part of NASA's Proving Ground phase operations concept. Leaving a crew stranded in trans-lunar or cislunar space because a self-rescue like Apollo 13 is not possible is an ethically unsustainable policy. Unlike Apollo 13, Orion cannot rely on a Lunar Module equivalent whose redundant and independent systems were critical to April 1970's self-rescue. A HSF mission abort concept limited to self-rescue should be confined to JTM's Earth Independent phase, where there really is no alternative. If a crew is left to perish during a Proving Ground mission without being able to even attempt a rescue from Earth, adverse public reaction might well delay JTM progress by decades.

On JTM p. 23, Earth Independent phase capabilities are envisioned to include "surface mobility [and] permanent surface habitats". This statement conveys a highly misleading impression about living on Mars, where no appreciable atmospheric or magnetospheric shielding from galactic cosmic radiation (GCR) exists. Given current U.S. HSF radiation exposure limits[viii], routine human surface activity concepts on Mars require a leap of faith. To comply with these limits, humans spending months or years on Mars will likely occupy GCR-shielded subsurface habitats and transport systems whenever possible. Since "Design Mars surface habitats" is cited as an Earth Independent phase decision not to be made until the next decade at the bottom of JTM p. 26, assuming surface habitats on Mars anywhere in JTM is inconsistent and premature.

On JTM p. 30, "rapid and frequent [Extra-Vehicular Activities] EVAs" are associated with "multiple destinations within the cislunar and Martian environments". Because EVA systems provide virtually zero GCR shielding, anything like a daily cadence for these events will not be ethically sustainable for more than a few weeks even if individuals rotate into EVA duty over a multi-day cycle. Overexposure to GCR during frequent EVAs will only be aggravated if habitats in these environments and in interplanetary space transports are insufficiently shielded.

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[vii] Reference https://en.wikipedia.org/wiki/Kennedy_Space_Center_Launch_Complex_39 (accessed 20 October 2015).

[viii] Reference "Radiation Risk Acceptability and Limitations" by F. A. Cucinotta, Ph. D. at https://three.jsc.nasa.gov/articles/AstronautRadLimitsFC.pdf (accessed 20 October 2015).

According to the bottom of JTM p. 26, an Earth Independent phase decision already made and being implemented is: "Pursue an evolvable SLS via Exploration Upper Stage before advanced solid rocket boosters". This decision implies the open competition between liquid and solid propellant designs for SLS advanced boosters has been won by a solid propellant design. A NASA press release confirming this selected design could not be found, but an unattributed February 2015 report expects advanced boosters will not fly on SLS before the late 2020s. Modifications to LC-39B also reflect a decision to indefinitely postpone using advanced boosters, particularly those with liquid propellant[ix]. Consequences of failing to implement any advanced booster design are not disclosed in JTM. Is the evolved SLS performance goal of 130 t in payload mass delivered to LEO by a single launch still achievable? If not, how is JTM affected?

The graphic on JTM p. 28 is thoroughly incomprehensible. Annotations "GROUND" and "EARTH INDEPENDENT" appearing at the top of p. 28 have no apparent relevance to thumbnail images and annotations appearing below them. One annotation near the bottom of p. 28 proclaims "Human/robotic missions to Mars orbit/moons/surface". A network of trajectories in the p. 28 schematic connects the inner martian moon Phobos with interplanetary space and the surface of Mars, but the outer moon Deimos orbits Mars in isolation. For the following reasons, Deimos is arguably a better human-occupied platform than Phobos from which to explore Mars.

1) Deimos is more accessible from interplanetary space, and interplanetary space is more accessible from Deimos.
2) The Sun and Earth are eclipsed less by Mars at Deimos. From high Deimos latitudes near the local summer solstice, the Sun and Earth are continuously in view for months.
3) Proximity operations with respect to Deimos are easier because Mars tidal effects are less dominant.
4) A fixed location on the surface of Mars can be kept in view longer from Deimos (days instead of hours).
5) Higher latitudes on the surface of Mars can be viewed from Deimos.

## 5. Summary

The JTM document generally succeeds in relating NASA's logical three-phase HSF plan to reach Mars. Its indiscriminant use of "exploring" and "pioneering" will likely confuse most readers, however. Furthermore, pioneering space is not in NASA's charter and therefore inappropriate language for JTM. To comprehend how and why Mars has been chosen as the penultimate destination for JTM, readers will need to search elsewhere.

An overly optimistic attitude toward developing interplanetary HSF capability and a continuous human presence on Mars is evident at multiple points in JTM. The advisable strategy of using NEAs as "stepping stone" HSF destinations between cislunar space and the vicinity of Mars is omitted from JTM. Some strategic knowledge gaps, such as whether or not humans will suffer debilitating effects from reduced gravity on Mars, are not even recognized in JTM.

[ix] Reference https://en.wikipedia.org/wiki/Space_Launch_System#Advanced_boosters (accessed 20 October 2015).

Inexperienced and government-subsidized private sector firms are called "commercial" and "proven" NASA partners on whom JTM can depend. Launch capability for SLS is termed "robust", but the lone SLS launch facility at LC-39B embodies a critical single point of failure once JTM must access HSF destinations beyond LEO.

Finally, JTM appears to confirm NASA has failed to clearly communicate in publicly accessible media that SLS advanced boosters may never be developed, let alone competitively as mandated by Congress. As a consequence of flying without advanced boosters, SLS may never evolve to deliver 130 t of payload mass in a single launch. Without this capability, a timely buildup of interplanetary HSF systems may prove to be impossible as early as JTM's Proving Ground phase.

Even ignoring the politics of pioneering off-Earth, HSF's journey to Mars appears to be a very bumpy ride compared to JTM's outlook.

## References

1. Office of Science and Technology Policy, *National Space Policy of the United States of America*, June 28, 2010.[x]
2. B. G. Drake (ed.), *Human Exploration of Mars Design Reference Architecture 5.0*, NASA/SP-2009-566, July 2009.[xi]

[x] This document may be downloaded at https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf (accessed 14 October 2015).
[xi] This document may be downloaded at http://www.nasa.gov/exploration/library/esmd_documents.html (accessed 18 October 2015).